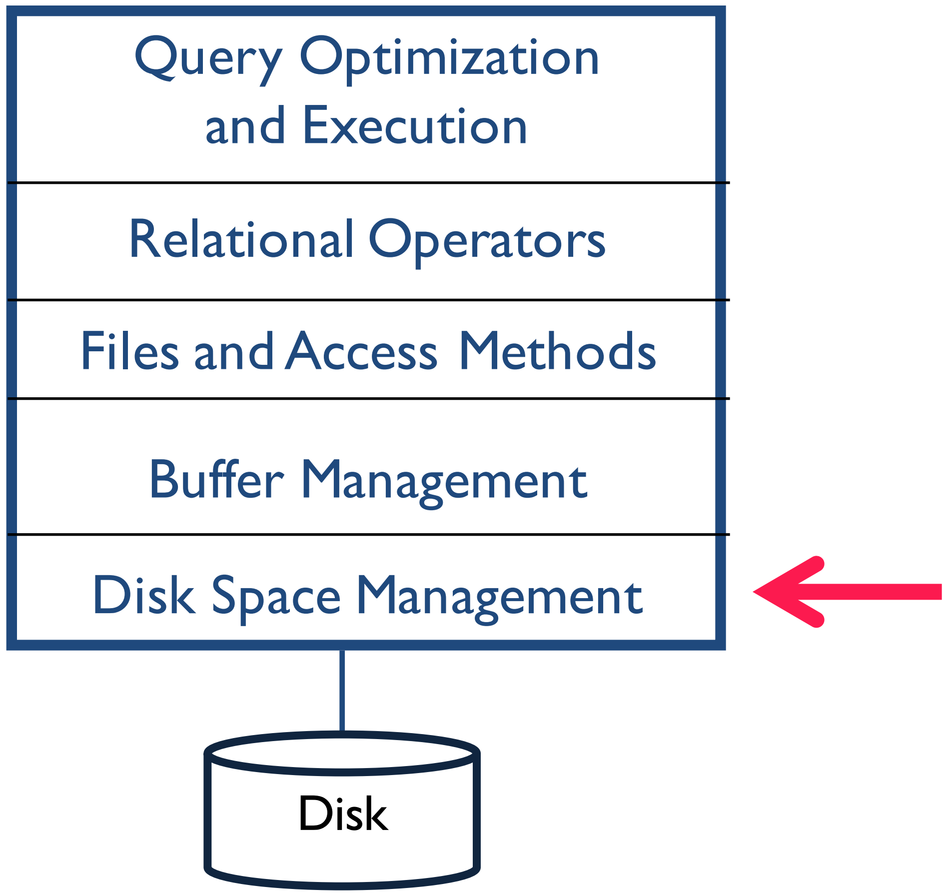
L8
Disk, Storage, and Indexing

Eugene Wu

Fall 2015

Work from the bottom up



$ Matters

- Why not store all in RAM?
  - Costs too much
    - High-end Databases today ~Petabyte (1000TB) range.
    - ~60% cost of a production system is in the disks.
  - Main memory not persistent
    - Obviously important if DB stops/crashes
- Some systems are *main-memory* DBMSes, topic for advanced DB course

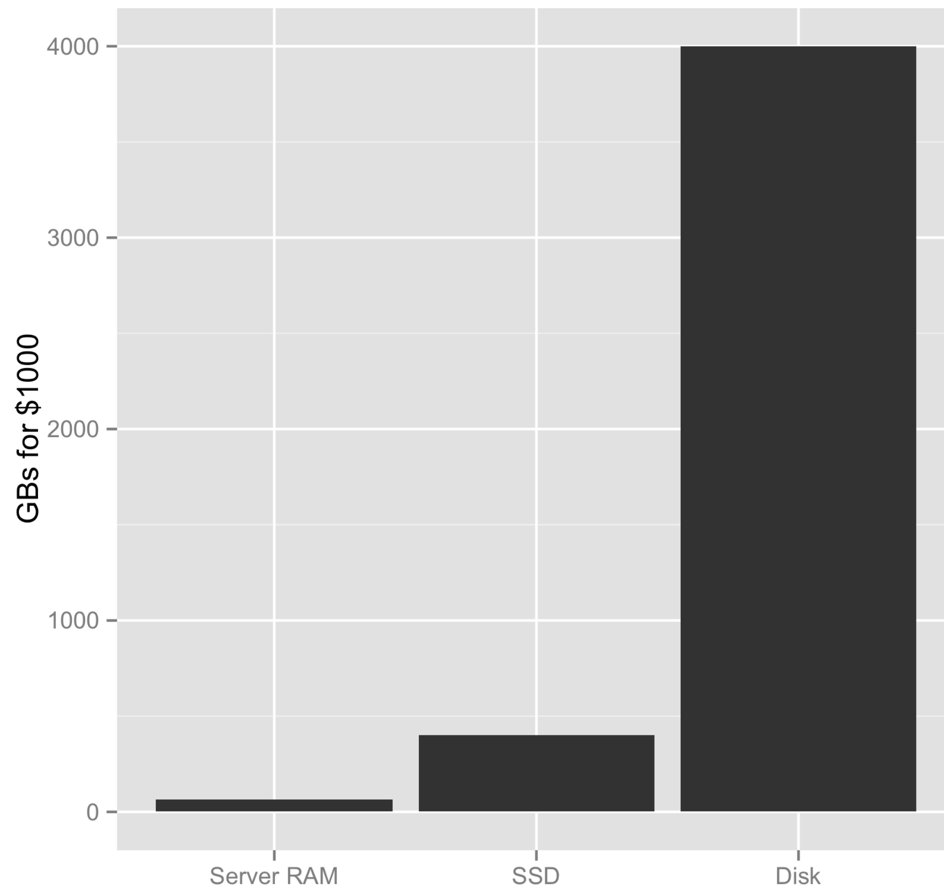
$ Matters

Newegg enterprise $1000

RAM: 64

SSD: 400

Disk: 4000

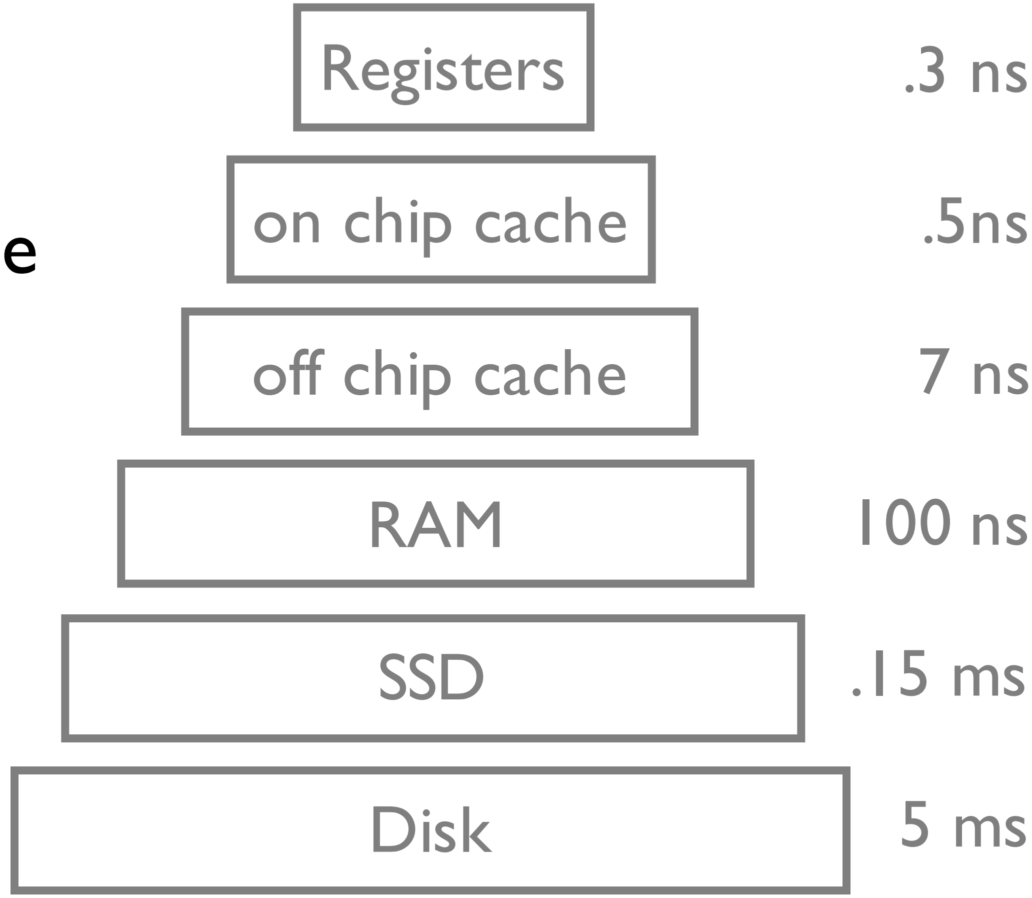


RAM for active data

Disk for main database
secondary storage

Tapes for archive

SSD is still in flux,
some in use

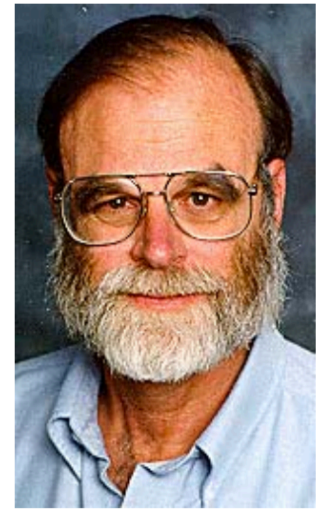


Interesting numbers

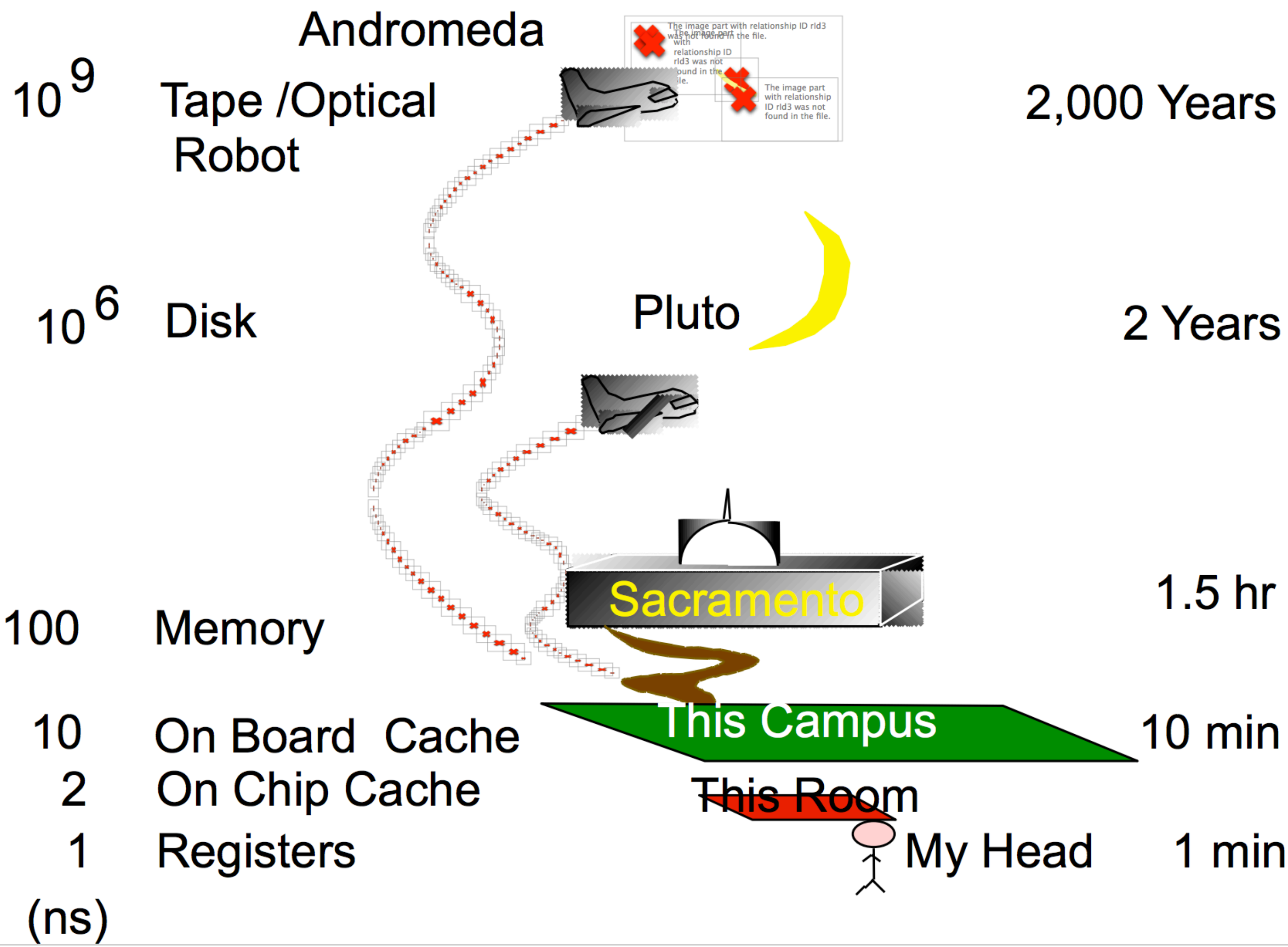
compress 1k bytes:	3000 ns
roundtrip in data center:	.5 ms

https://gist.github.com/jboner/2841832

Jim Gray's Storage Latency Analogy: How Far Away is the Data?

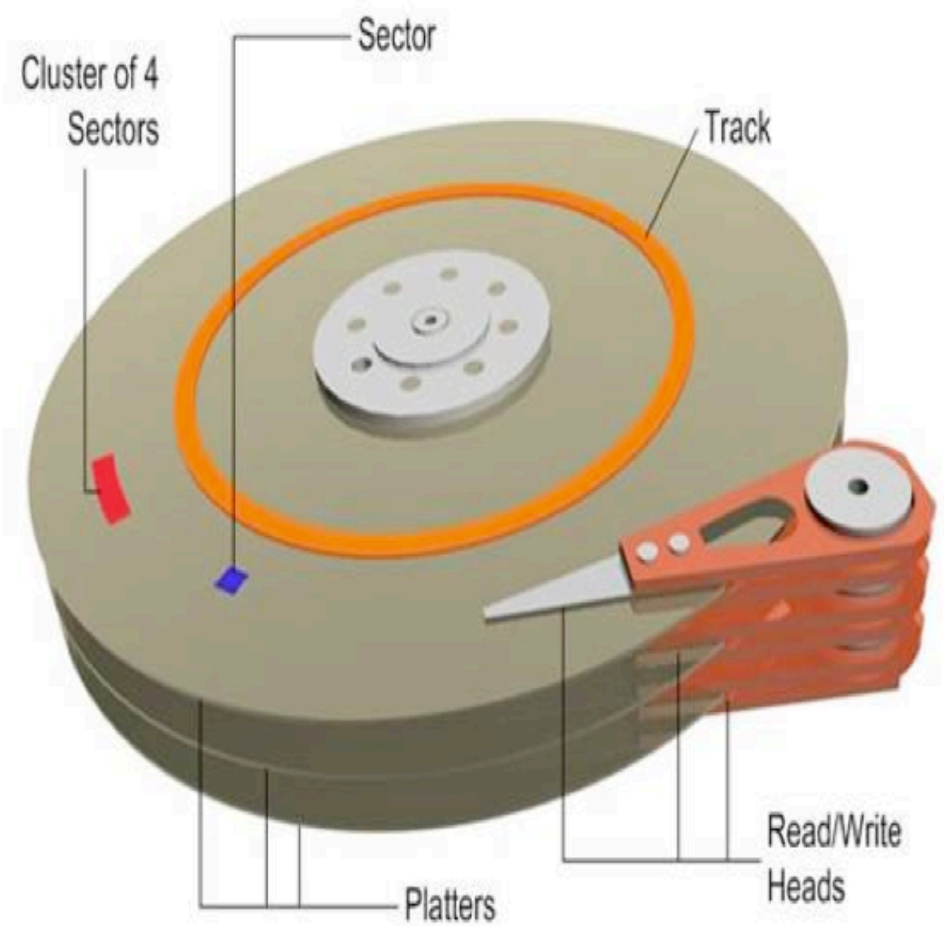


Jim Gray
Turing Award
B.S. Cal 1966
Ph.D. Cal 1969!



Spin speed: ~7200 RPM

Arm moved in/out to position head over a track



Time to access (read or write) a disk block

seek time	2-4 msec avg
rotational delay	2-4 msec
transfer time	0.3 msec/64kb page

Throughput

read	~150 MB/sec
write	~50 MB/sec

Key: reduce seek and rotational delays

HW & SW approaches

Next block concept (in order of speed)

- blocks on same track
- blocks on same cylinder
- blocks on adjacent cylinder

Sequentially arrange files

- minimize seek and rotation latency

When sequentially scanning: Pre-fetch

- >1 page/block at once

SSD maybe

Fast changing, not yet stabilized

Read small & fast

- single read: 0.03ms
- 4kb random reads: 500MB/sec
- seq reads: 525MB/sec

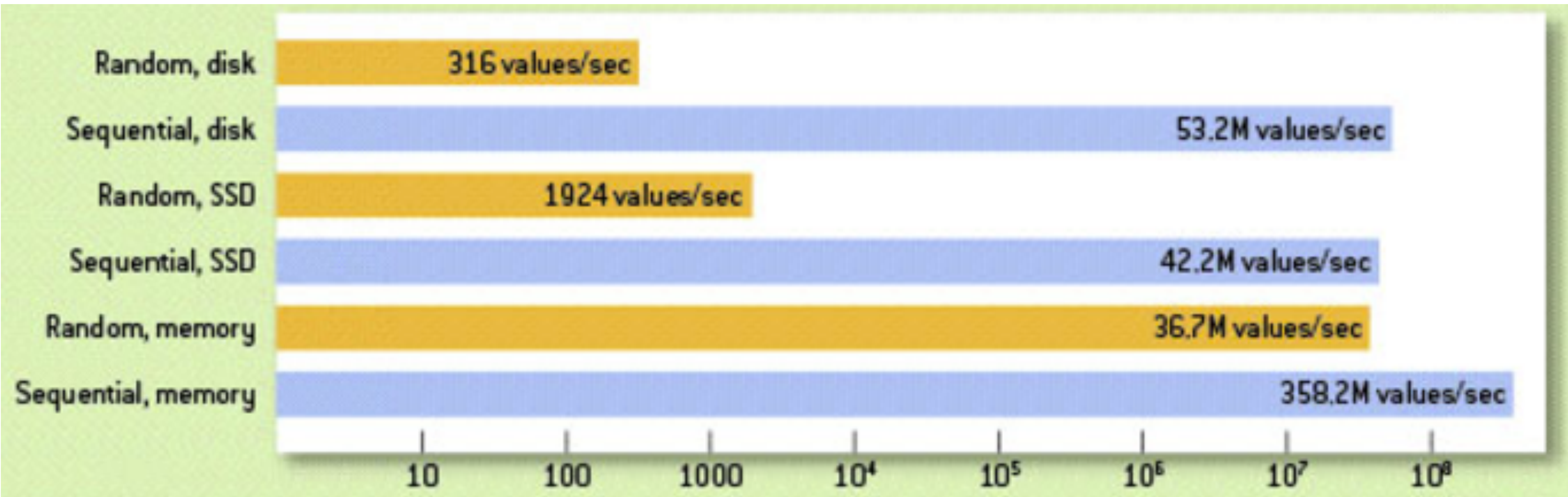
Write is slower for random

- single write: 0.03ms
- 4kb random writes: 120MB/sec
- seq writes: 120MB/sec

Write endurance limited

- 2-3k cycle lifetimes
- 6-10 months

4 byte values read per second



5 orders of magnitude

Pragmatics of Databases

Most databases are pretty small

- All global daily weather since 1929: 20GB
- 2000 US Census: 200GB
- 2009 english wikipedia: 14GB

Data sizes grow faster than moore's law

Disk Space Management

VLDBs	SSDs: reduce variance
Small DBs	interesting data is small

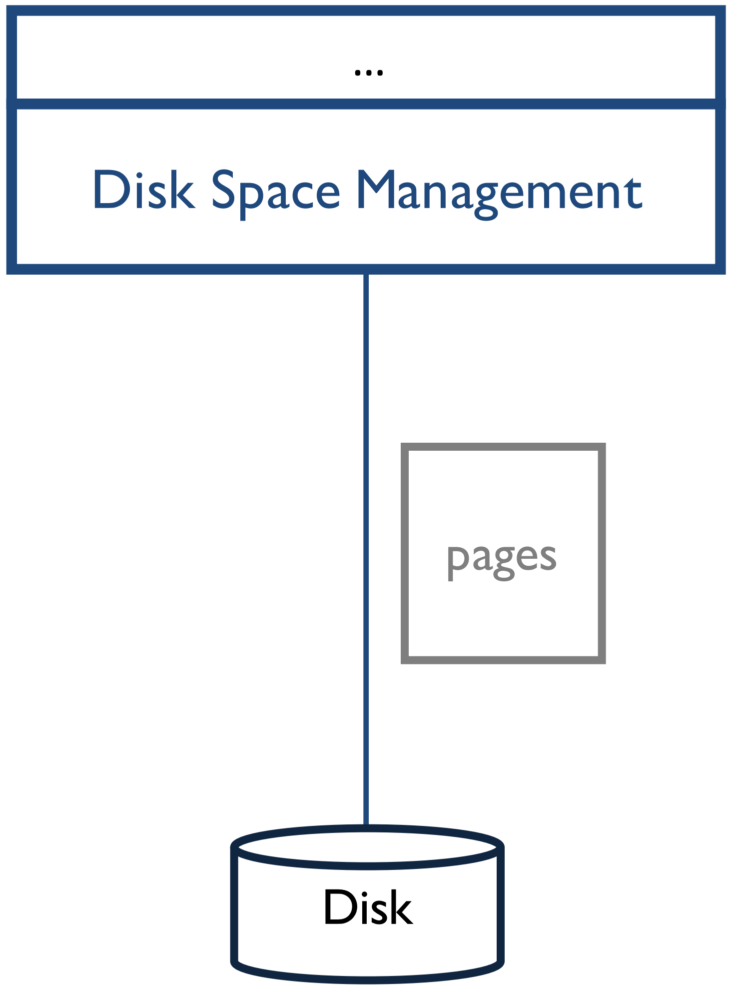
Huge data exists

Many interesting data is small

People will still worry about magnetic disk.

May not care about it

Work from the bottom up



Disk Space Management

Lowest layer of DBMS, manages space on disk

Low level IO interface:
- allocate/deallocate a page
- read/write page

Sequential performance desirable
- try to ensure sequential pages are sequential on disk
- hidden from rest of DBMS
- but algorithms may assume sequential performance

Files

Pages are IO interface
Higher levels work on records and files (of records)

File: collection of pages
    insert/delete/modify record
    get(record_id) a record
    scan all records

Page: collection of records
    typically *fixed size* (8kb in PostgreSQL)

May be stored in multiple OS files spanning multiple disks

Units that we'll care about

Ignore CPU cost
Ignore RAM cost

B # *data* pages on disk for relation
R # records per data page
D avg time to read/write data page to/from disk

Simplifies life when computing costs
Very rough approximation, but OK for now
    ignores prefetching, bulk writes/reads, CPU/RAM

Unordered Heap Files

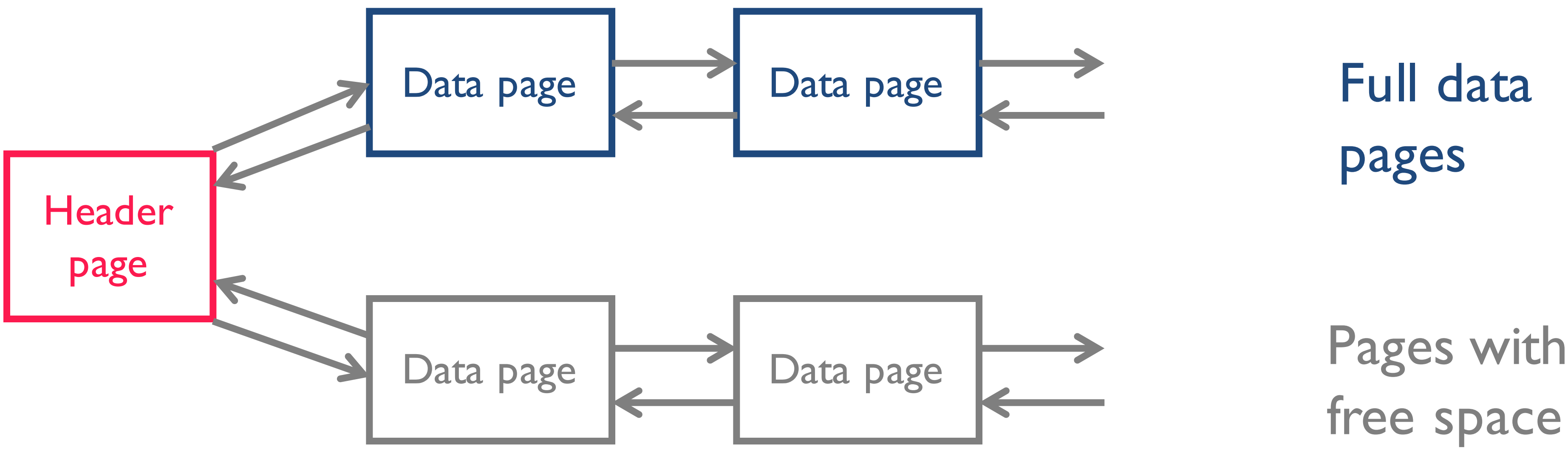
Collection of records (no order)

As add/rm records, pages de/allocated

To support record level ops, need to track:

- pages in file
- free space on pages
- records on page

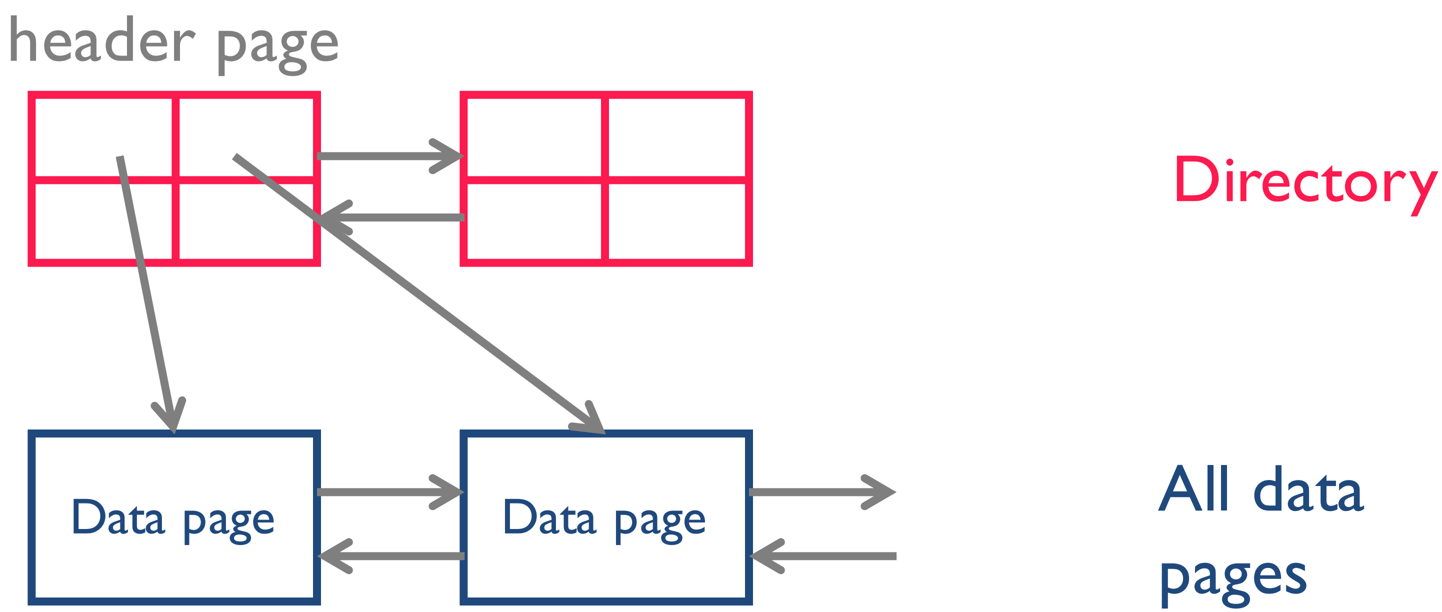
Heap File



Header page and heap file pointers stored in catalog

Data page = 2 pointers + data

Use a directory



Directory entries track #free bytes on data pages

Directory is collection of pages

Indexes

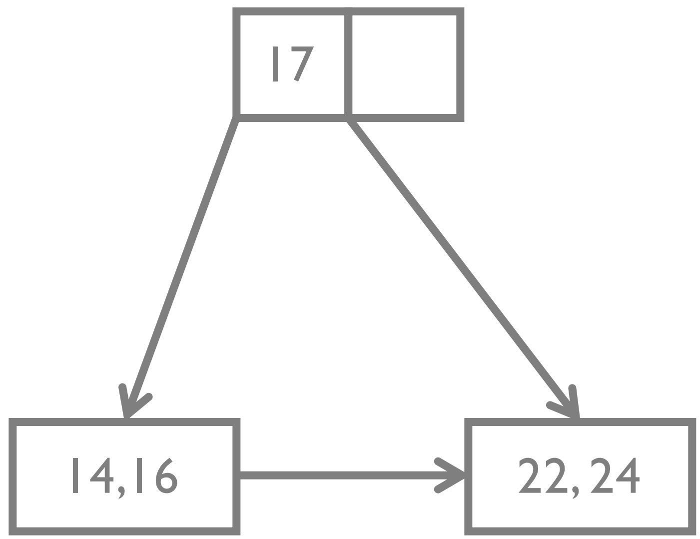
Heap files can get data
- by rid
- by sequential scan

Queries use *qualifications* (predicates)
- find students in "CS"
- find students from CA

Indexes
- file structures for value-based queries
- B+-tree index (~1970s)
- Hash index

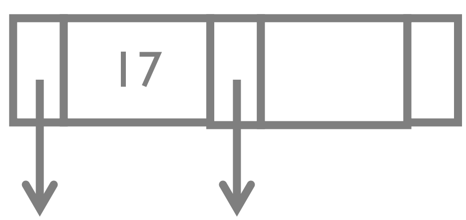
Overview! Details in 4112

B+ Tree

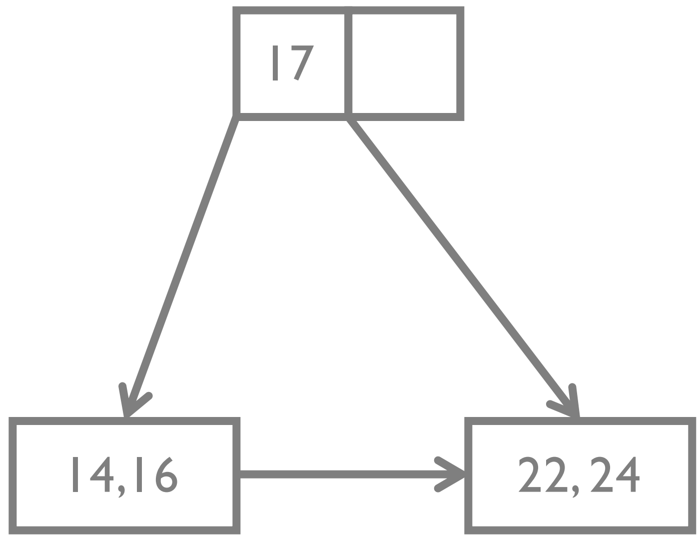


Query: SELECT * WHERE val = 14

directory page

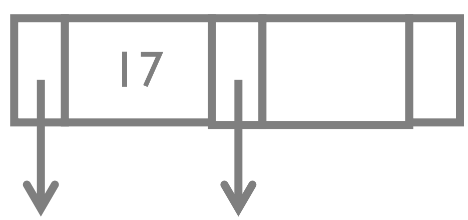


B+ Tree

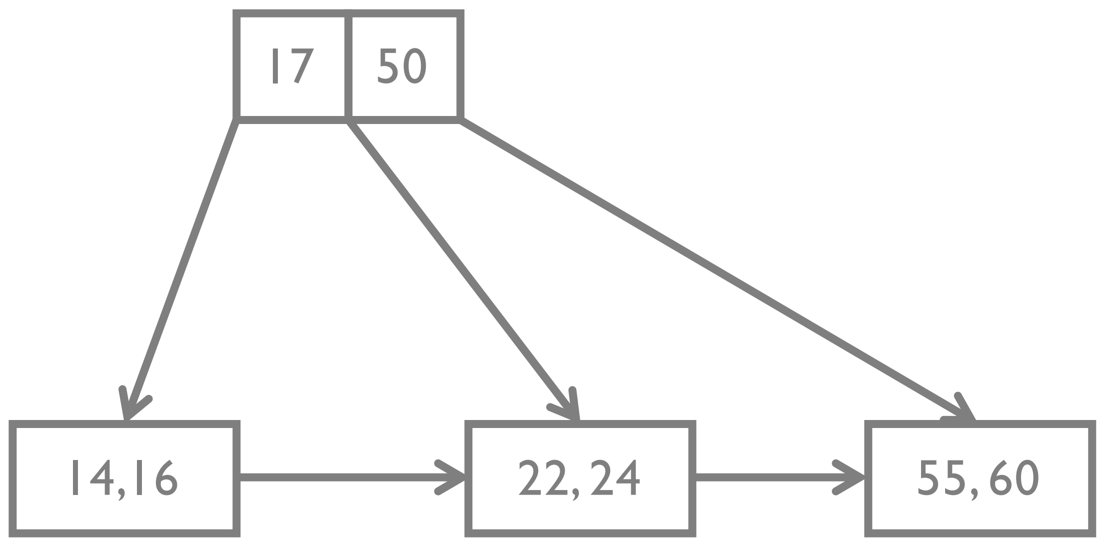


Query: SELECT val WHERE val = 14
(index only)

directory page

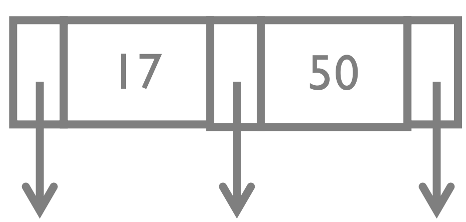


B+ Tree

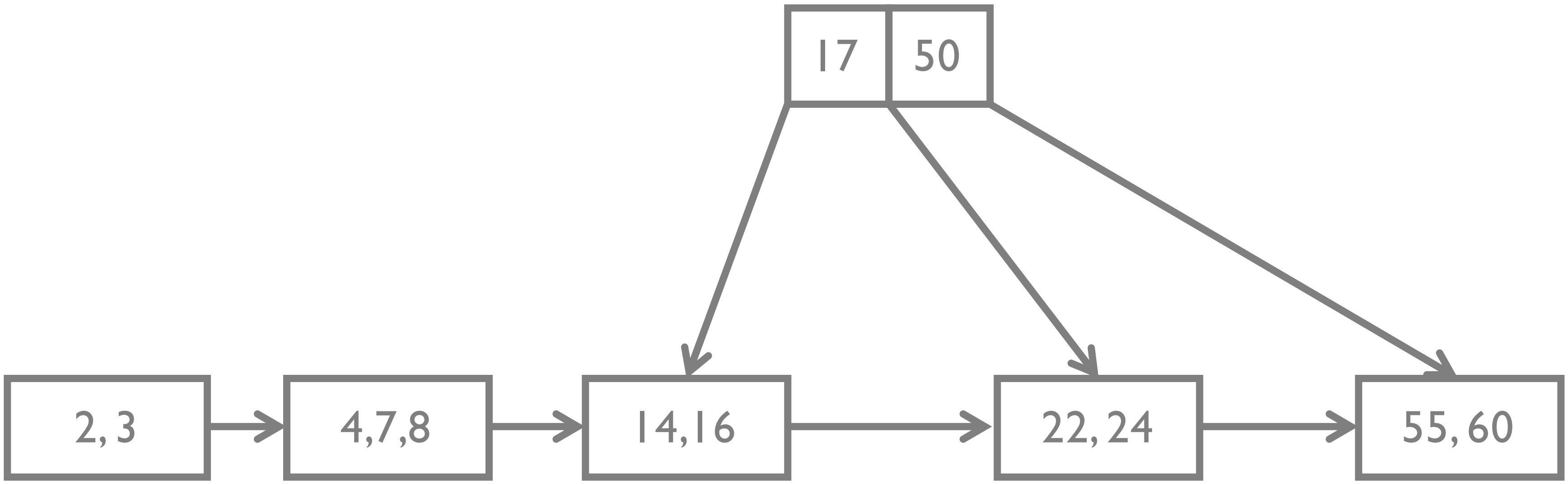


Query: SELECT * WHERE val = 55

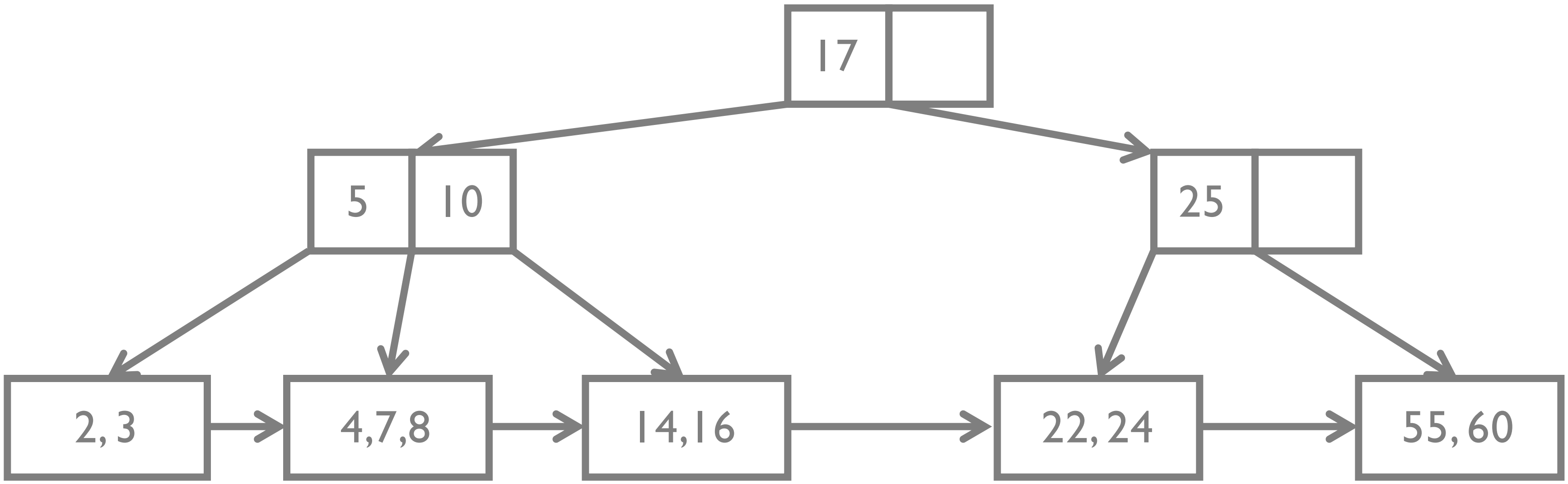
directory page



B+ Tree



B+ Tree



Query: SELECT * WHERE val > 20

Some numbers (8kb pages)

How many levels?

fill-factor: ~66%

~300 entries per directory page

if fill completely

height 2: 300^3 ~ 27 Million

height 3: 300^4 ~ 8.1 Billion

Top levels often in memory

Level 3 only 90k pages ~750MB

Cool B+Tree viz: https://www.cs.usfca.edu/~galles/visualization/BPlusTree.html

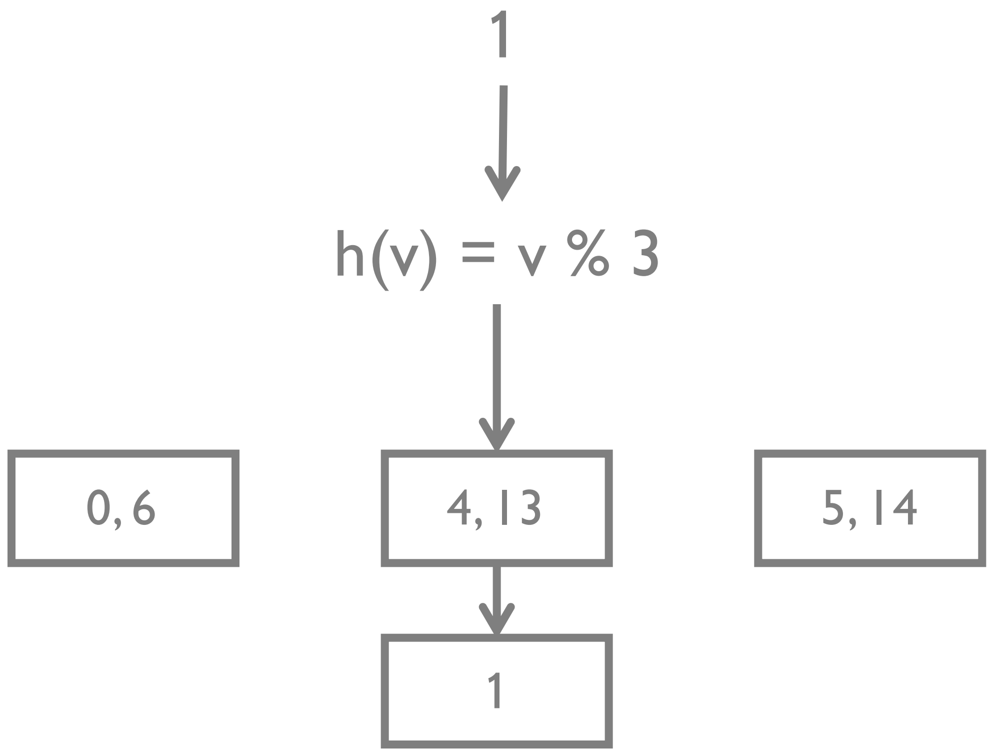
Hash Index

1

h(v) = v % 3

0, 6	4, 13	5, 14

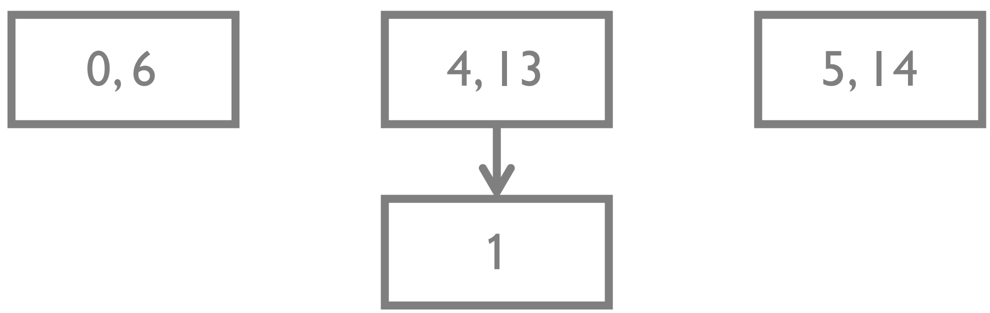
Hash Index



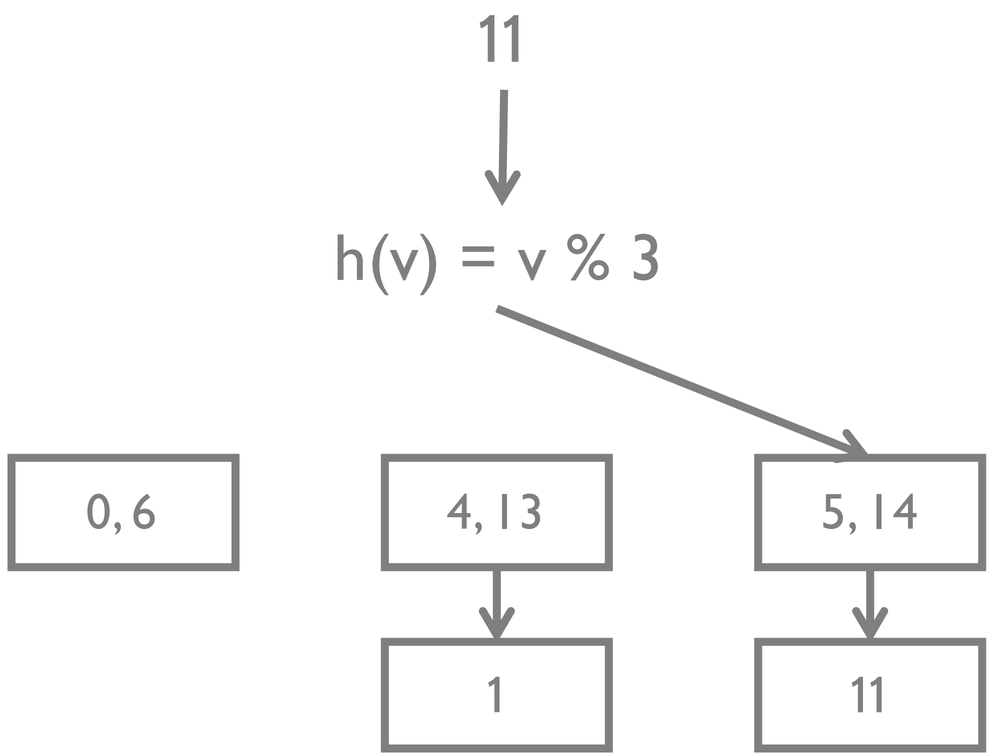
Hash Index

11

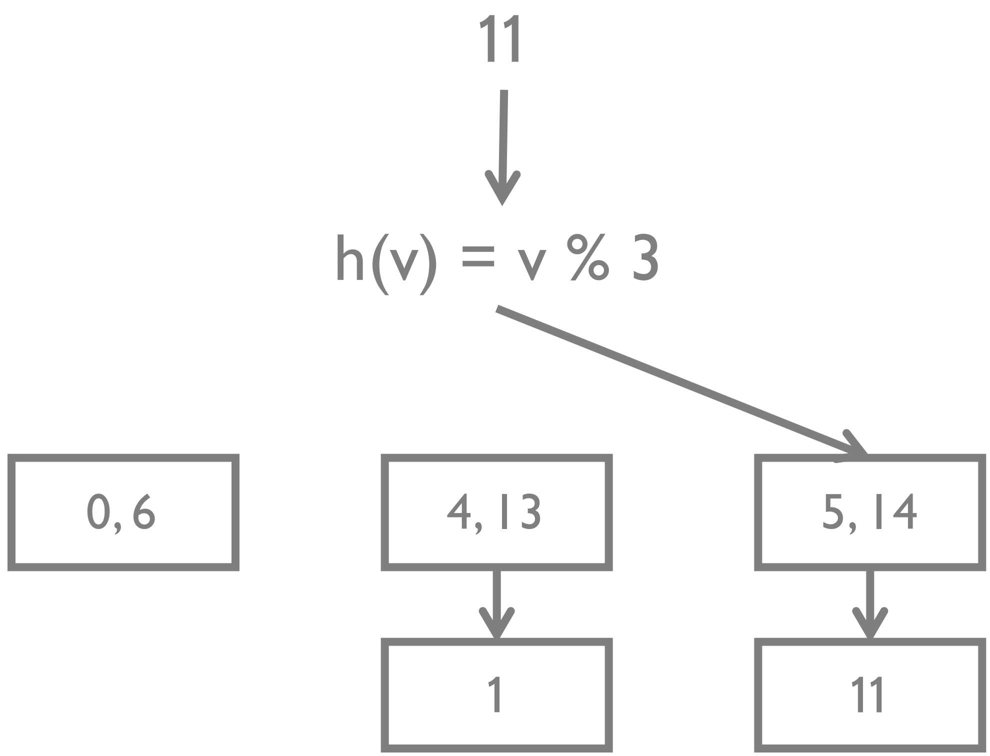
h(v) = v % 3



Hash Index



Hash Index



Good for equality selections

Index = data pages + overflow data pages

Hash function h(v) takes as input the *search key*

Costs

Three file types

- Heap, B+ Tree, Hash

Operations we care about

Scan all data	SELECT * FROM R
Equality	SELECT * FROM R WHERE x = 1
Range	SELECT * FROM R WHERE x > 10 and x < 50
Insert record	
Delete record	

	Heap File	Sorted Heap	B+ Tree	Hash
Scan everything				
Equality				
Range				
Insert				
Delete				

B # *data* pages

D time to read/write page

M # pages in range query

	Heap File	Sorted Heap	B+ Tree	Hash
Scan everything	BD			
Equality	0.5BD			
Range	BD			
Insert	2D			
Delete	Search + D			

Heap File

equality on a key. How many results?

B # *data* pages

D time to read/write page

M # pages in range query

	Heap File	Sorted Heap	B+ Tree	Hash
Scan everything	BD	BD		
Equality	0.5BD	$D(\log_2 B)$		
Range	BD	$D(\log_2 B + M)$		
Insert	2D	Search + BD		
Delete	Search + D	Search + BD		

Heap File

equality on a key. How many results?

Sorted File

files compacted after deletion

B # *data* pages

D time to read/write page

M # pages in range query

	Heap File	Sorted Heap	B+ Tree	Hash
Scan everything	BD	BD	1.2BD	
Equality	0.5BD	$D(\log_2 B)$	$D(\log_{80} B + 1)$	
Range	BD	$D(\log_2 B + M)$	$D(\log_{80} B + M)$	
Insert	2D	Search + BD	$D(\log_{80} B)$	
Delete	Search + D	Search + BD	$D(\log_{80} B)$	

Heap File

equality on a key. How many results?

Sorted File

files compacted after deletion

B+ Tree

100 entries/directory page

80% fill factor

B # *data* pages

D time to read/write page

M # pages in range query

	Heap File	Sorted Heap	B+ Tree	Hash
Scan everything	BD	BD	1.2BD	1.2BD
Equality	0.5BD	$D(\log_2 B)$	$D(\log_{80} B + 1)$	D
Range	BD	$D(\log_2 B + M)$	$D(\log_{80} B + M)$	1.2BD
Insert	2D	Search + BD	$D(\log_{80} B)$	2D
Delete	Search + D	Search + BD	$D(\log_{80} B)$	2D

Heap File

equality on a key. How many results?

Sorted File

files compacted after deletion

B+ Tree

100 entries/directory page

80% fill factor

Hash index

no overflow

80% fill factor

B # *data* pages

D time to read/write page

M # pages in range query

How to pick?

Depends on your queries (workload)

- Which relations?
- Which attributes?
- Which types of predicates (=, <,>)
- *Selectivity*
- Insert/delete/update queries? how many?

How to choose indexes?

Considerations

- which relations should have indexes?
- on what attributes?
- how many indexes?
- what type of index (hash/tree)?

Naïve Algorithm

for each query in order of importance

- calculate best cost using current indexes
- if there’s best plan with a new index
  - create it

Why not create every index?

- update queries slowed down (upkeep costs)
- takes up space

High level guidelines

Check the WHERE clauses

- attributes in WHERE are search/index keys
- equality predicate → hash index
- range predicate → tree index

Multi-attribute search keys supported

- order of attributes matters for range queries
- may enable queries that don't look at data pages (*index-only*)

Summary

Design depends on economics, access cost ratios

Disk still dominant wrt cost/capacity ratio

Many physical layouts for files

- same APIs, difference performance
- remember physical independence

Indexes

- Structures to speed up read queries
- Multiple indexes possible
- Decision depends on workload