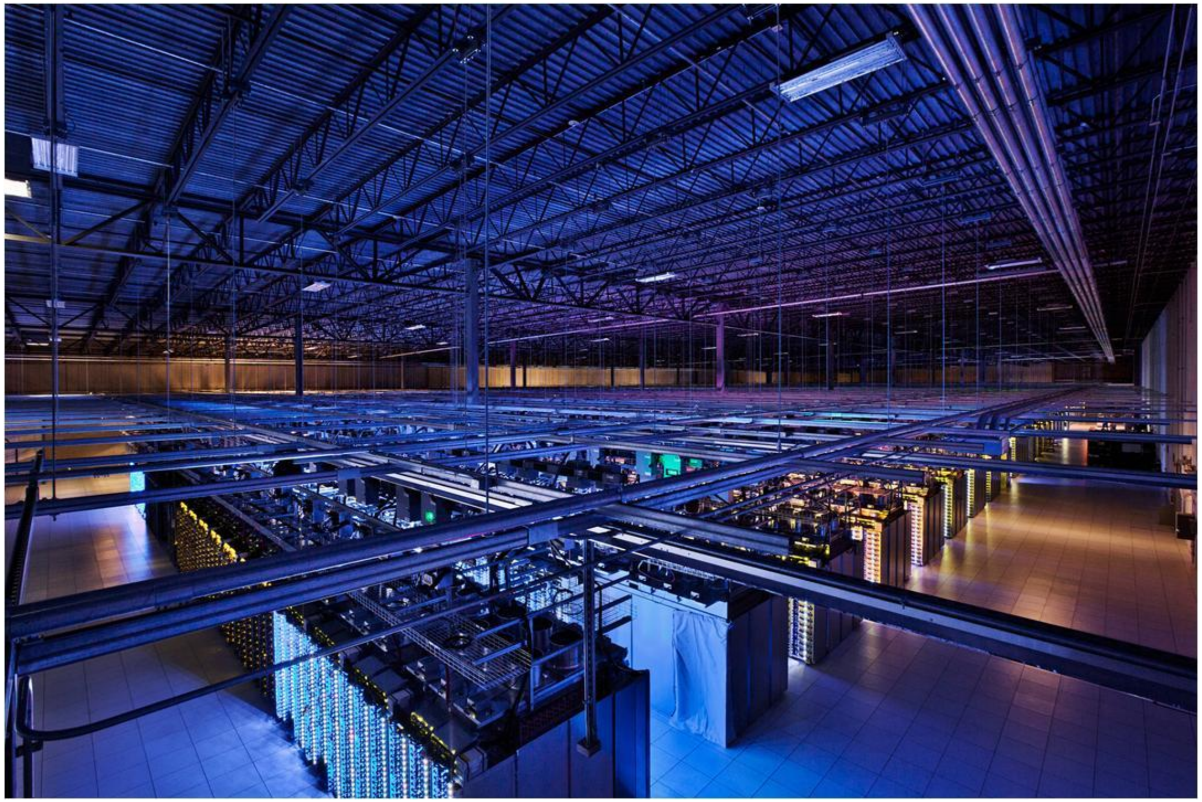
Centrum Wiskunde & Informatica

Large-Scale Data Engineering

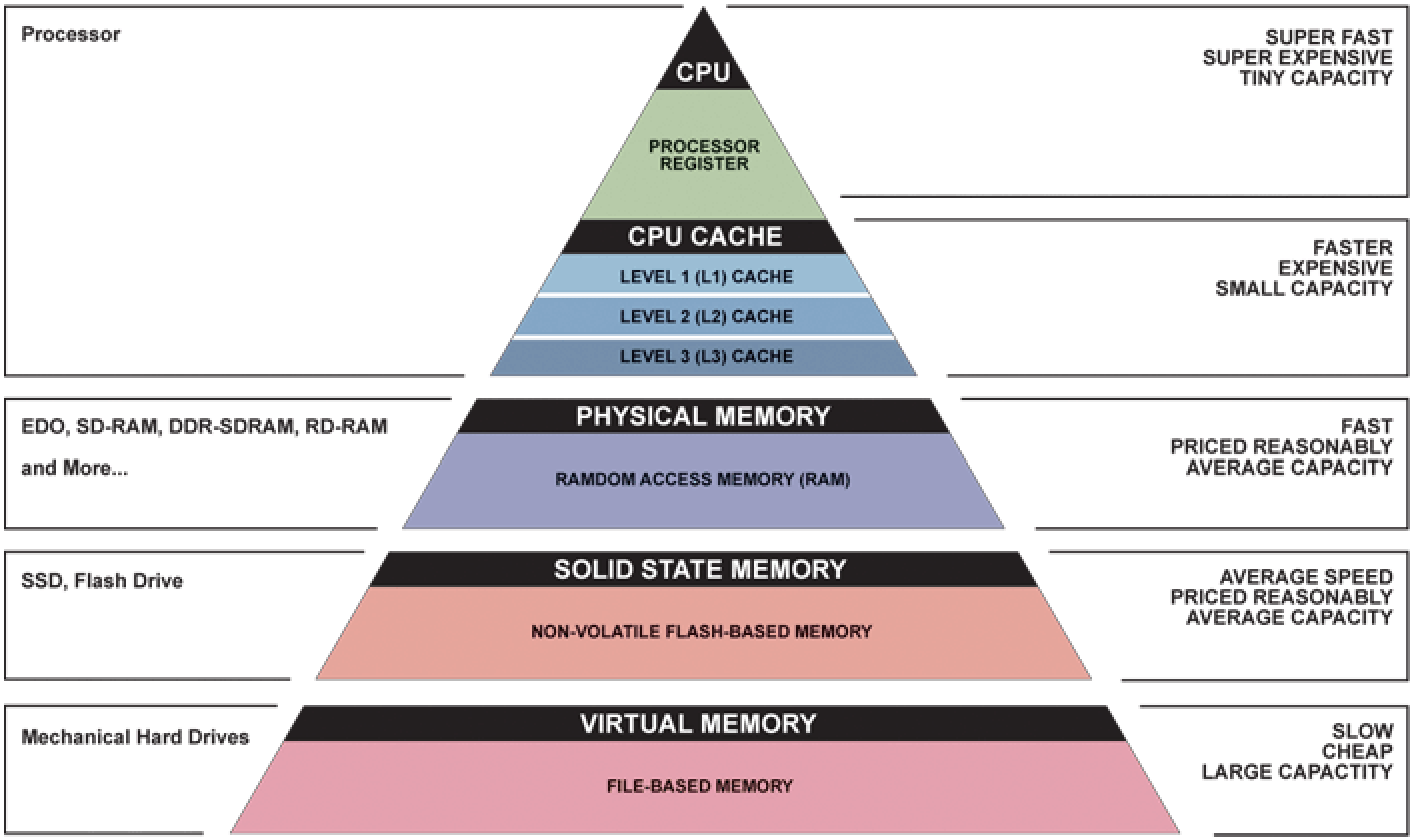
Some notes on Access Patterns, Latency, Bandwidth



+ Tips for practical

event.cwi.nl/lsde

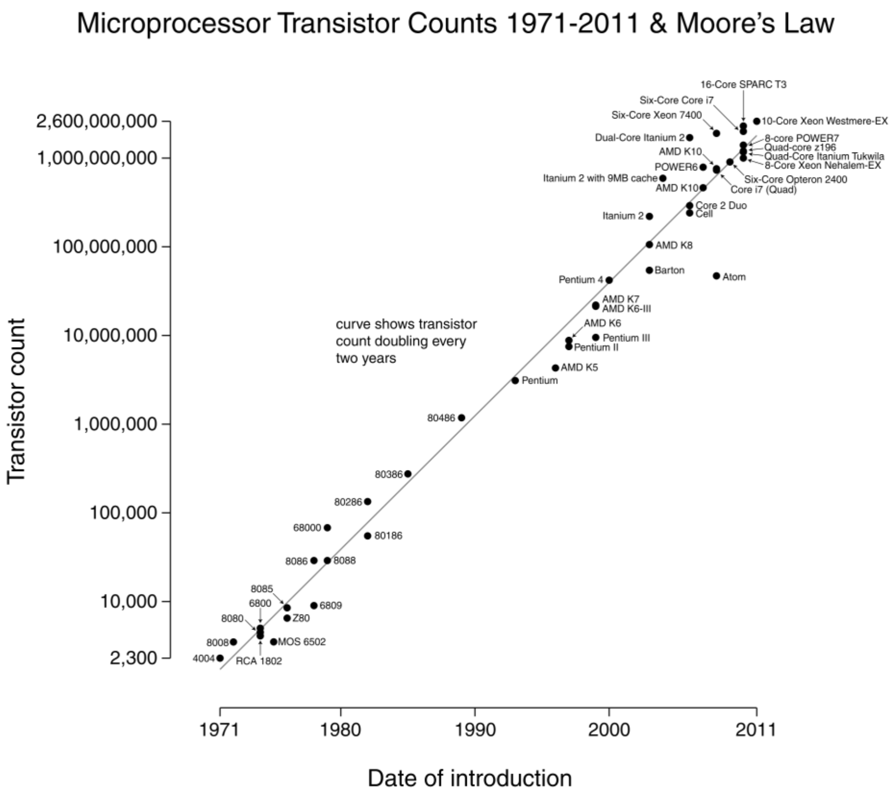
Memory Hierarchy



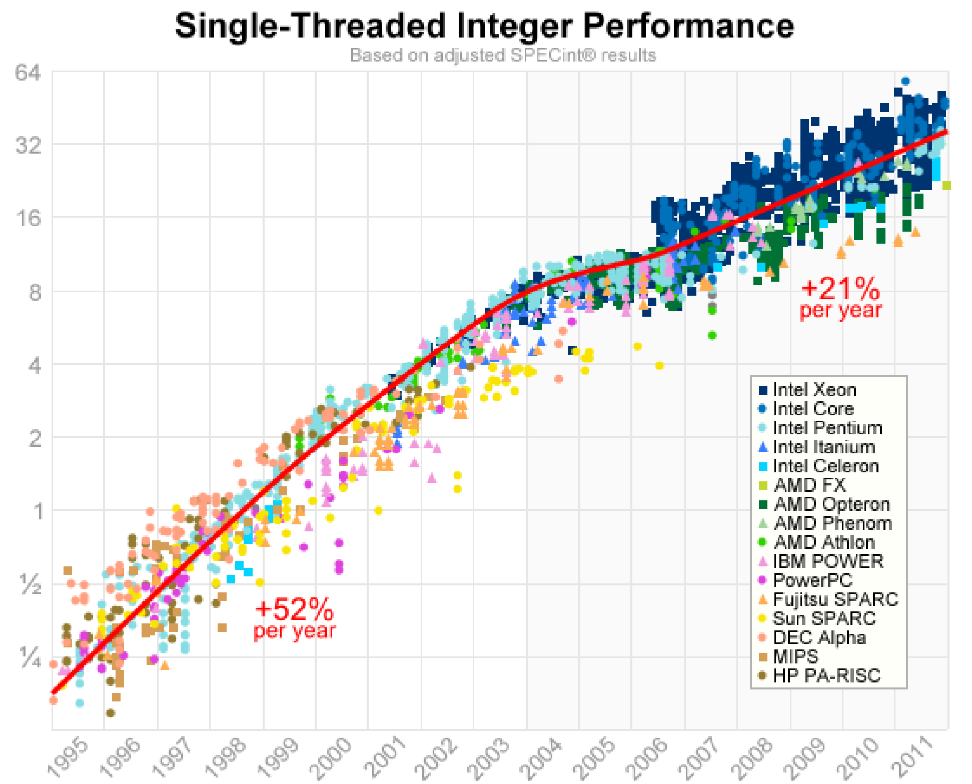
▲ Simplified Computer Memory Hierarchy
Illustration: Ryan J. Leng

Centrum Wiskunde & Informatica

Hardware Progress

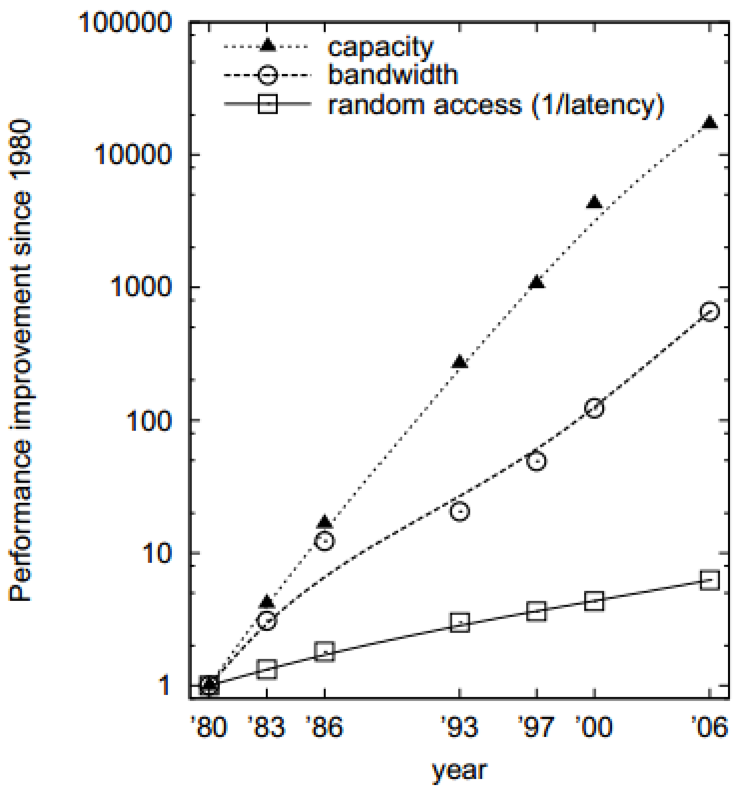


Transistors

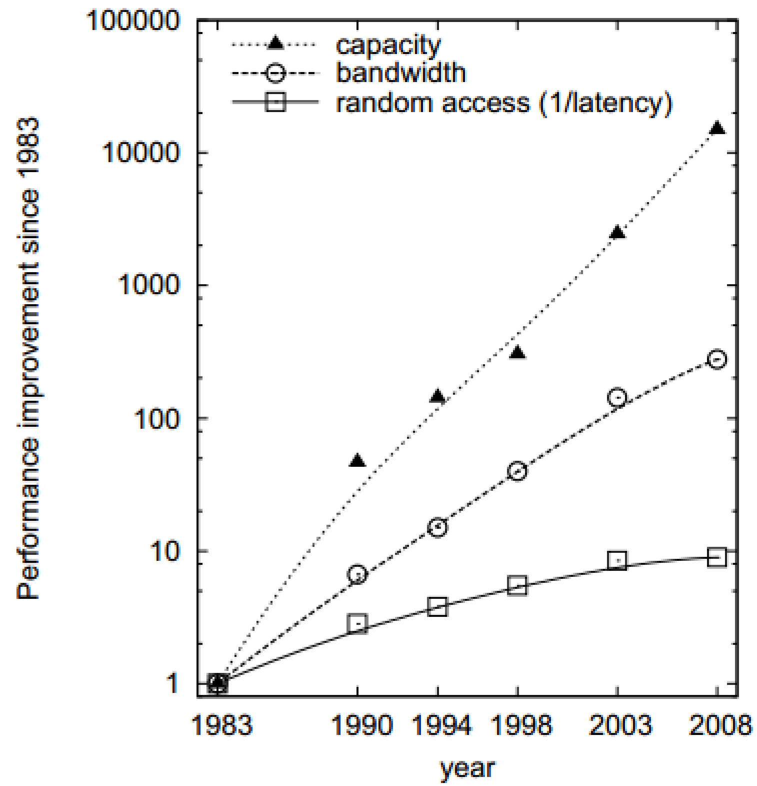


CPU performance

RAM,Disk Improvement Over the Years



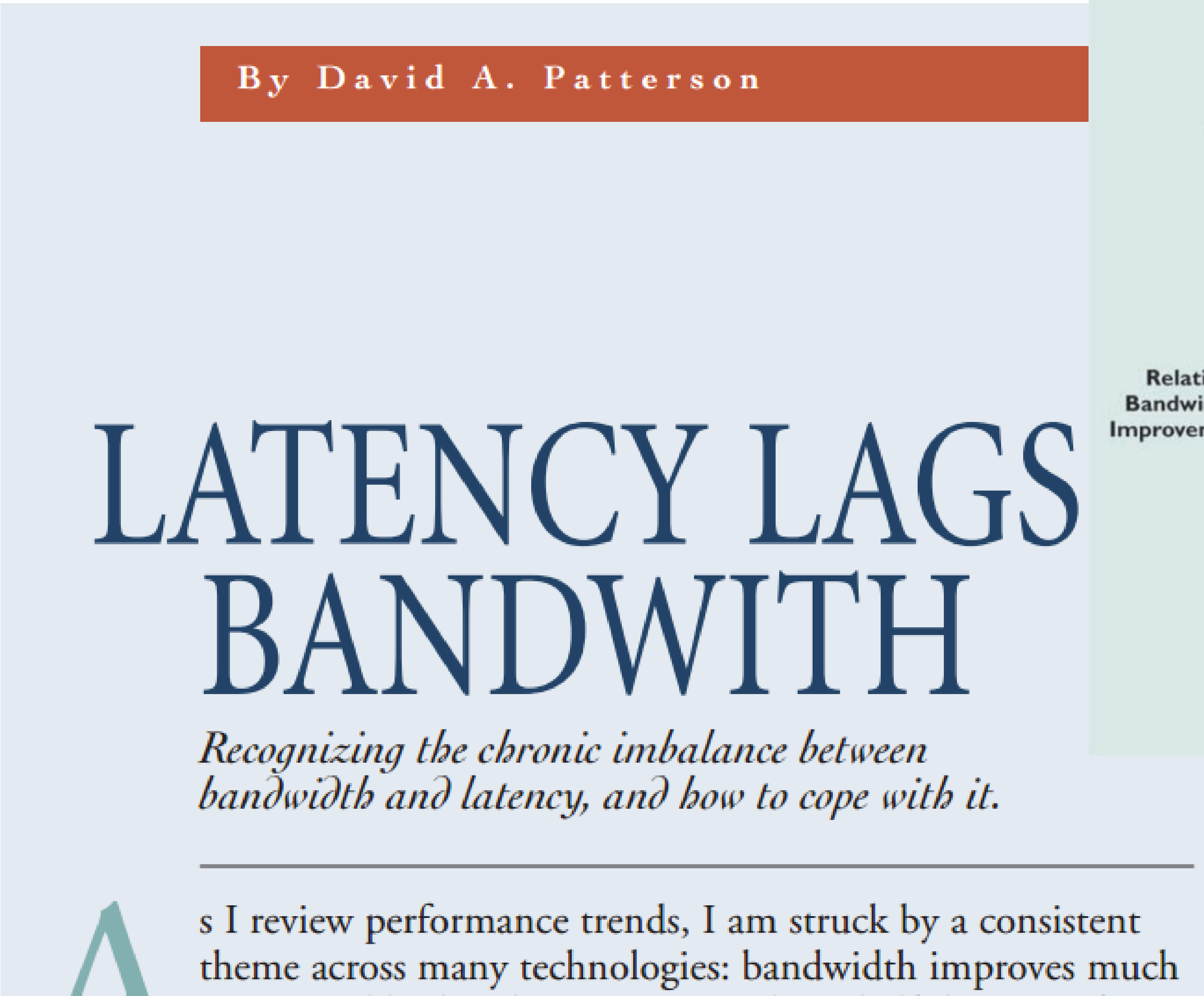
RAM



Magnetic Disk

Latency Lags Bandwidth

- Communications of the ACM, 2004

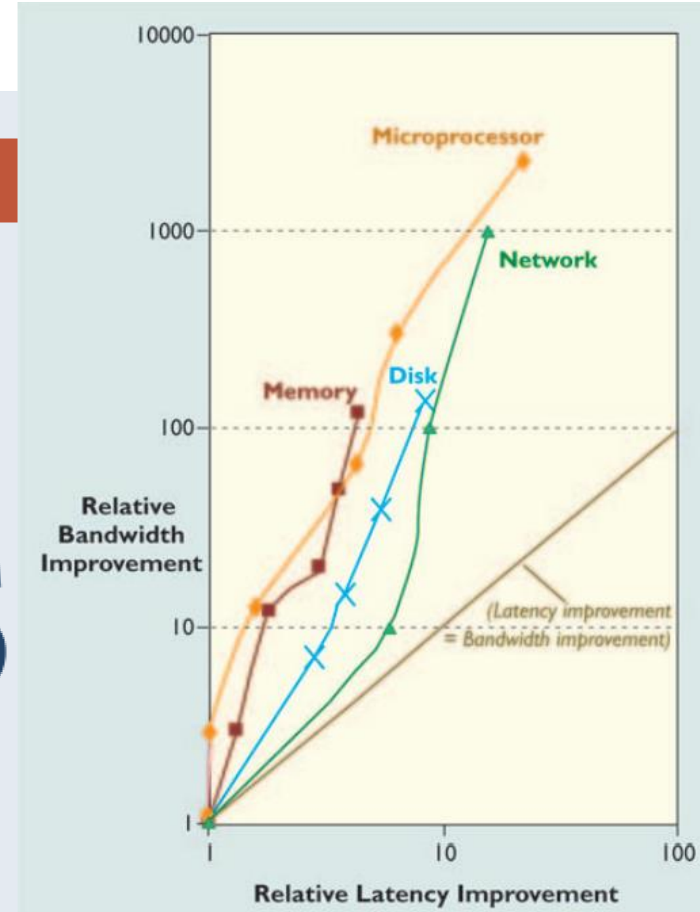


By David A. Patterson

LATENCY LAGS BANDWITH

Recognizing the chronic imbalance between bandwidth and latency, and how to cope with it.

As I review performance trends, I am struck by a consistent theme across many technologies: bandwidth improves much



Geeks on Latency

jboner / **latency.txt**

Created on 31 May 2012

Latency Numbers Every Programmer Should Know

latency.txt

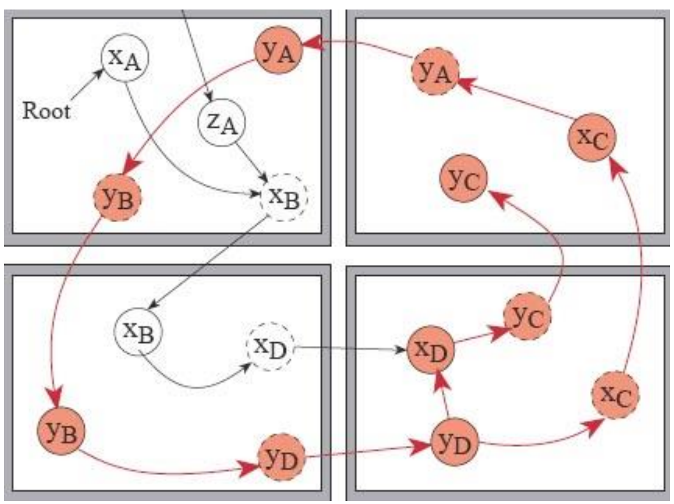
```
Latency Comparison Numbers
--------------------------
L1 cache reference                            0.5 ns
Branch mispredict                             5   ns
L2 cache reference                            7   ns             14x L1 cache
Mutex lock/unlock                            25   ns
Main memory reference                       100   ns             20x L2 cache, 200x L1 cache
Compress 1K bytes with Zippy              3,000   ns
Send 1K bytes over 1 Gbps network        10,000   ns    0.01 ms
Read 4K randomly from SSD*              150,000   ns    0.15 ms
Read 1 MB sequentially from memory      250,000   ns    0.25 ms
Round trip within same datacenter       500,000   ns    0.5  ms
Read 1 MB sequentially from SSD*      1,000,000   ns    1    ms  4X memory
Disk seek                            10,000,000   ns   10    ms  20x datacenter roundtrip
Read 1 MB sequentially from disk     20,000,000   ns   20    ms  80x memory, 20X SSD
Send packet CA->Netherlands->CA     150,000,000   ns  150    ms

Notes
-----
1 ns = 10-9 seconds
1 ms = 10-3 seconds
* Assuming ~1GB/sec SSD
```

Sequential Access Hides Latency

- Sequential RAM access
  - CPU prefetching: multiple consecutive cache lines being requested concurrently
- Sequential Magnetic Disk Access
  - Disk head moved once
  - Data is streamed as the disk spins under the head
- Sequential Network Access
  - Full network packets
  - Multiple packets in transit concurrently

Consequences For Algorithms

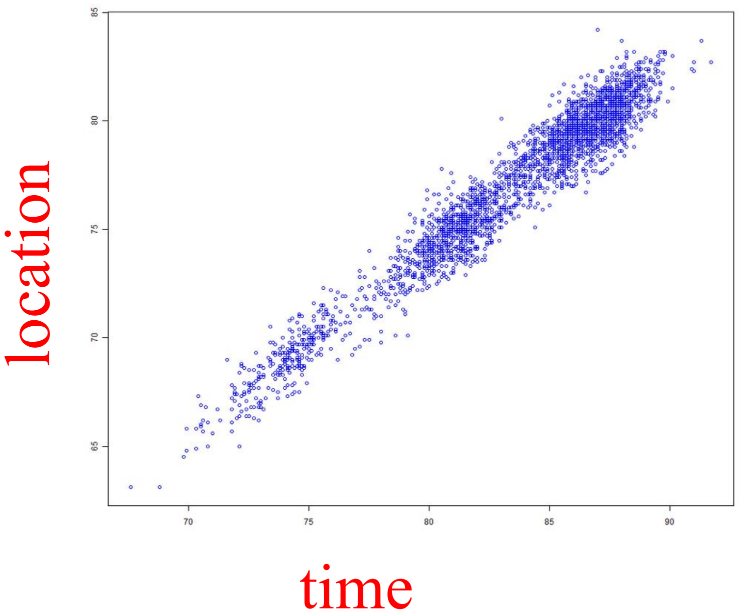
- Analyze the main data structures
  - How big are they?
    - Are they bigger than RAM?
    - Are they bigger than CPU cache (a few MB)?
  - How are they laid out in memory or on disk?
    - One area, multiple areas?

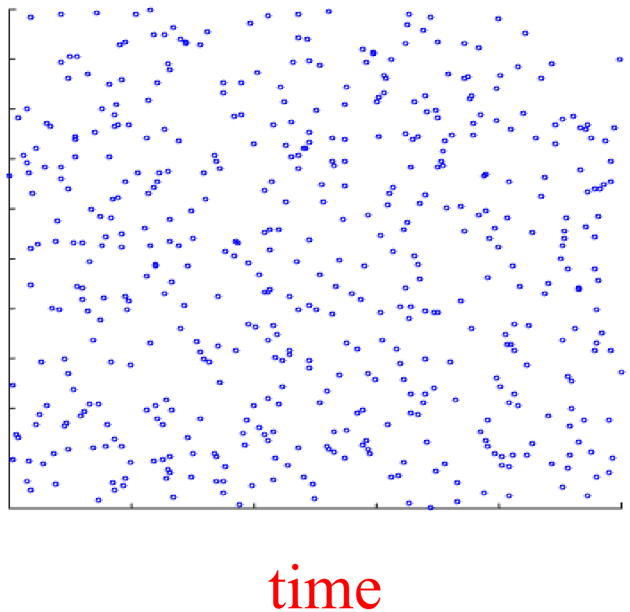


Java Object Data Structure
vs
memory pages (or cache lines)

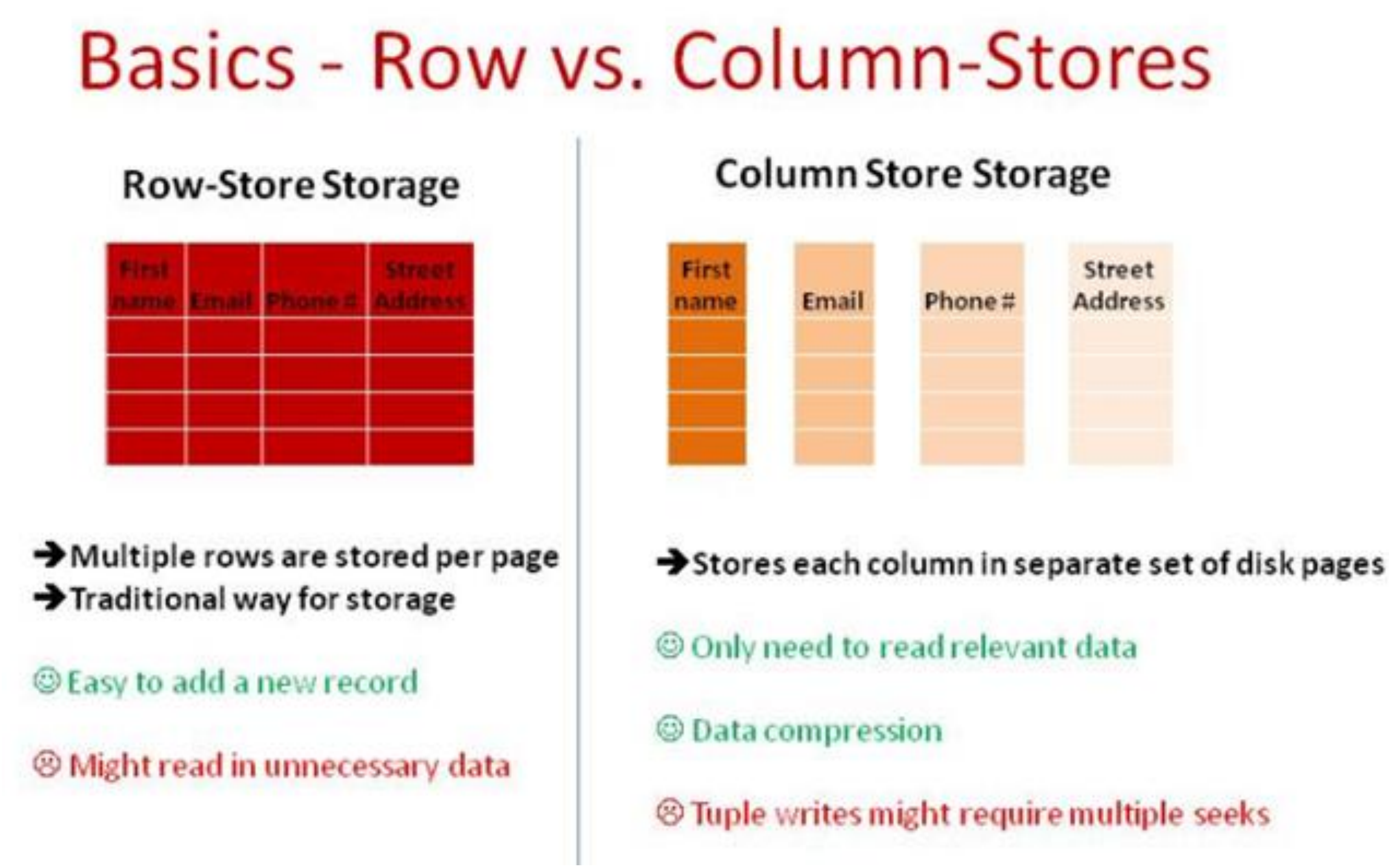
Consequences For Algorithms

- Analyze your access patterns
  - Sequential: you're OK
  - Random: it better fit in cache!
    - What is the access granularity?
    - Is there temporal locality?
    - Is there spatial locality?





Storage Layout of a Table



Improving Bad Access Patterns

- Minimize Random Memory Access
  - Apply filters first. Less accesses is better.
- Denormalize the Schema
  - Remove joins/lookups, add looked up stuff to the table (but.. makes it bigger)
- Trade Random Access For Sequential Access
  - perform a 100K random key lookups in a large table

    ➔ put 100K keys in a hash table, then

    scan table and lookup keys in hash table
- Try to make the randomly accessed region smaller
  - Remove unused data from the structure
  - Apply data compression
  - Cluster or Partition the data (improve locality) …hard for social graphs
- If the random lookups often fail to find a result
  - Use a Bloom Filter

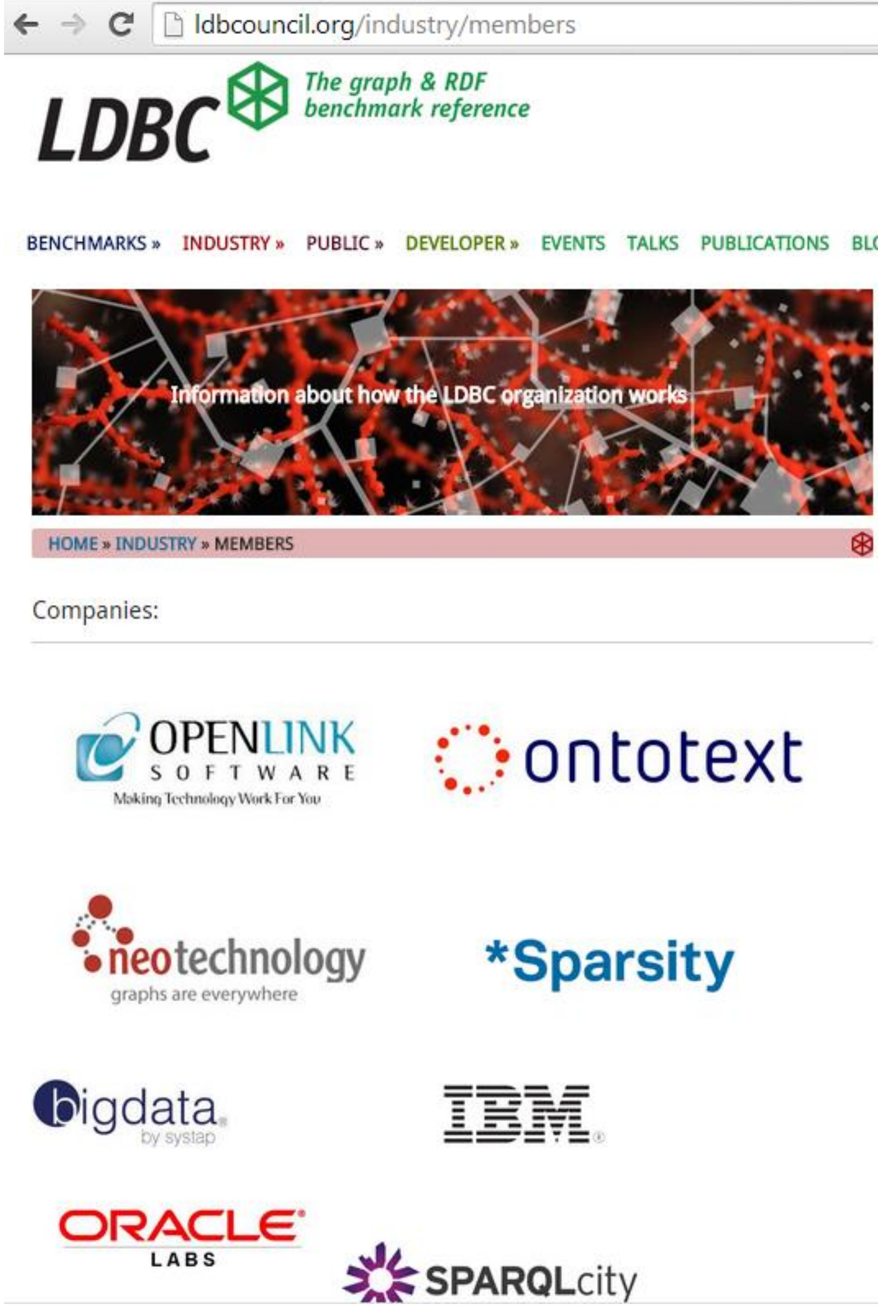
Assignment 1: Querying a Social Graph

LDBC Data generator

- Synthetic dataset available in different scale factors
  - SF100 🡐 for quick testing
  - SF3000 🡐 the real deal
- Very complex graph
  - Power laws (e.g. degree)
  - Huge Connected Component
  - Small diameter
  - Data correlations

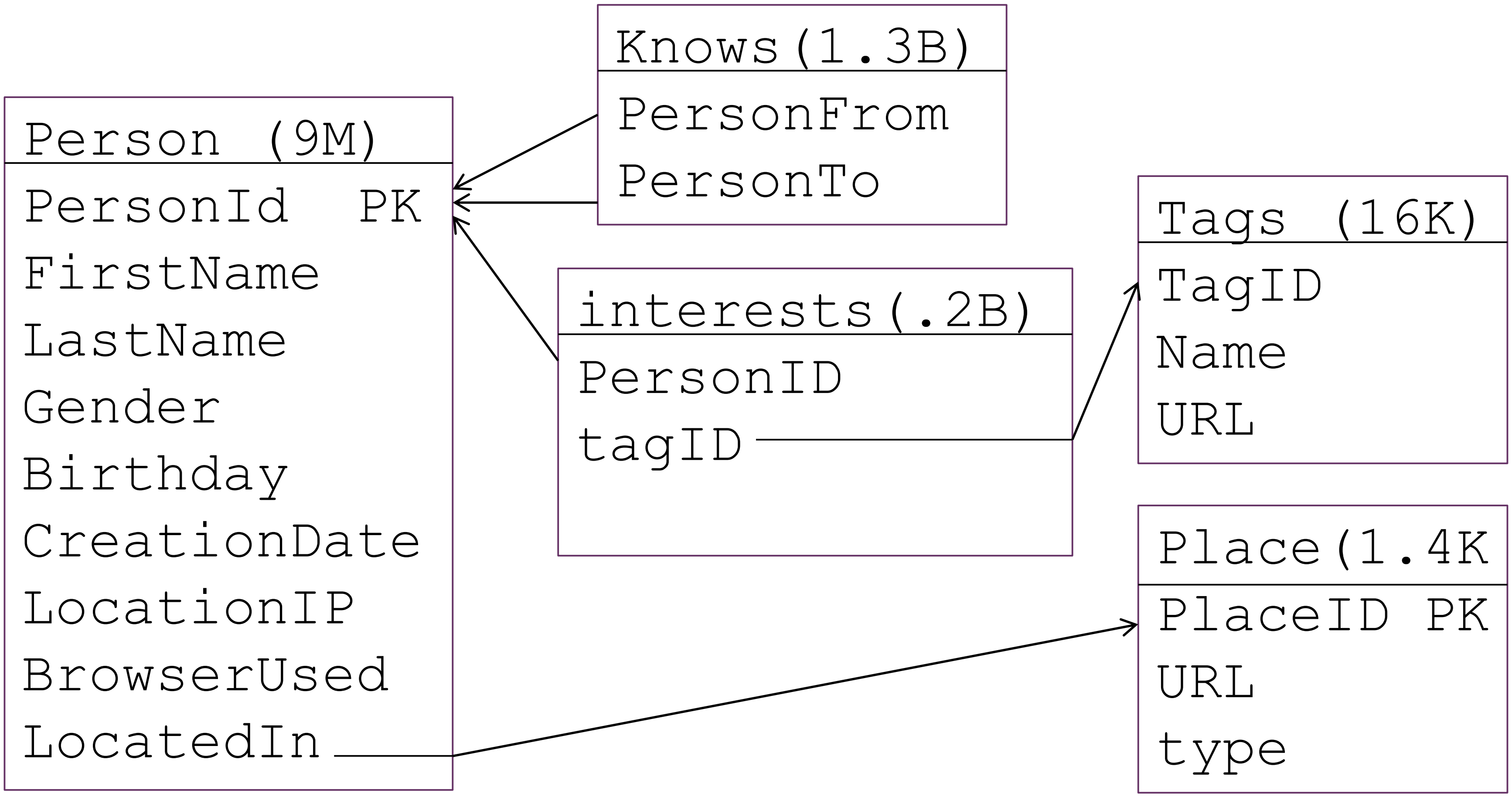
    Chinese have more Chinese names
  - Structure correlations

    Chinese have more Chinese friends



CSV file schema

- See: http://wikistats.ins.cwi.nl/lsde-data/practical_1
- Counts for sf3000 (total 37GB)



The Query

- The marketeers of a social network have been data mining the musical preferences of their users. They have built statistical models which predict given an interest in say artists A2 and A3, that the person would also like A1 (i.e. rules of the form: A2 and A3 ➔ A1). Now, they are commercially exploiting this knowledge by selling targeted ads to the management of artists who, in turn, want to sell concert tickets to the public but in the process also want to expand their artists' fanbase.
- The ad is a suggestion for people who already are interested in A1 to buy concert tickets of artist A1 (with a discount!) as a birthday present for a friend ("who we know will love it" - the social network says) who lives in the same city, who is not yet interested in A1 yet, but is interested in other artists A2, A3 and A4 that the data mining model predicts to be correlated with A1.

The Query

For all persons P :

- *who have their birthday on or in between D1..D2*
- *who do not like A1 yet*

  we give a score of

  - *1 for liking any of the artists A2, A3 and A4 and*
  - *0 if not*

  the final score, the sum, hence is a number between 0 and 3.

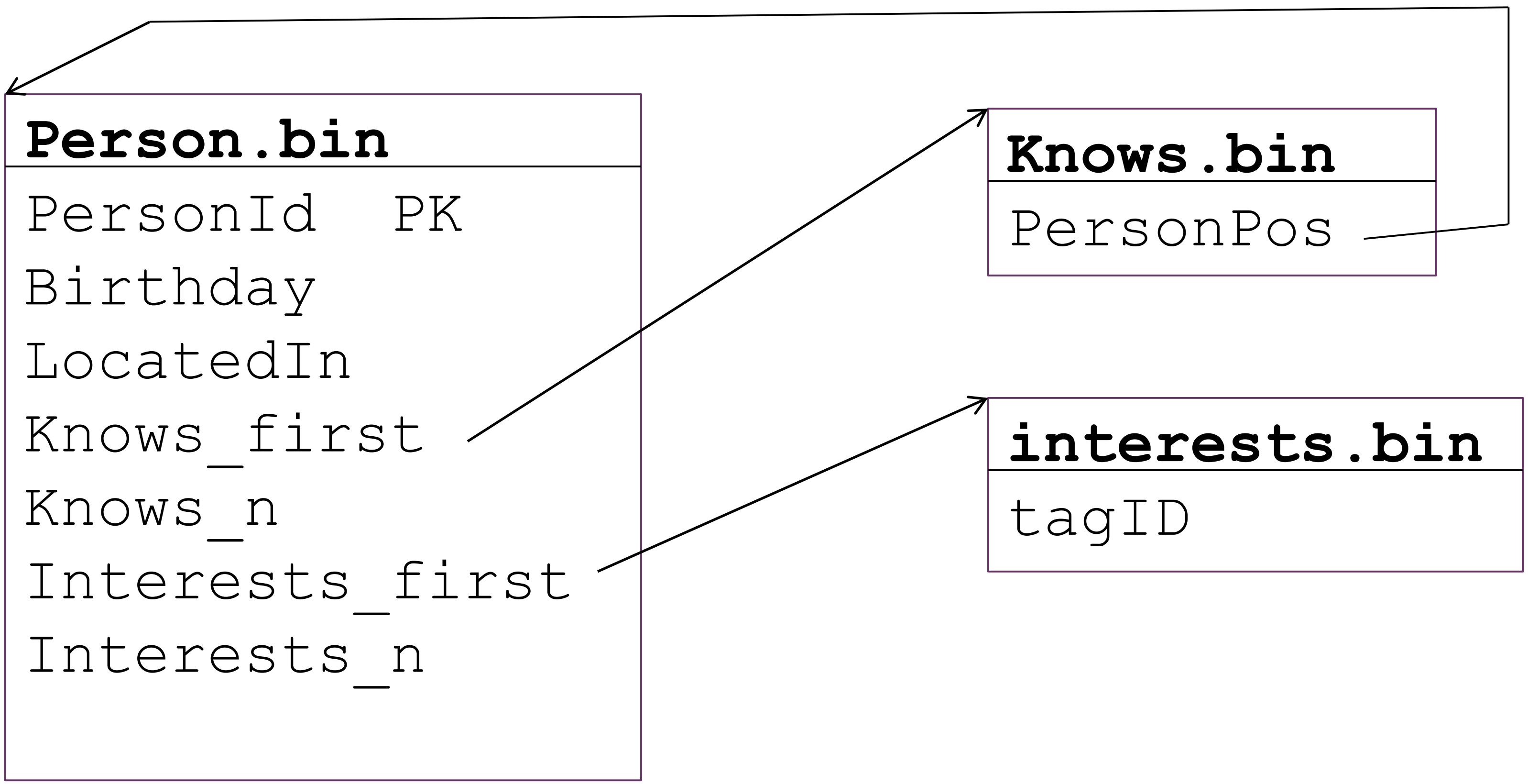
  Further, we look for friends F:

  - *Where P and F who know each other mutually*
  - *Where P and F live in the same city and*
  - *Where F already likes A1*

    The answer of the query is a table (score, P, F) with only scores > 0

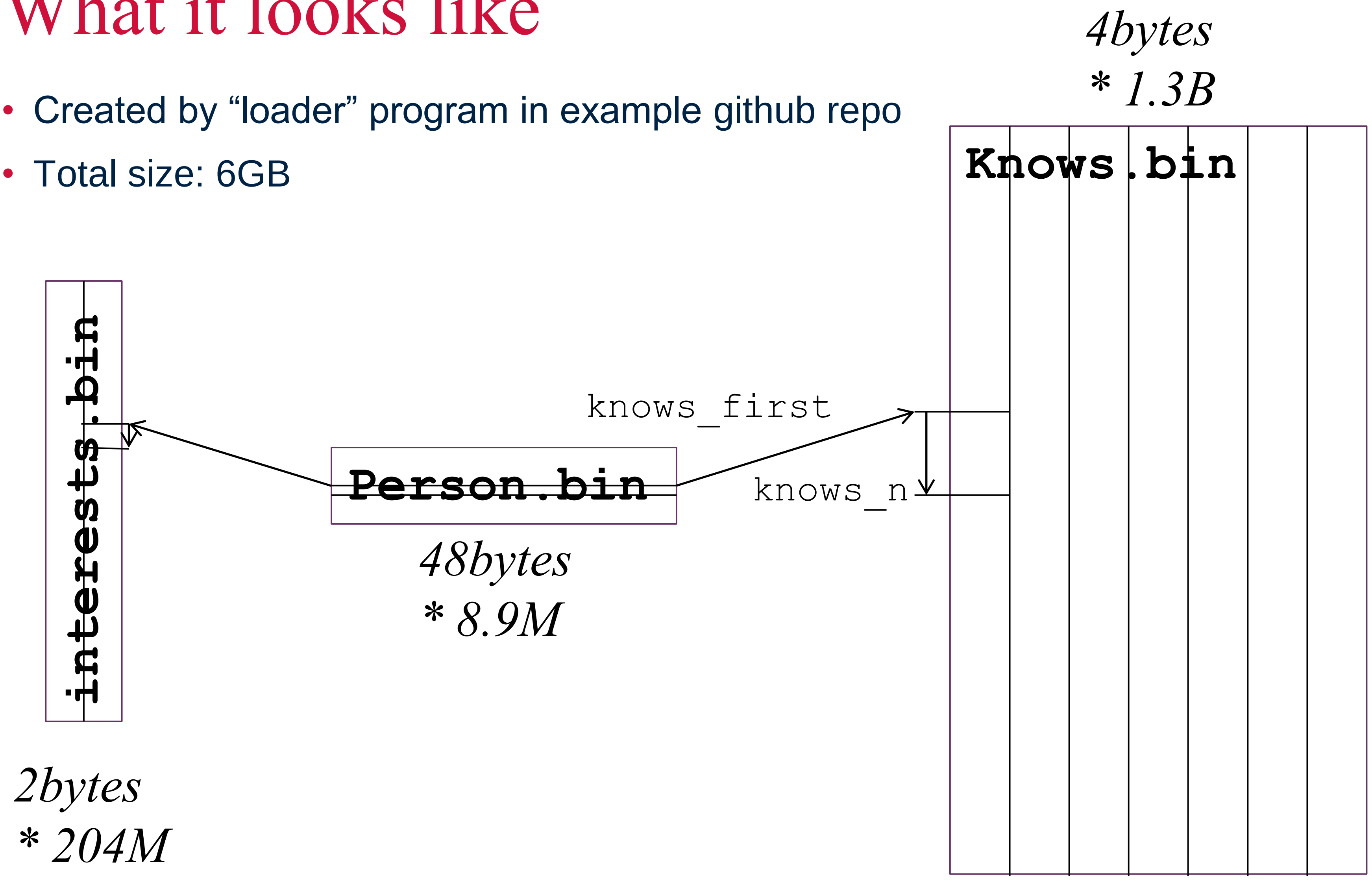
Binary files

- Created by "loader" program in example github repo
- Total size: 6GB



What it looks like

- Created by “loader” program in example github repo
- Total size: 6GB



The Naïve Implementation

The "cruncher" program

Go through the persons P sequentially

- *counting how many of the artists A2,A3,A4 are liked as the score*

  for those with score>0:

  - *visit all persons F known to P.*

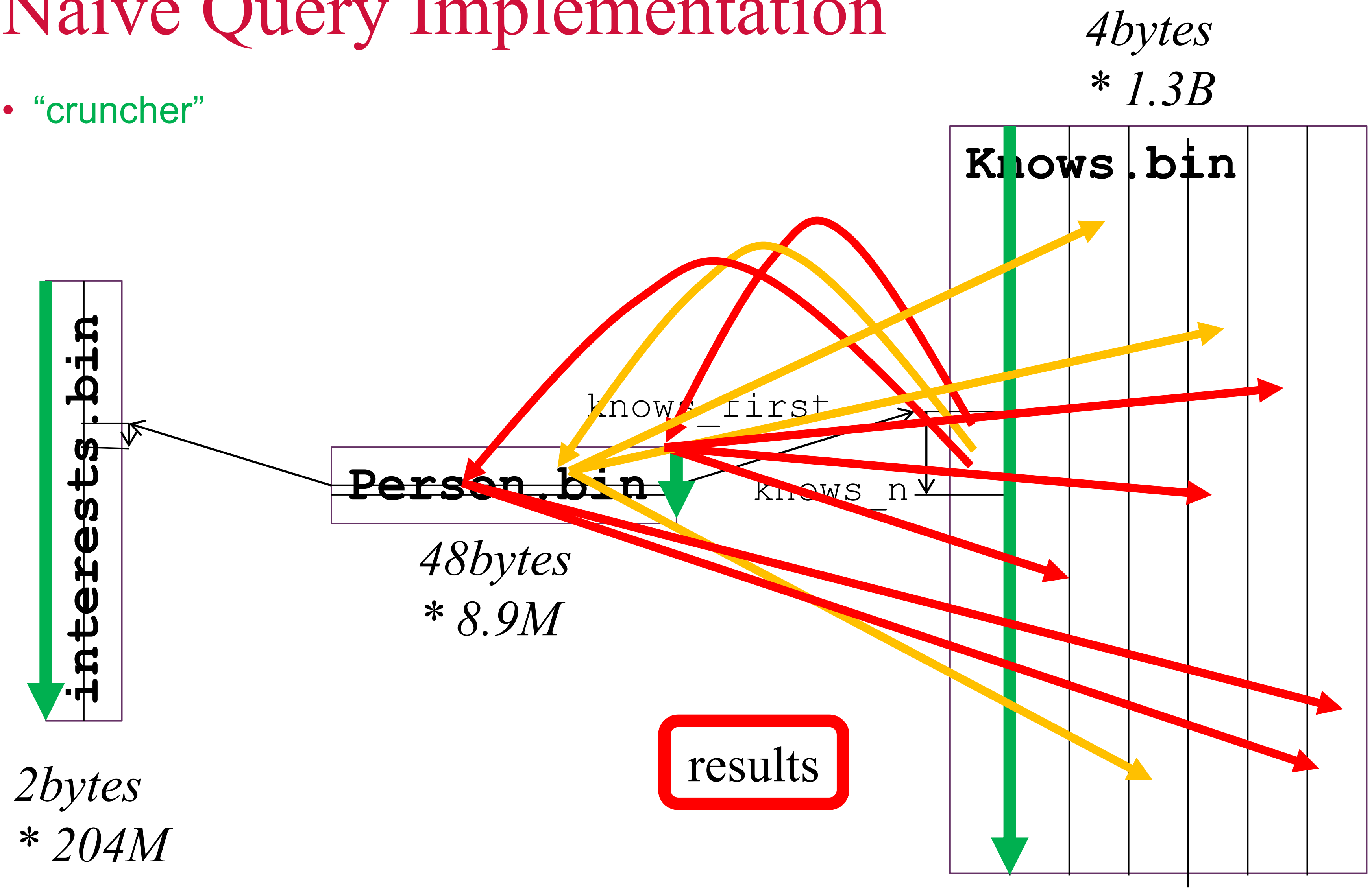
    For each F:

    - *checks on equal location*
    - *check whether F already likes A1*
    - *check whether F also knows P*

    if all this succeeds (score,P,F) is added to a result table.

Naïve Query Implementation

- "cruncher"



Challenges, questions

For the “reorg” program:

- Can we throw way unneeded data?
- Can we store the data more efficiently?
- Can we put the data in some order to improve access patterns?

For the “query” program:

- Can we move some of the work to the re-org phase?
- Can we improve the access pattern?
  - we trade random access for sequential access?
    - Multiple passes, instead of one?

We will meet on the leaderboard!