

Master of Science (MSc)

Applied Information and Data Science

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Database Management for Data Scientists
5 – SQL Performance



Note: Blue speech bubbles contain additional information for you. They are **not** part of the exam.

Also, the appendix is **not** part of the exam; the appendix provides you additional information you might use in your daily job.

An icon of PostgreSQL or MSSQL indicates that the appendix contains syntax differences.



REVIEW EXERCISE 4 SQL Language Concepts



Performance

Time to wait for a query result?

4 PIECES FOR PERFORMANCE

1. I/O vs. Memory
2. Indexes
3. Query Optimizer
4. Good SQL
5. ()

Hardware components for data – Capacity and Latency (Speed)

	CPU Cache	RAM/Memory	Disk (HDD/SSD)
			
Capacity	1MB – 50MB	Up to 128/256GB (more is possible)	Up to x TB
Access Latency	1 - 30ns	100 - 1'000ns	1 - 10ms (SSD: 0.05-0.15ms)
Scaled Latency*	2 sec - 1 min	4 - 40 min	SSD : 17 hrs - 4 days HDD: 1 - 9 months

*Baseline:
 • 1 CPU Cycle
 • Scaled to 1 sec

3-40x slower

1'000x !



Consequence

A 300GB database **might not fit** into the fast memory!

Queries should process **as little data as possible** in order to use data in **memory** and **avoid** unnecessary **disk** access!

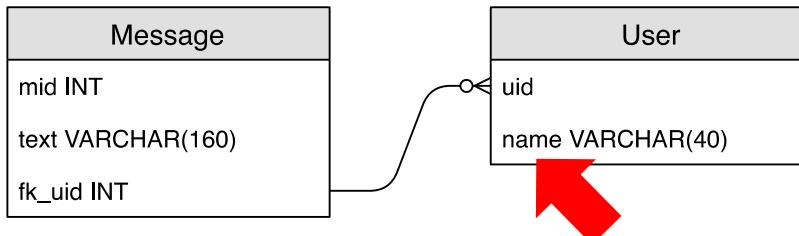
Table Joins

Table joins can be bottlenecks.

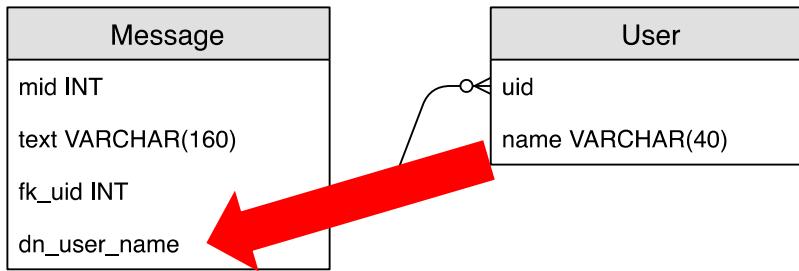
Especially without indexes, they need to process a lot of data and, thus, might heavily use I/O.

<https://www.datacamp.com/community/tutorials/sql-tutorial-query>

Normalized



Denormalized



For query performance, you can **denormalize** joins by using

- **denormalized** table design
- **materialized view**

<https://rubygarage.org/blog/database-denormalization-with-examples>

```

SELECT u.name, COUNT(*)
FROM Message AS m
INNER JOIN User AS u
ON m.fk_uid = m.uid
GROUP BY u.name;
  
```

Think web-scale
→ Millions of users
→ Billions of messages

```

SELECT
  m.dn_user_name,
  COUNT(*)
FROM Message AS m
GROUP BY m.dn_user_name;
  
```

What might be some drawbacks with the table design on the right?



Locate data quickly / Minimize data access

INDEXES

Question

The **dictionary** is one example of an **index** you might use from time to time.

Do you know **more examples?**



DBMS implement **different types** of indexes. Let's get to know some common index types.

Index

Clustered Index

Attributes:

- Tables **physically ordered** by key
- The **key(s)** and the **data** of a row are **stored together**
- **Only one** clustered index per table

Terminology in DBMS:

MySQL: **Clustered Index**

MSSQL: Clustered Index

PostgreSQL: n/a

Metaphor: Dictionary



Source: By Langenscheidt - Langenscheidt, CC BY-SA 4.0,
<https://commons.wikimedia.org/w/index.php?curid=31355102>

Index

Nonclustered / Secondary Index

Attributes:

- **Additional** data structure containing key(s)
- **More than one** index possible per table
- Data is **separate** from index

Terminology in DBMS (max. indexes)

MySQL:	Secondary Index (64)
MSSQL:	Nonclustered Index (999)
PostgreSQL:	Secondary Index (unlim.)

Metaphor: Keyword index

Index

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Aliase 36

Index

Heap (not an index)

Attributes:

- **Table content unordered**
- Data usually **appended** to the end
- **Identifier** necessary to access the row (additional 6 bytes per row!)
 - Row Identifier [RID] or
 - Tuple Identifier [TID]

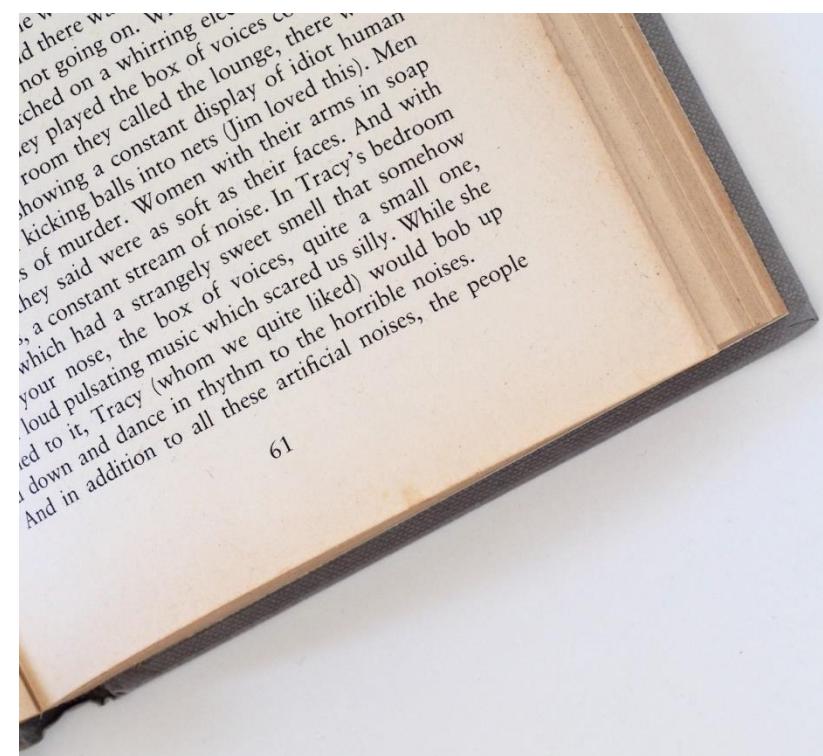
Terminology in DBMS:

MySQL: n/a

MSSQL: Heap (Row Identifier)

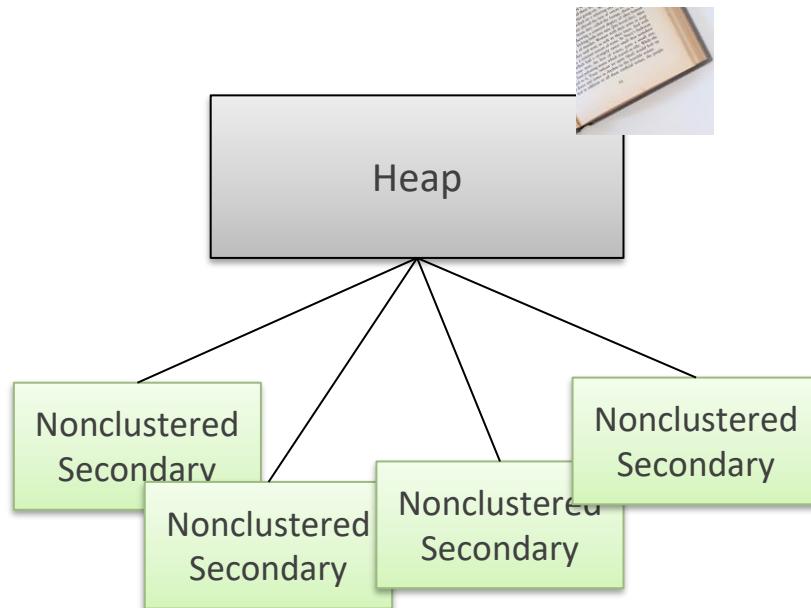
PostgreSQL: Heap (Tuple Identifier)

Metaphor: Novel/Notebook

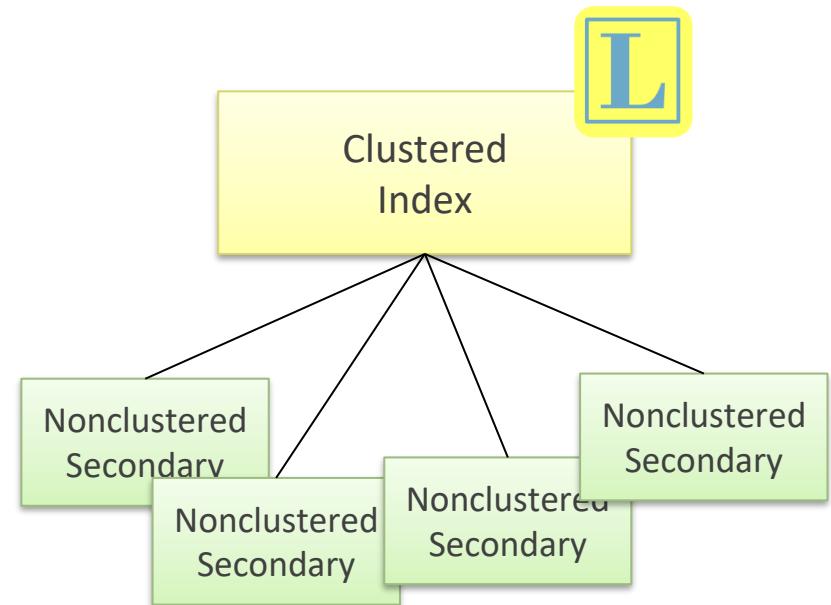


Index

Table and Index layout



PostgreSQL: Only this layout
 MSSQL: Possible but not preferred*



MySQL: Only this layout
 MSSQL: Preferred*

MySQL



Index

Storage impact



Heap / Clustered Table				Nonclustered / Secondary Indexes				
Heap	<i>RID</i>	<i>PK</i>	<i>Surname</i>	<i>Firstname</i>	<i>PK</i>	<i>RID</i>	<i>Surname</i>	<i>RID</i>
	xA	51	Randal	Paul S.	51	xA	Beck	xD
	xB	77	Fowler	Martin	77	xB	Fowler	xB
	xC	86	Martin	Robert C.	86	xC	Lerman	xE
	xD	89	Beck	Kent	89	xD	Martin	xC
	xE	91	Lerman	Julie	91	xE	Randal	xA

Clustered Index	<i>PK</i>	<i>Surname</i>	<i>Firstname</i>	<i>Surname</i>	<i>PK</i>
	51	Randal	Paul S.	Beck	89
	77	Fowler	Martin	Fowler	77
	86	Martin	Robert C.	Lerman	91
	89	Beck	Kent	Martin	86
	91	Lerman	Julie	Randal	51

¹⁾ RID (=Row Identifier for MSSQL) or TID(= Tuple Identifier for PostgreSQL)

Benefits of indexes?



Benefits of indexes?

- Improving **search & join** operations
- Improving **referential integrity** (RI) enforcement (i.e. Foreign keys)
- **Reducing disk IO, CPU and Memory** consumption



Drawbacks of indexes?



Drawbacks of indexes?

- **Useless** indexes do **waste** space
- **Updating indexes** in an OLTP environment (with lots of inserts, updates and deletes)
- **Continuous maintenance & monitoring** necessary
- **Time** and **know-how** needed to find useful indexes



Index

SQL – Clustered Index

MySQL:

- MySQL **automatically** clusters the table!
- It uses the **primary key** or – if missing – a **unique** index
- Fallback: it creates a hidden index

```
CREATE TABLE person(  
    PersonId INTEGER NOT NULL,  
    CONSTRAINT PK_Person  
    PRIMARY KEY (PersonId));  
  
ALTER TABLE person  
    ADD CONSTRAINT PK_Person  
    PRIMARY KEY (PersonId);
```



Note: “PK_Person” is the name (or identifier) of the primary key constraint.



Index

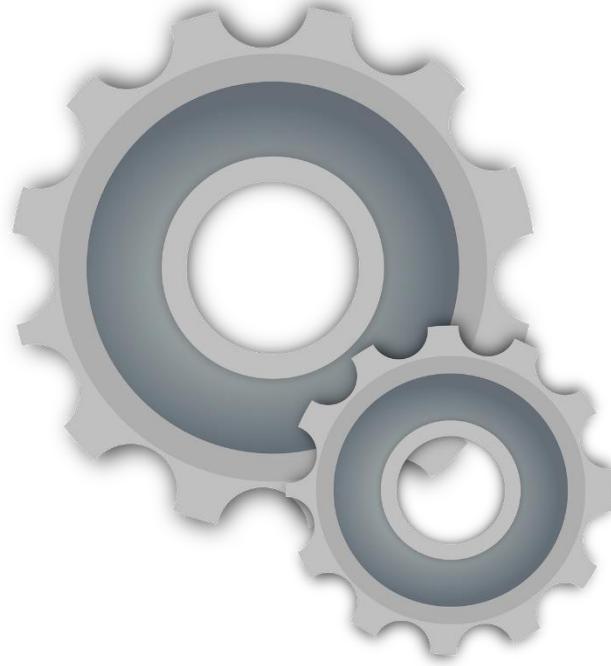
SQL – Nonclustered / Secondary Index

MySQL / PostgreSQL:

- Simple statement!

```
CREATE INDEX  
IDX_Person_Name  
ON person (Name);
```





Query Optimizer / Index usage

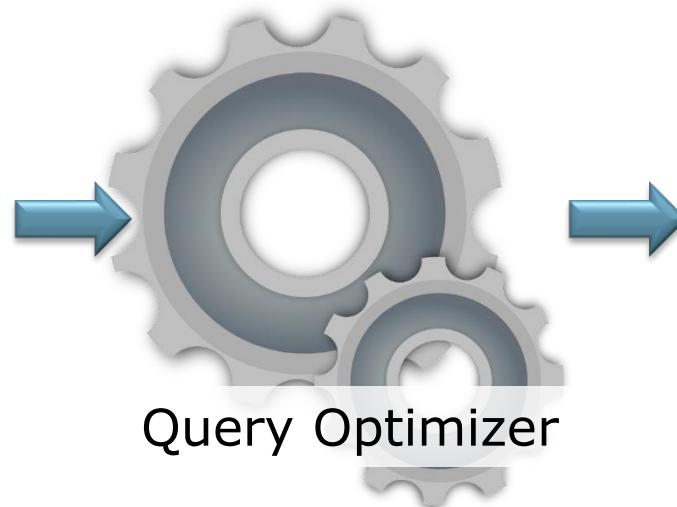
EXECUTION PLAN



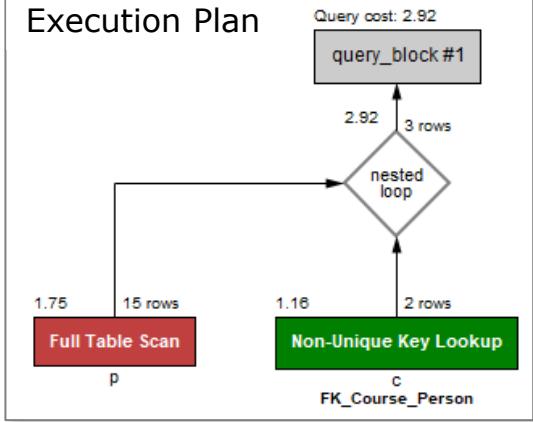
Query Optimizer – Overview

Declarative statement

```
SELECT c.CourseNo, p.Name
FROM course AS c
INNER JOIN person AS p
ON c.ProfessorPersonId
= p.PersonId
WHERE p.Name LIKE 'K%';
```



Execution Plan



Result

CourseNo	Name	Birthdate
Die 3 Kritiken	Kant	1950-10-03
Grundzüge	Kant	1950-10-03

*) We treat this as blackbox.
Not part of this course.

MSSQL tip: Your DBA needs to keep the statistics up-to-date

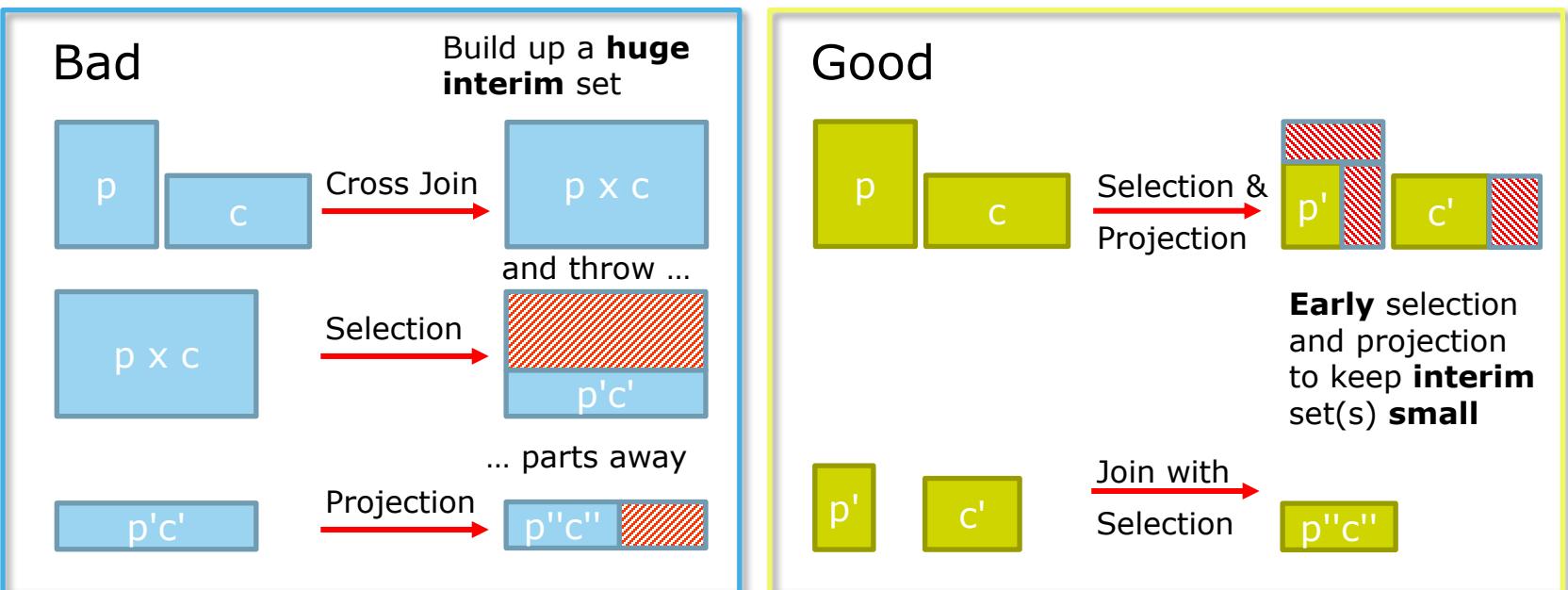
- Metadata *)
- Tables
- Columns
- Data types
- Nullable
- Indexes etc.
- Statistics *)
- # of rows
- Distribution
- Cardinality
- Up-to-date?



Query Optimizer – Algebraic Transformation

- The Query Optimizer supports you to **reduce the amount** of data processed and also saved in the **interim result sets**
- Consider the following example

```
SELECT c.CourseNo, p.Name, p.Birthdate
FROM course AS c
INNER JOIN person AS p
ON c.ProfessorPersonId = p.PersonId
WHERE p.Name LIKE 'K%';
```





Query Optimizer – Indexes

- To do its job, the Query Optimizer needs your help
- Build **adequate indexes** that the Optimizer can perform optimal "selection"



In this example, a secondary index on column "Name" helps to find all entries that match "Marlone". The Optimizer only needs to read 2 rows instead of the whole table (= Scan).

With this interim result, the Optimizer can use these 2 rows to join with other tables!

`WHERE b.Name = 'Marlone';`

Without index

Lopez
Elders
Marlone
Alvarro
Vendetta
Richards
Chief
Peters
Navarro
Goodman
Marlone
Marlone
Benitez

Table or index scan

Secondary Index

Alvarro
Benitez
Chief
Elders
Goodman
Lopez
Marlone
Marlone
Navarro
Peters
Richards
Vendetta

Index seek or range



Query Optimizer – Execution Plan

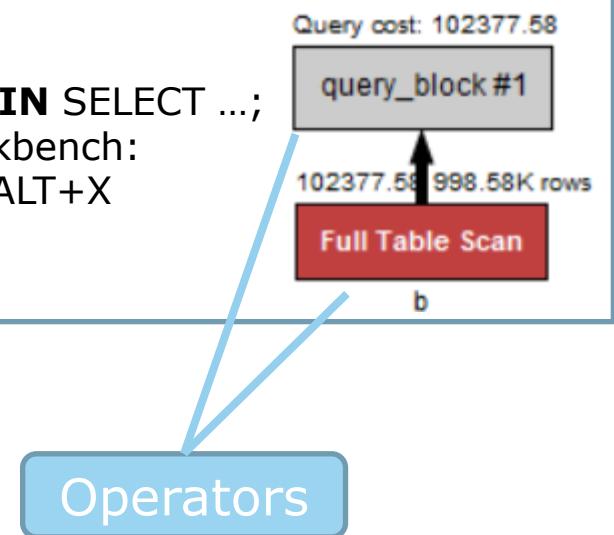
- Most DBMS provide a **textual** or **graphical** execution **plan** to estimate query performance

```
SELECT b.PersonId, b.Name, b.Birthdate  
FROM bigperson AS b  
WHERE b.Name LIKE 'M%';
```

MySQL:

- **EXPLAIN** SELECT ...;
- In Workbench:
CTRL+ALT+X

MySQL





Query Optimizer – Execution Plan Operators

MySQL Operations/Operators	
Good ¹⁾	<p>Unique Key Lookup Non-Unique Key Lookup Index Range Scan https://dev.mysql.com/doc/workbench/en/wb-performance-explain.html</p>
Bad ^{1) 2)}	<p>Full Table Scan ("ALL") Full Index Scan ("INDEX")</p>

```

graph TD
    UKL[Unique Key Lookup] --> SJP[Search/Join for Primary Key]
    NUKL[Non-Unique Key Lookup] --> INUC[Indexed non-unique column(s)]
    IRS[Index Range Scan] --> EGB["e.g. >= x < BETWEEN ... AND"]
    FTS[Full Table Scan] --> OMIS[Often missing index and/or bad SQL]
    FIS[Full Index Scan] --> IAOS[Index available but often bad SQL]
  
```

¹⁾ An operation in the execution plan is often represented by an "operator", e.g. Full Index Scan

²⁾ On (very) small tables, the Optimizer might choose a Scan because reading the whole table is faster than accessing the index and lookup the data in the table (= 2 seeks per row). Therefore, on small tables a Scan might not be bad.



Query Optimizer – Some index guidelines

- Generally, only create indexes **that are used** by one or more queries
- **Do not** just **index each** and every **column** in your tables (they must be updated with each insert, update and delete!). Create indexes that **serve several different** queries!
- Use the Execution **plan** to **check** whether the **index is used** for your SQL statement (test with enough data)
- When you **load** a huge amount of data, you might **drop** the indexes and **recreate** them after the import



MySQL:

- Note that MySQL **automatically** creates indexes on **foreign key columns** (unless the column already has an index)



These are guidelines. In your project, there might be other rules. Make sure to know the differences and do not just blindly apply new guidelines.



Good vs.
bad SQL

SYNTACTICAL QUERY OPTIMIZATION



Question

The following statement is **not** Optimizer-friendly. How could you **improve** it?

```
SELECT COUNT(*)
FROM bigperson AS b
WHERE LEFT(b.Name, 2) = 'An';
```



The Optimizer does the best job possible.
Assist the Optimizer with optimal SQL code!

Good
vs.
Bad

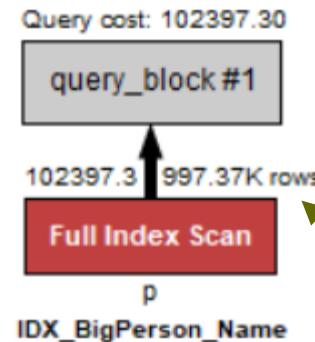
Do not use functions on search columns (1)



```
SELECT COUNT(*)
FROM bigperson AS b
```

```
WHERE LEFT(b.Name, 2) = 'An';
```

The Optimizer actually uses the index. But it needs to **scan** the index and **executes the function** on each value.

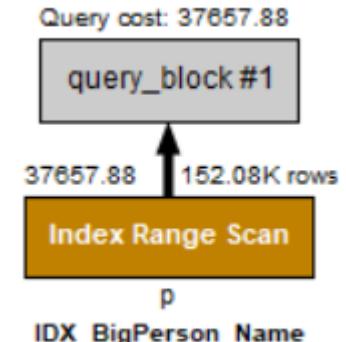


```
SELECT COUNT(*)
FROM bigperson AS b
```

```
WHERE b.Name LIKE 'An%';
```

The Optimizer can read the range
 \geq "An"
 $<$ "AO"

Estimated number of rows
(997K vs. 152K) !



Good
vs.
Bad

SARGable queries

- Pseudo acronym = search argument can take **advantage** of an index
- SARGable queries **speed up** execution time, **reduce resource** usage and **minimize blocking** other users
- Consider writing SARGable queries
- A lot of non-SARGable queries **can be rewritten** into SARGable queries

Good
vs.
Bad



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE YEAR(b.Birthdate) = 1960;
```



```
SELECT COUNT(*)  
FROM bigperson AS b
```



Good
vs.
Bad

Do not use functions on search columns (2)



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE YEAR(b.Birthdate) = 1960;
```



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE b.Birthdate >= '1960-01-01'  
AND b.Birthdate < '1961-01-01';
```



Note: Do not use BETWEEN ... AND for data comparison because it is translated into $\geq \dots \leq$.

Example business requirement: Get data of the first two months in 2020 (spot the bug):

x BETWEEN '2020-01-01' AND '2020-02-28'
vs.
x \geq '2020-01-01' AND x < '2020-03-01'

Good
vs.
Bad

Do not use functions on search columns (2)



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE YEAR(b.Birthdate) = 1960;
```

```
SELECT COUNT(*)  
FROM bigexamresult AS e  
  
WHERE e.ExamNote + @Adjust = 4.0;
```



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE b.Birthdate >= '1960-01-01'  
AND b.Birthdate < '1961-01-01';
```

```
SELECT COUNT(*)  
FROM bigexamresult AS e
```



Good
vs.
Bad

Do not use functions on search columns (2)



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE YEAR(b.Birthdate) = 1960;
```

```
SELECT COUNT(*)  
FROM bigexamresult AS e  
  
WHERE e.ExamNote + @Adjust = 4.0;
```



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE b.Birthdate >= '1960-01-01'  
AND b.Birthdate < '1961-01-01';
```

```
SELECT COUNT(*)  
FROM bigexamresult AS e  
  
WHERE e.ExamNote = 4.0 - @Adjust;
```

No calculation on search columns!

Good
vs.
Bad



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE b.ExternalCRM_No = 41;
```

	Column Name	Data Type	Allow Nulls
!	PersonId	int	<input type="checkbox"/>
	Name	nvarchar(100)	<input type="checkbox"/>
	Birthdate	date	<input checked="" type="checkbox"/>
	ExternalCRM_No	varchar(20)	<input checked="" type="checkbox"/>
			<input type="checkbox"/>



```
SELECT COUNT(*)  
FROM bigperson AS b
```



Good
vs.
Bad

Avoid implicit type conversion



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE b.ExternalCRM_No = 41;
```

BigPerson			
	Column Name	Data Type	Allow Nulls
!	PersonId	int	<input type="checkbox"/>
	Name	nvarchar(100)	<input type="checkbox"/>
	Birthdate	date	<input checked="" type="checkbox"/>
	ExternalCRM_No	varchar(20)	<input checked="" type="checkbox"/>
			<input type="checkbox"/>



```
SELECT COUNT(*)  
FROM bigperson AS b  
  
WHERE b.ExternalCRM_No = '41';
```



Minimize the amount of data to process with **good SQL** and **indexes** (Lamborghini). Otherwise, you get slow queries due to huge amount of data (Excavator)

Processed data matters



4 PIECES FOR PERFORMANCE

1. I/O vs. Memory
2. Indexes
3. Query Optimizer
4. Good SQL
5. (*Table design/ERD*)

Learning objectives 5: SQL Performance

1. Understand **bottlenecks** (I/O vs. memory, amount of data, joins)
2. Apply **indexes** (types, layout and access pattern) to optimize query performance
3. Show **execution plans** and recognize **good/bad operators** for optimizing queries (explain, scan vs. seek)
4. **Syntactical** SQL performance optimization (good vs. bad SQL, **sargable** queries)





Q & A

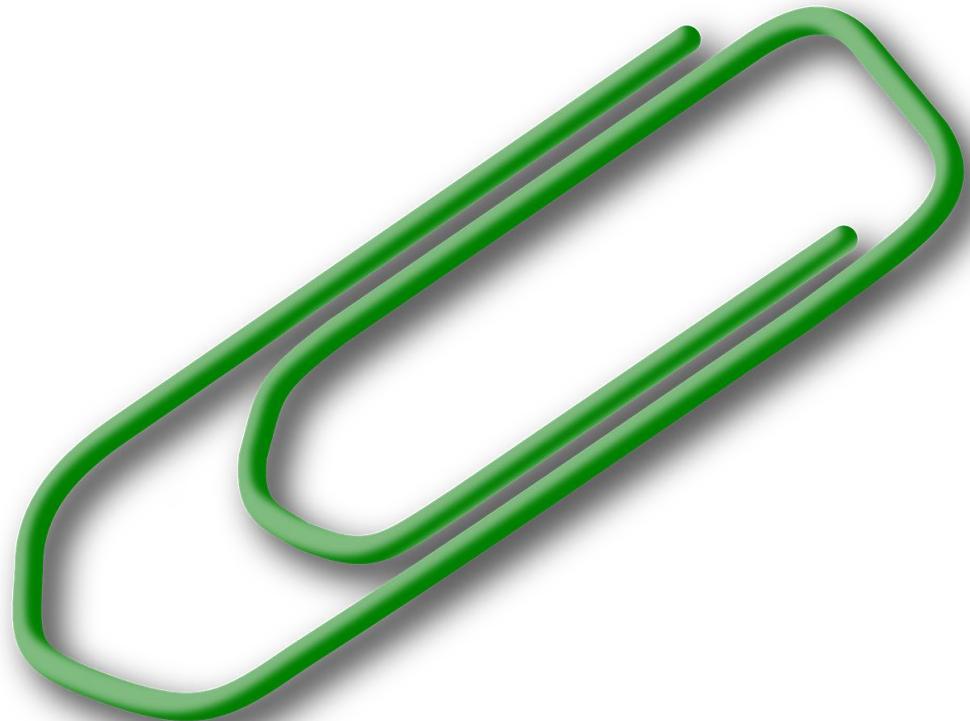
Thank you!



EXERCISE

APPENDIX

MSSQL / PostgreSQL



Index

SQL – Clustered Index (MSSQL syntax)

MySQL:

- MySQL **automatically** clusters the table!
- It uses the **primary key** or – if missing – a **unique** index
- Fallback: it creates a hidden index

```
CREATE TABLE person(
    PersonId INTEGER NOT NULL,
    CONSTRAINT PK_Person
    PRIMARY KEY (PersonId));
ALTER TABLE person
    ADD CONSTRAINT PK_Person
    PRIMARY KEY (PersonId);
```



MSSQL:

- **Recommended to explicitly** define the clustered index
- As a **starting point**, use the **primary key** as clustered index
- But you can define **any** column(s) as clustered index (MSSQL will make it unique behind the scenes)

```
CREATE TABLE Course(
    CourseId INTEGER NOT NULL,
    CourseNo VARCHAR(20) NOT NULL,
    CONSTRAINT PK_Course
    PRIMARY KEY CLUSTERED (CourseId));
```

```
ALTER TABLE Course
    ADD CONSTRAINT PK_Course
    PRIMARY KEY CLUSTERED (CourseId);
```



```
CREATE CLUSTERED INDEX
IDX_CourseNo ON Course(CourseNo);
```

Index

SQL – Nonclustered / Secondary Index (MSSQL syntax)

MySQL / PostgreSQL:

- Simple statement!

```
CREATE INDEX  
IDX_Person_Name  
ON person (Name);
```



MSSQL:

- **Recommended to explicitly** use the keyword NONCLUSTERED!

```
CREATE NONCLUSTERED INDEX  
IDX_Person_Name  
ON Person (Name);
```





Query Optimizer – Execution Plan (MSSQL / PostgreSQL)

- Most DBMS provide a **textual or graphical execution plan** to estimate query performance

```
SELECT b.PersonId, b.Name, b.Birthdate
FROM bigperson AS b
WHERE b.Name LIKE 'M%';
```

MSSQL:

- SET XML STATISTICS ON;
- In SSMS: **CTRL+M**

```
Query 1: Query cost (relative to the batch): 100%
SELECT b.PersonId, b.Name, b.Birthdate FROM Person
```

```
SELECT
Cost: 0 %
```



```
Clustered Index Scan (Clustered)
[Person].[PK_dbo_Person] [b]
Cost: 100 %
```

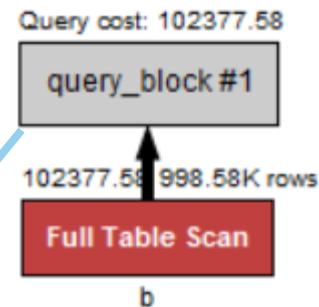


Operators

MySQL:

- **EXPLAIN** SELECT ...;
- In Workbench: CTRL+ALT+X

MySQL



PostgreSQL:

- **EXPLAIN [ANALYZE]** SELECT ...;
- In pgAdmin: F7



Tooltip:

Node Type	Seq Scan
Parallel Aware	false
Relation Name	bigperson
Alias	b
Filter	((name)::text ~~ 'M%'::text)



Query Optimizer – Execution Plan Operators

DBMS	 Bad operators ^{1) 2)}	 Good operators
MSSQL 	<ul style="list-style-type: none"> Clustered Index scan Index scan / Table scan Key / RID Lookup 	<ul style="list-style-type: none"> Index seek Clustered Index seek
MySQL 	<ul style="list-style-type: none"> Full Table Scan ("ALL") Full Index Scan ("INDEX") <p>Bad operators are red-colored</p>	<ul style="list-style-type: none"> Unique Key Lookup Non-Unique Key Lookup Index Range Scan <p>https://dev.mysql.com/doc/workbench/en/wb-performance-explain.html</p>
PostgreSQL 	<ul style="list-style-type: none"> Seq Scan (= Table scan) <ul style="list-style-type: none"> Index Scan Index Only Scan <p>You need to dig deeper whether an "Index (Only) Scan" is good or bad. Use Explain Analyze to output the rows affected and the costs.</p>	

¹⁾ A step in the execution plan is called "operator", e.g. Full Index Scan

²⁾ On (very) small tables, the Optimizer might choose a Scan because reading the whole table is faster than accessing the index and lookup the data in the table (= 2 seeks per row)



Query Optimizer – Some index guidelines (MSSQL / PostgreSQL)

- Generally, only create indexes **that are used** by one or more queries
- **Do not just index each** and every **column** in your tables (they must be updated with each insert, update and delete!)
- Use the Execution **plan** to check whether the **index is used** for your SQL statement (test with enough data)

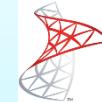


These are guidelines. In your project, there might be other rules. Make sure to know the differences and do not just blindly apply new guidelines.



MySQL:

- Note that MySQL **automatically** creates indexes on **foreign key columns** (unless the column already has an index)



MSSQL – Recommendations:

- Create indexes on **foreign key columns** (MSSQL will not do it automatically)
- Create **clustered indexes** on your tables (normally on the primary key)

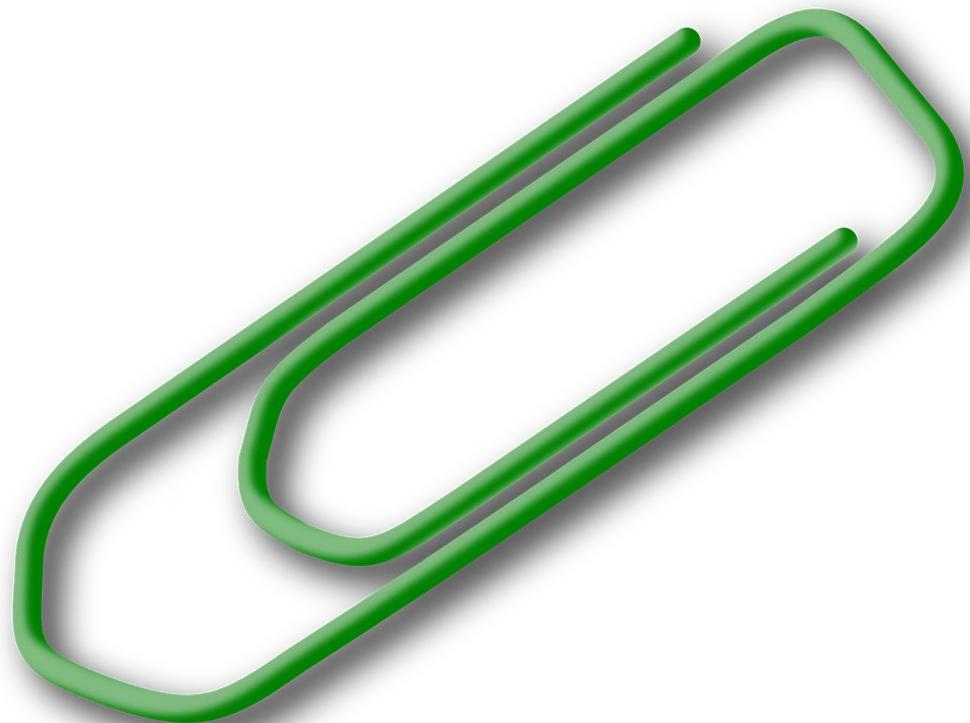


PostgreSQL - Recommendations:

- Again, create indexes on **foreign key columns**

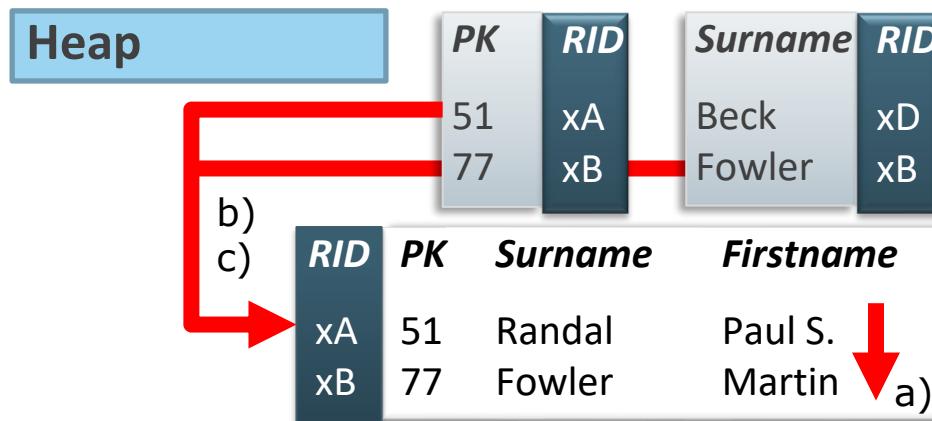
APPENDIX

Additional information



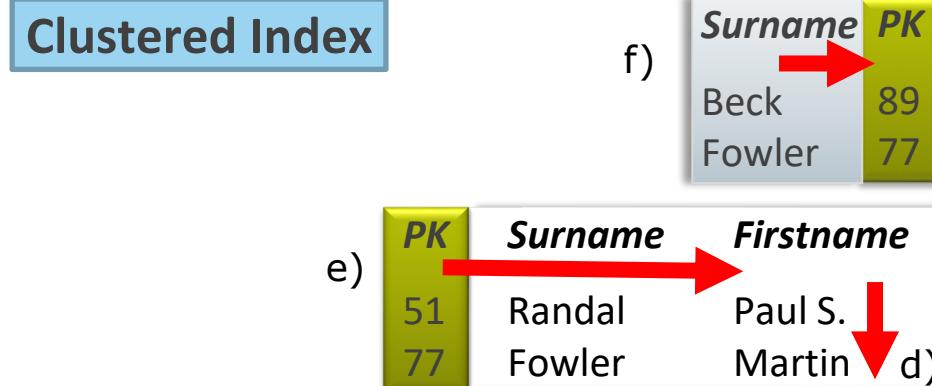
Index

Access data – Number of seeks (vs. a scan)



Search process	Access
a) Find Firstname	Heap Scan
b) Find Firstname by PK	2 Seek
c) Find PK by Surname	2 Seek

b) c): Find RID (or TID) in the secondary index; then seek the row in the heap to read the requested data (Firstname or PK)



Search process	Access
d) Find Firstname	Table Scan
e) Find Firstname by PK	1 Seek
f) Find PK by Surname	1 Seek

a) d): Column "Firstname" has no secondary index. The table (heap or clustered) is always scanned.