CS143: Index

Book Chapters:
(4th) 12.1-3, 12.5-8
(5th) 12.1-3, 12.6-8, 12.10

Topics to Learn

- Important concepts
  - Dense index vs. sparse index
  - Primary index vs. secondary index (= clustering index vs. non-clustering index)
  - Tree-based vs. hash-based index
- Tree-based index
  - Indexed sequential file
  - B+-tree
- Hash-based index
  - Static hashing
  - Extendible hashing

Basic Problem

- SELECT *
  FROM Student
  WHERE sid = 40

sid	name	GPA
20	Elaine	3.2
70	Peter	2.6
40	Susan	3.7

- How can we answer the query?

Random-Order File

- How do we find sid=40?

sid	name	GPA
20	Susan	3.5
60	James	1.7
70	Peter	2.6
40	Elaine	3.9
30	Christy	2.9

Sequential File

- Table sequenced by sid. Find sid=40?

sid	name	GPA
20	Susan	3.5
30	James	1.7
40	Peter	2.6
50	Elaine	3.9
60	Christy	2.9

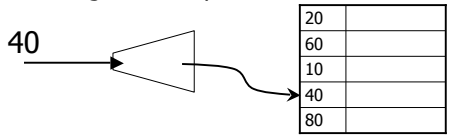
Binary Search

- 100,000 records
- Q: How many blocks to read?

- Any better way?
  - In a library, how do we find a book?

Basic Idea

- Build an "index" on the table
  - An auxiliary structure to help us locate a record given a "key"



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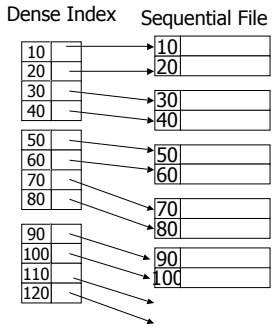
Dense, Primary Index



- Primary index (clustering index)
  - Index on the search key
- Dense index
  - (key, pointer) pair for every record
- Find the key from index and follow pointer
  - Maybe through binary search
- Q: Why dense index?
  - Isn't binary search on the file the same?

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Why Dense Index?

- Example
  - 10,000,000 records (900-bytes/rec)
  - 4-byte search key, 4-byte pointer
  - 4096-byte block. Unspanned tuples
- Q: How many blocks for table (how big)?
- Q: How many blocks for index (how big)?

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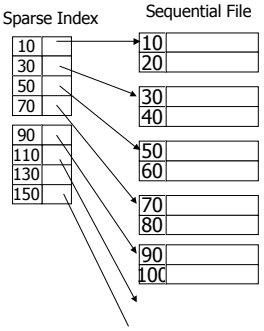
Sparse, Primary Index



- Sparse index
  - (key, pointer) pair per every "block"
  - (key, pointer) pair points to the first record in the block
- Q: How can we find 60?

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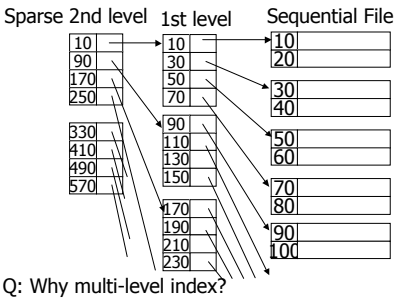
Multi-level index



Q: Why multi-level index?

Q: Does dense, 2nd level index make sense?

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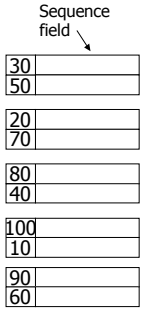
Secondary (non-clustering) Index



- Secondary (non-clustering) index
  - When tuples in the table are not ordered by the index search key
    - Index on a non-search-key for sequential file
    - Unordered file
- Q: What index?
  - Does sparse index make sense?

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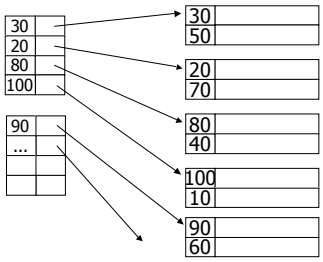
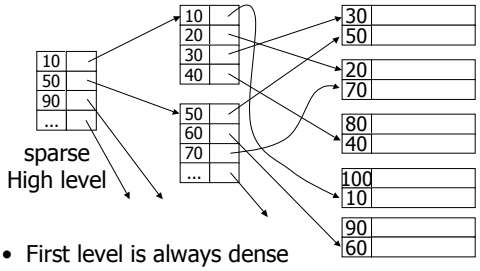
Sparse and secondary index?



Secondary index



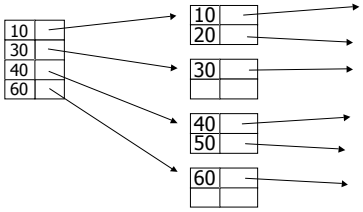
- First level is always dense
- Sparse from the second level

Important terms

- Dense index vs. sparse index
  - Clustering index vs. non-clustering index
- Primary index vs. secondary index
- Multi-level index
- Indexed sequential file
  - Sometimes called ISAM (indexed sequential access method)
- Search key (≠ primary key)

Insertion

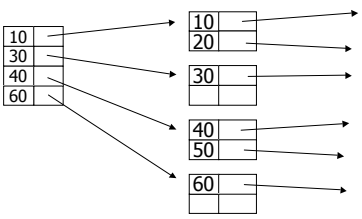
Insert 35



Q: Do we need to update higher-level index?

Insertion

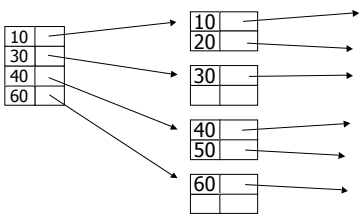
Insert 15 (overflow)



Q: Do we need to update higher-level index?

Insertion

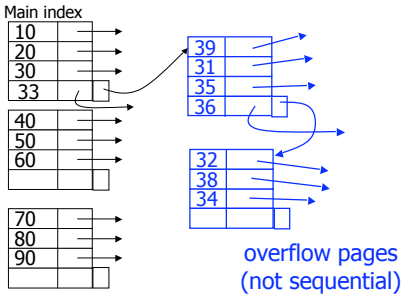
Insert 15 (redistribute)



Q: Do we need to update higher-level index?

Potential performance problem

After many insertions…



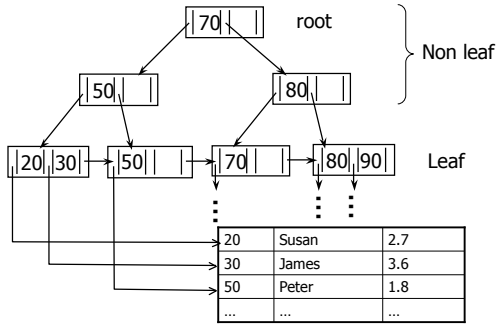
Traditional Index (ISAM)

- Advantage
  - Simple
  - Sequential blocks
- Disadvantage
  - Not suitable for updates
  - Becomes ugly (loses sequentiality and balance) over time

B+Tree

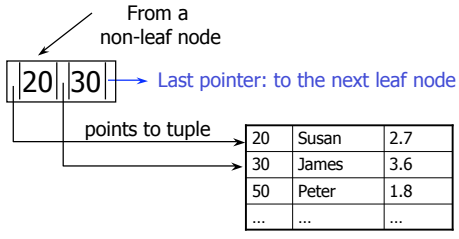
- Most popular index structure in RDBMS
- Advantage
  - Suitable for dynamic updates
  - Balanced
  - Minimum space usage guarantee
- Disadvantage
  - Non-sequential index blocks

B+Tree Example (n=3)



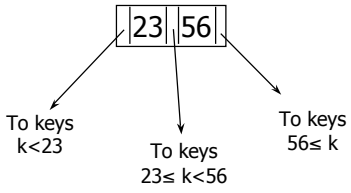
Balanced: All leaf nodes are at the same level

Sample Leaf Node (n=3)



- n: max # of pointers in a node
- All pointers (except the last one) point to tuples
- At least half of the pointers are used. (more precisely, ⌈(n+1)/2⌉ pointers)

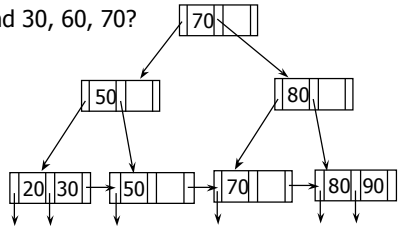
Sample Non-leaf Node (n=3)



- Points to the nodes one-level below
  - No direct pointers to tuples
- At least half of the ptrs used (precisely, ⌈n/2⌉)
  - except root, where at least 2 ptrs used

Search on B+tree

- Find 30, 60, 70?



- Find a greater key and follow the link on the left
  (Algorithm: Figure 12.10 on textbook)

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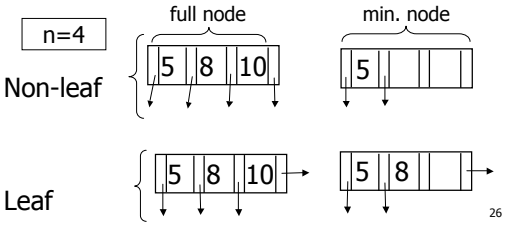
Nodes are never too empty

- Use at least
  Non-leaf: ⌈n/2⌉ pointers
  Leaf: ⌈(n+1)/2⌉ pointers



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Number of Ptrs/Keys for B+tree

	Max Ptrs	Max keys	Min ptrs	Min keys
Non-leaf (non-root)	n	n-1	⌈n/2⌉	⌈n/2⌉-1
Leaf (non-root)	n	n-1	⌈(n+1)/2⌉	⌈(n-1)/2⌉
Root	n	n-1	2	1

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B+Tree Insertion

(a) simple case (no overflow)
(b) leaf overflow
(c) non-leaf overflow
(d) new root

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B+Tree Insertion

- Leaf node overflow
  - The first key of the new node is *copied* to the parent
- Non-leaf node overflow
  - The middle key is *moved* to the parent
- Detailed algorithm: Figure 12.13

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B+Tree Deletion

(a) Simple case (no underflow)
(b) Leaf node, coalesce with neighbor
(c) Leaf node, redistribute with neighbor
(d) Non-leaf node, coalesce with neighbor
(e) Non-leaf node, redistribute with neighbor

In the examples, n = 4
- Underflow for non-leaf when fewer than ⌈n/2⌉ = 2 ptrs
- Underflow for leaf when fewer than ⌈(n+1)/2⌉ = 3 ptrs
- Nodes are labeled as *a, b, c, d, …*

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B+Tree Deletion

- Remember:
  - For *leaf node* merging, we *delete* the mid-key from the parent
  - For *non-leaf node* merging/redistribution, we *pull down* the mid-key from their parent.
- Exact algorithm: Figure 12.17
- In practice
  - Coalescing is often not implemented
    - Too hard and not worth it

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Where does *n* come from?

- *n* determined by
  - Size of a node
  - Size of search key
  - Size of an index pointer
- Q: 1024B node, 10B key, 8B ptr → *n*?

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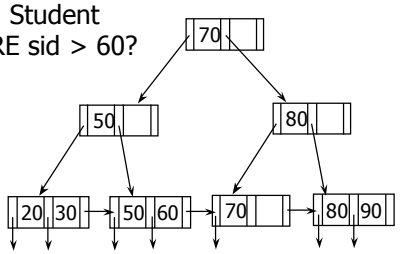
Question on B+tree

- SELECT *
  FROM Student
  WHERE sid > 60?



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Summary on tree index

- Indexed sequential file (ISAM)
  - Sparse vs. dense
  - Primary (clustering) vs. secondary (non-clustering)
  - Not suitable for dynamic environment
- B+trees
  - Balanced, minimum space guarantee
  - Insertion, deletion algorithms

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Index Creation in SQL

- `CREATE INDEX <index_name> ON <table>(<attr>,<attr>,…)`
- Example
  - `CREATE INDEX st_id ON Student(sid)`
    - Creates a B+tree on the attributes
    - Speeds up lookup on sid
- Clustering index (in DB2)
  - `CREATE INDEX cls_idx ON Student(sid) CLUSTER`
    - Tuples are sequenced by sid

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Next topic

- Hash index
  - Static hashing
  - Extendible hashing

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What is a Hash Table?

- Hash Table
  - Hash function
    - h(k): key → integer [0…n]
    - e.g., h('Susan') = 7
  - Array for keys: T[0…n]
  - Given a key k, store it in T[$h(k)$]

h(Susan) = 4
h(James) = 3
h(Neil) = 1

0	
1	Neil
2	
3	James
4	Susan
5	

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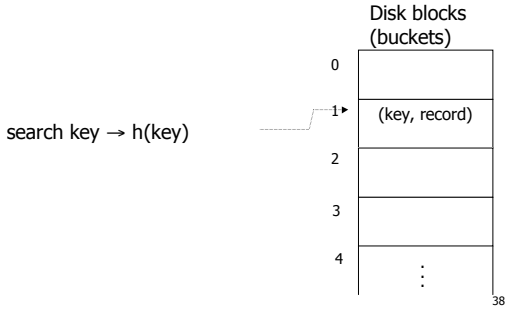
Hashing for DBMS (Static Hashing)



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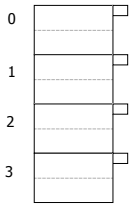
Overflow and Chaining

- Insert
  h(a) = 1
  h(b) = 2
  h(c) = 1
  h(d) = 0
  h(e) = 1
- Delete
  h(b) = 2
  h(c) = 1



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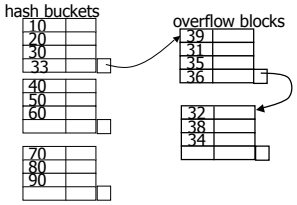
Major Problem of Static Hashing

- How to cope with growth?
  - Data tends to grow in size
  - Overflow blocks unavoidable



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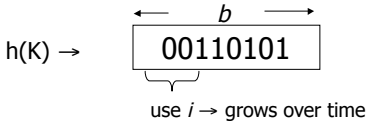
Extendible Hashing (two ideas)

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



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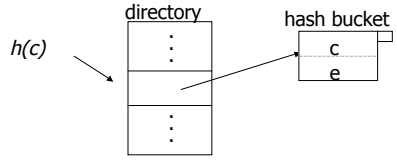
Extendible Hashing (two ideas)

(b) Use directory that maintains pointers to hash buckets (indirection)



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Bucket Merge Condition

- Bucket merge condition
  - Bucket i's are the same
  - First (i-1) bits of the hash key are the same
- Directory shrink condition
  - All bucket i's are smaller than the directory i

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Questions on Extendible Hashing

- Can we provide minimum space guarantee?

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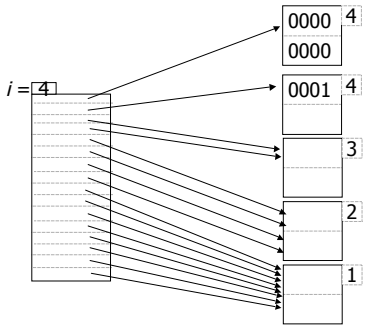
Space Waste



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Hash index summary

- Static hashing
  - Overflow and chaining
- Extendible hashing
  - Can handle growing files
    - No periodic reorganizations
  - Indirection
    - Up to 2 disk accesses to access a key
  - Directory doubles in size
    - Not too bad if the data is not too large

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Hashing vs. Tree

- Can an extendible-hash index support?

```
SELECT
FROM R
WHERE R.A > 5
```

- Which one is better, B+tree or Extendible hashing?

```
SELECT
FROM R
WHERE R.A = 5
```

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