# CSE 562
# Database Systems

## Hashing and More

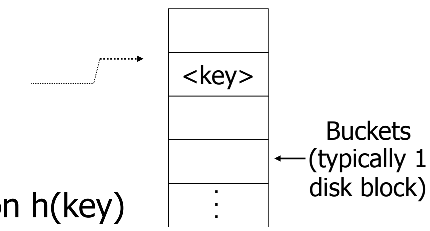
Some slides are based or modified from originals by
*Database Systems: The Complete Book,*
*Pearson Prentice Hall 2nd Edition*


cse@buffalo



## Hashing

key → h(key)

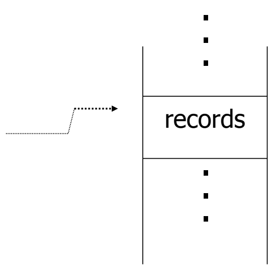



- hash function h(key) returns address of bucket or record



## Two alternatives

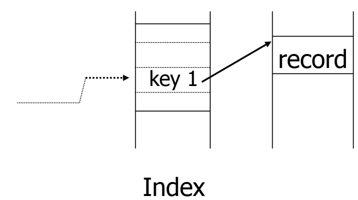
(1) key → h(key)






## Two alternatives

(2) key → h(key)




- Alt (2) for "secondary" search key

## Example hash function

- Key = '$x_1$ $x_2$ … $x_n$'   *n* byte character string
- Have *b* buckets
- h: add $x_1 + x_2 + \ldots\ldots x_n$
  - compute sum modulo *b*



➡ This may not be best function …

➡ Read Knuth Vol. 3 if you really need to select a good function

Good hash function: ☞ Expected number of keys/bucket is the same for all buckets

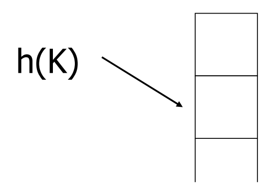


## Within a bucket:

- Do we keep keys sorted?
- Yes, if CPU time critical
  & Inserts/Deletes not too frequent

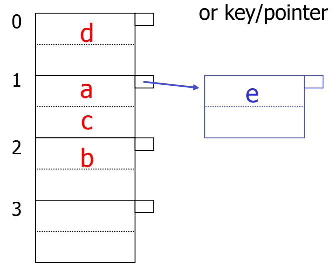


Next: example to illustrate inserts, overflows, deletes



## EXAMPLE 2 records/bucket

INSERT:
h(a) = 1
h(b) = 2
h(c) = 1
h(d) = 0
h(e) = 1

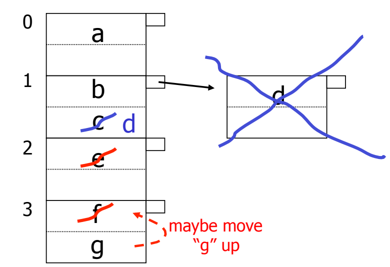



Record may be full tuple or key/pointer combo



## EXAMPLE: deletion

Delete:
e
f
c






## Rule of thumb:

- Try to keep space utilization between 50% and 80%

  Utilization = $\frac{\text{\# keys used}}{\text{total \# keys that fit}}$

- If < 50%, wasting space
- If > 80%, overflows significant
  depends on how good hash function is & on # keys/bucket



## How do we cope with growth?

- Overflows and reorganizations
- Dynamic hashing
  - Extensible
  - Linear

## Extensible hashing: two ideas

(a) Use *i* of *b* bits output by hash function

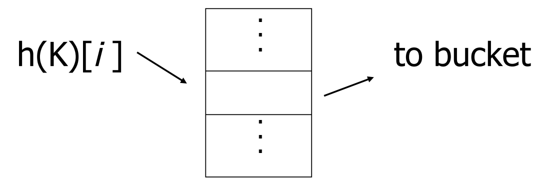
$\longleftarrow \; b \; \longrightarrow$

h(K) → $\boxed{00110101}$

use *i* → grows over time....

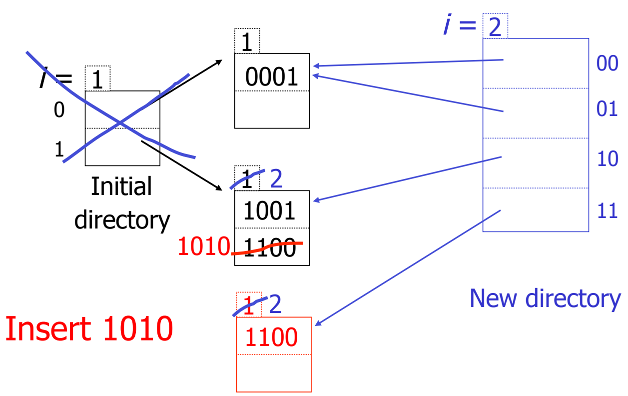


(b) Use directory



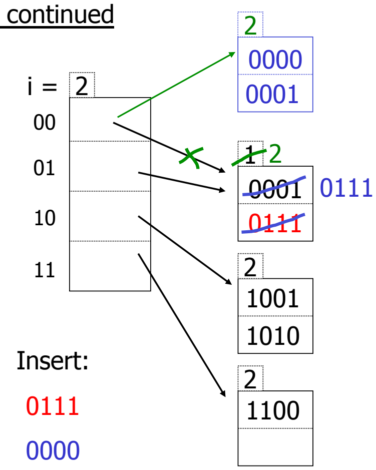



## Example: h(k) is 4 bits; 2 keys/bucket

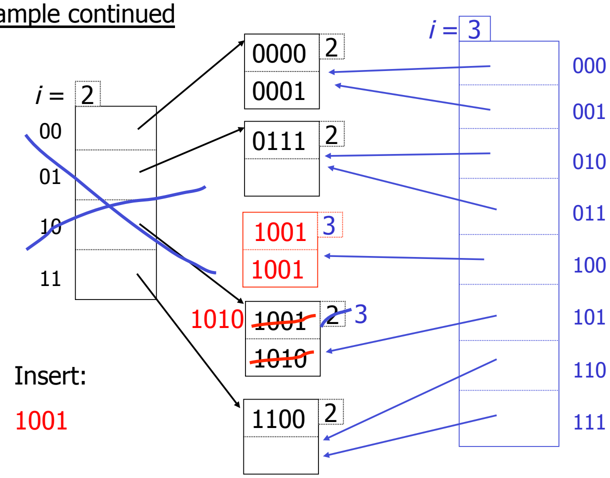





Example continued



Example continued






## Extensible hashing: deletion

- No merging of blocks
- Merge blocks
  and cut directory if possible
  (Reverse insert procedure)



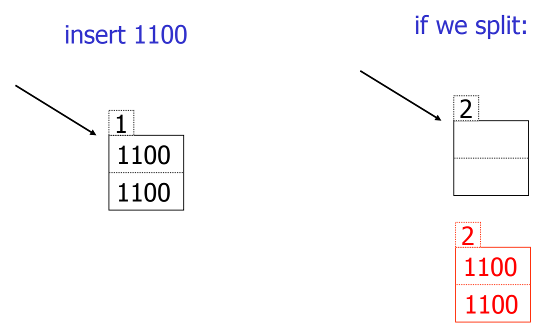
## Deletion example:

- Run thru insert example in reverse!



## Note: Still need overflow chains

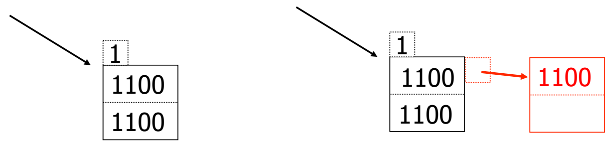
- Example: many records with duplicate keys



# Solution: overflow chains

insert 1100

add overflow block:






Summary Extensible hashing

+ Can handle growing files
  - with less wasted space
  - with no full reorganizations

- Indirection

  (Not bad if directory in memory)

- Directory doubles in size

  (Now it fits, now it does not)

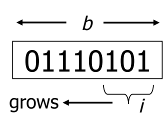


# Linear hashing

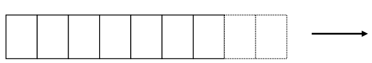
- Another dynamic hashing scheme

Two ideas:

(a) Use *i* low order bits of hash



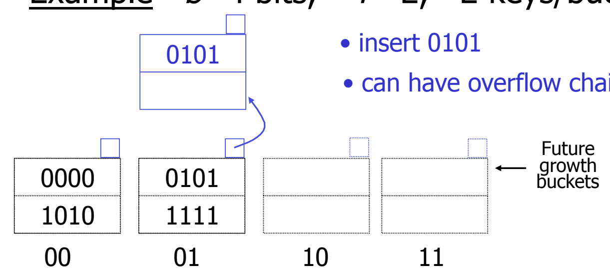

(b) File grows linearly





Example *b*=4 bits, *i* =2, 2 keys/bucket

- insert 0101
- can have overflow chains!

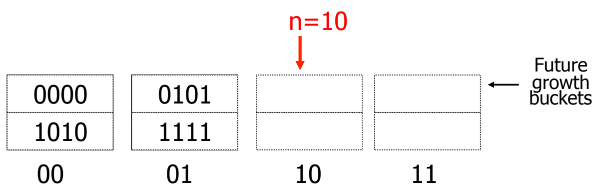



$m$ = 01 (max used block)

Rule If $h(k)[i] \leq m$, then
look at bucket h(k)[i ]
else, look at bucket $h(k)[i] - 2^{i-1}$

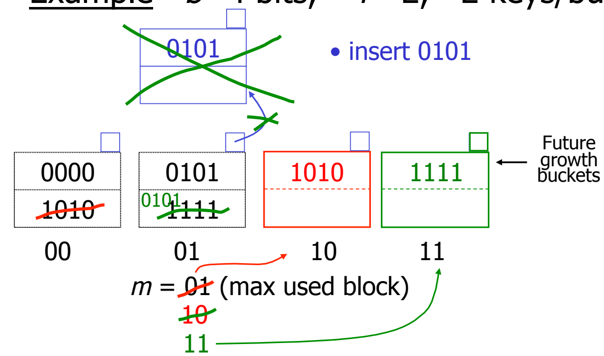
# Note

- In textbook, n is used instead of m
- n=m+1



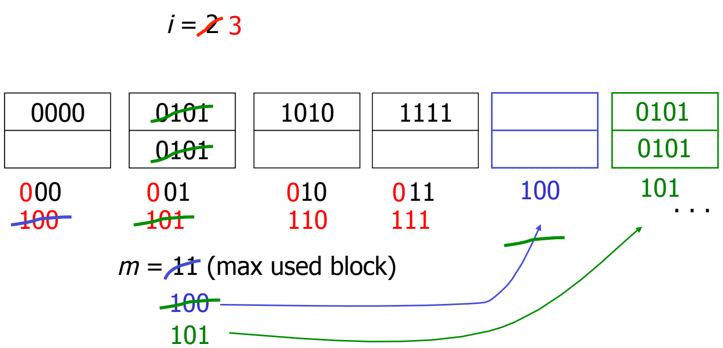



## Example $b$=4 bits, $i$ =2, 2 keys/bucket






## Example Continued: How to grow beyond this?






☛ When do we expand file?

- Keep track of: $\frac{\text{\# used slots}}{\text{total \# of slots}} = U$

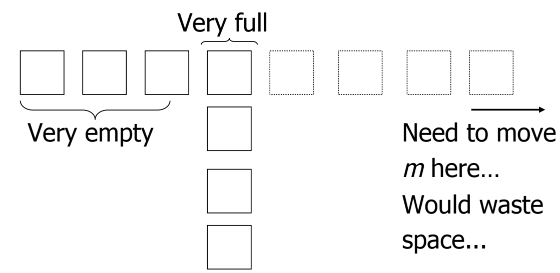
- If U > threshold then increase $m$
  (and maybe $i$ )

## Summary — Linear Hashing

- (+) Can handle growing files
  - with less wasted space
  - with no full reorganizations
- (+) No indirection like extensible hashing
- (-) Can still have overflow chains



## Example: BAD CASE






## Summary

Hashing
- How it works
- Dynamic hashing
  - Extensible
  - Linear



## Next:

- Indexing vs Hashing
- Index definition in SQL
- Multiple key access

## Indexing vs Hashing

- Hashing good for probes given key

  e.g., SELECT …
  FROM R
  WHERE R.A = 5



## Indexing vs Hashing

- INDEXING (Including B-Trees) good for Range Searches:

  e.g., SELECT
  FROM R
  WHERE R.A > 5



## Index definition in SQL

- CREATE INDEX name ON rel (attr)
- CREATE UNIQUE INDEX name ON rel (attr)

  → defines candidate key

- DROP INDEX name



Note CANNOT SPECIFY TYPE OF INDEX
(e.g. B-Tree, Hashing, …)
OR PARAMETERS
(e.g. Load Factor, Size of Hash,...)

... at least in SQL...

Note ATTRIBUTE <u>LIST</u> ⇒ MULTIKEY INDEX (next)

e.g., <u>CREATE</u> <u>INDEX</u> foo <u>ON</u> R(A,B,C)



## Multi-key Index

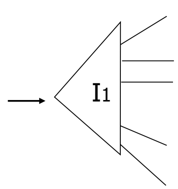
Motivation: Find records where

DEPT = "Toy" AND SAL > 50k



## <u>Strategy I:</u>

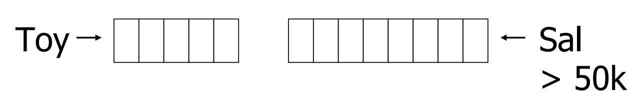
- Use one index, say Dept.
- Get all Dept = "Toy" records and check their salary






## <u>Strategy II:</u>

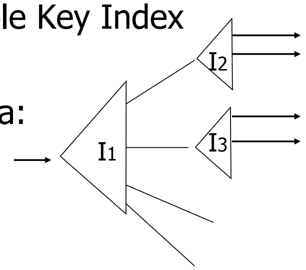
- Use 2 Indexes; Manipulate Pointers



## Strategy III:

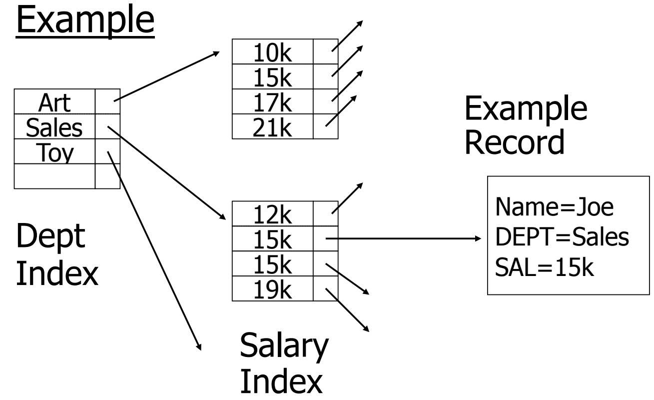
- Multiple Key Index

One idea:






## Example





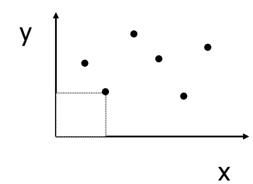

For which queries is this index good?

- ☐ Find RECs Dept = "Sales" $\wedge$ SAL=20k
- ☐ Find RECs Dept = "Sales" $\wedge$ SAL $\geq$ 20k
- ☐ Find RECs Dept = "Sales"
- ☐ Find RECs SAL = 20k



## Interesting application:

- Geographic Data




DATA:

<X1,Y1, Attributes>

<X2,Y2, Attributes>

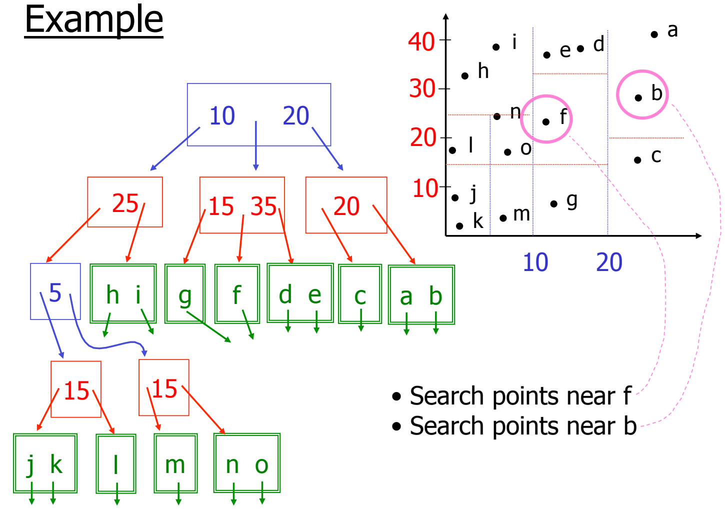
⋮

## Queries:

- What city is at <Xi,Yi>?
- What is within 5 miles from <Xi,Yi>?
- Which is closest point to <Xi,Yi>?



## Example




- Search points near f
- Search points near b



## Queries

- Find points with Yi > 20
- Find points with Xi < 5
- Find points “close” to i = <12,38>
- Find points “close” to b = <7,24>



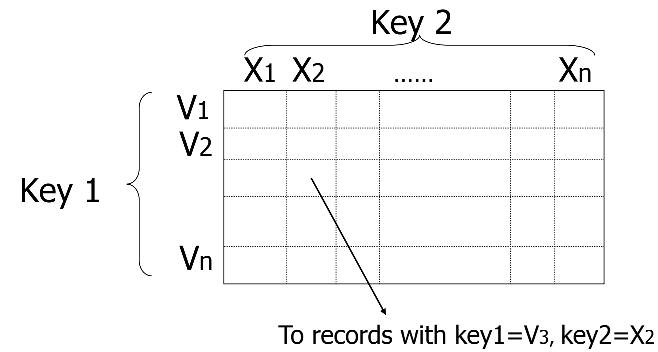
- Many types of geographic index structures have been suggested
  - kd-Trees (very similar to what we described here)
  - Quad Trees
  - R Trees
  - …

## Two more types of multi key indexes

- Grid
- Partitioned hash



## Grid Index






## CLAIM

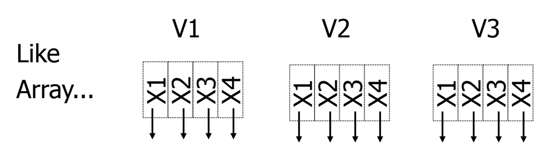
- Can quickly find records with
  - key 1 = $V_i$ $\wedge$ Key 2 = $X_j$
  - key 1 = $V_i$
  - key 2 = $X_j$

- And also ranges….
  - E.g., key 1 $\geq$ $V_i$ $\wedge$ key 2 < $X_j$



☛ But there is a <u>catch</u> with Grid Indexes!

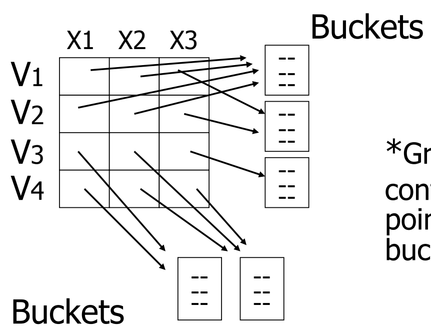
- How is Grid Index stored on disk?




**<u>Problem:</u>**

- Need regularity so we can compute position of <Vi,Xj> entry

## Solution: Use Indirection




*Grid only contains pointers to buckets

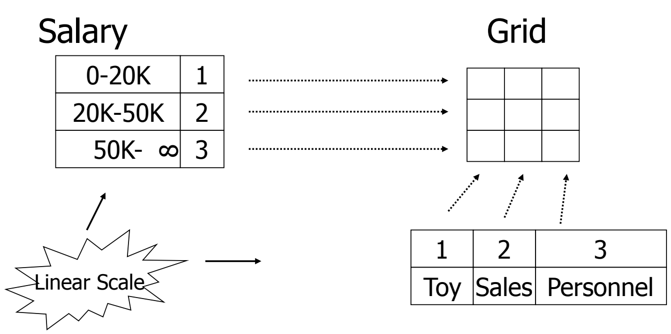


## With indirection:

- Grid can be regular without wasting space
- We do have price of indirection



## Can also index grid on value ranges






## Grid files

⊕ Good for multiple-key search

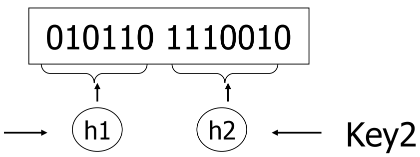
⊖ Space, management overhead

(nothing is free)

⊖ Need partitioning ranges that evenly split keys

## Partitioned hash function

Idea:






## EX:

| | | | |
|---|---|---|---|
| h1(toy) | =0 | 000 | |
| h1(sales) | =1 | 001 | <Fred> |
| h1(art) | =1 | 010 | |
| . | | 011 | |
| h2(10k) | =01 | 100 | |
| h2(20k) | =11 | 101 | <Joe><Sally> |
| h2(30k) | =01 | 110 | |
| h2(40k) | =00 | 111 | |
| : | | | |

Insert ⇒ <Fred,toy,10k>,<Joe,sales,10k>
<Sally,art,30k>



| | | | |
|---|---|---|---|
| h1(toy) | =0 | 000 | <Fred> |
| h1(sales) | =1 | 001 | <Joe><Jan> |
| h1(art) | =1 | 010 | <Mary> |
| . | | 011 | |
| h2(10k) | =01 | 100 | <Sally> |
| h2(20k) | =11 | 101 | |
| h2(30k) | =01 | 110 | <Tom><Bill> |
| h2(40k) | =00 | 111 | <Andy> |
| : | | | |

- Find Emp. with Dept. = Sales $\wedge$ Sal=40k



| | | | |
|---|---|---|---|
| h1(toy) | =0 | 000 | <Fred> |
| h1(sales) | =1 | 001 | <Joe><Jan> |
| h1(art) | =1 | 010 | <Mary> |
| . | | 011 | |
| h2(10k) | =01 | 100 | <Sally> |
| h2(20k) | =11 | 101 | |
| h2(30k) | =01 | 110 | <Tom><Bill> |
| h2(40k) | =00 | 111 | <Andy> |
| : | | | |

- Find Emp. with Sal=30k

look here

h1(toy) =0
h1(sales) =1
h1(art) =1
:
h2(10k) =01
h2(20k) =11
h2(30k) =01
h2(40k) =00
:

| | |
|---|---|
| 000 | <Fred> |
| 001 | <Joe><Jan> |
| 010 | <Mary> |
| 011 | |
| 100 | <Sally> |
| 101 | |
| 110 | <Tom><Bill> |
| 111 | <Andy> |

- Find Emp. with Dept. = Sales

look here



## Summary

Post hashing discussion:

- Indexing vs. Hashing
- SQL Index Definition
- Multiple Key Access
  - Multi Key Index
    Variations: Grid, Geo Data
  - Partitioned Hash



## Reading Chapter 14

- Skim the following sections:
  – Sections 14.6.6, 14.6.7, 14.6.8
  – Sections 14.7.2, 14.7.3, 14.7.4
- Read the rest



## The BIG picture….

- Chapter 13: Storage, records, blocks...
- Chapter 14: Access Mechanisms
  - Indexes
  - B-Trees
  - Hashing
  - Multi key
- Chapter 15 & 16: Query Processing NEXT