Lecture 20: Indexes

Friday, November 16, 2001

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Outline

- Index Structures (4.1, 4.2)
- B+ trees (4.3)
- Hash tables (4.4)

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Indexes

- An *index* on a file speeds up selections on the *search key fields* for the index.
  - Any subset of the fields of a relation can be the search key for an index on the relation.
  - *Search key* is not the same as *key* (minimal set of fields that uniquely identify a record in a relation).
- An index contains a collection of *data entries*, and supports efficient retrieval of all data entries with a given key value **k**.

Index Classification

- Primary/secondary
- Clustered/unclustered
- Dense/sparse
- B+ tree / Hash table / …

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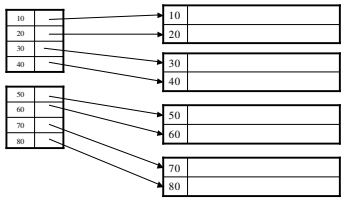
Primary Index

- File is sorted on the index attribute
- *Dense* index: sequence of (key,pointer) pairs



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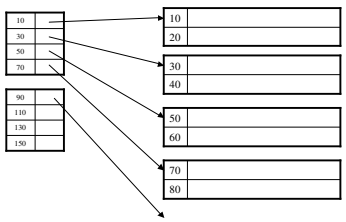
Primary Index

- *Sparse* index



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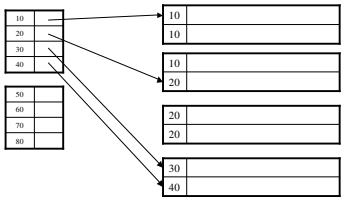
Primary Index with Duplicate Keys

- Dense index:



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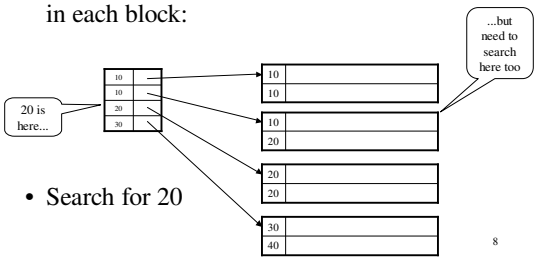
Primary Index with Duplicate Keys

- Sparse index: pointer to lowest search key in each block:



- Search for 20

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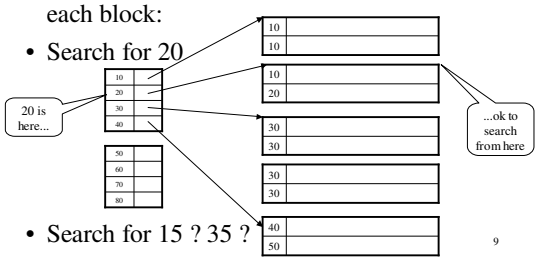
Primary Index with Duplicate Keys

- Better: pointer to ***lowest new search key*** in each block:
- Search for 20



- Search for 15 ? 35 ?

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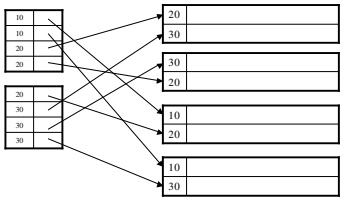
Secondary Indexes

- To index other attributes than primary key
- Always dense (why ?)



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Clustered/Unclustered

- Primary indexes = usually clustered
- Secondary indexes = usually unclustered

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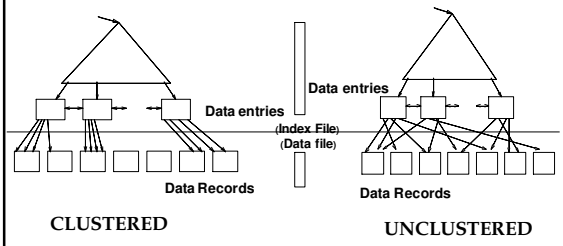
Clustered vs. Unclustered Index



Secondary Indexes

- Applications:
  - index other attributes than primary key
  - index unsorted files (heap files)
  - index clustered data

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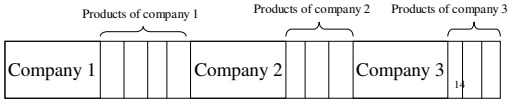
Applications of Secondary Indexes

- *Clustered data*

  Company(name, city), Product(pid, maker)

```
Select city
From Company, Product
Where name=maker
    and pid="p045"
```

```
Select pid
From Company, Product
Where name=maker
    and city="Seattle"
```



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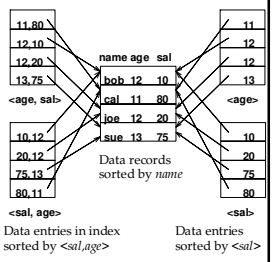
Composite Search Keys

- *Composite Search Keys*: Search on a combination of fields.
  - Equality query: Every field value is equal to a constant value. E.g. wrt <sal,age> index:
    - age=20 and sal =75
  - Range query: Some field value is not a constant. E.g.:
    - age =20; or age=20 and sal > 10

Examples of composite key indexes using lexicographic order.



B+ Trees

- Search trees
- Idea in B Trees:
  - make 1 node = 1 block
- Idea in B+ Trees:
  - Make leaves into a linked list (range queries are easier)

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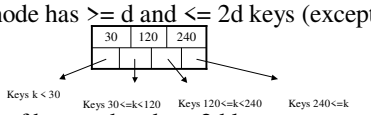
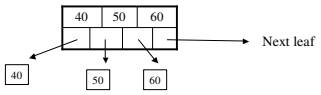
B+ Trees Basics

- Parameter d = the *degree*
- Each node has >= d and <= 2d keys (except root)



- Each leaf has >=d and <= 2d keys:



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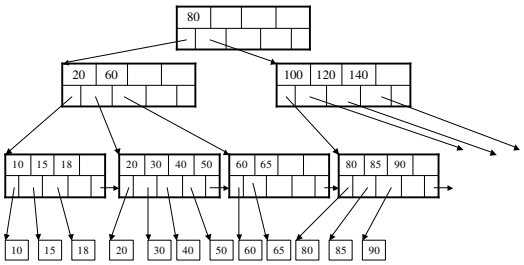
B+ Tree Example

d = 2



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B+ Tree Design

- How large d ?
- Example:
  - Key size = 4 bytes
  - Pointer size = 8 bytes
  - Block size = 4096 byes
- 2d x 4 + (2d+1) x 8 <= 4096
- d = 170

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Searching a B+ Tree

- Exact key values:
  - Start at the root
  - Proceed down, to the leaf

```
Select name
From people
Where age = 25
```

- Range queries:
  - As above
  - Then sequential traversal

```
Select name
From people
Where 20 <= age
 and  age <= 30
```

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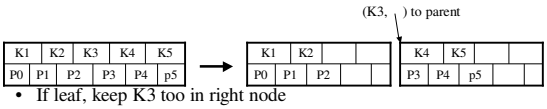
B+ Trees in Practice

- Typical order: 100. Typical fill-factor: 67%.
  - average fanout = 133
- Typical capacities:
  - Height 4: 133^4 = 312,900,700 records
  - Height 3: 133^3 = 2,352,637 records
- Can often hold top levels in buffer pool:
  - Level 1 = 1 page = 8 Kbytes
  - Level 2 = 133 pages = 1 Mbyte
  - Level 3 = 17,689 pages = 133 MBytes

Insertion in a B+ Tree

Insert (K, P)

- Find leaf where K belongs, insert
- If no overflow (2d keys or less), halt
- If overflow (2d+1 keys), split node, insert in parent:



- If leaf, keep K3 too in right node
- When root splits, new root has 1 key only

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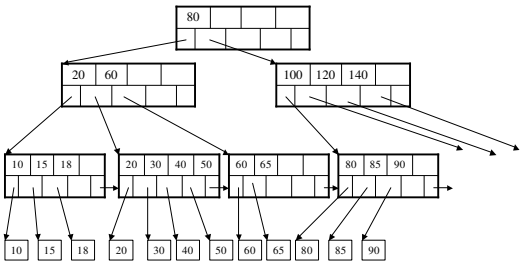
Insertion in a B+ Tree

Insert K=19



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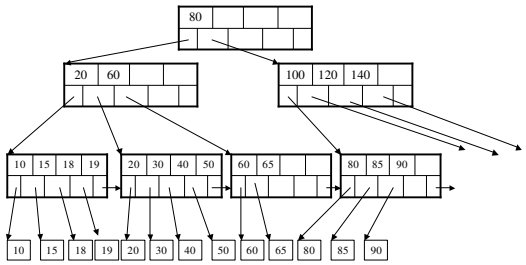
Insertion in a B+ Tree

After insertion



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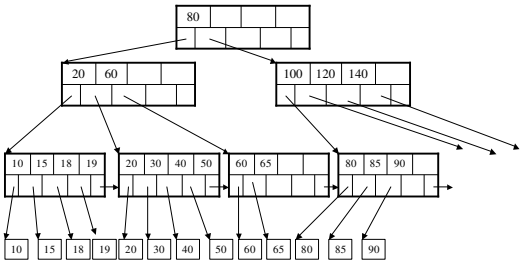
Insertion in a B+ Tree

Now insert 25



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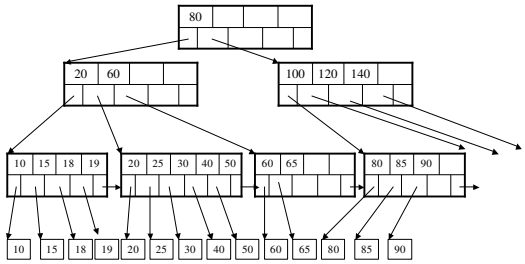
Insertion in a B+ Tree

After insertion



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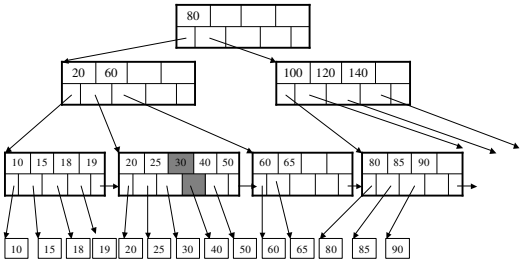
Insertion in a B+ Tree

But now have to split !



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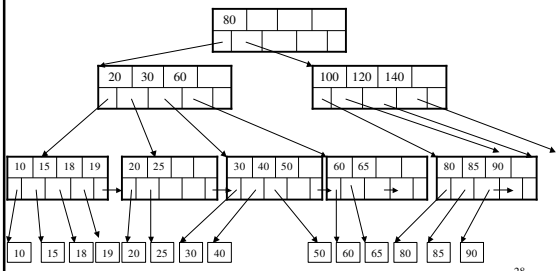
Insertion in a B+ Tree

After the split



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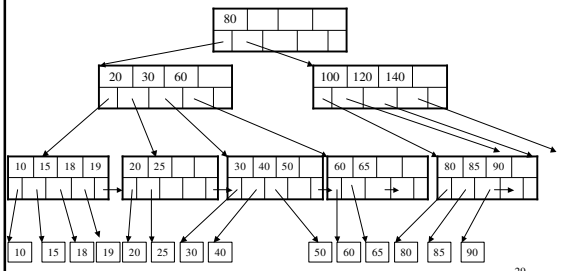
Deletion from a B+ Tree

Delete 30



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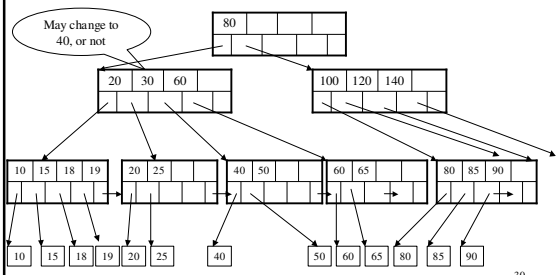
Deletion from a B+ Tree

After deleting 30



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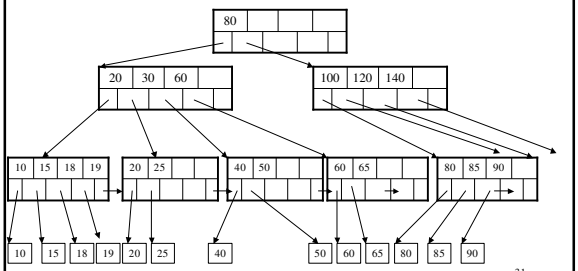
Deletion from a B+ Tree

Now delete 25



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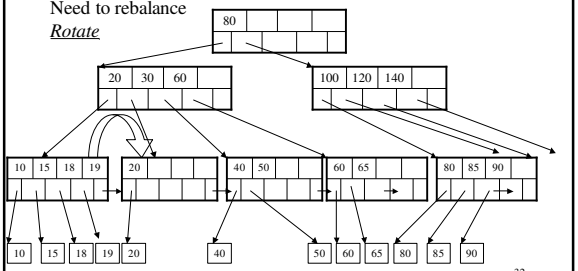
Deletion from a B+ Tree

After deleting 25
Need to rebalance
Rotate



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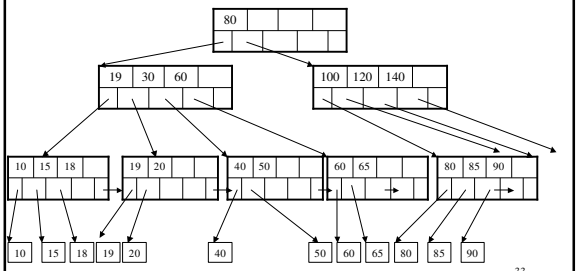
Deletion from a B+ Tree

Now delete 40



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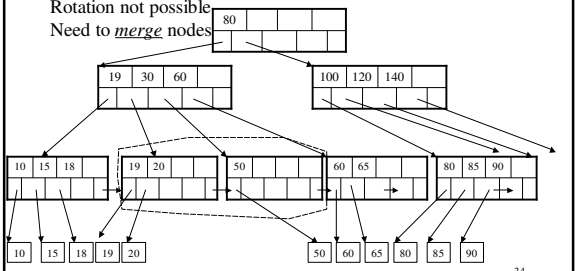
Deletion from a B+ Tree

After deleting 40
Rotation not possible
Need to *merge* nodes



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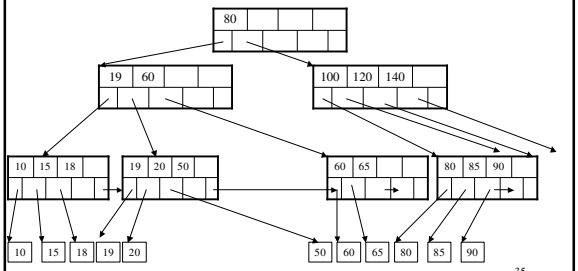
Deletion from a B+ Tree

Final tree



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