Lecture 6:
Indexes and Database Tuning

Wednesday, November 1st, 2011

Announcement

- HW 5 is posted, due Monday, 11/14
- Next lecture: required reading!
  - Shapiro, *Join Processing*
  - This is the paper where *Grace Join* was introduced, which is today standard
  - The paper is from 1986, yet still the best description of Grace Join

Outline

- Storage and indexing: Chapter 8, 9, 10
  - Discussed today
- Database Tuning: Chapter 20
  - Discussed today
- Security in SQL: Chapter 21
  - Will not discuss in class

You need all of this for HW5

Storage Model

- DBMS needs spatial and temporal control over storage
  - Spatial control for performance
  - Temporal control for correctness and performance

- For spatial control, two alternatives
  - Use “raw” disk device interface directly
  - Use OS files

Spatial Control Using "Raw" Disk Device Interface

- **Overview**
  - DBMS issues low-level storage requests directly to disk device
- **Advantages**
  - DBMS can ensure that important queries access data sequentially
  - Can provide highest performance
- **Disadvantages**
  - Requires devoting entire disks to the DBMS
  - Reduces portability as low-level disk interfaces are OS specific
  - Many devices are in fact "virtual disk devices"

Spatial Control Using OS Files

- **Overview**
  - DBMS creates one or more very large OS files
- **Advantages**
  - Allocating large file on empty disk can yield good physical locality
- **Disadvantages**
  - OS can limit file size to a single disk
  - OS can limit the number of open file descriptors
  - But these drawbacks have mostly been overcome by modern OSs

Commercial Systems

- Most commercial systems offer both alternatives
  - Raw device interface for peak performance
  - OS files more commonly used
- In both cases, we end-up with a DBMS file abstraction implemented on top of OS files or raw device interface

File Types

The data file can be one of:

- Heap file
  - Set of records, partitioned into blocks
  - Unsorted
- Sequential file
  - Sorted according to some attribute(s) called *key*

Note: "key" here means something else than "primary key"

Arranging Pages on Disk

- Block concept:
  - blocks on same track, followed by
  - blocks on same cylinder, followed by
  - blocks on adjacent cylinder
- Blocks in a file should be arranged sequentially on disk (by `next'), to minimize seek and rotational delay.

- For a sequential scan, pre-fetching several pages at a time is a big win!

Representing Data Elements

- Relational database elements:

```
CREATE TABLE Product (

        pid INT PRIMARY KEY,
        name CHAR(20),
        description VARCHAR(200),
        maker CHAR(10) REFERENCES Company(name)
)
```

- A tuple is represented as a record
- The table is a sequence of records

Issues

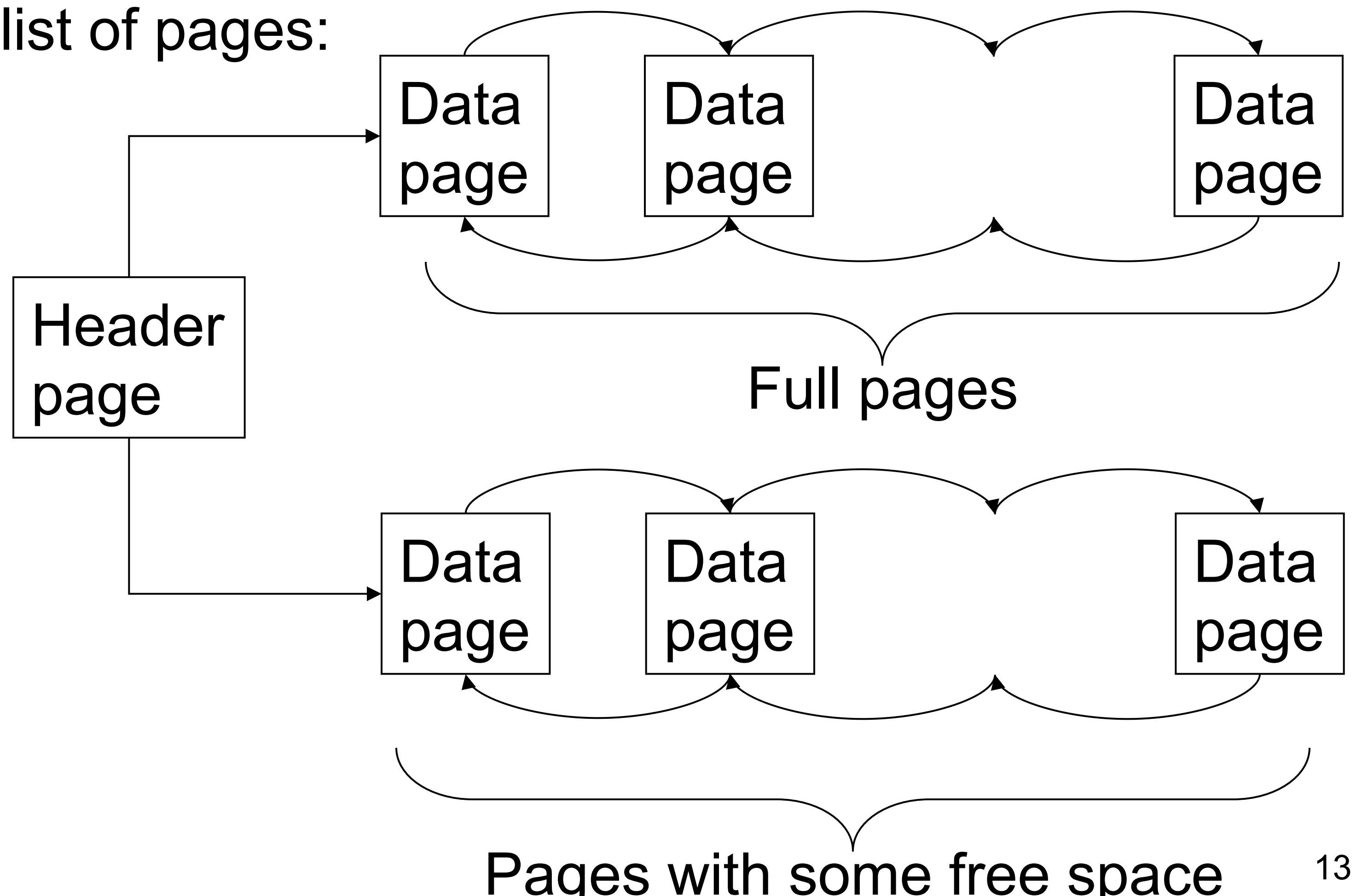
- Managing free blocks
- Represent the records inside the blocks
- Represent attributes inside the records

Managing Free Blocks

- Linked list of free blocks
- Or bit map

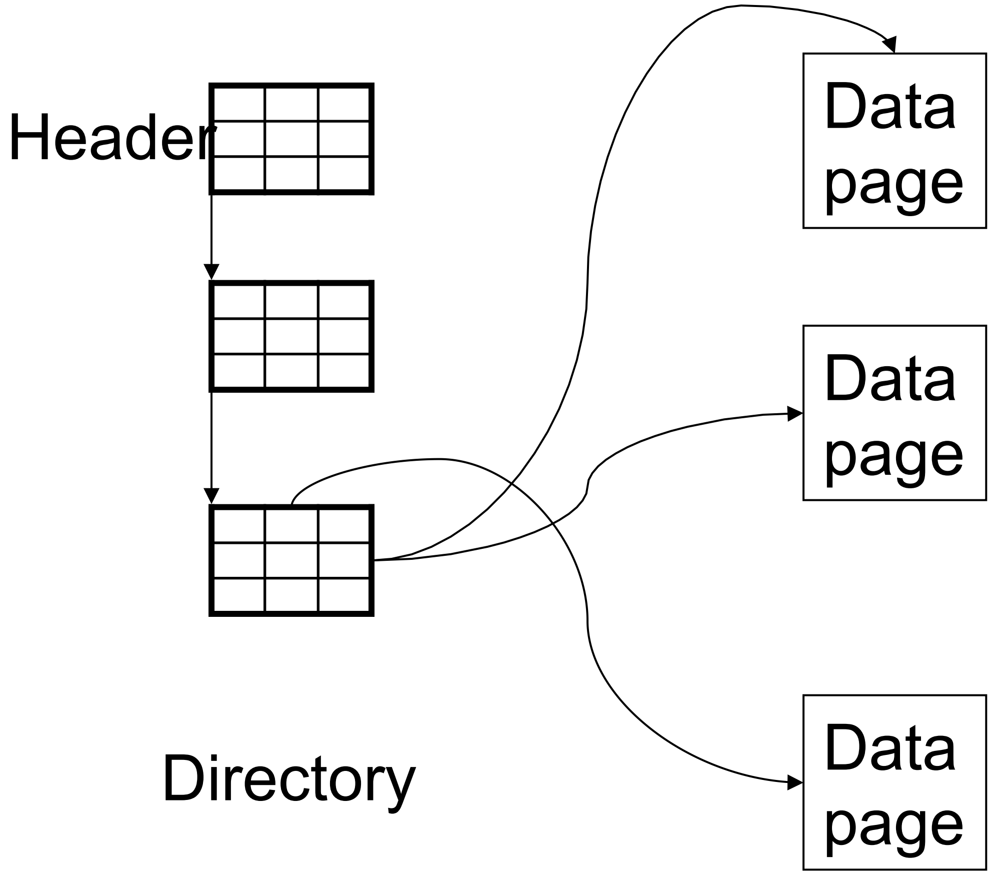
File Organization

Linked list of pages:



File Organization

Better: directory of pages



Page Formats

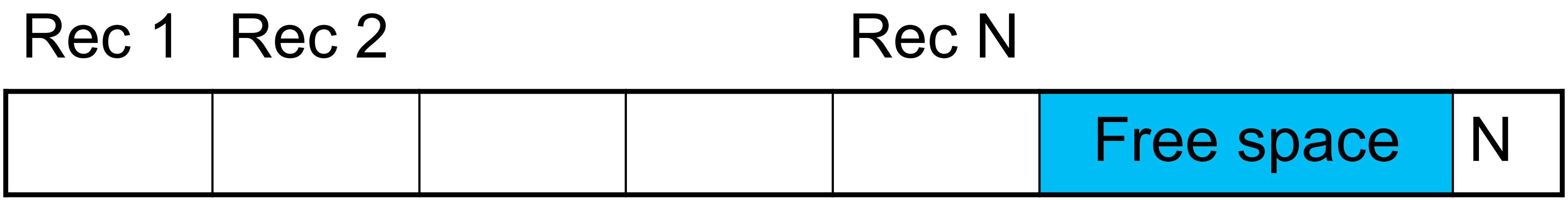
Issues to consider

- 1 page = fixed size (e.g. 8KB)
- Records:
  - Fixed length
  - Variable length
- Record id = RID
  - Typically RID = (PageID, SlotNumber)

Why do we need RID's in a relational DBMS ?

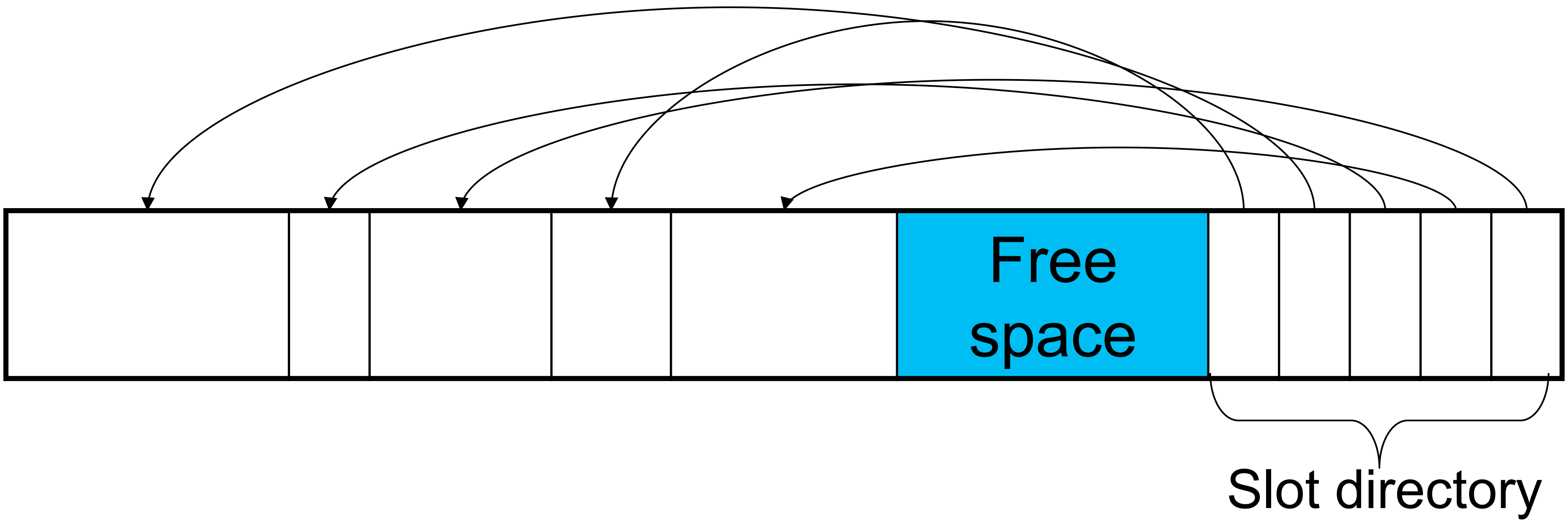
Page Formats

Fixed-length records: packed representation



Problems ?

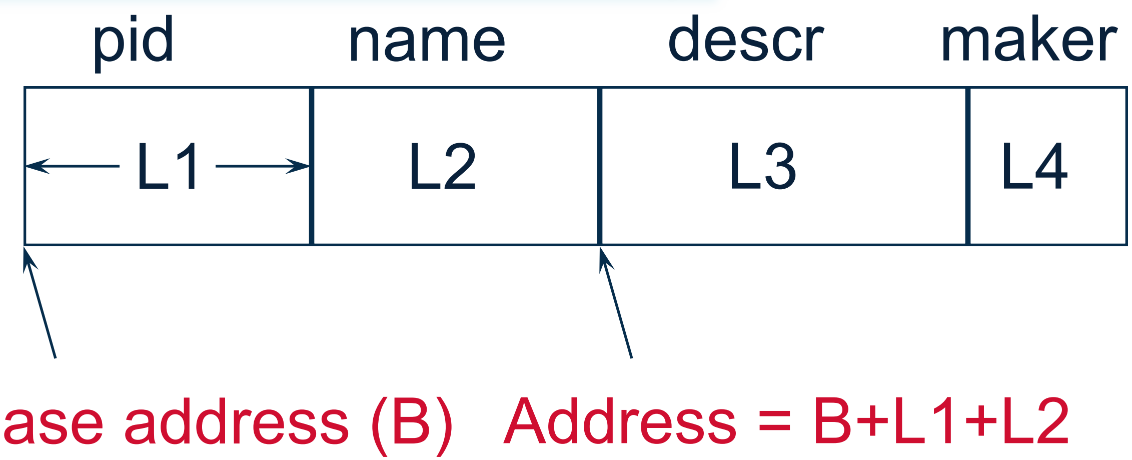
Page Formats



Variable-length records

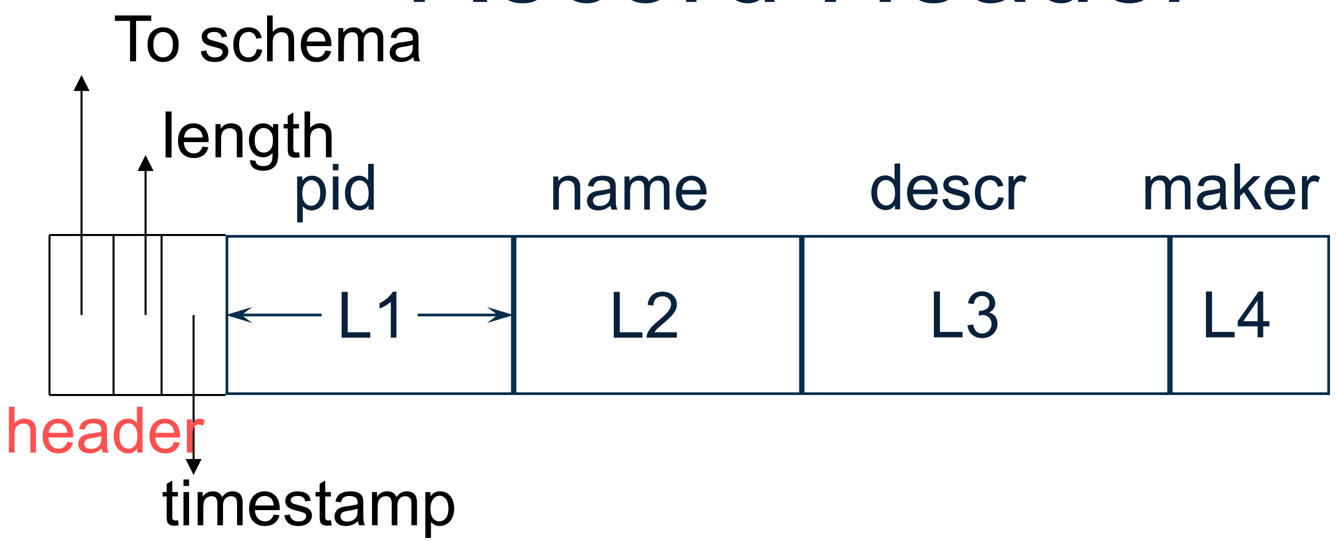
Record Formats: Fixed Length

Product (pid, name, descr, maker)



- Information about field types same for all records in a file; stored in *system catalogs.*
- Finding *i'th* field requires scan of record.
- **Note the importance of schema information!**

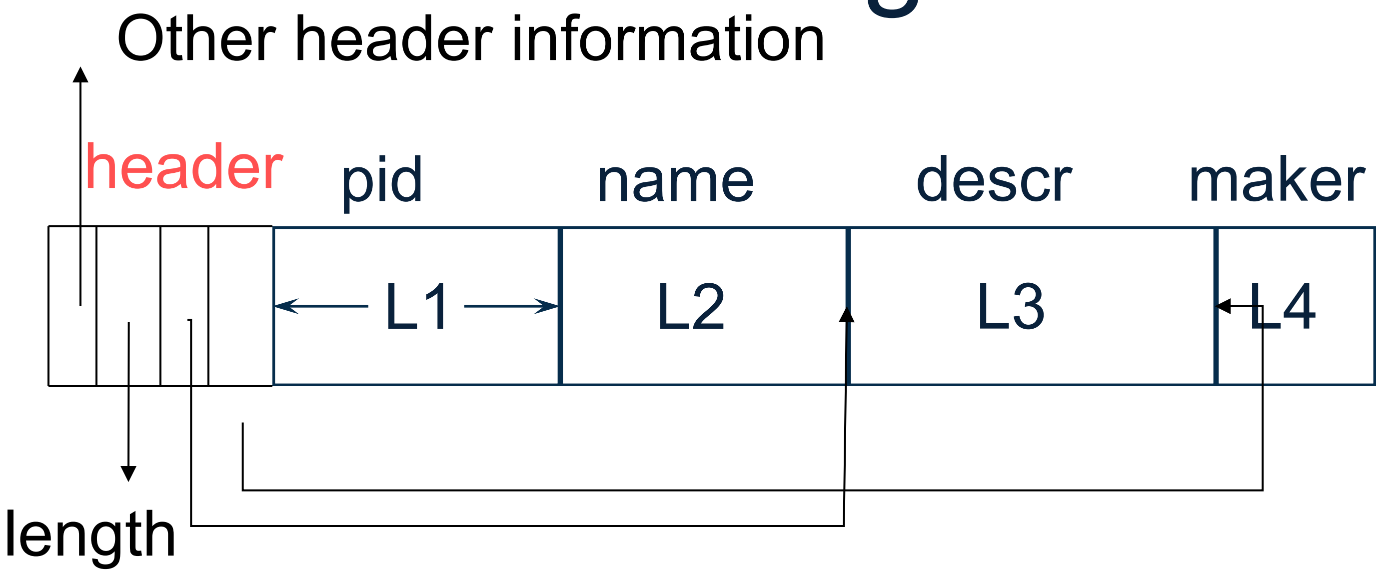
Record Header



Need the header because:

- The schema may change
  - for a while new+old may coexist
- Records from different relations may coexist

Variable Length Records



Place the fixed fields first: F1

Then the variable length fields: F2, F3, F4

Null values take 2 bytes only

Sometimes they take 0 bytes (when at the end)

BLOB

- Binary large objects
- Supported by modern database systems
- E.g. images, sounds, etc.
- Storage: attempt to cluster blocks together

CLOB = character large object

- Supports only restricted operations

File Organizations

- **Heap** (random order) files: Suitable when typical access is a file scan retrieving all records.
- **Sorted Files**: Best if records must be retrieved in some order, or only a `range' of records is needed.
- **Indexes**: Data structures to organize records via trees or hashing.
  - Like sorted files, they speed up searches for a subset of records, based on values in certain ("search key") fields
  - Updates are much faster than in sorted files.

Modifications: Insertion

- File is unsorted: add it to the end (easy ☺)
- File is sorted:
  - Is there space in the right block ?
    - Yes: we are lucky, store it there
  - Is there space in a neighboring block ?
    - Look 1-2 blocks to the left/right, shift records
  - If anything else fails, create *overflow block*

Modifications: Deletions

- Free space in block, shift records
- May be able to eliminate an overflow block
- Can never really eliminate the record, because others may *point* to it
  - Place a tombstone instead (a NULL record)

Modifications: Updates

- If new record is shorter than previous, easy ☺
- If it is longer, need to shift records, create overflow blocks

Index

- A (possibly separate) file, that allows fast access to records in the data file
- The index contains (key, value) pairs:
  - The key = an attribute value
  - The value = one of:
    - pointer to the record *secondary index*
    - or the record itself *primary index*

Note: “key” (aka “search key”) again means something else

Index Classification

- **Clustered/unclustered**
  - Clustered = records close in index are close in data
  - Unclustered = records close in index may be far in data
- **Primary/secondary**
  - Meaning 1:
    - Primary = is over attributes that include the primary key
    - Secondary = otherwise
  - Meaning 2: means the same as clustered/unclustered
- **Organization**: B+ tree or Hash table

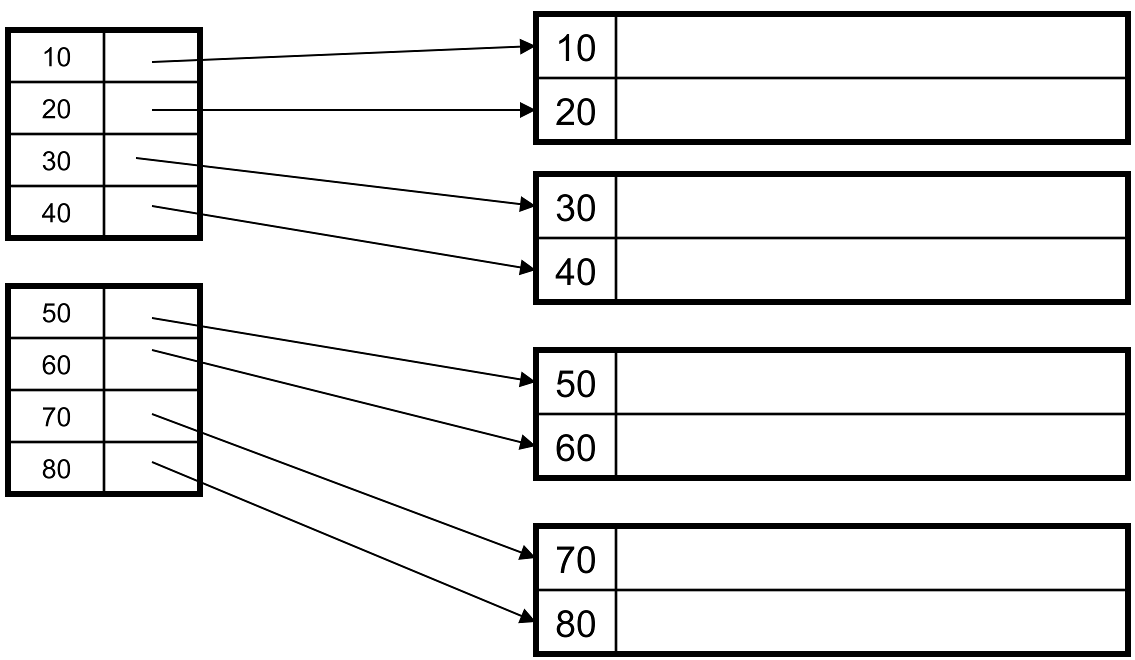
Clustered/Unclustered

- Clustered
  - Index determines the location of indexed records
  - Typically, clustered index is one where values are data records (but not necessary)

- Unclustered
  - Index cannot reorder data, does not determine data location
  - In these indexes: value = pointer to data record

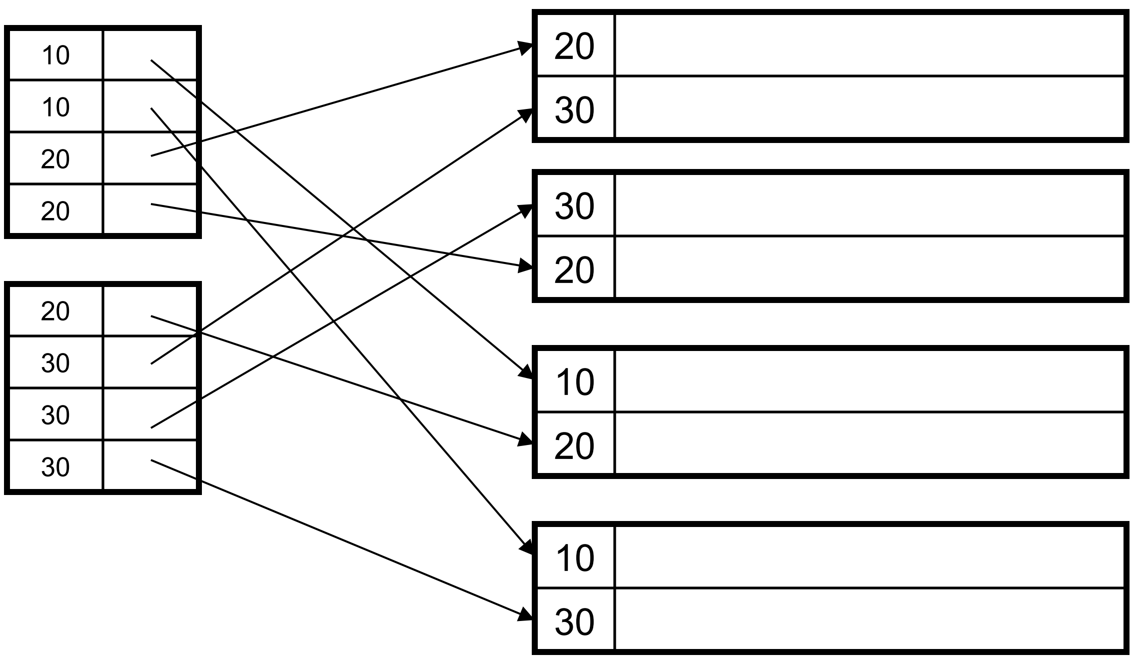
Clustered Index

- File is sorted on the index attribute
- Only one per table

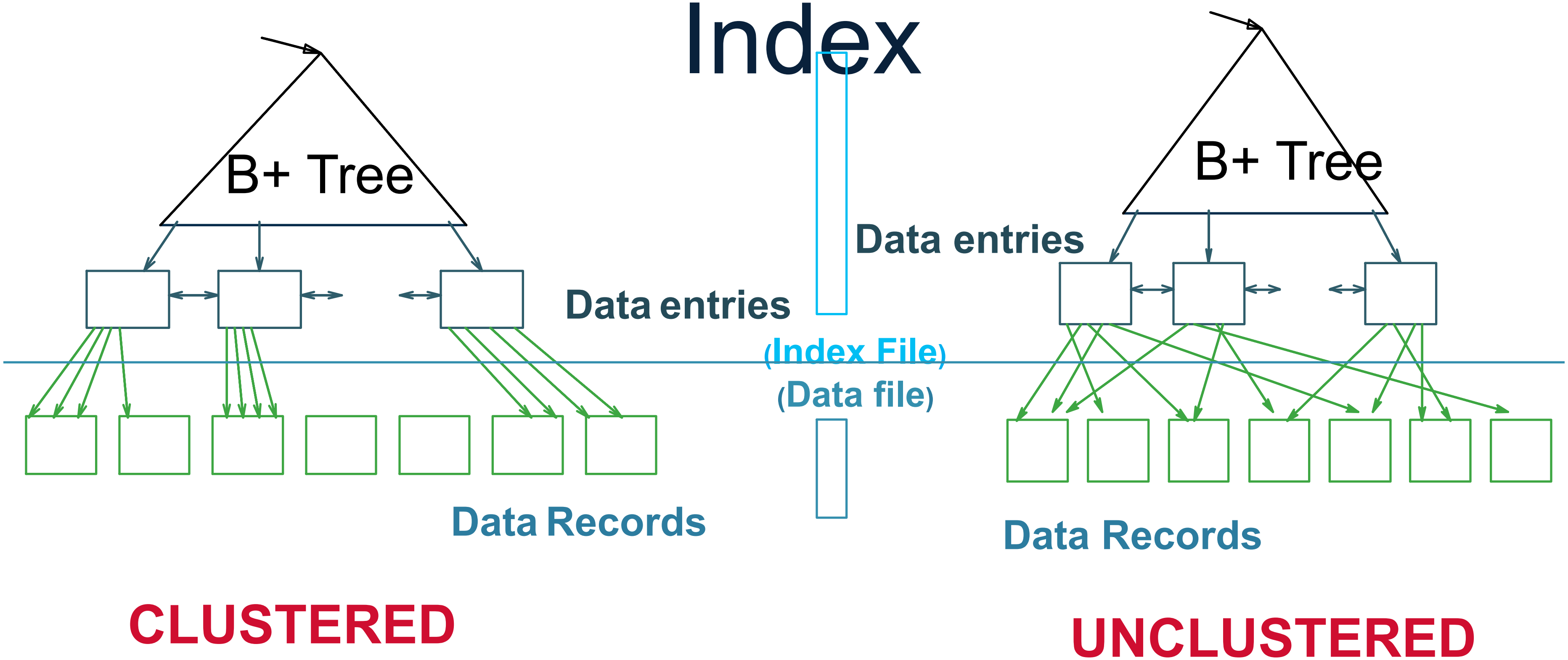


Unclustered Index

- Several per table

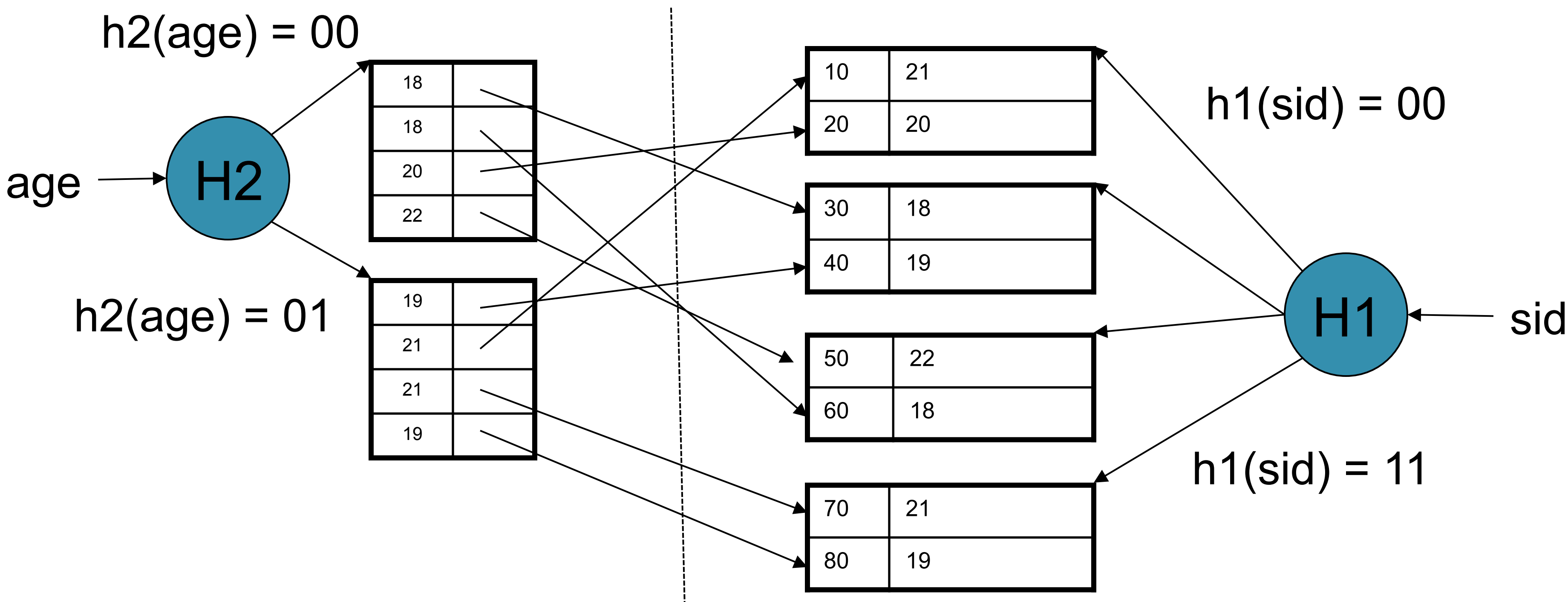


Clustered vs. Unclustered Index



Hash-Based Index

Good for point queries but not range queries



Another example
of unclustered/secondary index

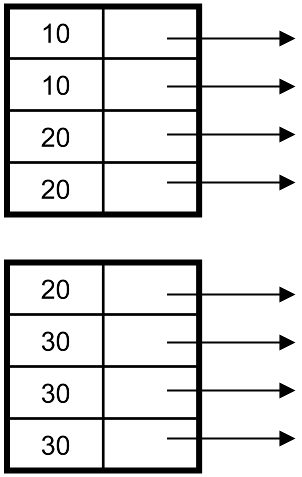
Another example of
clustered/primary index

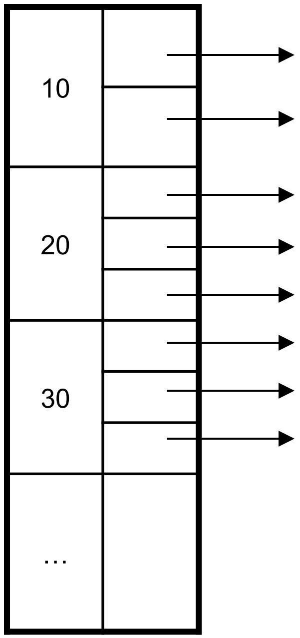
Alternatives for Data Entry k* in Index

Three alternatives for **k***:

- Data record with key value **k**
- <**k**, **rid** of data record with key = **k**>
- <**k**, list of **rids** of data records with key = **k**>

Alternatives 2 and 3



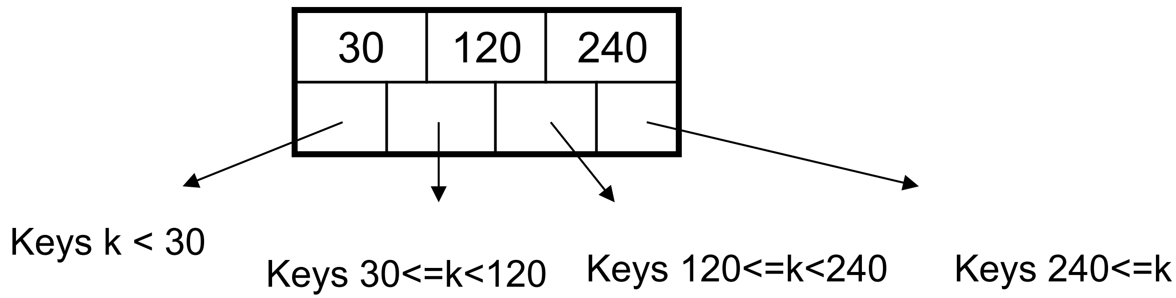


B+ Trees

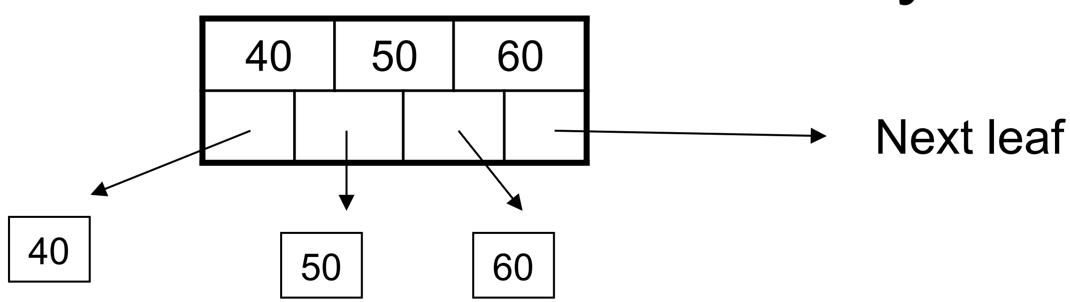
- Search trees
- Idea in B Trees
  - Make 1 node = 1 block
  - Keep tree balanced in height
- Idea in B+ Trees
  - Make leaves into a linked list: facilitates range queries

B+ Trees Basics

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



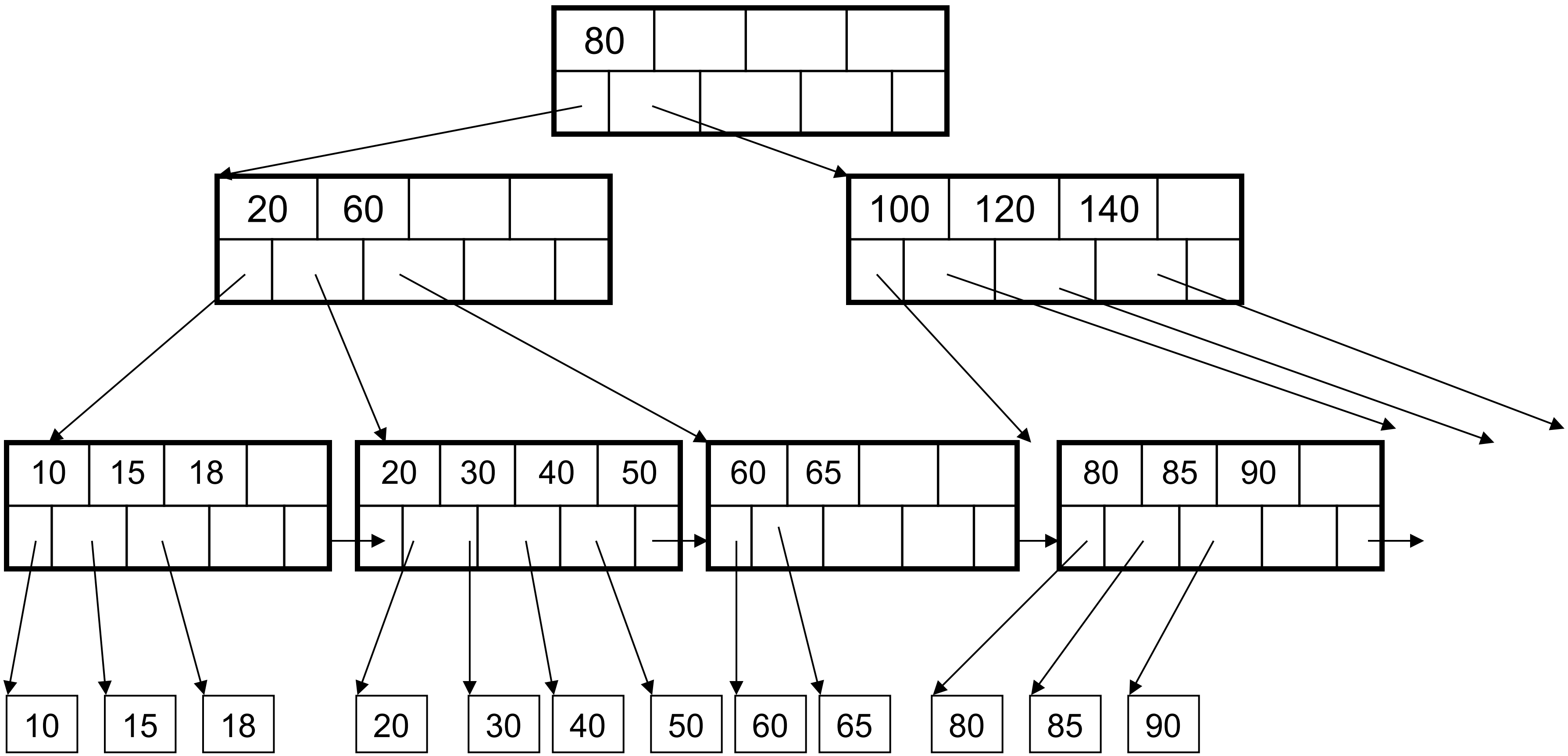
- Each leaf has >=d and <= 2d keys:



B+ Tree Example

d = 2

Find the key 40



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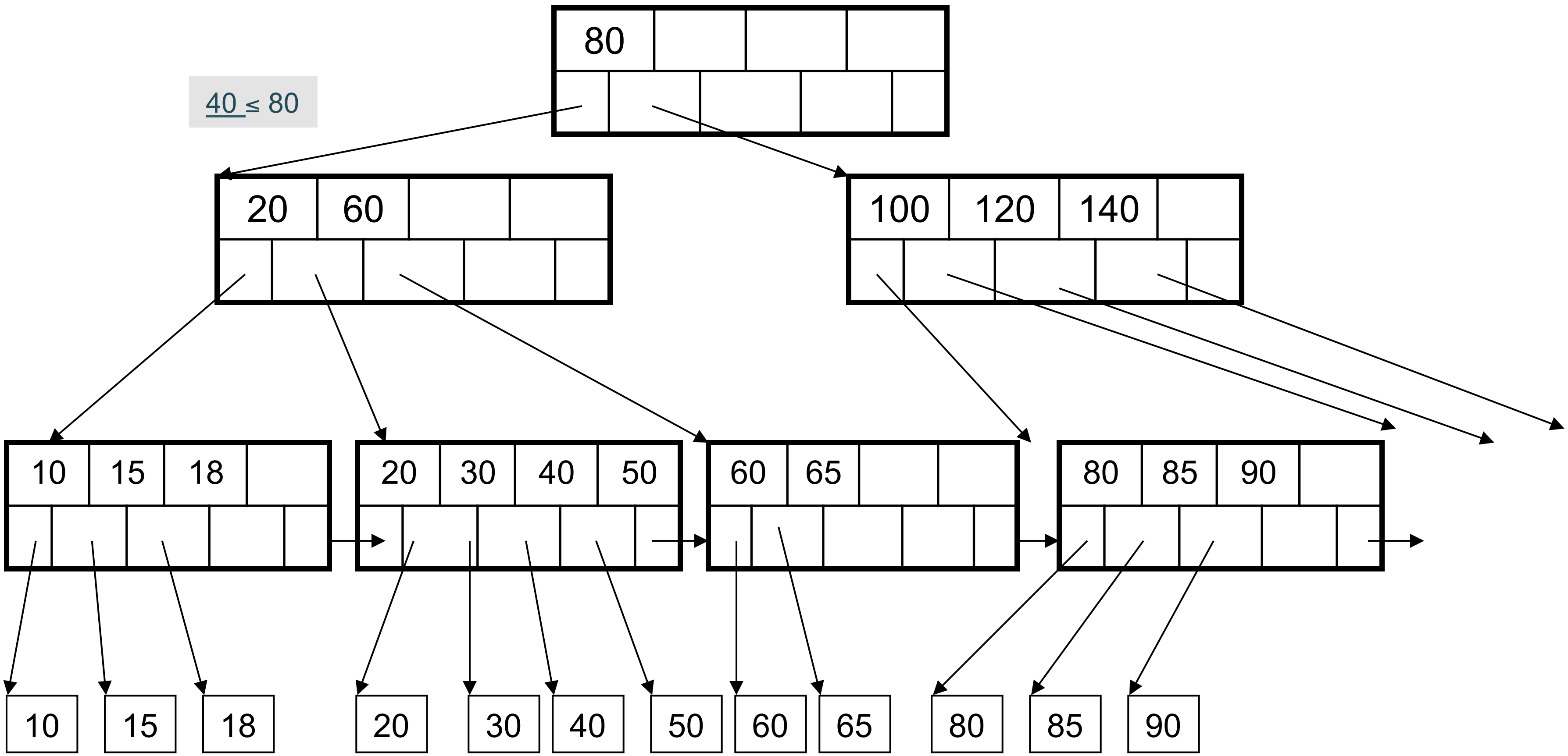
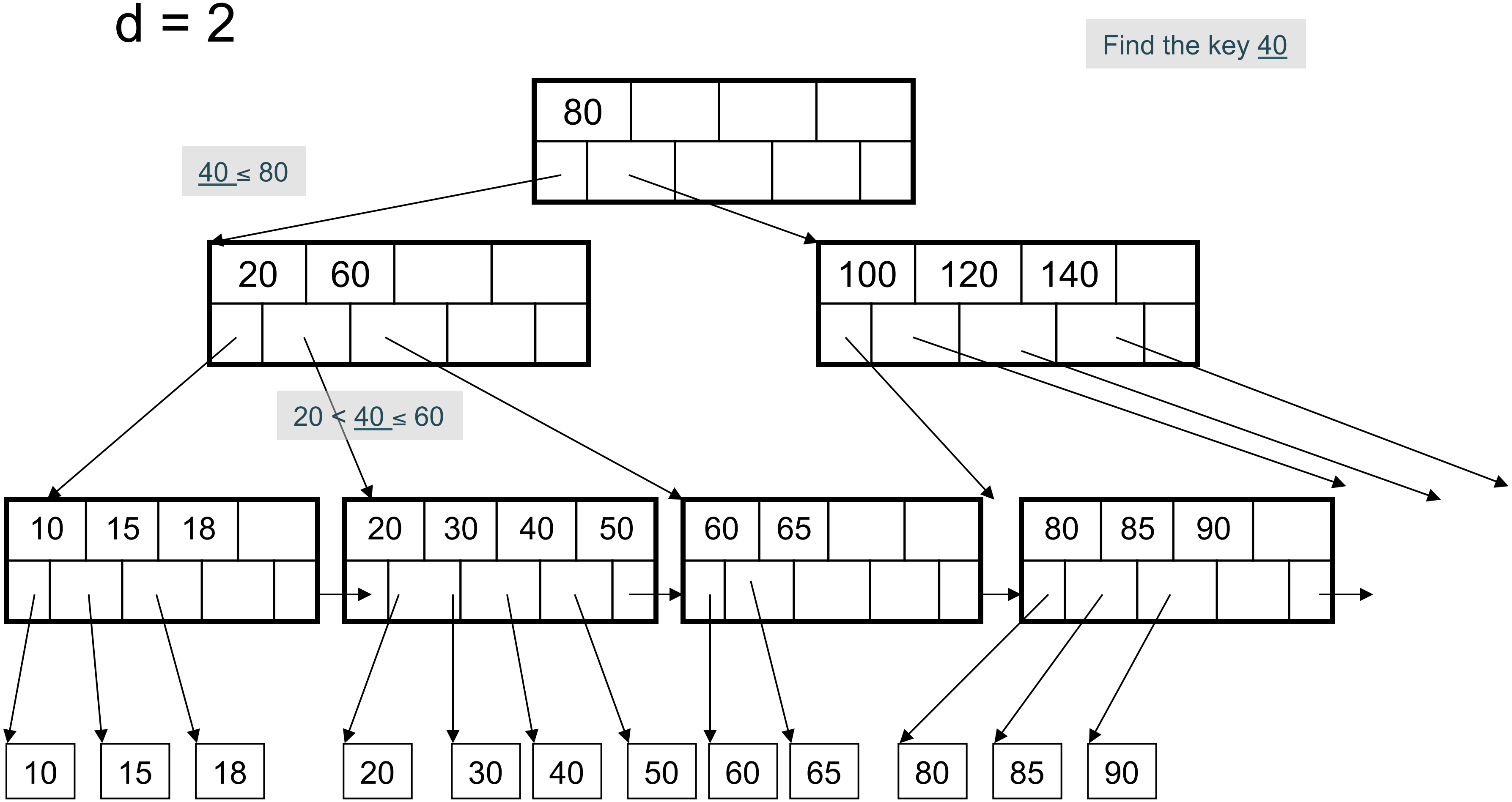


B+ Tree Example

d = 2



B+ Tree Example

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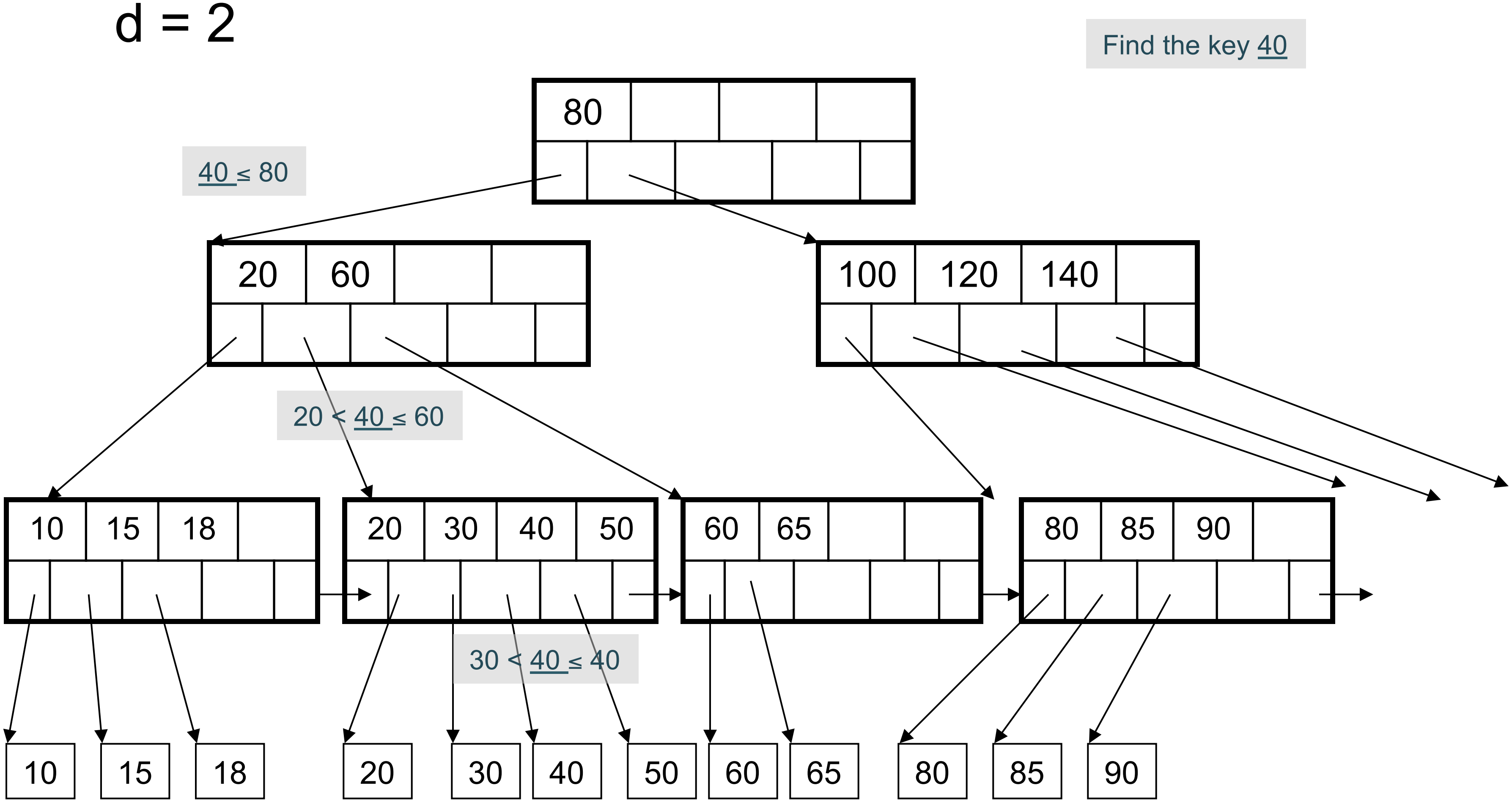


Using a B+ Tree

Index on People(age)

- 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
```

Which queries can use this index ?

Index on People(name, zipcode)

```
Select *
From People
Where name = 'Smith'
  and zipcode = 12345
```

```
Select *
From People
Where name = 'Smith'
```

```
Select *
From People
Where zipcode = 12345
```

B+ Tree Design

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

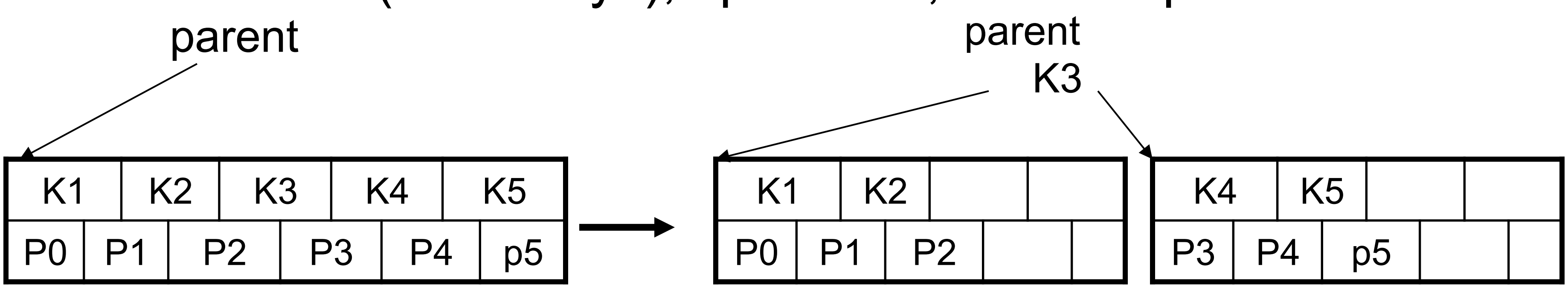
B+ Trees in Practice

- 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)

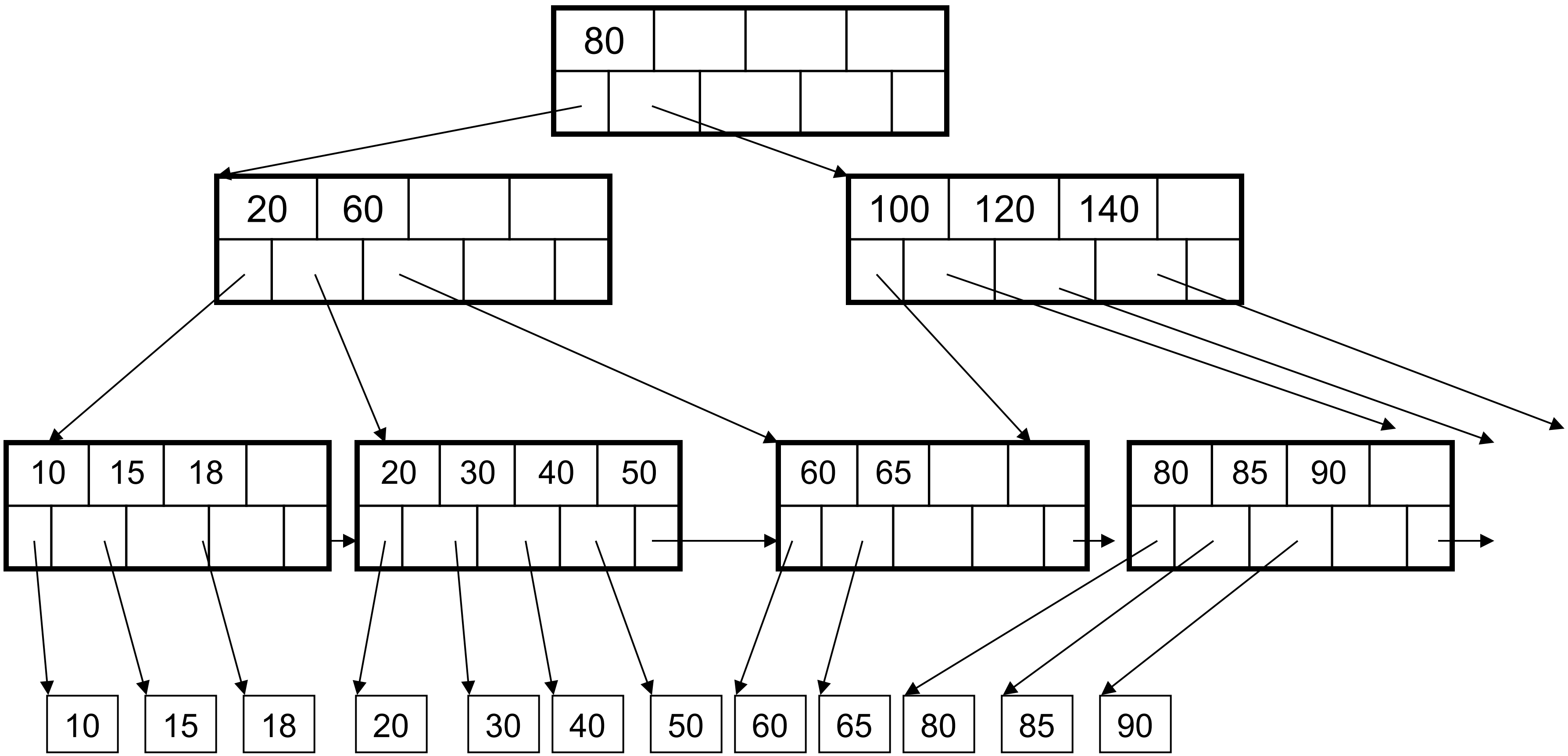
- Find leaf where K belongs, insert
- If no overflow (2d keys or less), halt
- If overflow (2d+1 keys), split node, insert in parent:



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

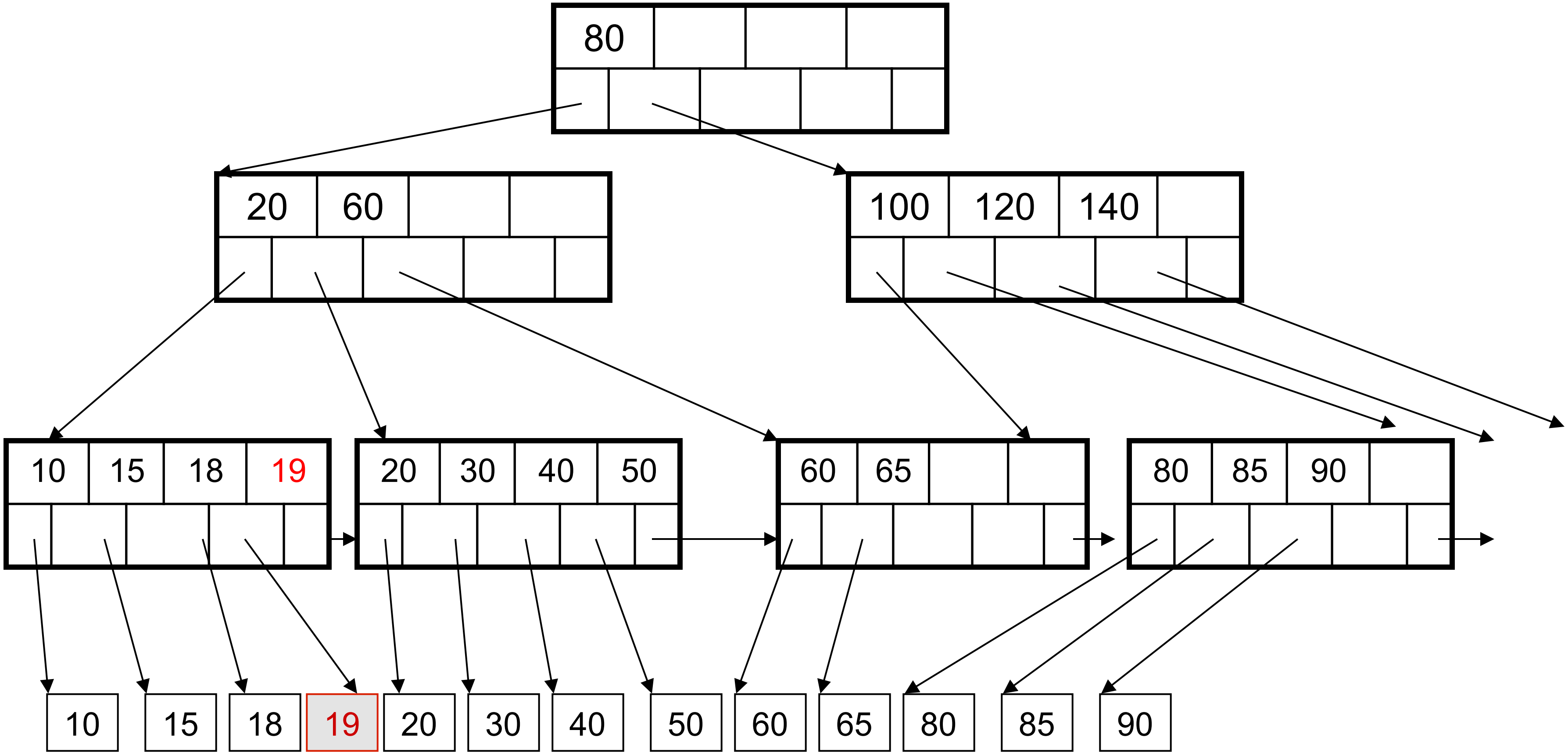
Insertion in a B+ Tree

Insert K=19



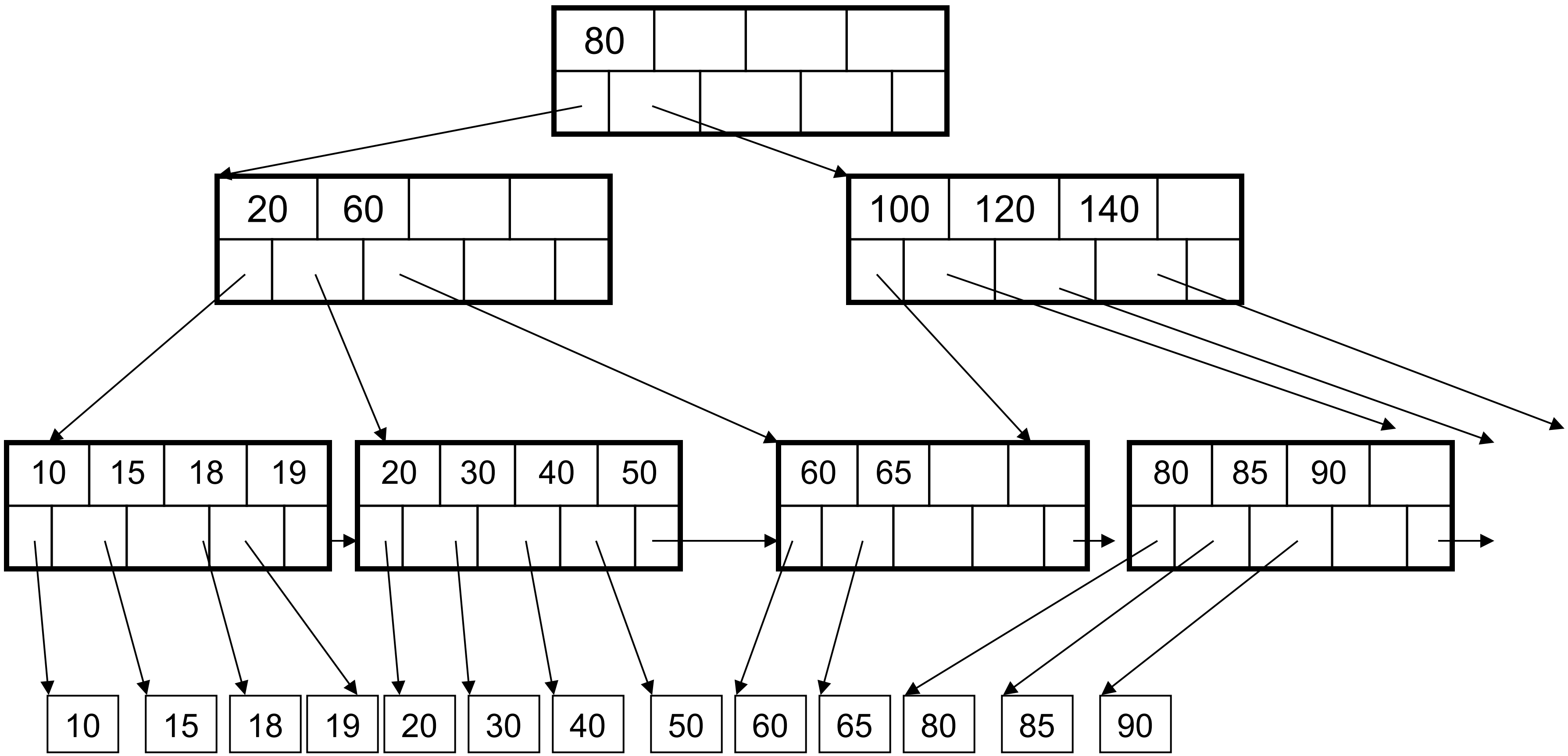
Insertion in a B+ Tree

After insertion



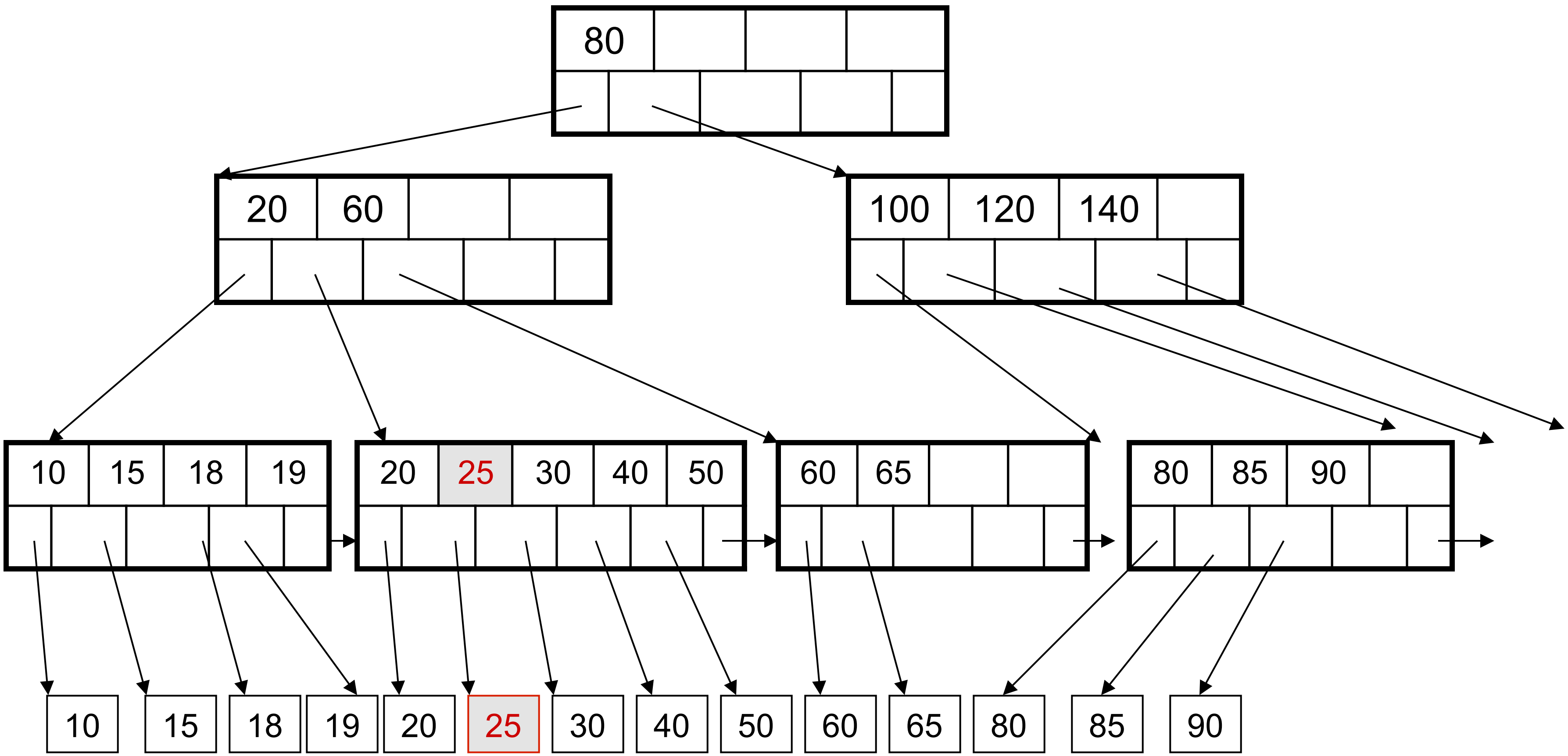
Insertion in a B+ Tree

Now insert 25



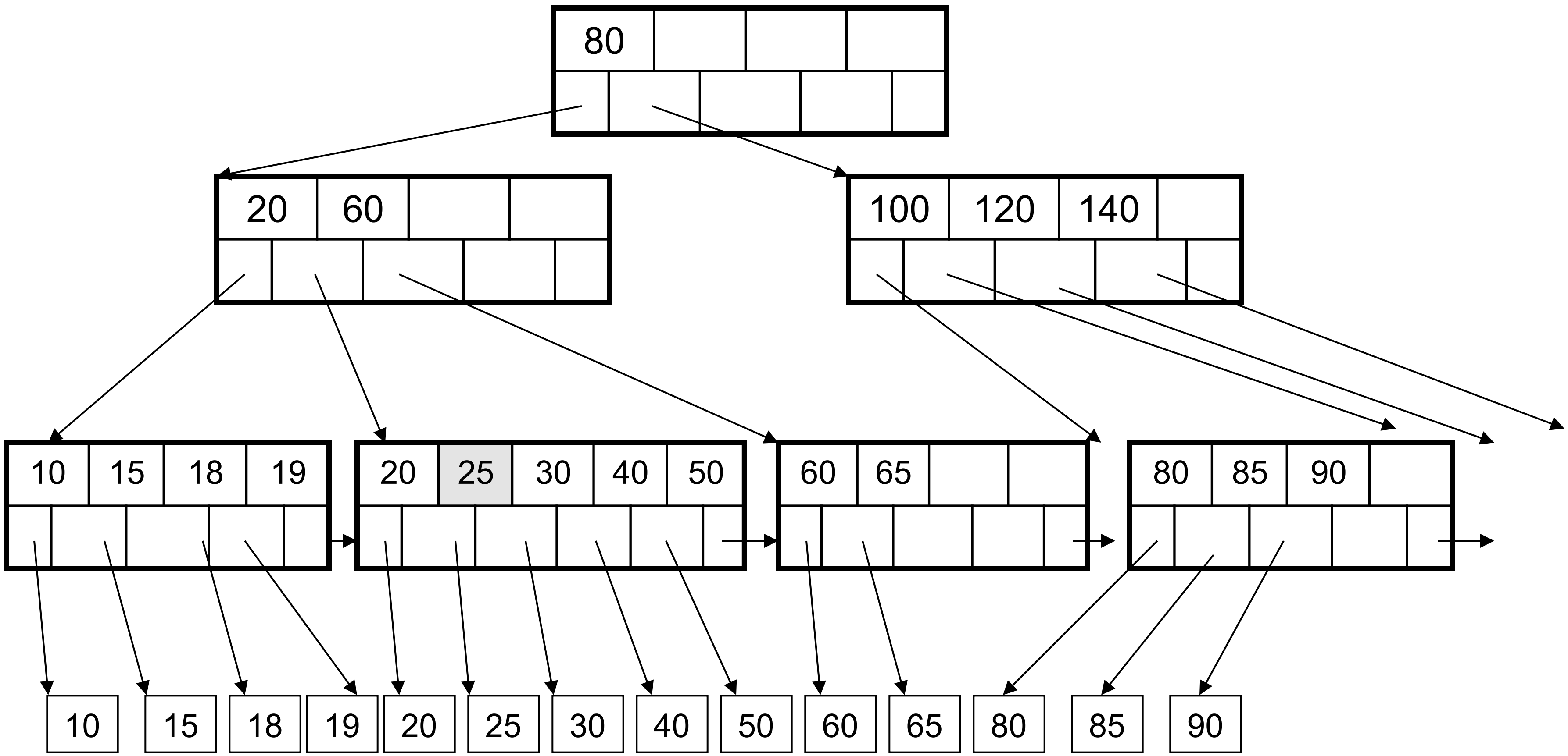
Insertion in a B+ Tree

After insertion



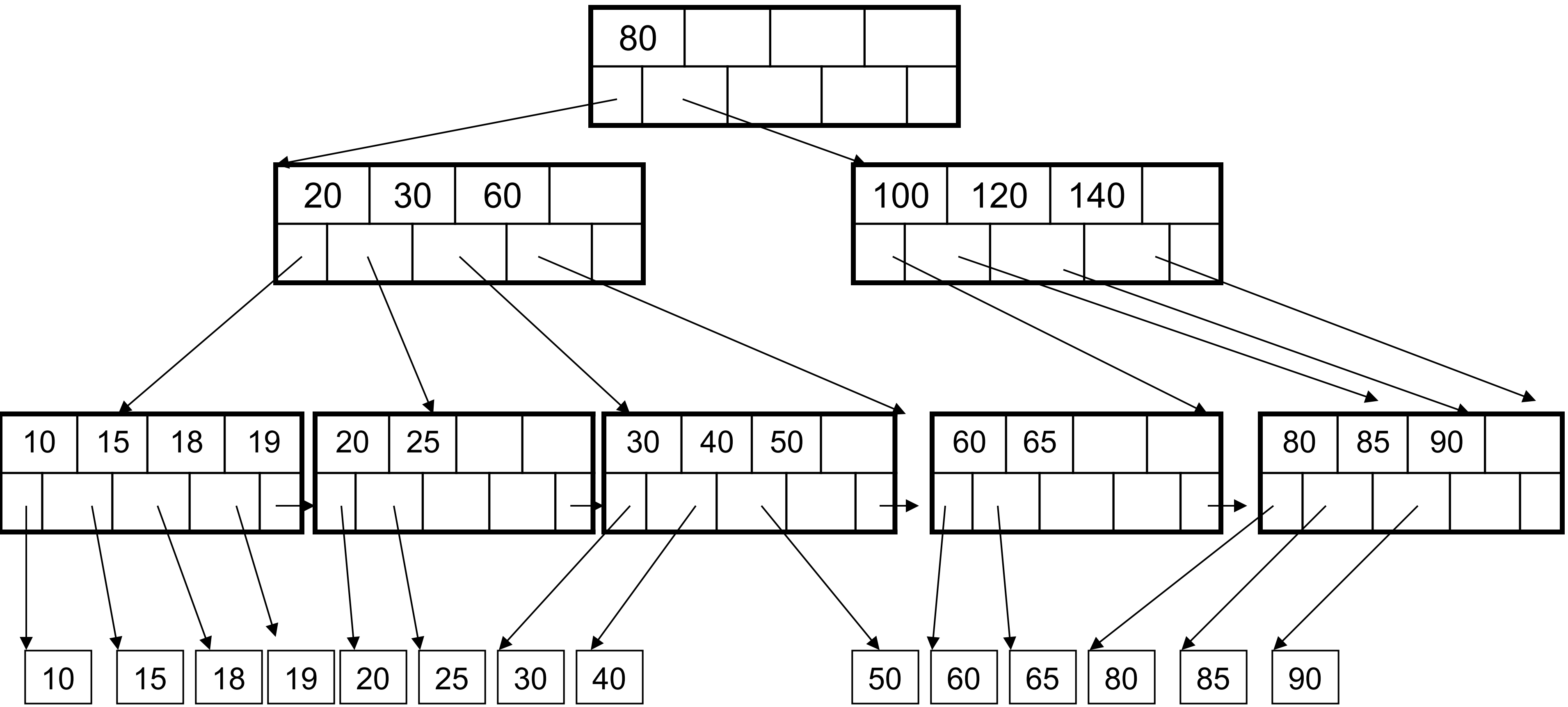
Insertion in a B+ Tree

But now have to split !



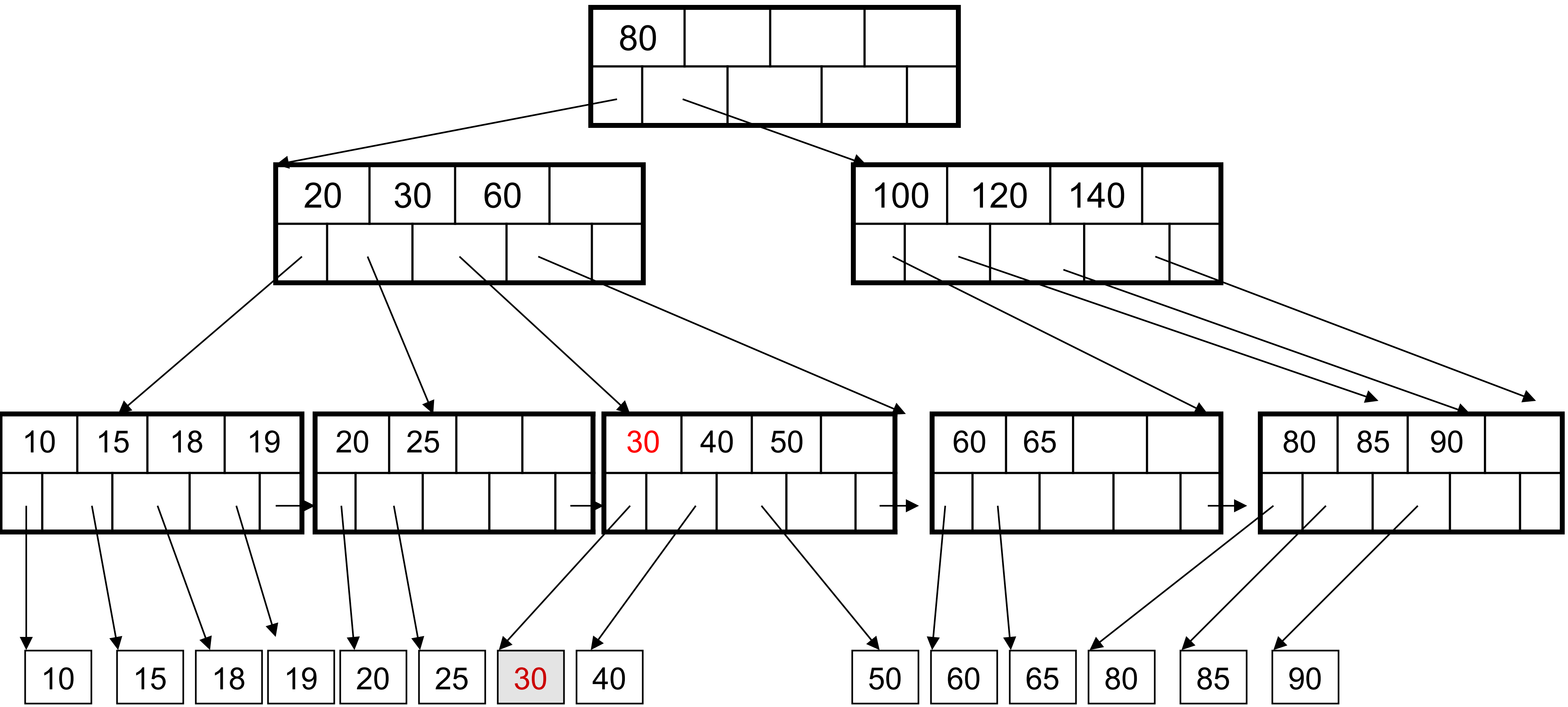
Insertion in a B+ Tree

After the split



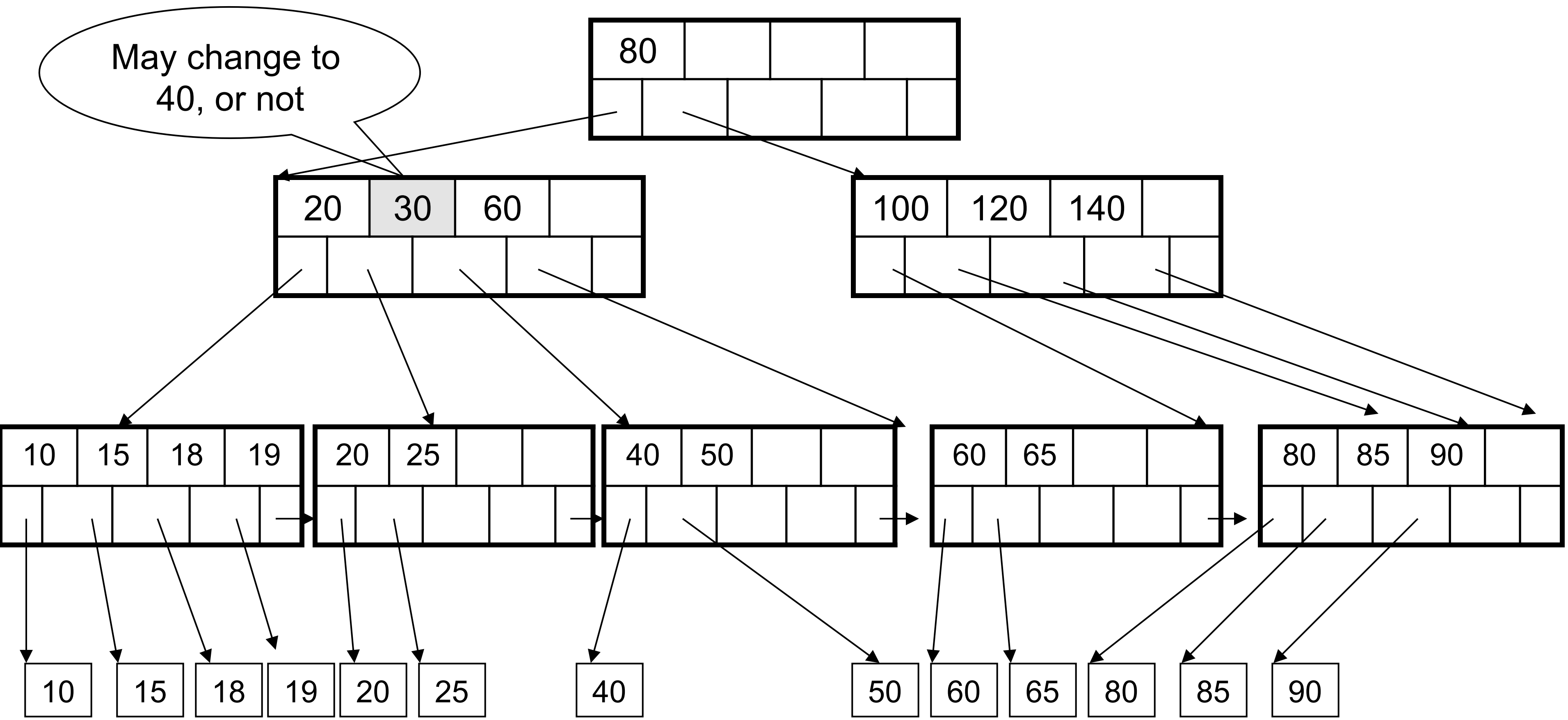
Deletion from a B+ Tree

Delete 30



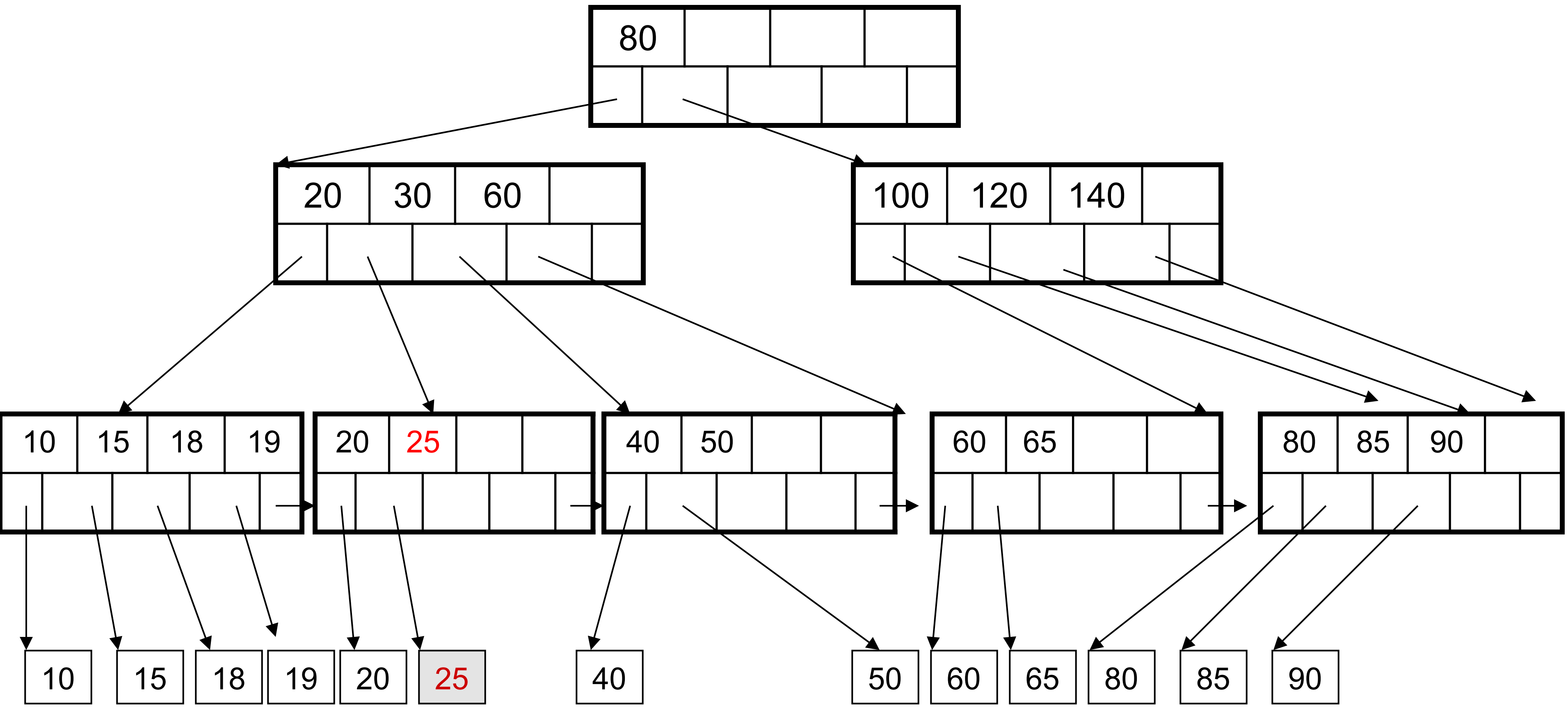
Deletion from a B+ Tree

After deleting 30



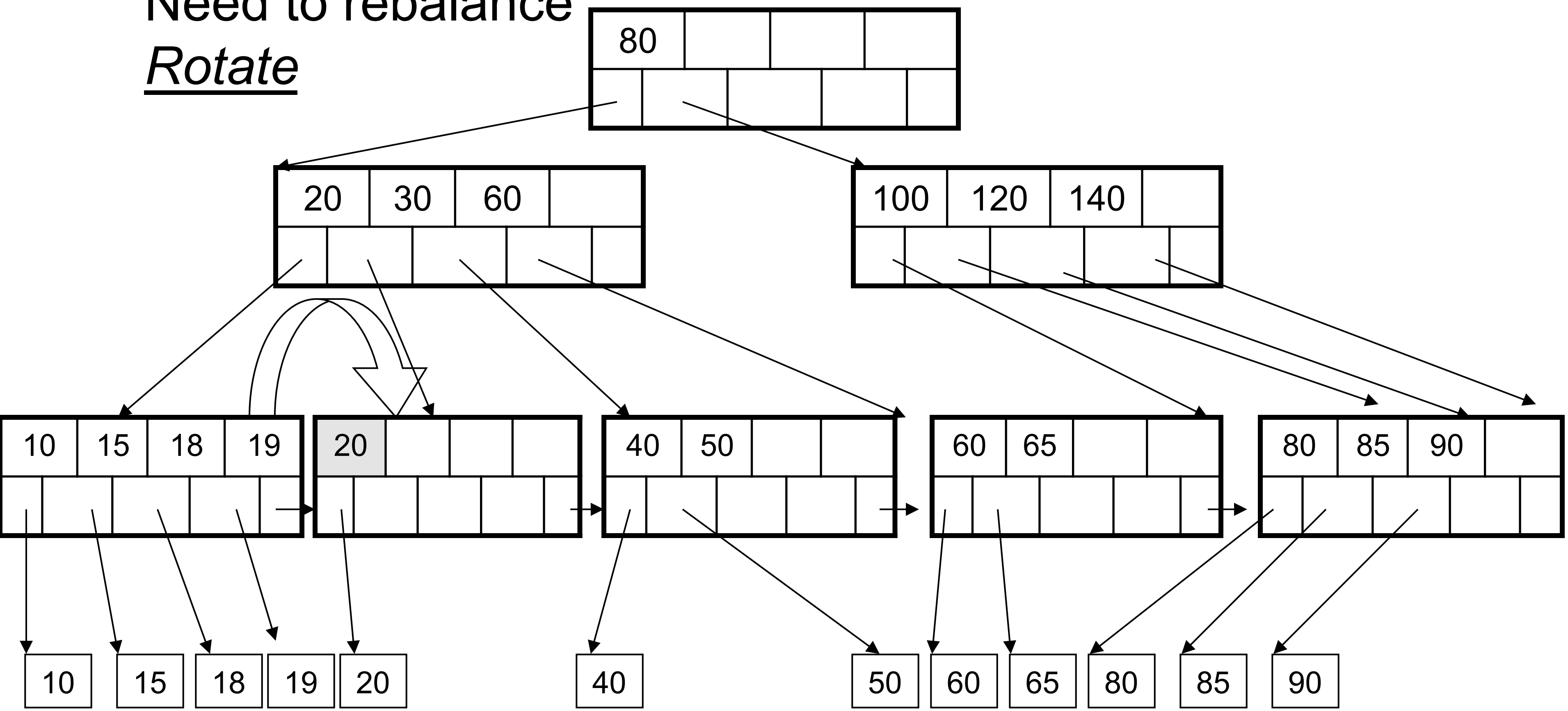
Deletion from a B+ Tree

Now delete 25



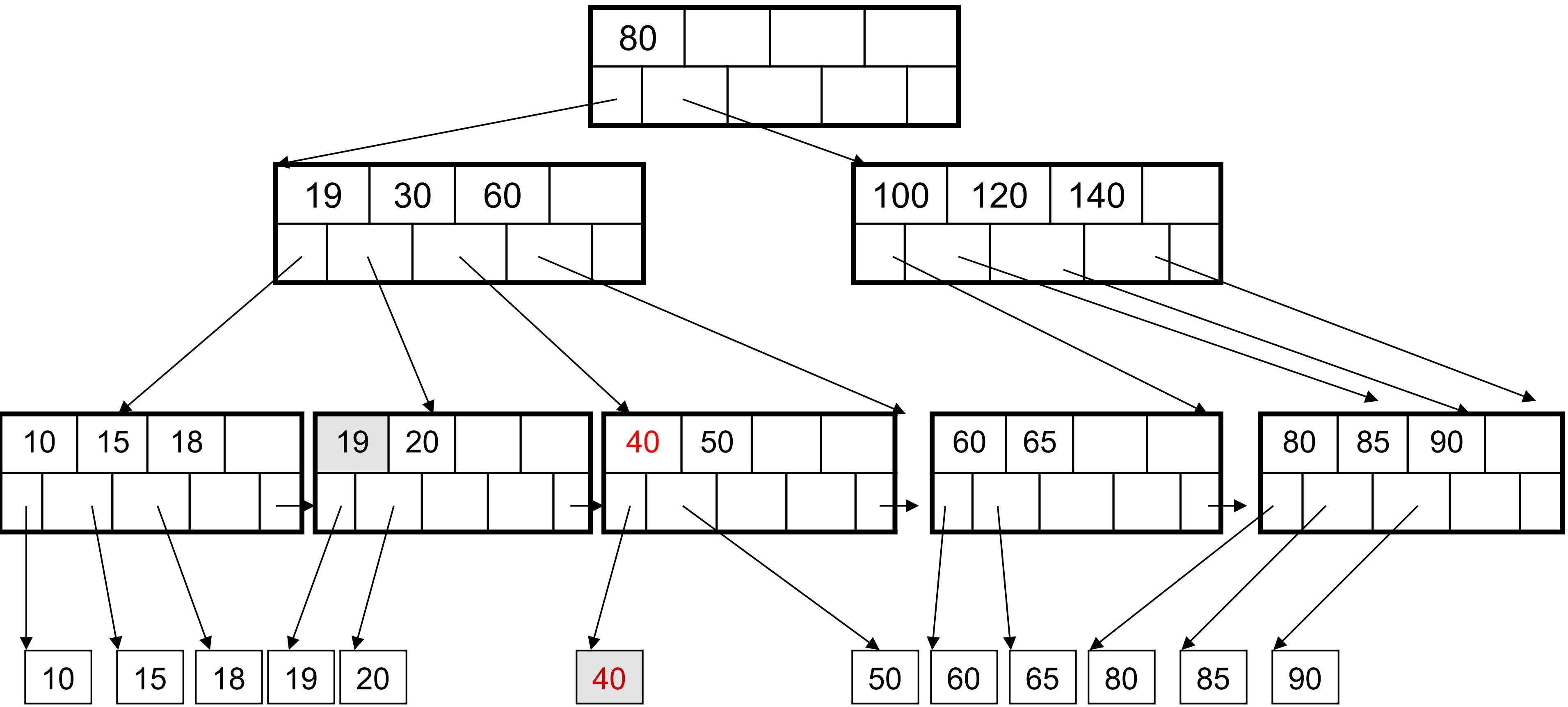
Deletion from a B+ Tree

After deleting 25
Need to rebalance
Rotate



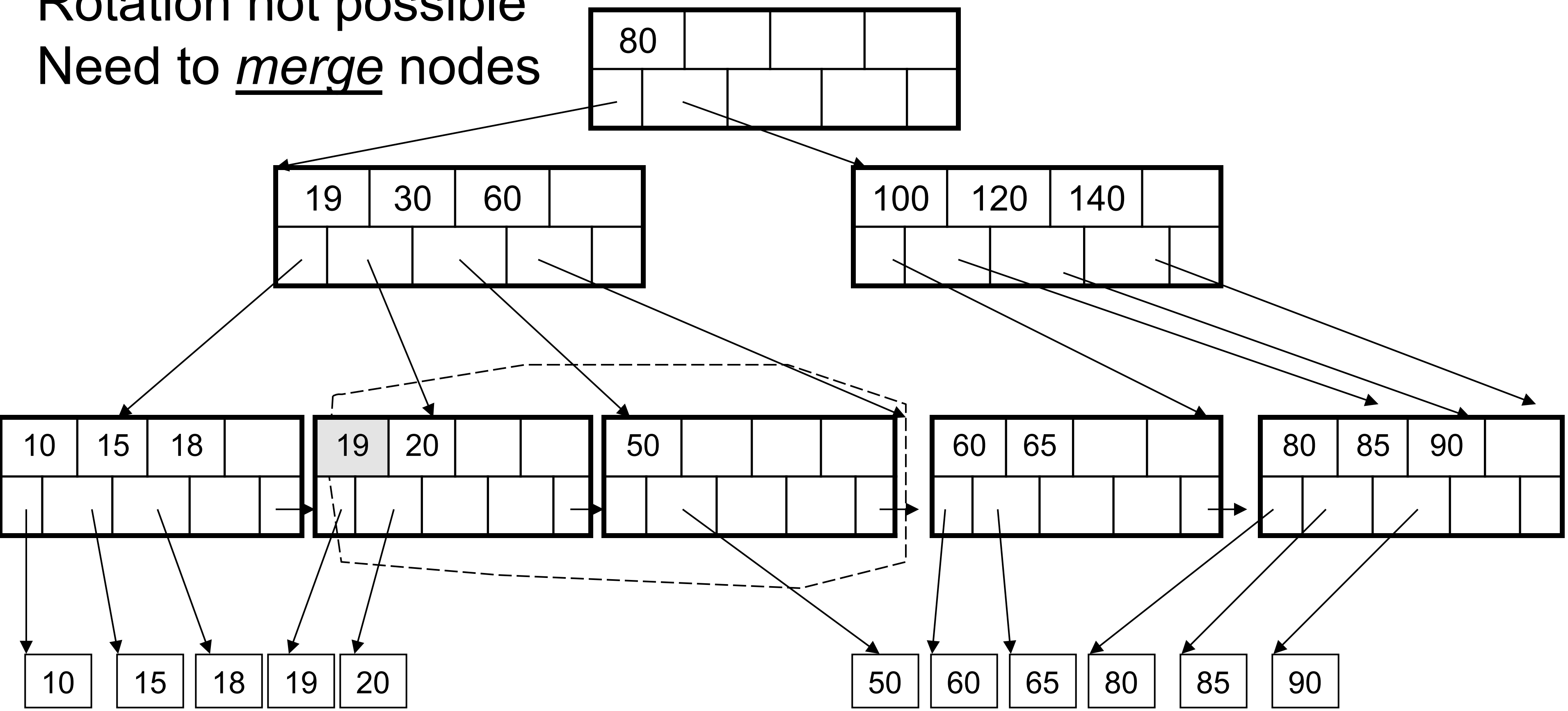
Deletion from a B+ Tree

Now delete 40



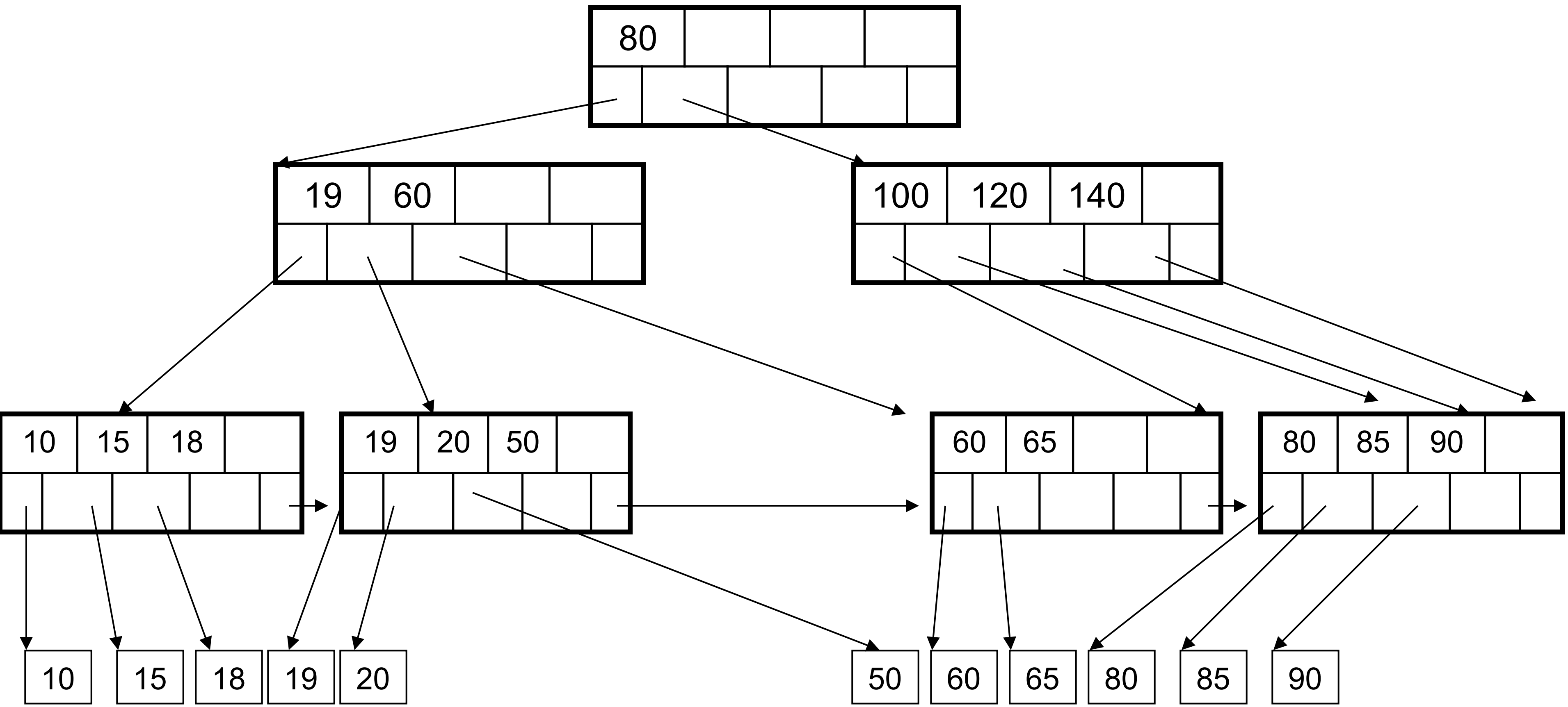
Deletion from a B+ Tree

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



Deletion from a B+ Tree

Final tree



Practical Aspects of B+ Trees

Key compression:

- Each node keeps only the from parent keys
- Jonathan, John, Johnsen, Johnson … →
  – Parent: Jo
  – Child: nathan, hn, hnsen, hnson, …

Practical Aspects of B+ Trees

Bulk insertion

- When a new index is created there are two options:
  - Start from empty tree, insert each key one-by-one
  - Do *bulk insertion* – what does that mean ?

Practical Aspects of B+ Trees

Concurrency control

- The root of the tree is a "hot spot"
  - Leads to lock contention during insert/ delete
- Solution: do proactive split during insert, or proactive merge during delete
  - Insert/delete now require only one traversal, from the root to a leaf
  - Use the "tree locking" protocol

Summary on B+ Trees

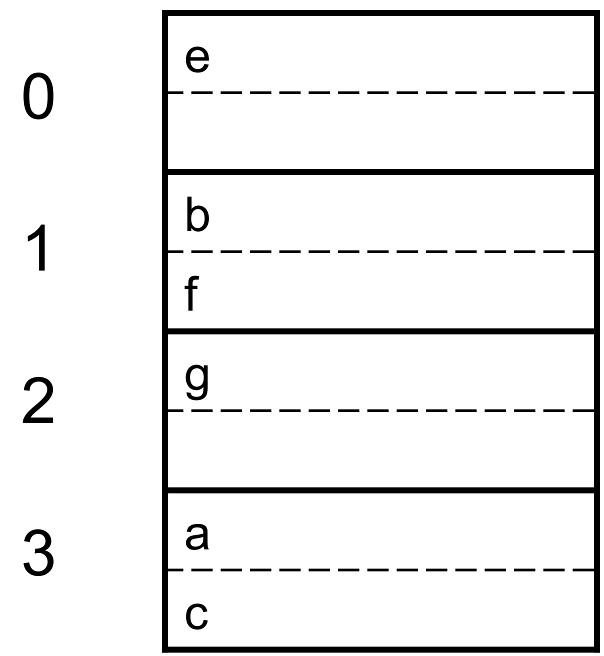
- Default index structure on most DBMS
- Very effective at answering ‘point’ queries:
  productName = ‘gizmo’
- Effective for range queries:
  $50 < \text{price}$ AND $\text{price} < 100$
- Less effective for multirange:
  $50 < \text{price} < 100$ AND $2 < \text{quant} < 20$

Hash Tables

- Secondary storage hash tables are much like main memory ones
- Recall basics:
  – There are n *buckets*
  – A hash function f(k) maps a key k to {0, 1, …, n-1}
  – Store in bucket f(k) a pointer to record with key k
- Secondary storage: bucket = block, use overflow blocks when needed

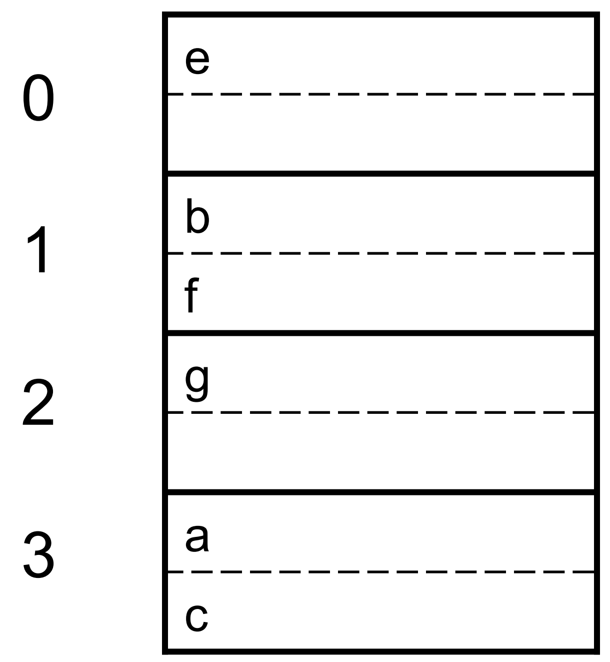
Hash Table Example

- Assume 1 bucket (block) stores 2 keys + pointers
- h(e)=0
- h(b)=h(f)=1
- h(g)=2
- h(a)=h(c)=3



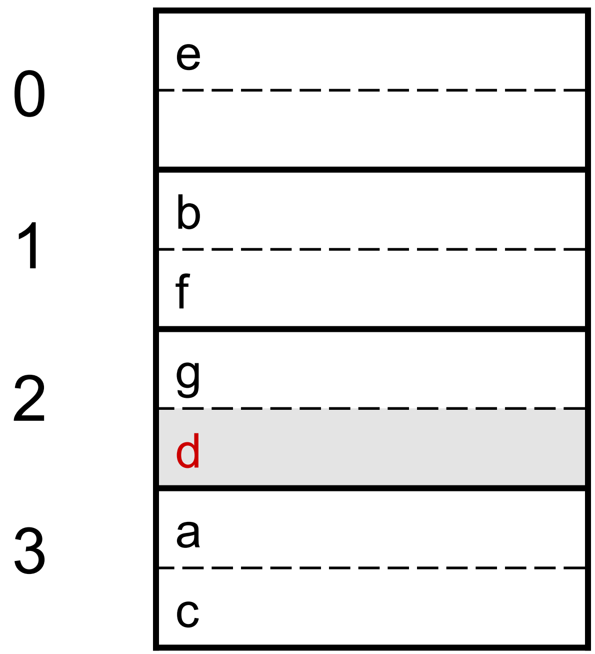
Searching in a Hash Table

- Search for a:
- Compute h(a)=3
- Read bucket 3
- 1 disk access



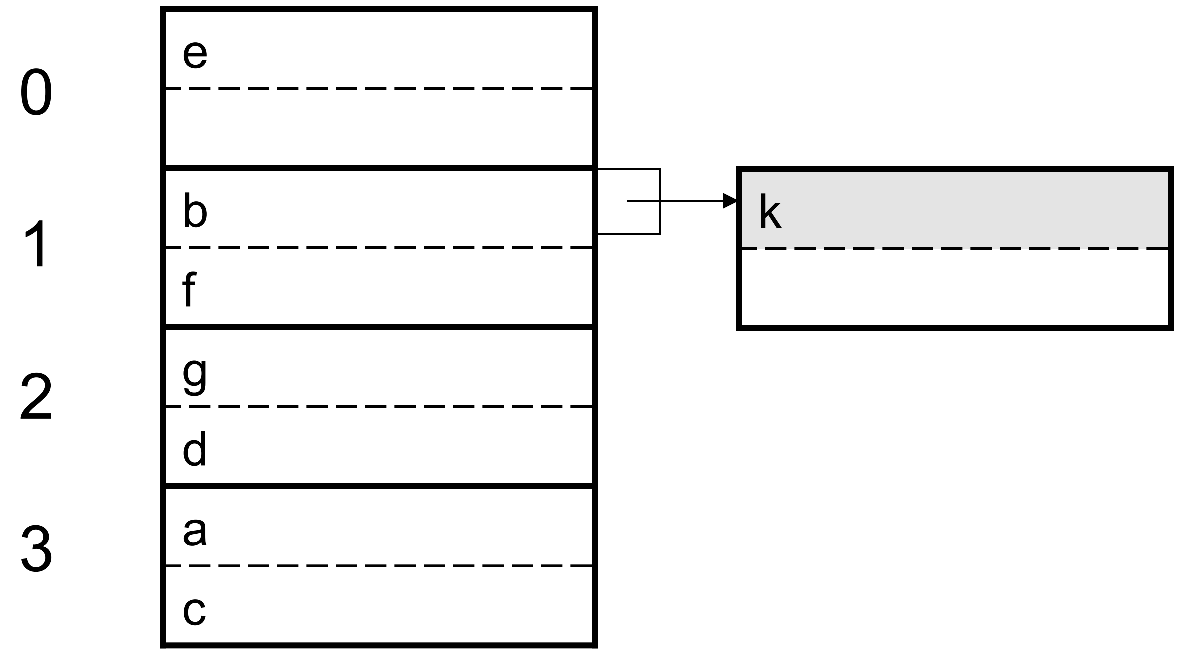
Insertion in Hash Table

- Place in right bucket, if space
- E.g. h(d)=2



Insertion in Hash Table

- Create overflow block, if no space
- E.g. h(k)=1



- More over-flow blocks may be needed

Hash Table Performance

- Excellent, if no overflow blocks
- Degrades considerably when number of keys exceeds the number of buckets (I.e. many overflow blocks).

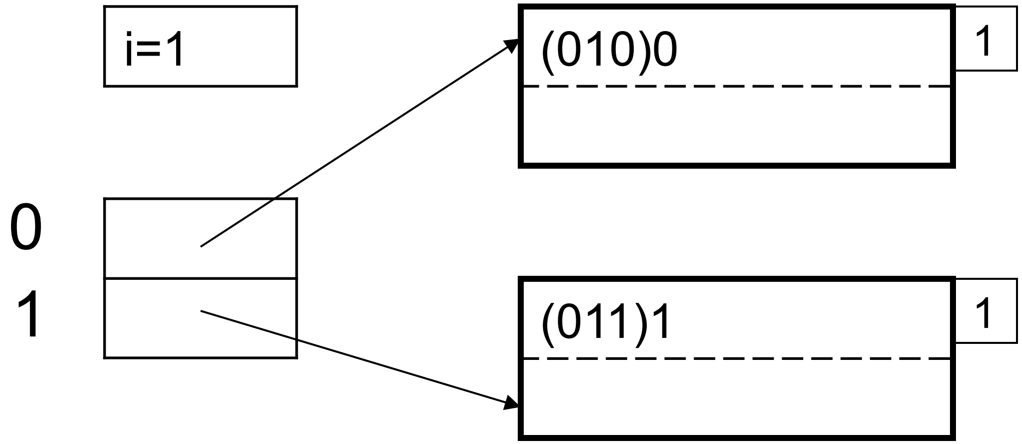
Extensible Hash Table

- Allows has table to grow, to avoid performance degradation
- Assume a hash function h that returns numbers in $\{0, \ldots, 2^k - 1\}$
- Start with $n = 2^i \ll 2^k$, only look at i least significant bits

Extensible Hash Table

- E.g. $i=1$, $n=2^i=2$, $k=4$

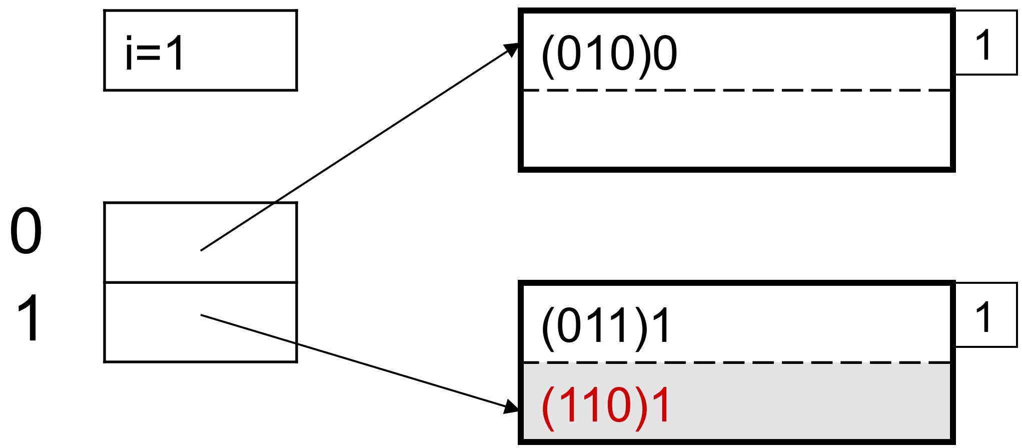
- Keys:
  - 4 (=0100)
  - 7 (=0111)



- Note: we only look at the last bit (0 or 1)

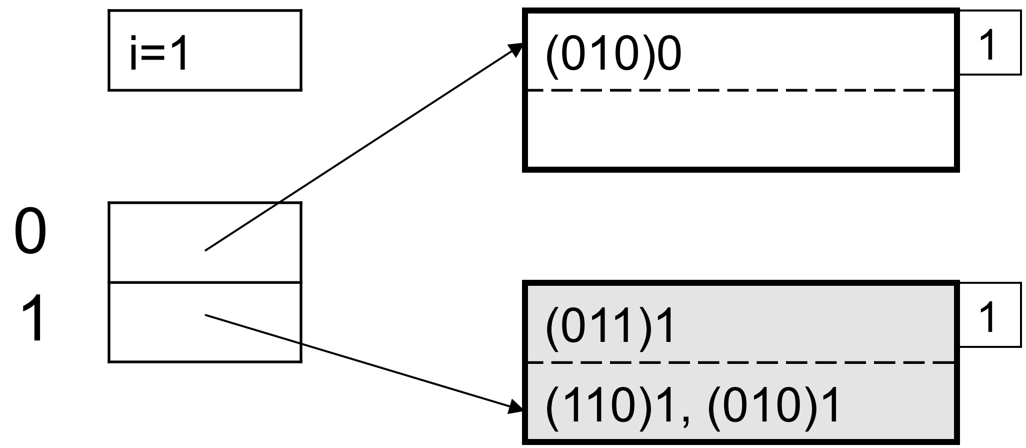
Insertion in Extensible Hash Table

- Insert 13 (=1101)



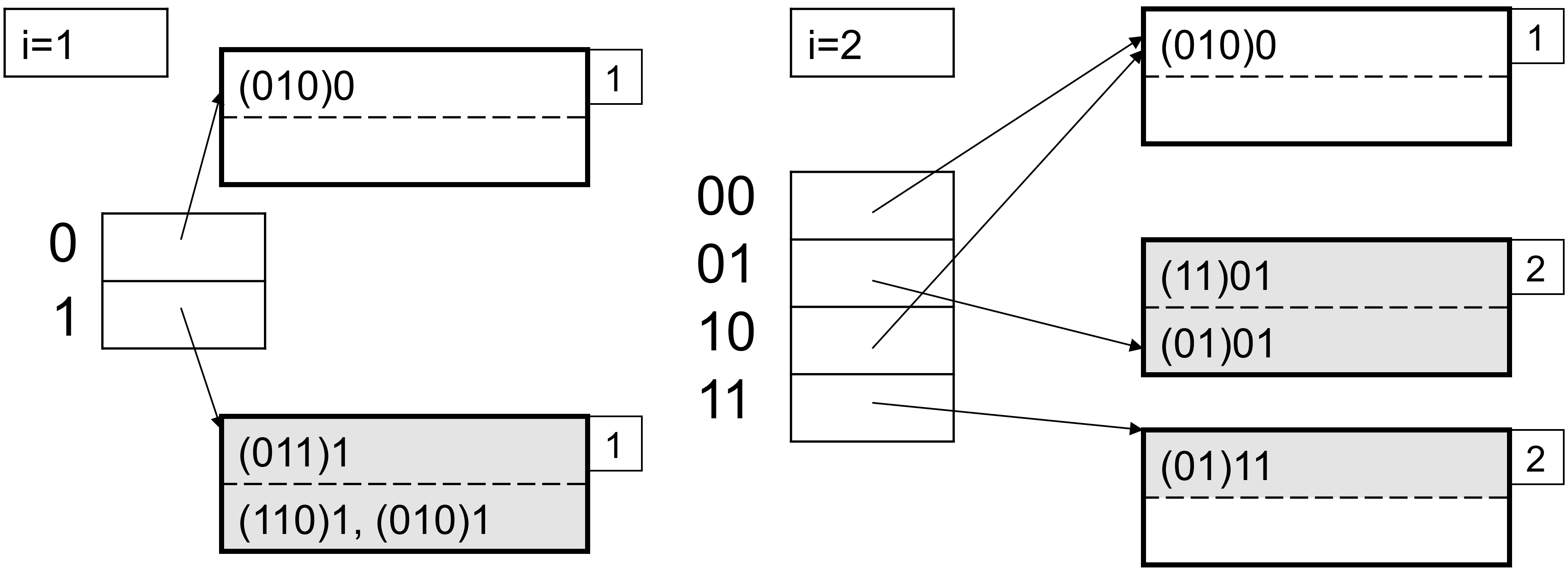
Insertion in Extensible Hash Table

- Now insert 0101



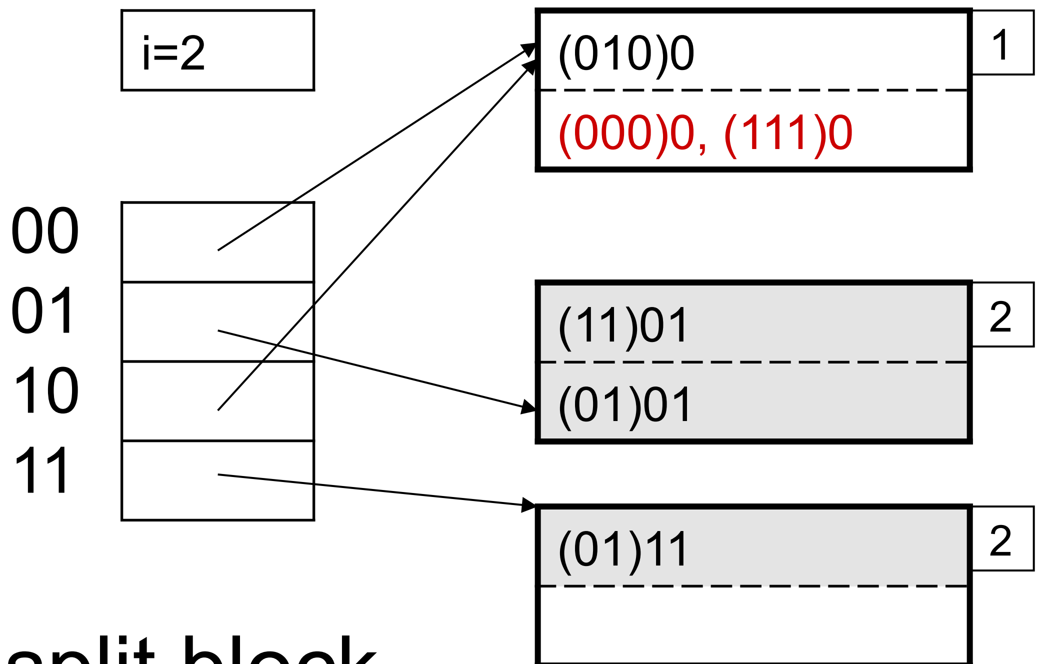
- Need to extend table, split blocks
- i becomes 2

Insertion in Extensible Hash Table



Insertion in Extensible Hash Table

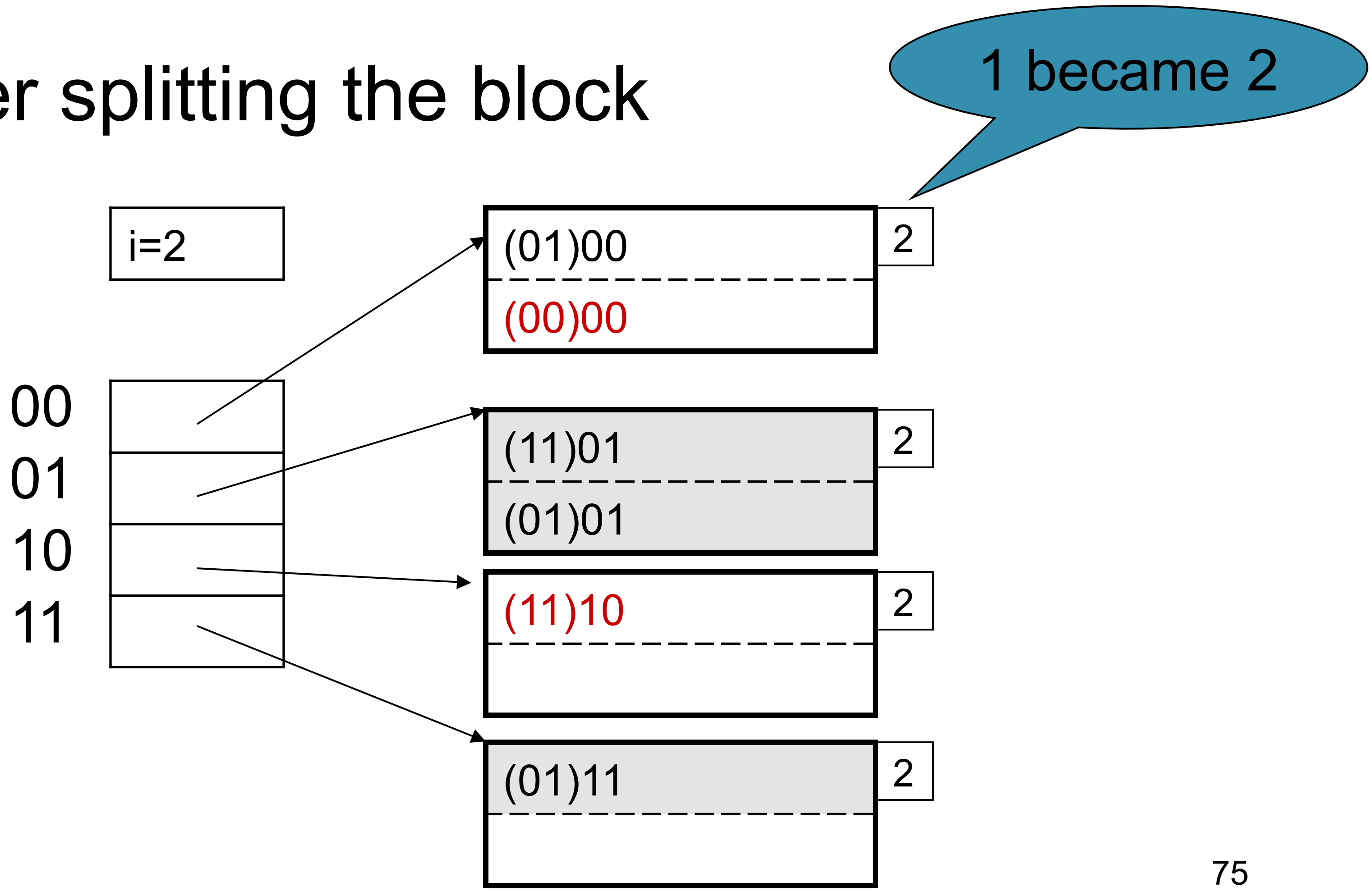
- Now insert 0000, 1110



- Need to split block

Insertion in Extensible Hash Table

- After splitting the block



Extensible Hash Table

- How many buckets (blocks) do we need to touch after an insertion ?

- How many entries in the hash table do we need to touch after an insertion ?

Performance Extensible Hash Table

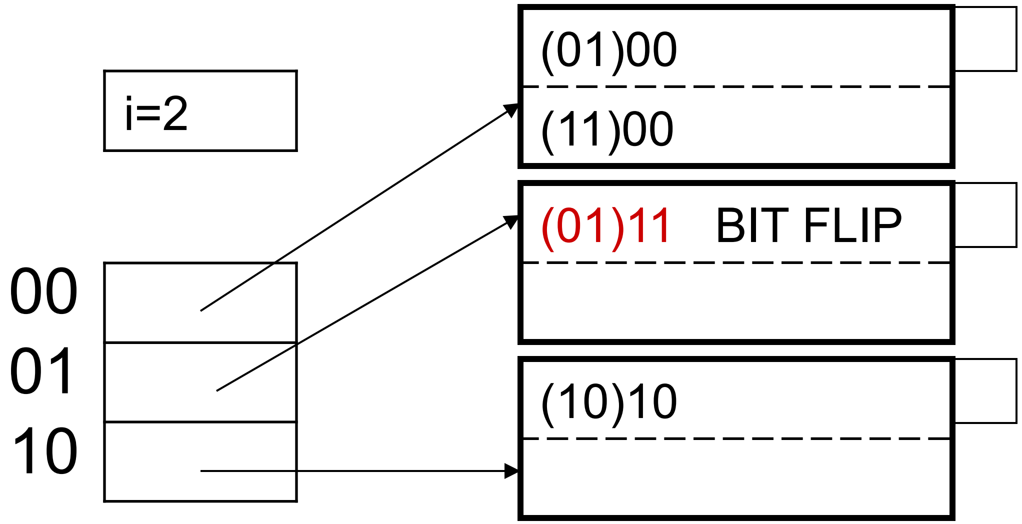
- No overflow blocks: access always one read
- BUT:
  - Extensions can be costly and disruptive
  - After an extension table may no longer fit in memory

Linear Hash Table

- Idea: extend only one entry at a time
- Problem: n= no longer a power of 2
- Let i be such that $2^i <= n < 2^{i+1}$
- After computing h(k), use last i bits:
  – If last i bits represent a number > n, change msb from 1 to 0 (get a number <= n)

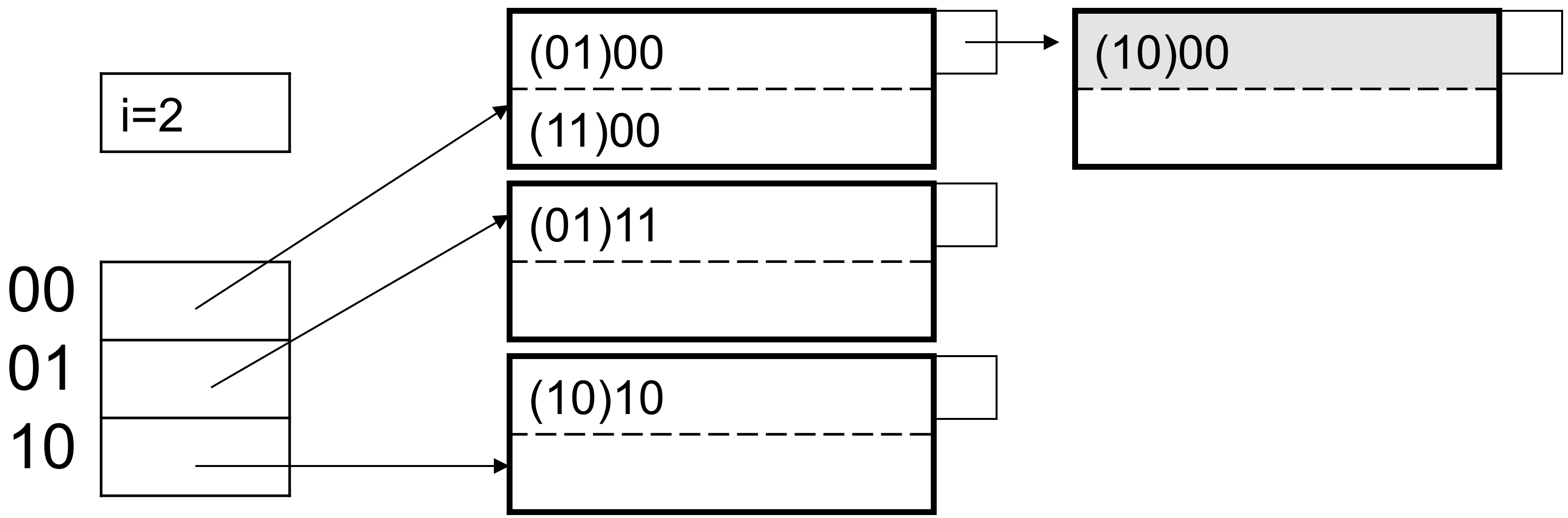
Linear Hash Table Example

- n=3



Linear Hash Table Example

- Insert 1000: overflow blocks…

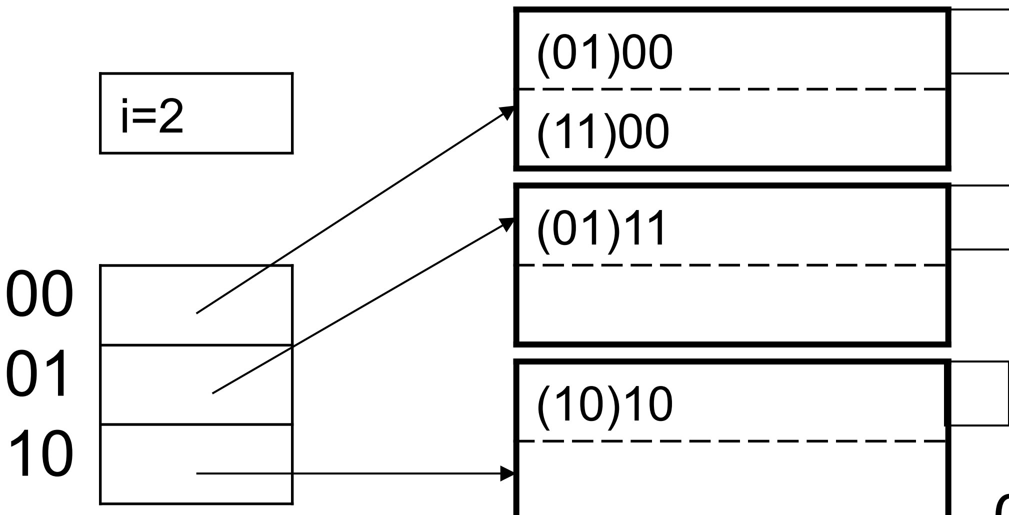


Linear Hash Tables

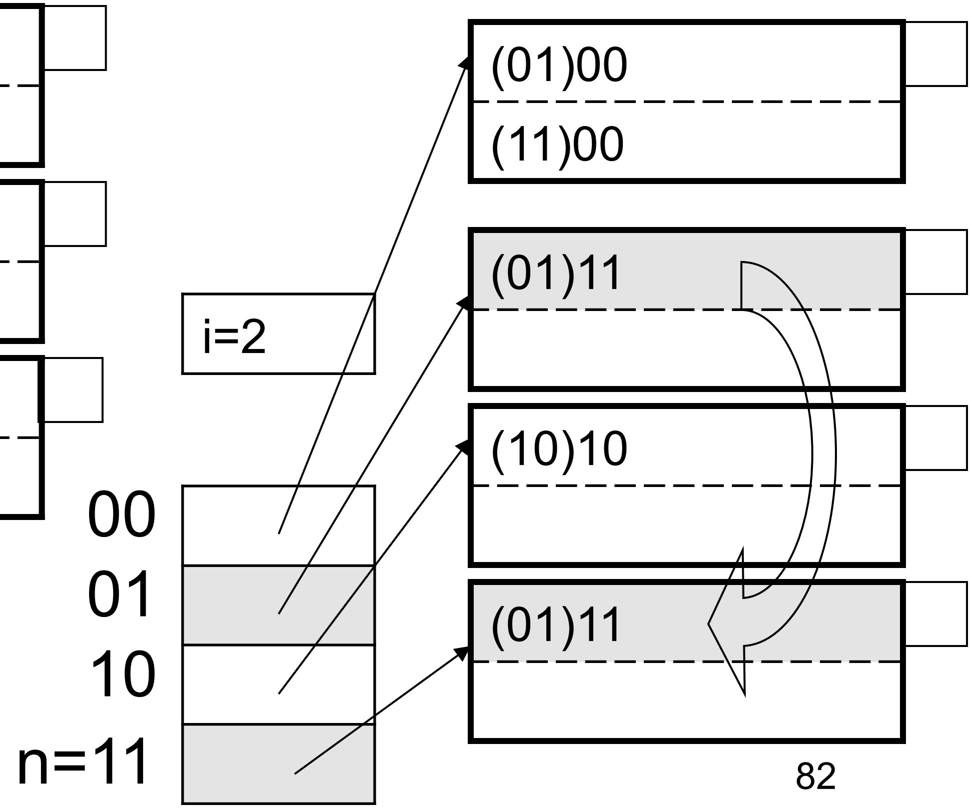
- Extension: independent on overflow blocks
- Extend n:=n+1 when average number of records per block exceeds (say) 80%

Linear Hash Table Extension

- From n=3 to n=4

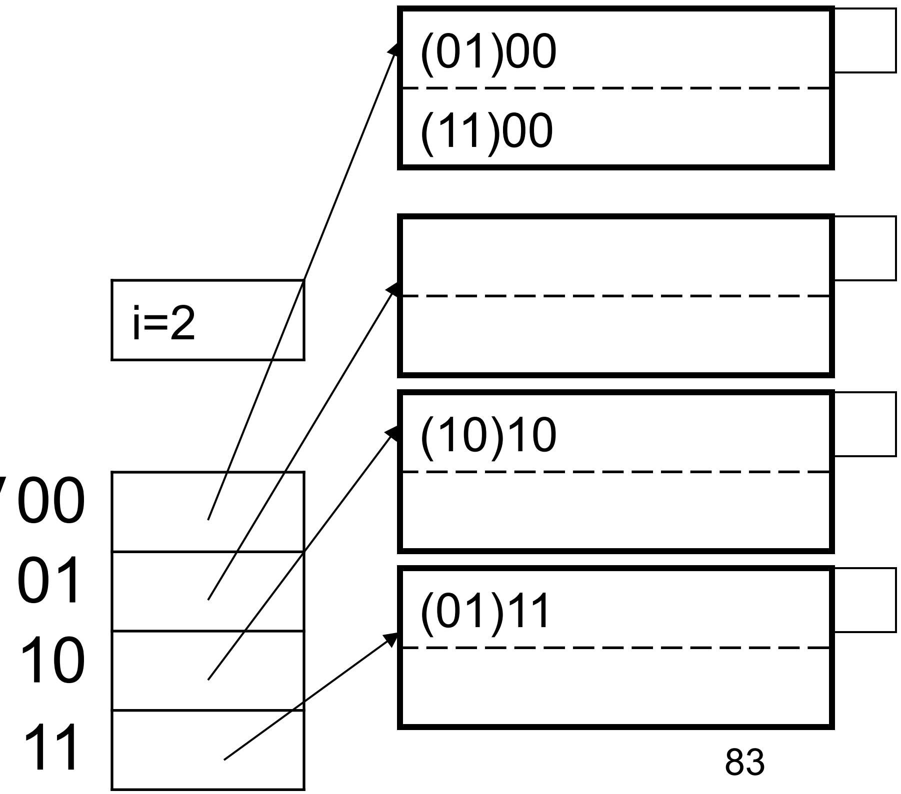


- Only need to touch one block (which one ?)



Linear Hash Table Extension

- From n=3 to n=4 finished
- Extension from n=4 to n=5 (new bit)
- Need to touch every single block (why ?)



Indexes in Postgres

```
CREATE TABLE V(M int, N varchar(20), P int);
```

```
CREATE INDEX V1_N ON V(N)
```

```
CREATE INDEX V2 ON V(P, M)
```

```
CREATE INDEX VVV ON V(M, N)
```

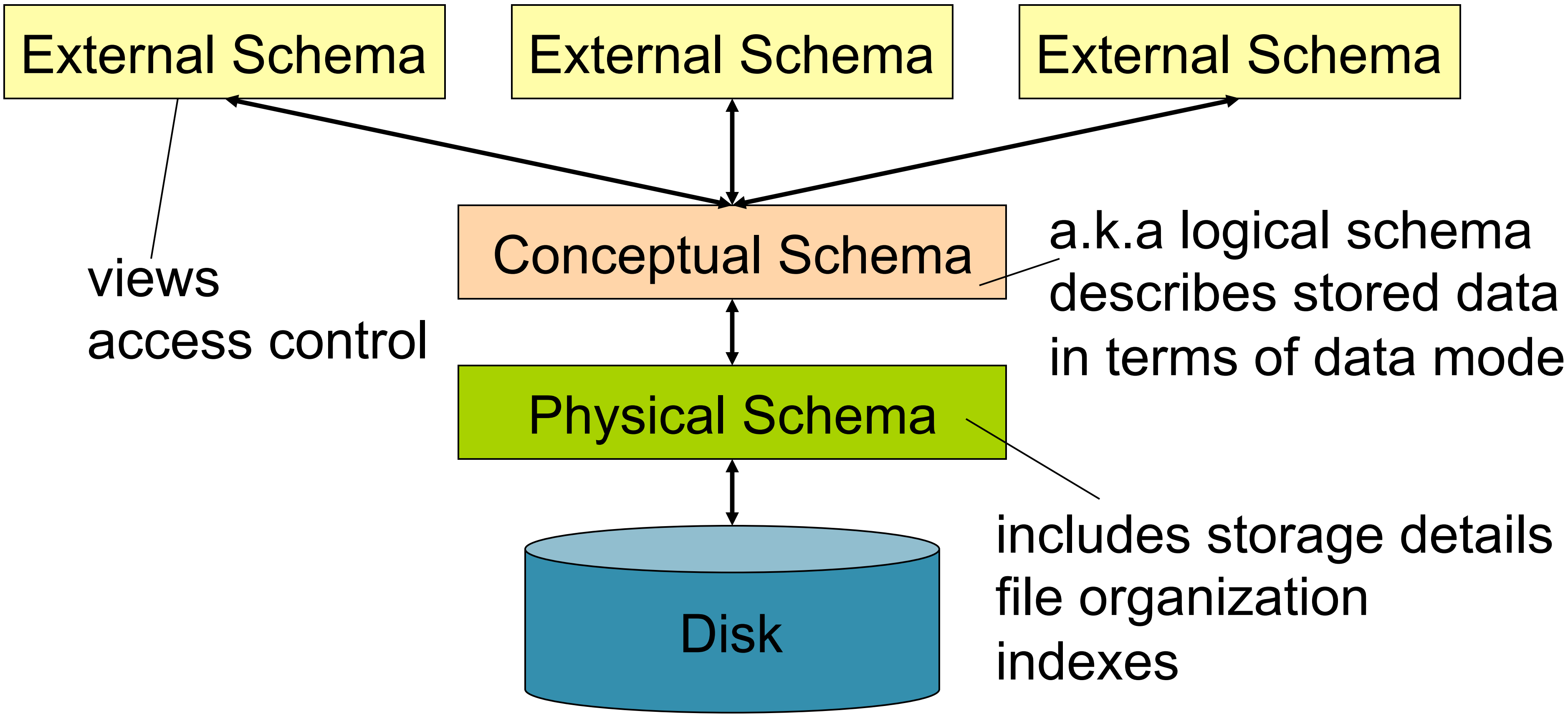
```
CLUSTER V USING V2
```

Makes V2 clustered

Database Tuning Overview

- The database tuning problem
- Index selection (discuss in detail)
- Horizontal/vertical partitioning (see lecture 3)
- Denormalization (discuss briefly)

Levels of Abstraction in a DBMS



The Database Tuning Problem

- We are given a workload description
  - List of queries and their frequencies
  - List of updates and their frequencies
  - Performance goals for each type of query
- Perform *physical database design*
  - Choice of indexes
  - Tuning the conceptual schema
    - Denormalization, vertical and horizontal partition
  - Query and transaction tuning

The Index Selection Problem

- Given a database schema (tables, attributes)
- Given a “query workload”:
  - Workload = a set of (query, frequency) pairs
  - The queries may be both SELECT and updates
  - Frequency = either a count, or a percentage
- Select a set of indexes that optimizes the workload

In general this is a very hard problem

Index Selection: Which Search Key

- Make some attribute K a search key if the WHERE clause contains:
  - An exact match on K
  - A range predicate on K
  - A join on K

Index Selection Problem 1

V(M, N, P);

Your workload is this

100000 queries:

```
SELECT *
FROM V
WHERE N=?
```

100 queries:

```
SELECT *
FROM V
WHERE P=?
```

Which indexes should we create?

Index Selection Problem 1

```
V(M, N, P);
```

Your workload is this

100000 queries:

```
SELECT *
FROM V
WHERE N=?
```

100 queries:

```
SELECT *
FROM V
WHERE P=?
```

A: V(N) and V(P) (hash tables or B-trees)

Index Selection Problem 2

```
V(M, N, P);
```

Your workload is this

100000 queries:

```
SELECT *
FROM V
WHERE N>? and N<?
```

100 queries:

```
SELECT *
FROM V
WHERE P=?
```

100000 queries:

```
INSERT INTO V
VALUES (?, ?, ?)
```

Which indexes should we create?

Index Selection Problem 2

```
V(M, N, P);
```

Your workload is this

100000 queries:

```
SELECT *
FROM V
WHERE N>? and N<?
```

100 queries:

```
SELECT *
FROM V
WHERE P=?
```

100000 queries:

```
INSERT INTO V
VALUES (?, ?, ?)
```

A: definitely V(N) (must B-tree); unsure about V(P)

Index Selection Problem 3

```
V(M, N, P);
```

Your workload is this

100000 queries:

```
SELECT *
FROM V
WHERE N=?
```

1000000 queries:

```
SELECT *
FROM V
WHERE N=? and P>?
```

100000 queries:

```
INSERT INTO V
VALUES (?, ?, ?)
```

Which indexes should we create?

Index Selection Problem 3

V(M, N, P);

Your workload is this

100000 queries:

```
SELECT *
FROM V
WHERE N=?
```

1000000 queries:

```
SELECT *
FROM V
WHERE N=? and P>?
```

100000 queries:

```
INSERT INTO V
VALUES (?, ?, ?)
```

A: V(N, P)

Index Selection Problem 4

```
V(M, N, P);
```

Your workload is this

1000 queries:

```
SELECT *
FROM V
WHERE N>? and N<?
```

100000 queries:

```
SELECT *
FROM V
WHERE P>? and P<?
```

Which indexes should we create?

Index Selection Problem 4

```
V(M, N, P);
```

Your workload is this

1000 queries:

```
SELECT *
FROM V
WHERE N>? and N<?
```

100000 queries:

```
SELECT *
FROM V
WHERE P>? and P<?
```

A: V(N) secondary,   V(P) primary index

The Index Selection Problem

- SQL Server
  - Automatically, thanks to *AutoAdmin* project
  - Much acclaimed successful research project from mid 90's, similar ideas adopted by the other major vendors

- PostgreSQL
  - You will do it manually, part of homework 5
  - But tuning wizards also exist

Index Selection: Multi-attribute Keys

Consider creating a multi-attribute key on K1, K2, … if

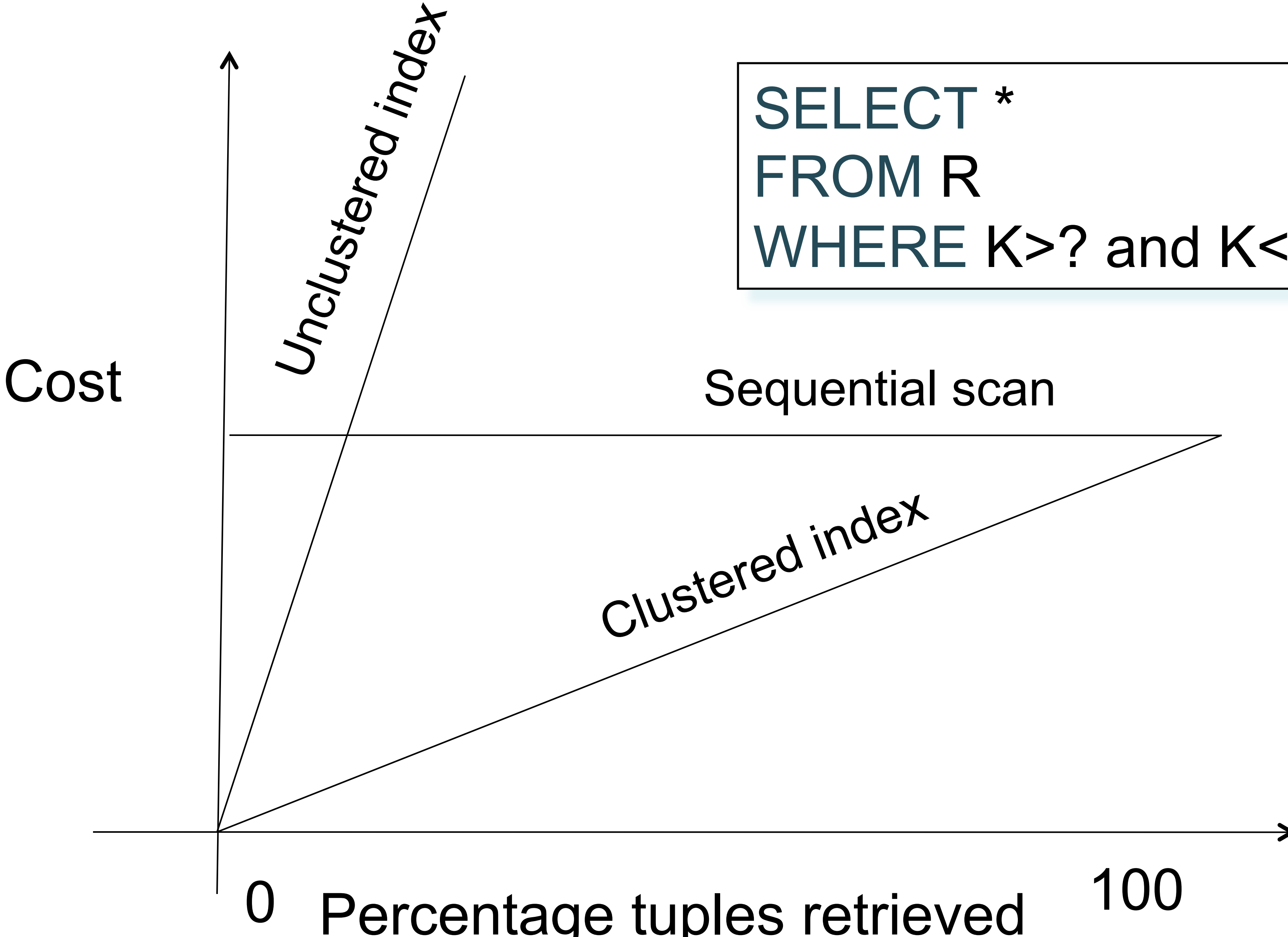
- WHERE clause has matches on K1, K2, …
  - But also consider separate indexes
- SELECT clause contains only K1, K2, ..
  - A *covering index* is one that can be used exclusively to answer a query, e.g. index R

```
SELECT K2 FROM R WHERE K1=55
```

To Cluster or Not

- Range queries benefit mostly from clustering
- Covering indexes do *not* need to be clustered: they work equally well unclustered

```sql
SELECT *
FROM R
WHERE K>? and K<?
```



Hash Table v.s. B+ tree

- Rule 1: always use a B+ tree ☺

- Rule 2: use a Hash table on K when:
  - There is a very important selection query on equality (WHERE K=?), and no range queries
  - You know that the optimizer uses a nested loop join where K is the join attribute of the inner relation (you will understand that in a few lectures)

Balance Queries v.s. Updates

- Indexes speed up queries
  - SELECT FROM WHERE
- But they usually slow down updates:
  - INSERT, DELECTE, UPDATE
  - However some updates benefit from indexes

```
UPDATE R
   SET A = 7
   WHERE K=55
```

Tools for Index Selection

- SQL Server 2000 Index Tuning Wizard
- DB2 Index Advisor

- How they work:
  - They walk through a large number of configurations, compute their costs, and choose the configuration with minimum cost

Tuning the Conceptual Schema

- Denormalization
- Horizontal Partitioning
- Vertical Partitioning

Denormalization

Product(**pid**, pname, price, cid)
Company(**cid**, cname, city)

A very frequent query:

```
SELECT x.pid, x.pname
FROM Product x, Company y
WHERE x.cid = y.cid and x.price < ? and y.city = ?
```

How can we speed up this query workload ?

Denormalization

Product(<u>**pid**</u>, pname, price, cid)
Company(<u>**cid**</u>, cname, city)

Denormalize:

ProductCompany(<u>**pid**</u>,pname,price,cname,city)

```
INSERT INTO ProductCompany
  SELECT x.pid, x.pname,.price, y.cname, y.city
  FROM Product x, Company y
  WHERE x.cid = y.cid
```

Denormalization

Next, replace the query

```
SELECT x.pid, x.pname
FROM Product x, Company y
WHERE x.cid = y.cid and x.price < ? and y.city = ?
```

↓

```
SELECT pid, pname
FROM ProductCompany
WHERE price < ? and city = ?
```

Issues with Denormalization

- It is no longer in BCNF
  - We have the hidden FD: cid $\rightarrow$ cname, city
- When Product or Company are updated, we need to propagate updates to ProductCompany
  - Use RULE in postgres (see below)
  - Or use a trigger on a different RDBMS
- Sometimes cannot modify the query
  - What do we do then ?

Denormalization Using Views

```
INSERT INTO ProductCompany
   SELECT x.pid, x.pname,.price, y.cid, y.cname, y.city
   FROM Product x, Company y
   WHERE x.cid = y.cid;

DROP Product; DROP Company;

CREATE VIEW Product AS
   SELECT pid, pname, price, cid FROM ProductCompany

CREATE VIEW Compnay AS
   SELECT DISTINCT cid, cname, city FROM ProductCompany
```

Denormalization Using Views

Keep the query unchaged

```
SELECT x.pid, x.pname
FROM Product x, Company y
WHERE x.cid = y.cid and x.price < ? and y.city = ?
```

What does the system do ?

Denormalization Using Views

- In postgres the rewritten query is non-minimal:
  - Means: has redundant joins
  - To see this in postgres, type “explain . . .”
  - For Project 2: it’s OK to use denormalization using views (don’t forget indexes); performance is reasonable
- SQL Server does a better job with this query

Horizontal Partition

Product(**pid**, pname, price, cid)

Horizontal partition on price < 10 and price >= 10

- When few products have price < 10 but most queries are about these products

Horizontal Partition

```
INSERT INTO CheapProduct      . . . WHERE price<10
INSERT INTO ExpensiveProduct     . . . WHERE price >=10

DROP Product

CREATE VIEW Product AS
    (select * from cheapProduct) UNION ALL
    (select * from expensiveProduct)
```

Horizontal Partition

```
SELECT *
FROM Product
WHERE price = 2
```

Which of the tables cheapProduct and expensiveProduct does it touch ?

Horizontal Partition

- The query will touch both cheapProduct and expensiveProduct because we haven't told the system the partition criteria (price < 10 and >= 10)
- We can do this in two ways:
  – As a predicate in the view definition
  – As a constraint in the table definition

Partition Criteria As View Predicates

```
CREATE VIEW Product AS
   (select * from cheapProduct where price < 10)
         UNION ALL
   (select * from expensiveProduct where price >= 10)
```

SQL Server correctly optimizes the query, but postgres doesn't

Partition Criteria As Table Constraints

```
CREATE TABLE CheapProduct (
    pid int primary key not null,
    pname varchar(20) not null,
    price int not null,
    CHECK (price < 10));

CREATE TABLE ExpesniveProduct (
    . . . .
    CHECK (price >= 10));
```

If you set “constraint_exclusion = on” in postgresql.conf, then postgres optimizes this fine.

Updates Through Views

- Product is a view:
  - What should “INSERT INTO Product” do ?

- Sometime it is possible for the system to figure out which base tables to update

- If not, then use RULES or TRIGGERS

RULES in Postgres

```
CREATE [ OR REPLACE ] RULE name AS ON event
    TO table [ WHERE condition ]
    DO [ ALSO | INSTEAD ] { NOTHING |
            command | ( command ; command ... ) }
```

Where
  name = a name for the rule
  event = SELECT, INSERT, UPDATE, or DELETE
  command = SELECT, INSERT, UPDATE, DELETE
    use **new** for the new tuple, and **old** for the old tuple

RULES in Postgres

```
CREATE OR REPLACE RULE productInsertRule AS
   ON INSERT TO Product DO INSTEAD
     (INSERT INTO cheapProducts
          SELECT DISTINCT new.pid, new.pname, new.price
          FROM anyDummyTablePreferablyWithOneTuple
          WHERE new.price < 10;
     INSERT INTO expensiveProducts
          SELECT DISTINCT new.pid, new.pname, new.price
          FROM anyDummyTablePreferablyWithOneTuple
          WHERE new.price >= 10);
```

RULES in Postgres

```
CREATE OR REPLACE RULE productDeleteRule AS
    ON DELETE TO Product DO INSTEAD
        (DELETE FROM cheapProducts
                WHERE pid = old.pid
        DELETE FROM expensiveProducts
                WHERE pid = old.pid);
```

Vertical Partition

Varchar(500)

Product(<u>**pid**</u>, pname, price, description)

Split vertically into:

- Product1(pid, name, price)
- Product2(pid, description)

Define Product as view

Vertical Partition

```
CREATE VIEW Product AS
   (select x.pid, x.pname, x.price, y.description
    from Product1 x, Product 2 y
    where x.pid = y.pid)
```

Vertical Partition

Now consider a query on Product:

```
SELECT pid, pname
FROM Product
WHERE price > 20
```

Which tables are touched by the system ?

Vertical Partition

- SQL Server does the right thing:
  – Touches only product1
- But postgres insists on joining product1 with product2 instead
  – I couldn't figure out how to coerce postgres to optimize this query
  – 10 bonus points for whoever finds out first !
  – In the meantime, we will cheat like this:

```
CREATE VIEW Product AS
    select pid, pname, price, ‘blah’ as description
    from Product1
```

NOT DISCUSSED IN CLASS

Security in SQL

- Discretionary access control in SQL
- Using views for security

Discretionary Access Control in SQL

```
GRANT privileges
    ON object
    TO users
    [WITH GRANT OPTIONS]
```

```
privileges = SELECT |
             INSERT(column-name) |
             UPDATE(column-name) |
             DELETE |
             REFERENCES(column-name)
object = table | attribute
```

Examples

```
GRANT INSERT, DELETE ON Customers
   TO Yuppy WITH GRANT OPTIONS
```

Queries allowed to Yuppy:

```
INSERT INTO Customers(cid, name, address)
     VALUES(32940, 'Joe Blow', 'Seattle')

DELETE Customers
     WHERE LastPurchaseDate < 1995
```

Queries denied to Yuppy:

```
SELECT Customer.address
FROM Customer
WHERE name = 'Joe Blow'
```

Examples

```
GRANT SELECT ON Customers TO Michael
```

Now **Michael** can SELECT, but not INSERT or DELETE

Examples

```
GRANT SELECT ON Customers
   TO Michael WITH GRANT OPTIONS
```

Michael can say this:
    GRANT SELECT ON Customers TO **Yuppi**

Now **Yuppi** can SELECT on Customers

Examples

GRANT UPDATE (price) ON Product TO **Leah**

Leah can update, but only Product.price, but not Product.name

Examples

Customer(<u>cid</u>, name, address, balance)
Orders(<u>oid</u>, cid, amount)   cid= foreign key

Bill has INSERT/UPDATE rights to Orders.
BUT HE CAN'T INSERT ! (why ?)

GRANT REFERENCES (cid) ON Customer TO **Bill**

Now **Bill** can INSERT tuples into Orders

Views and Security

David owns

Customers:

Name	Address	Balance
Mary	Huston	450.99
Sue	Seattle	-240
Joan	Seattle	333.25
Ann	Portland	-520

Fred is not allowed to see this

David says

```
CREATE VIEW PublicCustomers
        SELECT Name, Address
        FROM Customers
GRANT SELECT ON PublicCustomers TO Fred
```

David **owns**

Views and Security

Customers:

Name	Address	Balance
Mary	Huston	450.99
Sue	Seattle	-240
Joan	Seattle	333.25
Ann	Portland	-520

John is allowed to see only <0 balances

David says

```
CREATE VIEW BadCreditCustomers
        SELECT *
        FROM Customers
        WHERE Balance < 0
GRANT SELECT ON BadCreditCustomers TO John
```

Views and Security

David says

- Each customer should see only her/his record

Name	Address	Balance
Mary	Huston	450.99
Sue	Seattle	-240
Joan	Seattle	333.25
Ann	Portland	-520

```
CREATE VIEW CustomerMary
        SELECT *  FROM Customers
        WHERE name = 'Mary'
GRANT SELECT
ON CustomerMary TO Mary
```

```
CREATE VIEW CustomerSue
        SELECT *  FROM Customers
        WHERE name = 'Sue'
GRANT SELECT
ON CustomerSue TO Sue
```

Doesn't scale.

Need *row-level* access control !

. . .

Revocation

```
REVOKE   [GRANT OPTION FOR]   privileges
         ON object FROM users  {  RESTRICT  |   CASCADE   }
```

Administrator says:

REVOKE SELECT ON Customers FROM **David** CASCADE

John loses SELECT privileges on BadCreditCustomers

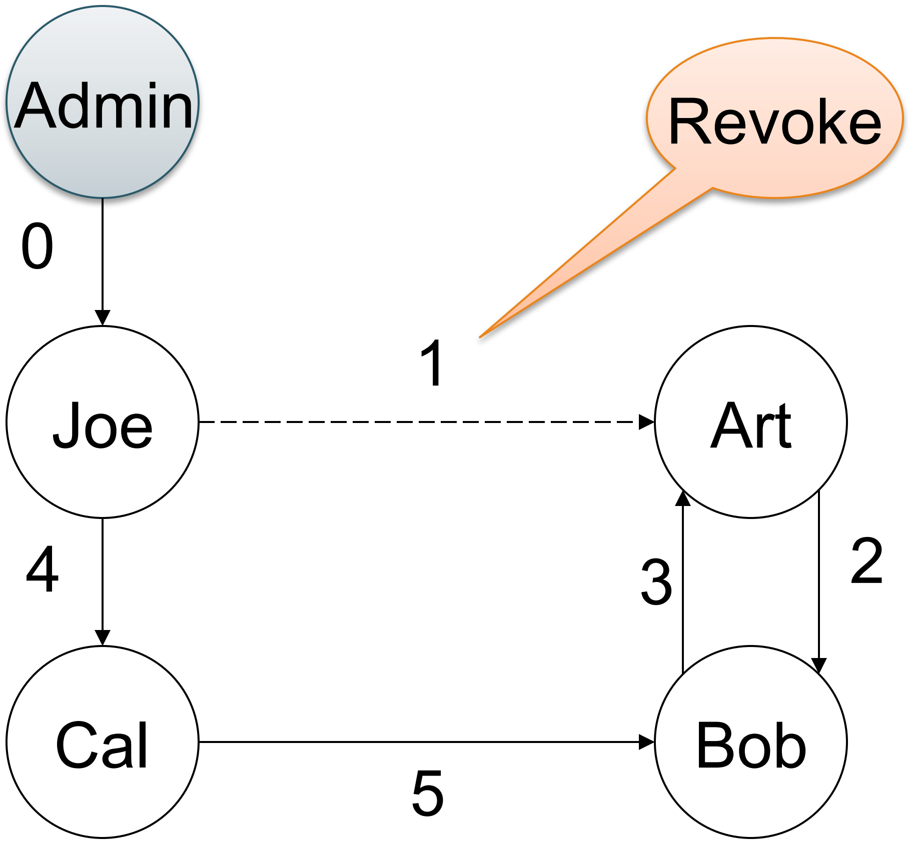
Revocation

Same privilege,
same object,
GRANT OPTION

Joe: GRANT [….] TO Art …
Art: GRANT [….] TO Bob …
Bob: GRANT [….] TO Art …
Joe: GRANT [….] TO Cal …
Cal: GRANT [….] TO Bob …
Joe: REVOKE [….] FROM Art CASCADE

What happens ??

Revocation



According to SQL everyone keeps the privilege

Summary of SQL Security

Limitations:

- No row level access control
- Table creator owns the data: that's unfair !
- Today the database is <u>not</u> at the center of the policy administration universe