

INDEXING

CS 564- Spring 2025

ACKs: Dan Suciu, Jignesh Patel, AnHai Doan

WHAT IS THIS LECTURE ABOUT?

- Indexes
 - what is an index?
- Index classifications:
 - clustered vs unclustered
 - primary vs secondary

FILE ORGANIZATION: RECAP

- So far we have seen **heap files**
 - unordered data
 - fast for scanning all records in a file
 - fast for retrieving by record id (rid)
- But we also need alternative organizations of a file to support other access patterns

MOTIVATING EXAMPLE

Sales (sid, product, date, price)

SELECT *

FROM Sales

WHERE Sales.date = “02-11-2019”

equality query




For a heap file, we need to scan all the pages of the file to return the correct result

MOTIVATING EXAMPLE

Sales (sid, product, date, price)

```
SELECT *  
FROM Sales  
WHERE Sales.date > "01-01-2019"  
AND Sales.date <= "01-31-2019"
```



range query

Here we also need to scan all the pages of the file!

ALTERNATIVE FILE ORGANIZATIONS

- We can *speed up* the query execution by better organizing the data in a file
- There are many alternatives:
 - **sorted files**
 - **indexes**
 - B+ tree
 - hash index
 - bitmap/bitslice index
 - ...

INDEX BASICS

WHAT IS AN INDEX?

Index: a data structure that organizes records of a table to speed up retrieval

Search Key: attribute or combination of attributes used to retrieve the records

- any subset of the attributes can be the search key
- a search key is **not the same** as the primary key!

EXAMPLE: HASH INDEX

Person(name, zipcode, phone)

- *search key*: {zipcode}
- *hash function h* : zipcode modulo 4

primary pages

bucket 0

(John, **53400**, 23218564)
(Alice, **54768**, 60743111)

bucket 1

(Mike, **53409**, 23200564)

bucket 2

bucket 3

(Maria, **34411**, 29010533)

To find the bucket for each record, we apply a hash function h on the search key.

INDEX ENTRIES

Index Entry: for a value **k** of the search key, it can take two forms:

#1: the record with key value **k**

#2: **<k, rid** of record with search key value **k>**

The choice of alternative for an index entry is **independent** of the indexing technique!

INDEX ENTRY #1

Person(name, zipcode, phone)

- *search key*: {zipcode}
- *hash function* ***h***: zipcode modulo 4

primary pages

bucket 0

(John, **53400**, 23218564)
(Alice, **54768**, 60743111)

index entry

bucket 1

(Mike, **53409**, 23200564)

bucket 2

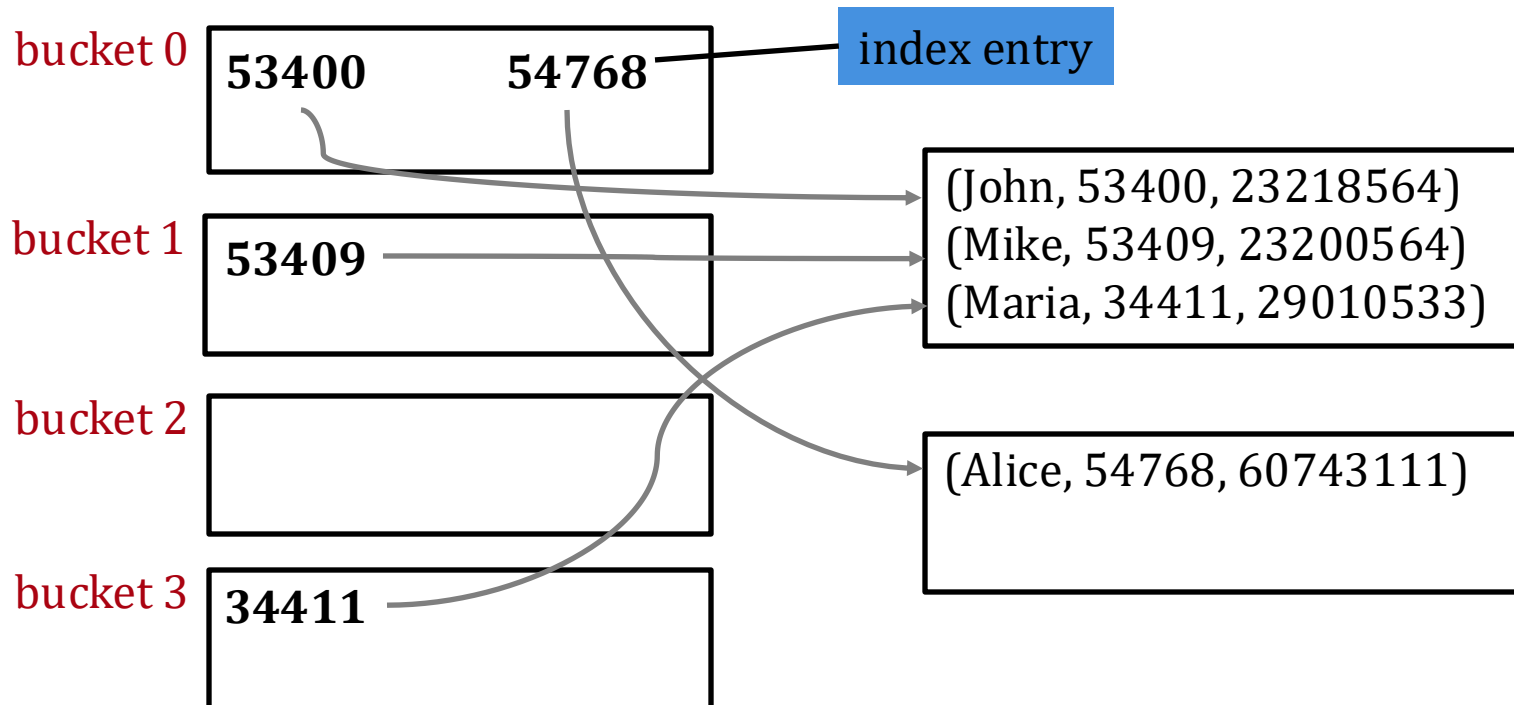
bucket 3

(Maria, **34411**, 29010533)

INDEX ENTRY #2

Person(name, zipcode, phone)

- *search key*: {zipcode}
- *hash function* ***h***: zipcode modulo 4



ALTERNATIVES FOR INDEX ENTRIES

#1: *the index entry contains the record*

- the index structure is *by itself* a file organization for records
- *at most one* index on a given table can use #1
- if records are very large, the number of pages containing index entries is high
 - this means possibly slower search!

ALTERNATIVES FOR INDEX ENTRIES

#2: the index entry contains the rid

- Index entries are typically much smaller than data records
- better than #1 with large data records, especially when the search key is small

MORE ON INDEXES

A file can have several indexes, on different search keys!

Index classification:

- *primary* **vs** *secondary*
- *clustered* **vs** *unclustered*

PRIMARY VS SECONDARY

- If the search key contains the primary key, it is called a **primary index**
 - in a primary index, there are no duplicates for a value of the search key
 - there can only be one primary index!
- Any other index is called a **secondary index**
- If the search key contains a candidate key, it is called a **unique index**
 - a unique index can also return no duplicates

EXAMPLE

Sales (sid, product, date, price)

- An index on {sid} is a primary and unique index
- An index on {date} is a secondary, but not unique, index

COMPOSITE INDEXES

Composite search key: search on a combination of attributes

Sales (sid, product, date, price)

- An index on {date, price} is a composite index
- **Order matters**: {price, date} is a different index!

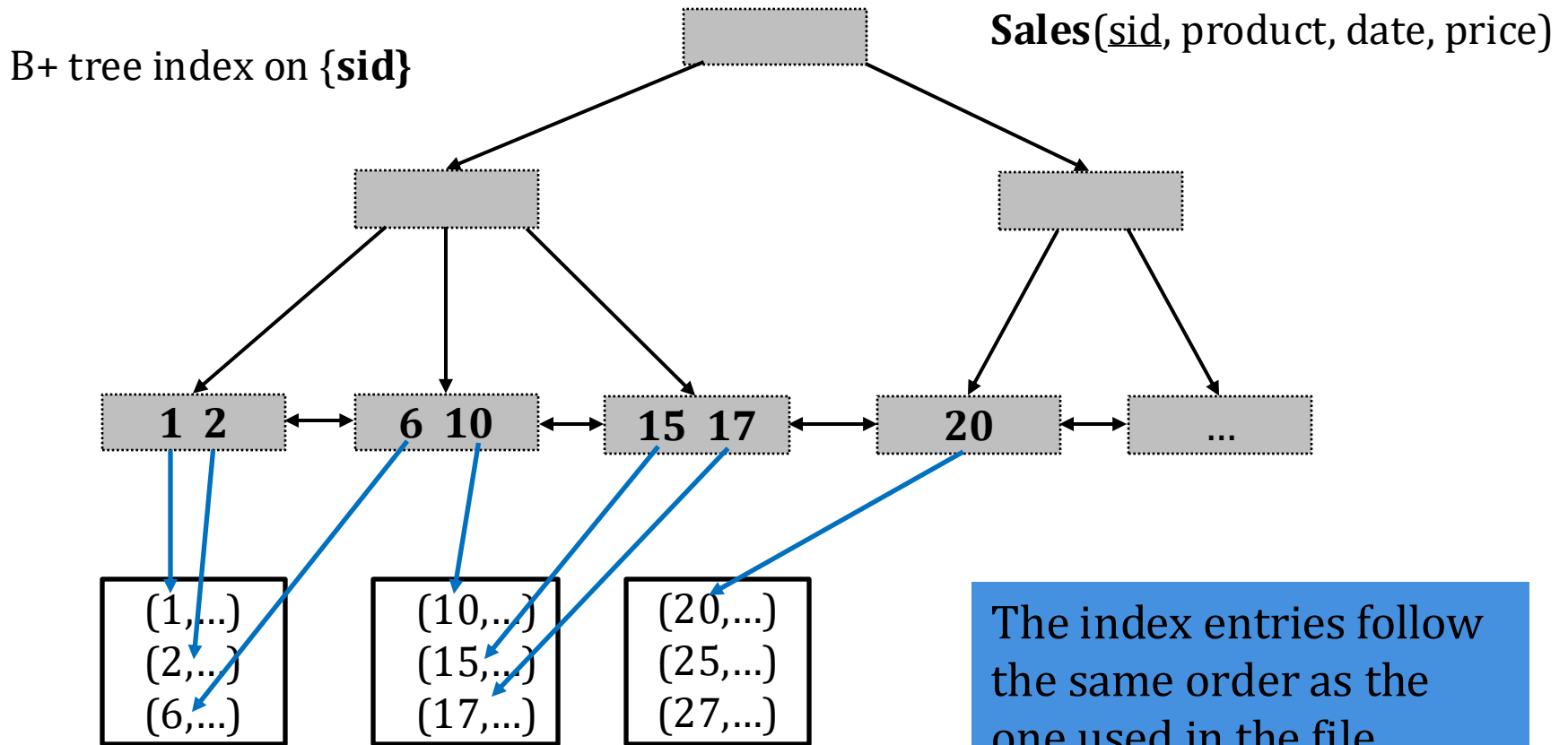
CLUSTERED INDEXES

Clustered index: the order of records **matches** the order of index entries

- alternative #1 implies that the index is clustered
- a table can have at most one clustered index
- the cost of retrieving data records through the index varies greatly based on whether index is clustered or not

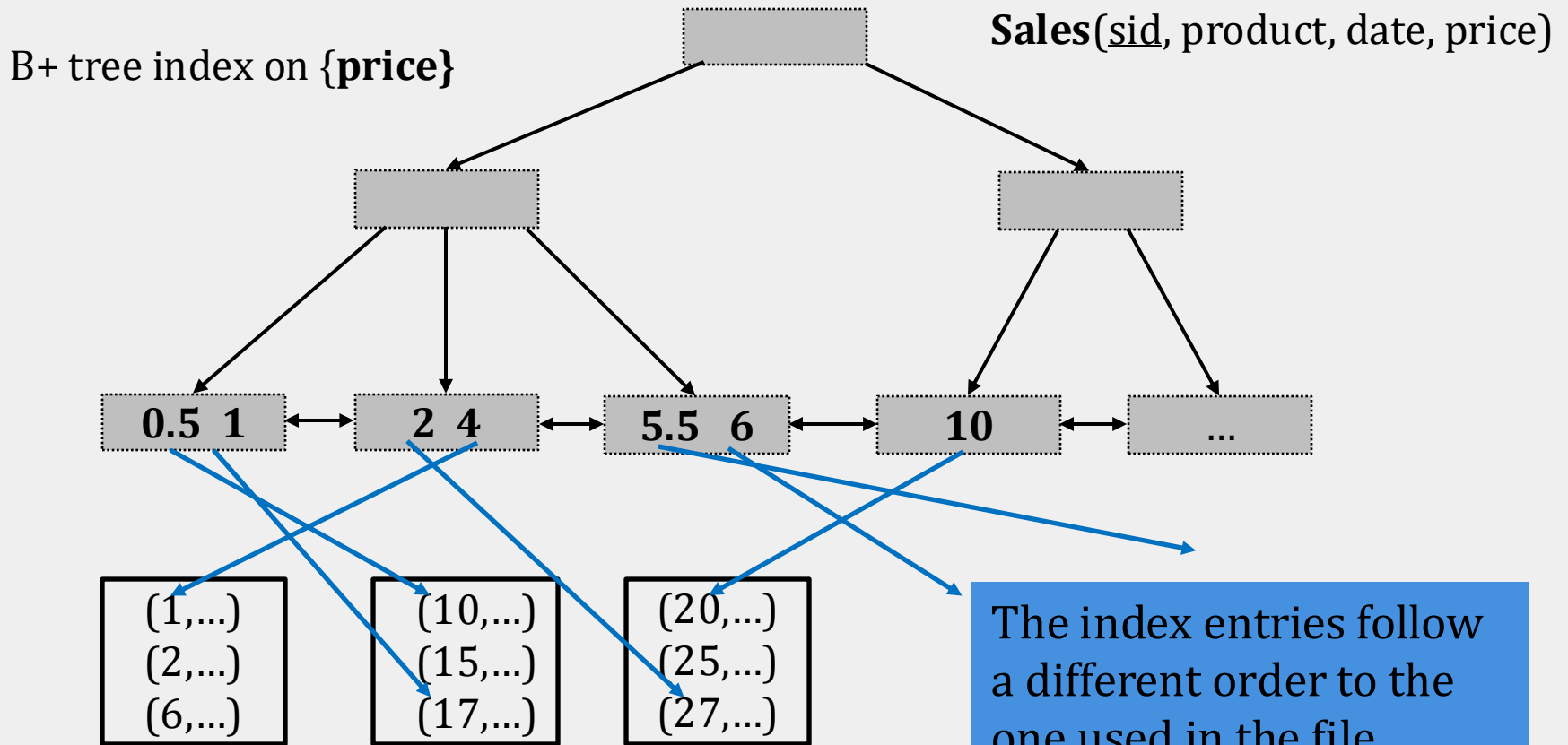
logical order of index ~ physical order of records

EXAMPLE: CLUSTERED INDEX



The file is sorted by {**sid**}

EXAMPLE: NON-CLUSTERED INDEX



The file is sorted by {**sid**}

INDEX PARAMETERS

- What **access types** does it support?
 - *e.g.* equality search, range search, etc.
- Time to **access** a record
- Time to **insert** a record
- Time to **delete** a record
- How much **space** does it use?

INDEXES IN PRACTICE

INDEXES IN SQL

```
CREATE INDEX index_name  
ON table_name (column_name);
```

Example of simple search key:

```
CREATE INDEX index1  
ON Sales (price);
```


INDEXES IN SQL

```
CREATE UNIQUE INDEX index2  
ON Sales (sid);
```

- A unique index does not allow any duplicate values to be inserted into the table
- It can be used to check efficiently integrity constraints: *a duplicate value will not be allowed to be inserted!*

INDEXES IN SQL

```
CREATE INDEX index3  
ON Sales (date, price);
```

- Indexes with composite search keys are larger and more expensive to update
- They can be used if we have multiple selection conditions in our queries

CHOOSING INDEXES

- What indexes should we create?
 - which tables should have indexes?
 - what field(s) should be the search key?
 - should we build several indexes or one?
- For each index, what kind of an index should it be?
 - clustered
 - hash/tree/bitmap

CHOOSING INDEXES

- Consider the best plan using the current indexes, and see if a better plan is possible with an additional index
- One must understand how a DBMS evaluates queries and creates query evaluation plans
- As we add more indexes:
 - queries go faster, updates are slower
 - more disk space is required

CHOOSING INDEXES

- Attributes in **WHERE** clause are candidates for index keys
 - exact match condition suggests hash index
 - indexes also speed up joins (later in class)
 - range query suggests tree index (B+ tree)
- Multi-attribute search keys should be considered when a **WHERE** clause contains several conditions
 - the order of attributes is important for range queries
 - such indexes enable **index-only** strategies for queries