Relational Databases and Datawarehousing
Indexes and performance

HO
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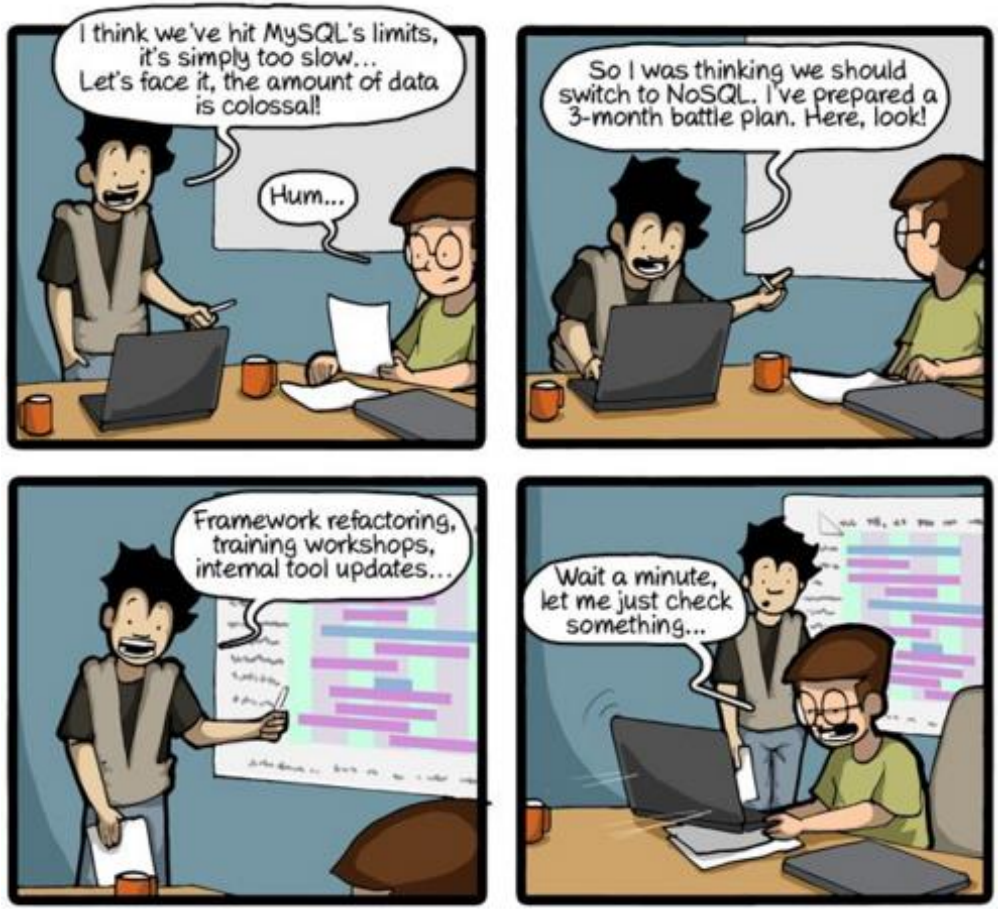
Is performance still relevant?

- On one side: Moore's law
  - Moore's law is the observation that the number of transistors in a dense integrated circuit (IC) doubles about every two years. Moore's law is an observation and projection of a historical trend. Rather than a law of physics, it is an empirical relationship linked to gains from experience in production.
  - No longer valid since 2016?

- On the other side: Wirth's law
  - Software is getting slower more rapidly than hardware is becoming faster.

- Anyway …


I think we've hit MySQL's limits, it's simply too slow... Let's face it, the amount of data is colossal!
Hum...
So I was thinking we should switch to NoSQL. I've prepared a 3-month battle plan. Here, look!
Framework refactoring, training workshops, internal tool updates...
Wait a minute, let me just check something...

- Often indexes offer the solution

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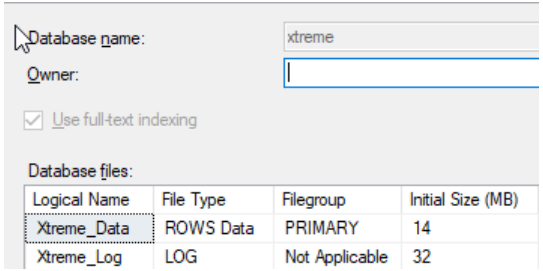
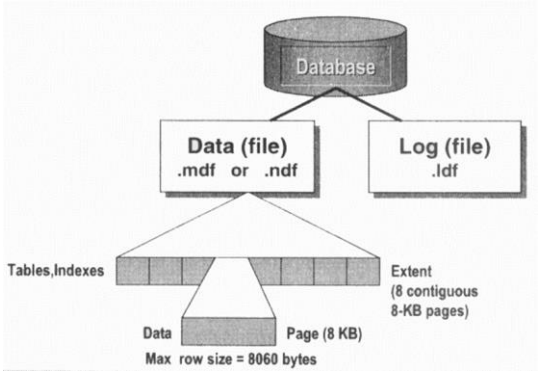


Space allocation by SQL Server



- SQL Server uses random access files
- Space allocation in extents and pages
- Page = 8 kB block of contiguous space
- Extent = 8 logical consecutive pages.
  - uniform extents: for one db object
  - mixed extents: can be shared by 8 db objects (=tables, indexes)
- New table or index: allocation in mixed extent
- Extension > 8 pages: in uniform extent
- https://techyaz.com/sql-server/understanding-sql-server-data-files-pages-extents/

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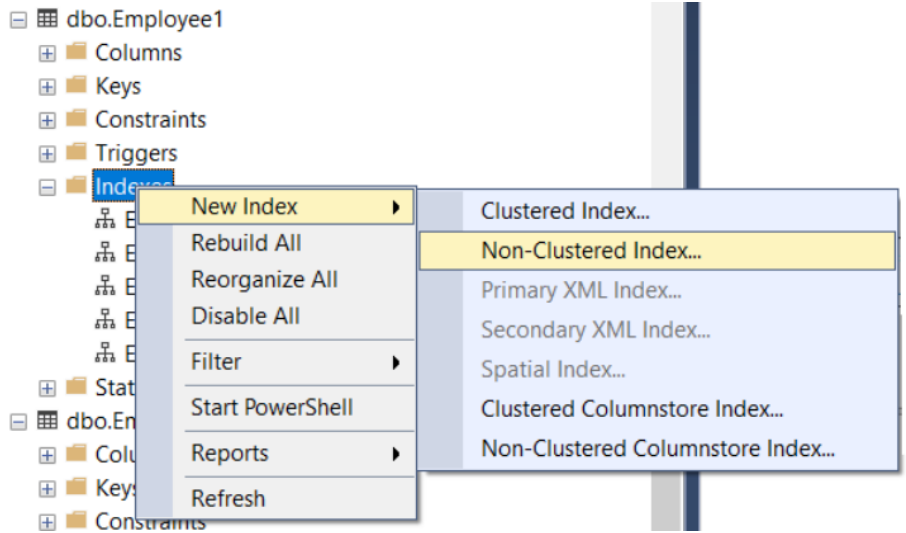
Creation of indexes

```
CREATE [UNIQUE] [| NONCLUSTERED]
  INDEX index_name ON table (kolom [,...n])
```

create index

- unique index: all values in the indexed column should be unique
- remark:
  - when defining an index the table can be empty or filled.
  - columns in a unique index should have the not null constraint



Removing indexes

```
DROP INDEX table_name.index [,...n]
```

deleting index

- unique all values in the indexed column should be unique
- remark:
  - when defining an index the table can be empty or filled.
  - columns in a unique index should have the not null constraint

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Clustered vs. Non-clustered indexes

- See the short version (2min)
  https://www.youtube.com/watch?v=AINh6_LqnDM
- See the long version (6min)
  https://www.youtube.com/watch?v=ITcOiLSfVJQ

Table scan

- Heap: unordered collection of data-pages without clustered index= default storage of a table
- Access via Index Alllocation Map (IAM)
- Table scan: if a query fetches all pages of the table
  often best to avoid!
- Other performance issues with heap:
  - fragmentation: table is scattered over several, non-consecutive pages
  - forward pointers: if a variable length row (e.g. varchar fields) becomes longer upon update, a forward pointer to another page is added. → table scan even slower

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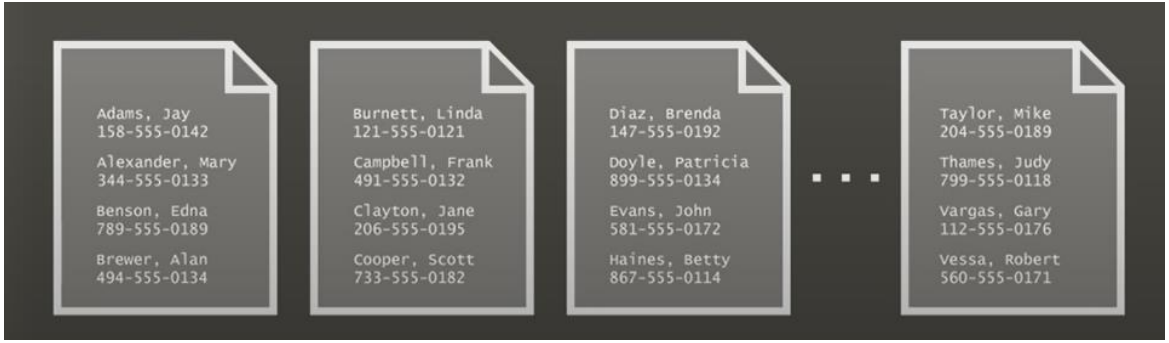
Table scan

- 1st step: put unordered data in tables
- Very inefficient: if we are looking for a phonenumber, we would have to go through all the phonenumbers, even when we found a match, because there are perhaps more matches later on
- Table scans aren't always a bad thing, e.g. when you have to retrieve a lot of data out of the table

Table scan

- In a phone book: data is ordered by last name and if there are duplicates, data is also ordered by first name
- => 2nd step: You can try to put the data in physical order
- Doesn't solve the performance problem. It would do a similar type of table scan, but this time it would know where to stop because the table data is ordered.



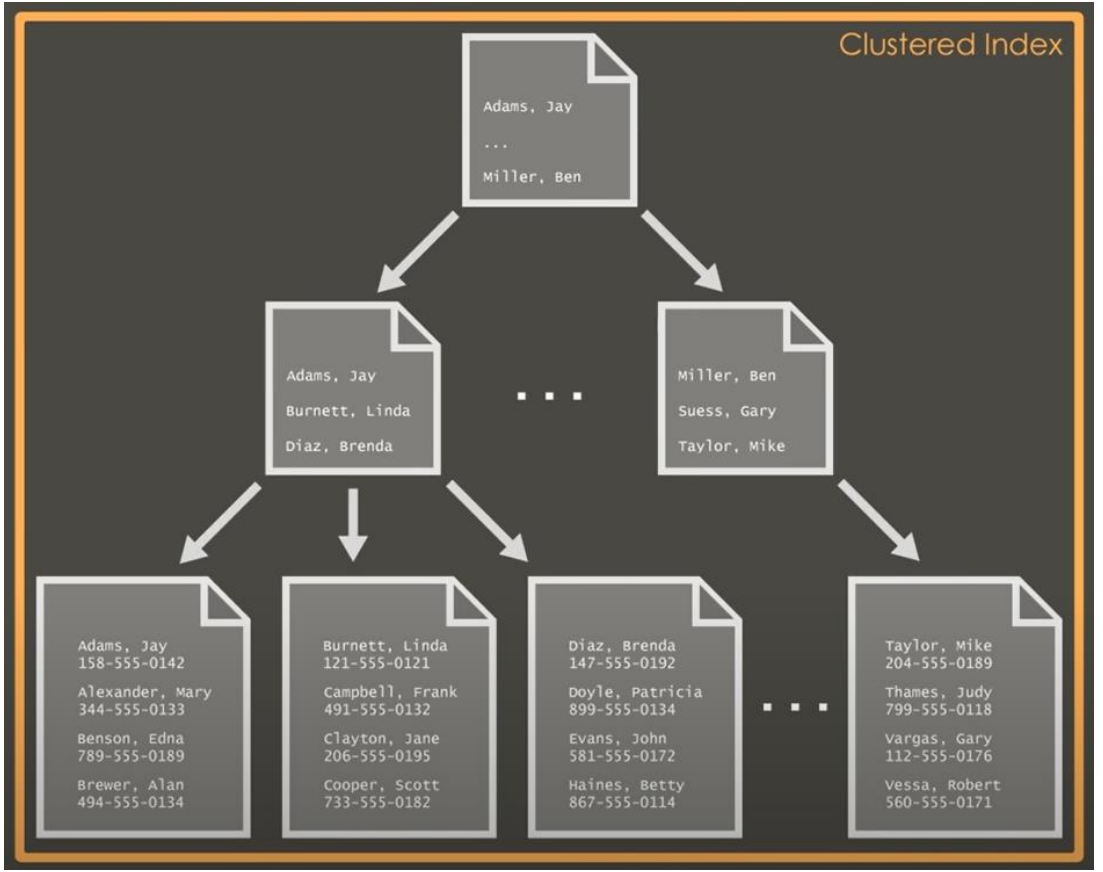
Clustered index

- After the table data is put into physical order, SQL Server builds up a set of index pages that allows queries to navigate directly to the data they're interested in. The entire structure, including the base table data, is called a clustered index. When a query navigates through the clustered index tree to the base table data, this is called a clustered index seek.

Clustered index

```
CREATE TABLE dbo.PhoneBook
(
   LastName varchar(50) NOT NULL,
   FirstName varchar(50) NOT NULL,
   PhoneNumber varchar(50) NOT NULL
);

CREATE CLUSTERED INDEX IX_PhoneBook_CI
   ON dbo.PhoneBook(LastName, FirstName);
```



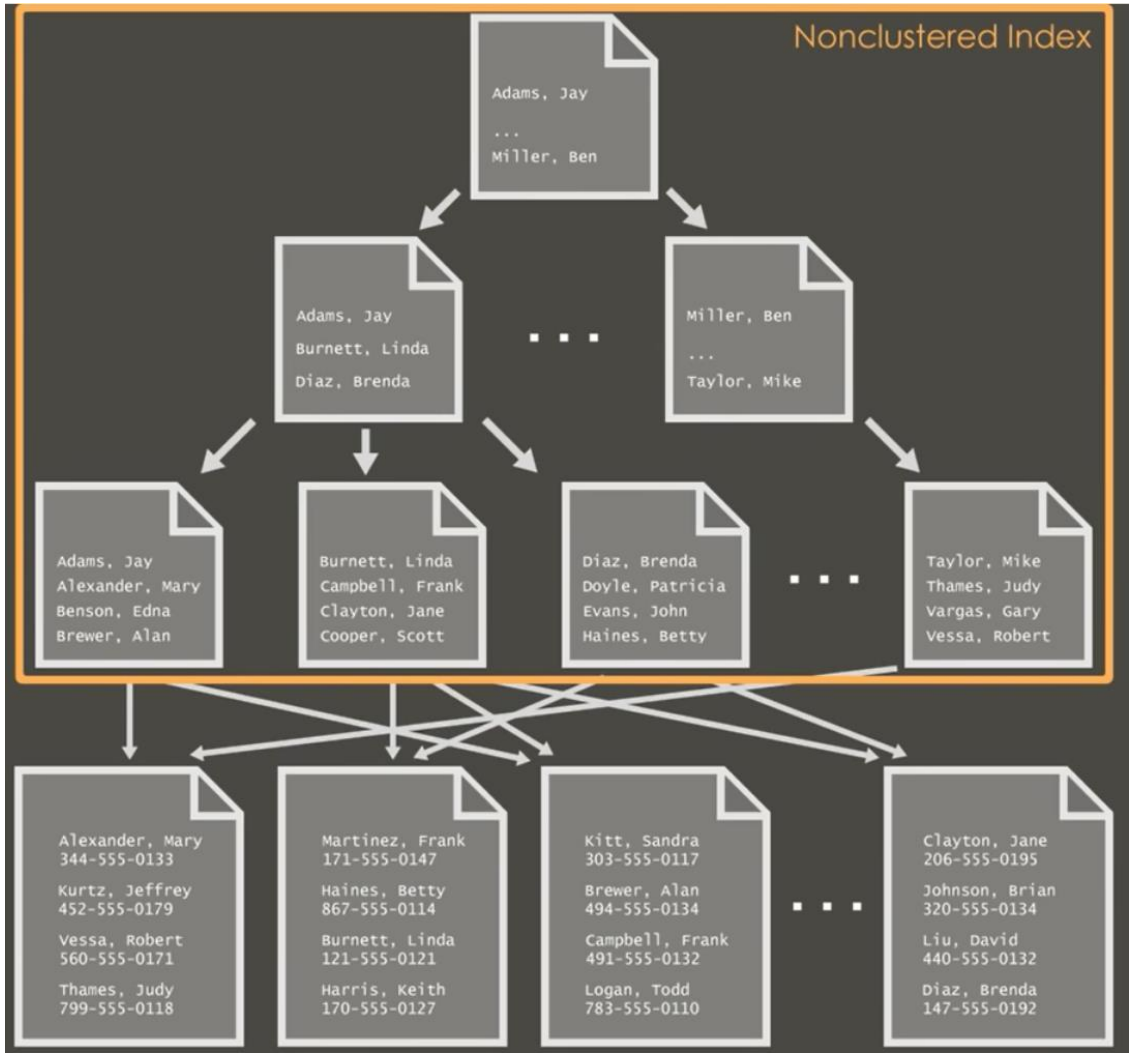
Non Clustered index

- Since a clustered index contains the base table data itself, you can only create one clustered index.
- You have to create a seperate physical structure that has the same index tree like the clustered index. This time, though, instead of having the base data at the bottom (or leaf) level of the tree, there is a set of pointers (or references), back to the base data => we can use any index key order

Non Clustered index

```
CREATE TABLE dbo.PhoneBook
(
   LastName varchar(50) NOT NULL,
   FirstName varchar(50) NOT NULL,
   PhoneNumber varchar(50) NOT NULL
);

CREATE NONCLUSTERED INDEX IX_PhoneBook_NCI
   ON dbo.PhoneBook(LastName, FirstName);
```



Non Clustered index

- In this example, the base data is a heap, and the references back to it are RIDs (row identifiers). These are the physical locations of the rows in the table.
- Since a non clustered index is separate from the base data, the base data could exist instead as a clustered index. If so, the references back to it arent't RIDs, but are the clustered index key values

Non Clustered index

- Like a clustered index scan and seek, non clustered indexes can have the same operations performed on them. But the data directly available may be limited because usually non clustered indexes only include a subset of column from the table. If values from columns not in the index are requested, the query may navigate back to the base data using the references.

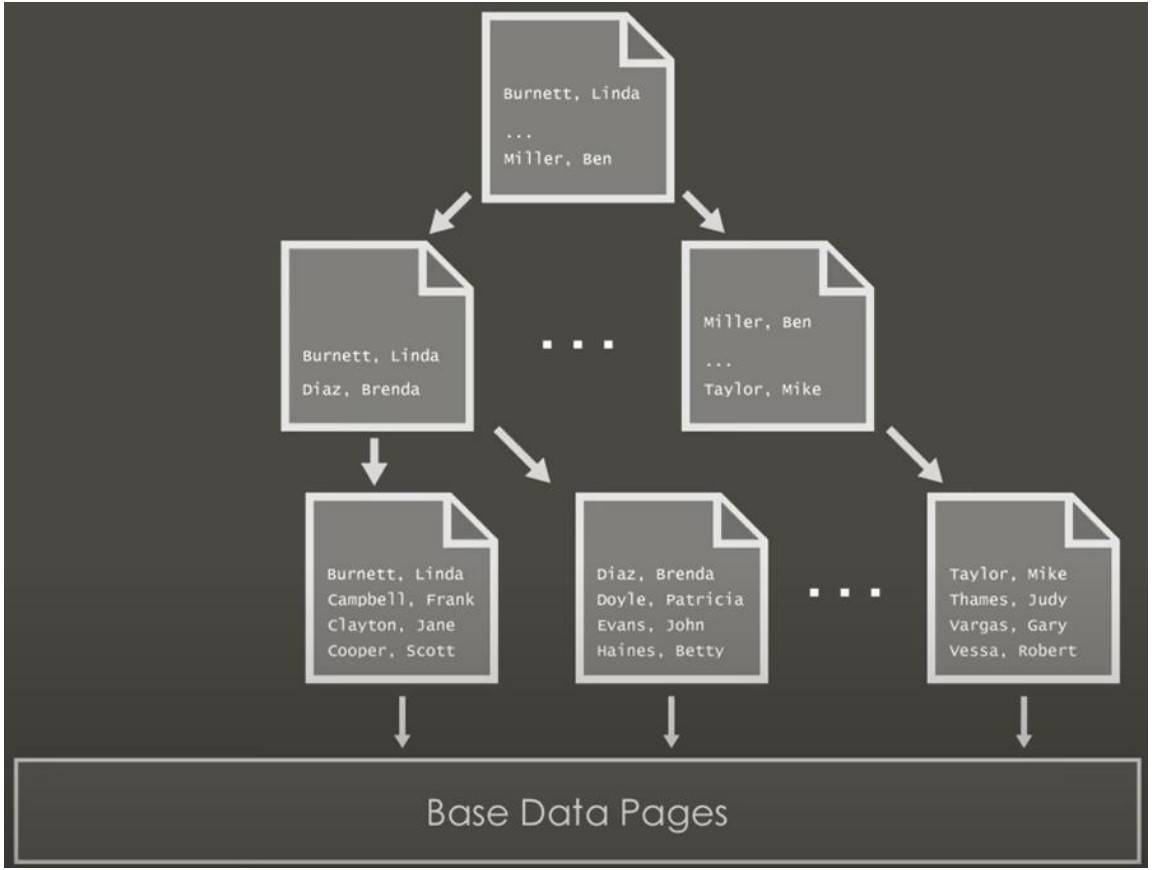
Filtered index

- Filtered indexes only contain rows that meet a user-defined predicate, and to create these, you have to add a WHERE clause to the index definition.
- A clustered index can't be filtered because it has to contain all the data in the table.

Filtered index

```
CREATE TABLE dbo.PhoneBook
(
   LastName varchar(50) NOT NULL,
   FirstName varchar(50) NOT NULL,
   PhoneNumber varchar(50) NOT NULL
);


CREATE NONCLUSTERED INDEX IX_PhoneBook_NCI
   ON dbo.PhoneBook(LastName, FirstName)
   WHERE (LastName >= 'Burnett');
```



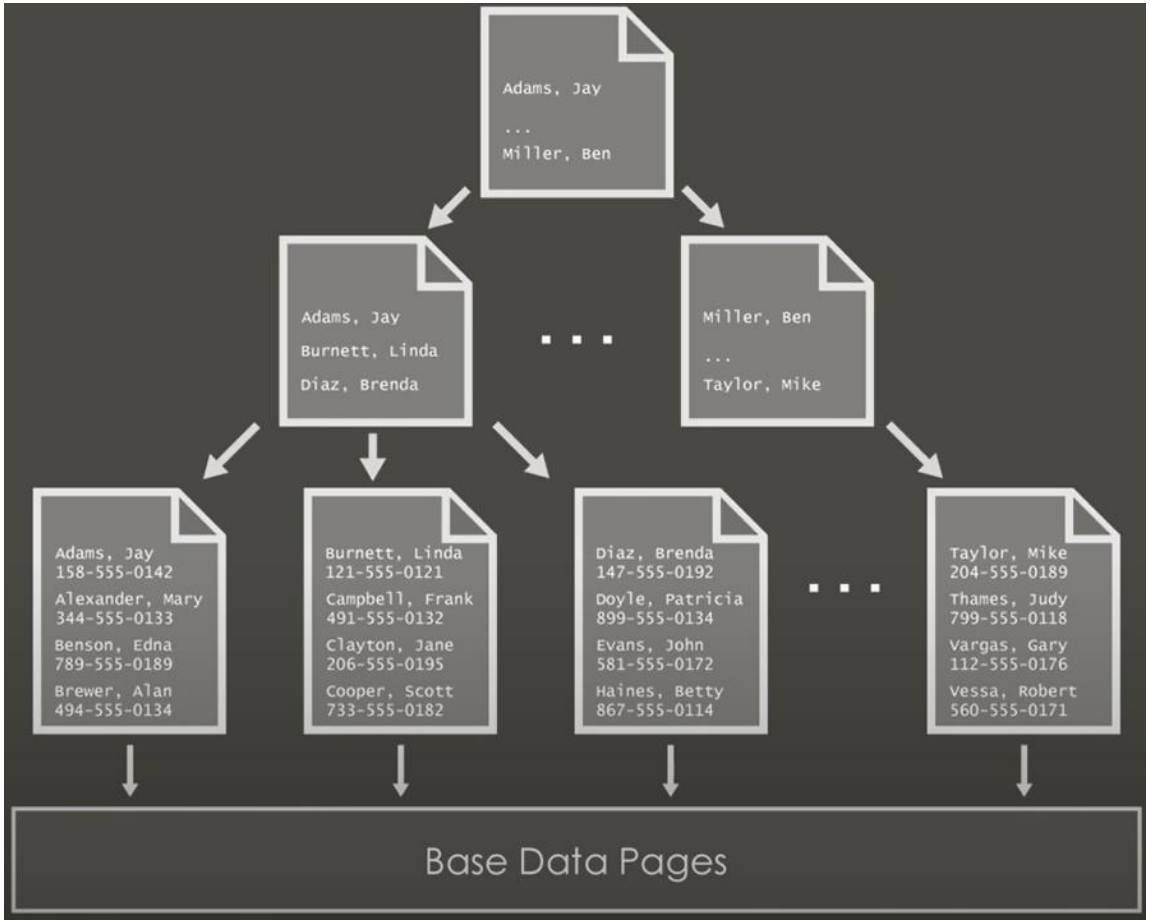
INCLUDE

- INCLUDE columns add copies of non-key column values to the leaf level of the index tree.
- This means that queries using the nonclustered index won't have to incur the expense of navigating back to the base data to get those non-key column values.
- A clustered index doesn't need INCLUDE columns, because all the columns are available in the leafs.

INCLUDE

```
CREATE TABLE dbo.PhoneBook
(
   LastName varchar(50) NOT NULL,
   FirstName varchar(50) NOT NULL,
   PhoneNumber varchar(50) NOT NULL
);


CREATE NONCLUSTERED INDEX IX_PhoneBook_NCI
   ON dbo.PhoneBook(LastName, FirstName)
   INCLUDE(PhoneNumber);
```



Clustered vs Non Clustered index

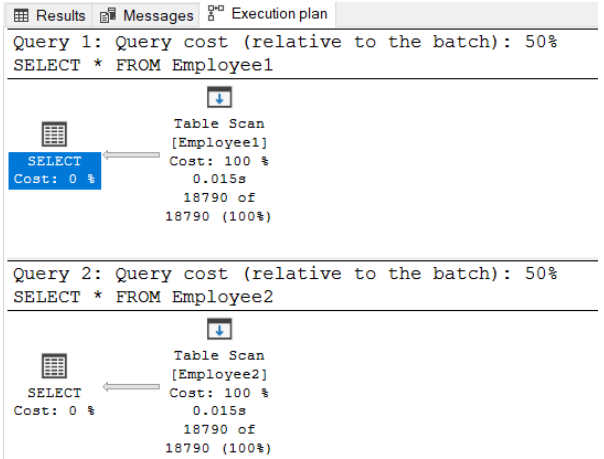
- The clustered index is a way of representing the base data as a whole.
- A non clustered index is a physically seperate structure that references the base data and it can have a different sort order.

Does my query use a table scan?

- Execute the scripts Employee1Idx and Employee2Idx to add the new tables Employee1 and Employee2
  Both tables have about 20 000 records
- Click on the button  before executing the query or choose Query >
  Include Actual Execution Plan

```
SELECT * FROM Employee1

SELECT * FROM Employee2
```

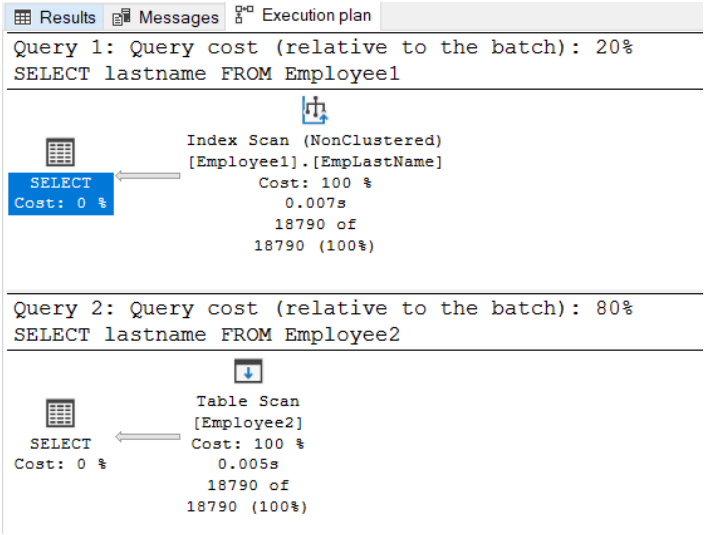


Does my query uses a table scan?

- Table Employee2 is a copy of Employee1, but without indexes
- Query on Employee2 takes 5x longer!

```
SELECT lastname FROM Employee1

SELECT lastname FROM Employee2
```



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What is the difference? Indexes!

- **What?**
  - ordered structure imposed on records from a table
  - Fast access through tree structure (B-tree = balanced tree)
- **Why?**
  - can speed up data retrieval
  - can force unicity of rows
- **Why not?**
  - indexes consume storage (overhead)
  - Indexes can slow down updates, deletes and inserts because indexes have to be updated too

Indexes: library analogy

Consider a card catalog in a library. If you wanted to locate a book named Effective SQL, you would go to the catalog and locate the drawer that contains cards for books starting with the letter E (maybe it will actually be labeled D–G). You would then open the drawer and flip through the index cards until you find the card you are looking for. The card says the book is located at 601.389, so you must then locate the section somewhere within the library that houses the 600 class. Arriving there, you have to find the bookshelves holding 600–610. After you have located the correct bookshelves, you have to scan the sections until you get to 601, and then scan the shelves until you find the 601.3XX books before pinpointing the book with 601.389

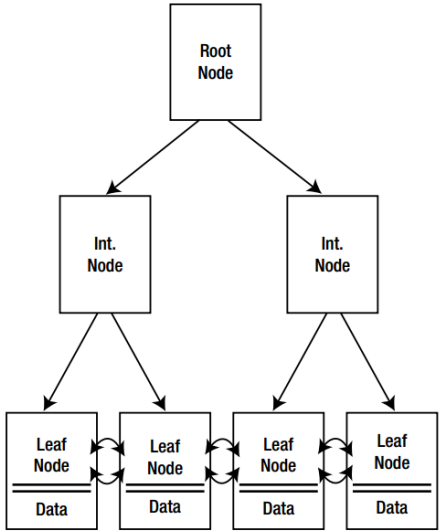
In an electronic database system, it is no different. The database engine needs to first access its index on data, locate the index page(s) that contains the letter E, then look within the page to get the pointer back to the data page that contains the sought data. It will jump to the address of the data page and read the data within that page(s). Ergo, an index in a database is just like the catalog in a library. Data pages are just like bookshelves, and the rows are like the
books themselves. The drawers in the catalog and the bookshelves represent the
B-tree structure for both index and data pages

SQL Optimizer

- SQL Optimizer: module in each DBMS
- Analyses and rephrases each SQL command sent to the DB
- Decides optimum strategy for e.g. index use, based on statistics about table size, table use and data distribution
- In SQL searching is used for fields in *where*, *group by*, *having* and *order by* clauses and for fields that are *joined*

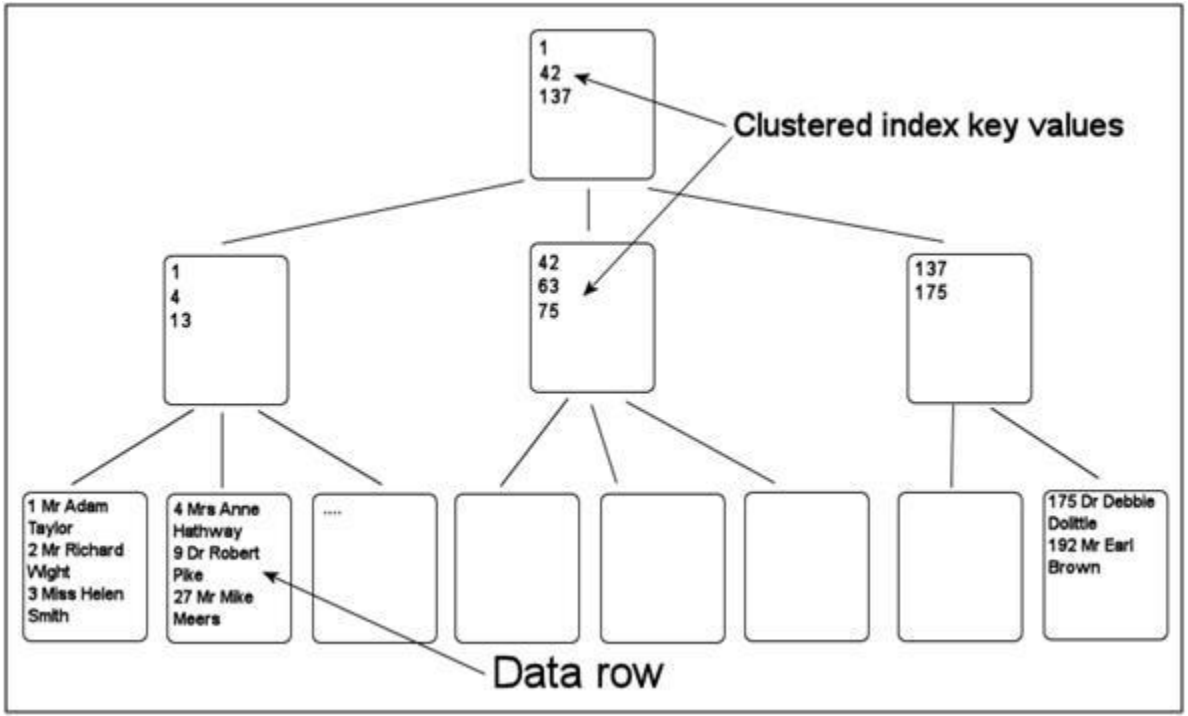
Clustered index

- The physical order of the rows in a table corresponds to the order in the clustered index.
- As a consequence, each table can have only one clustered index.
- The clustered index imposes unique values and the primary key constraint
- Advantages as opposed to table scan:
  - double linked list ensures order when reading sequential records + no forward pointers necessary



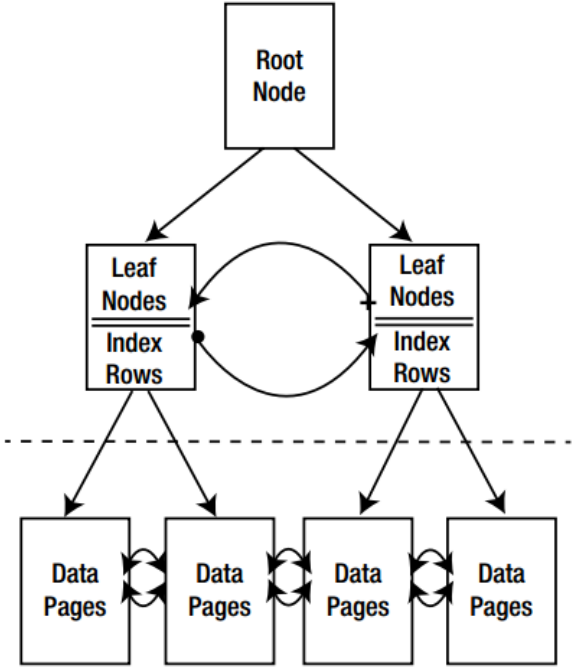
Int. Node = intermediate (tussenliggende) node

Clustered index



Non Clustered index

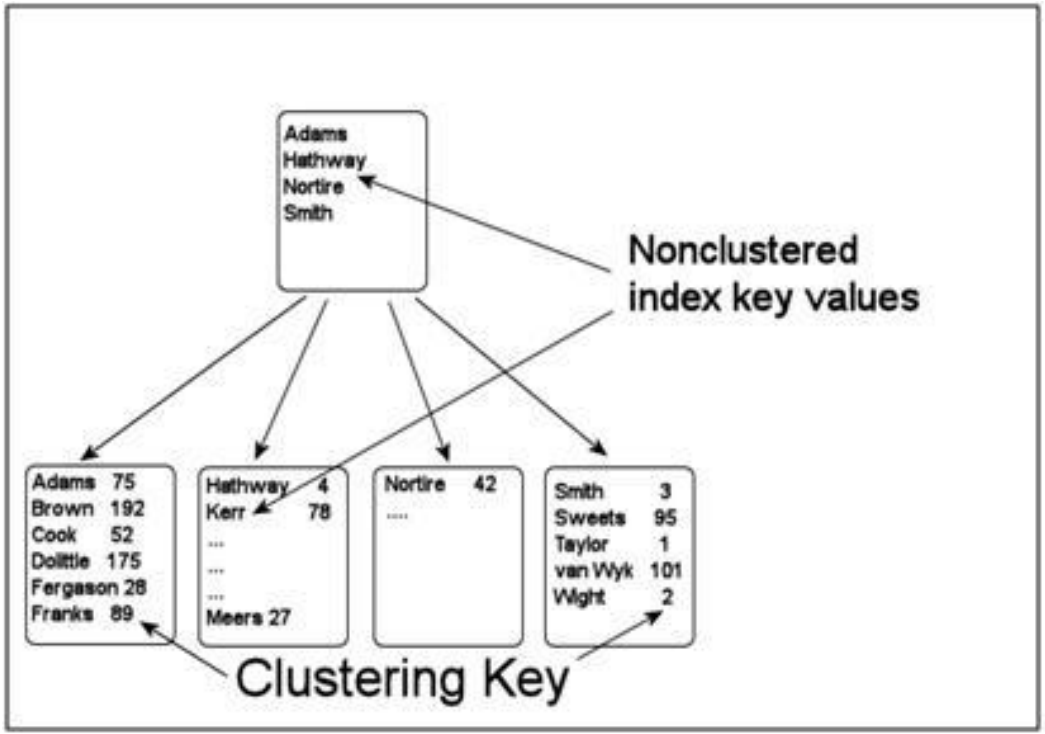
- default index
- slower than clustered index
- > 1 per table allowed
- Forward and backward pointers between leaf nodes
- each leaf contains key value and row locator
  - to position in clustered index if it exists
  - otherwise to heap



Non Clustered index

- If query needs more fields than present in index, these fields have to be fetched from data pages.
- When reading via non-clustered index:
  - either:
    RID lookup = bookmark lookups to the heap using RID's (= row identifiers)
  - Or:
    key lookup = bookmark lookups to a clustered index, if present

Non Clustered index

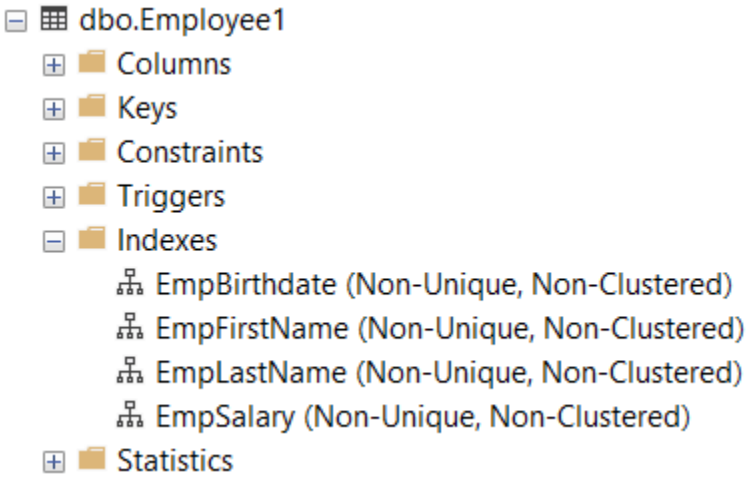


Covering index

- If a non clustered index not completely covers a query, SQL Server performs a lookup for each row to fetch the data
- Covering index = non-clustered index containing all columns necessary for a certain query
- With SQL Server you can add extra columns to the index (although those columns are not indexed!)

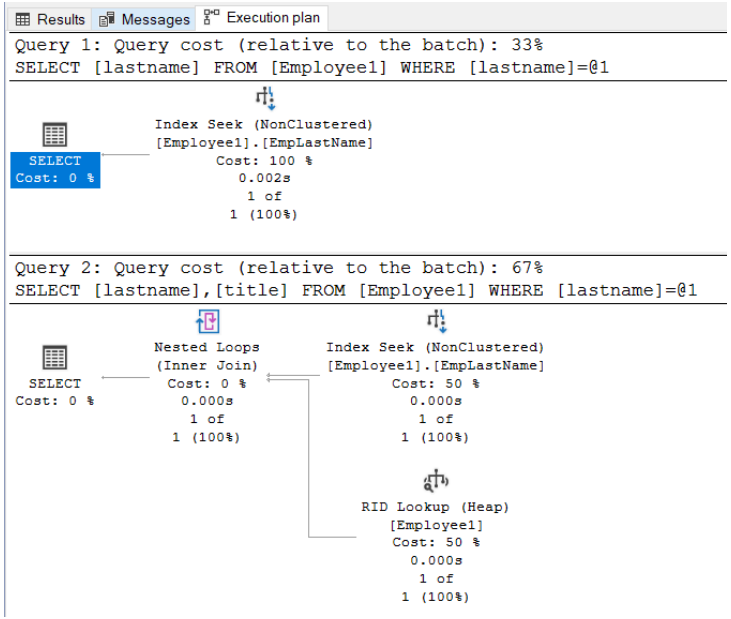
Covering index

- Current indexes on table Employee1: each index indexes a single field



Covering index

```
SELECT lastname FROM Employee1 WHERE lastname = 'Duffy'

SELECT lastname, title FROM Employee1 WHERE lastname = 'Duffy'
```



- Index seek via nonclustered index for seeking lastname = 'Duffy’
- Key loop up in clustered index (= data) for fetching title (not in index)

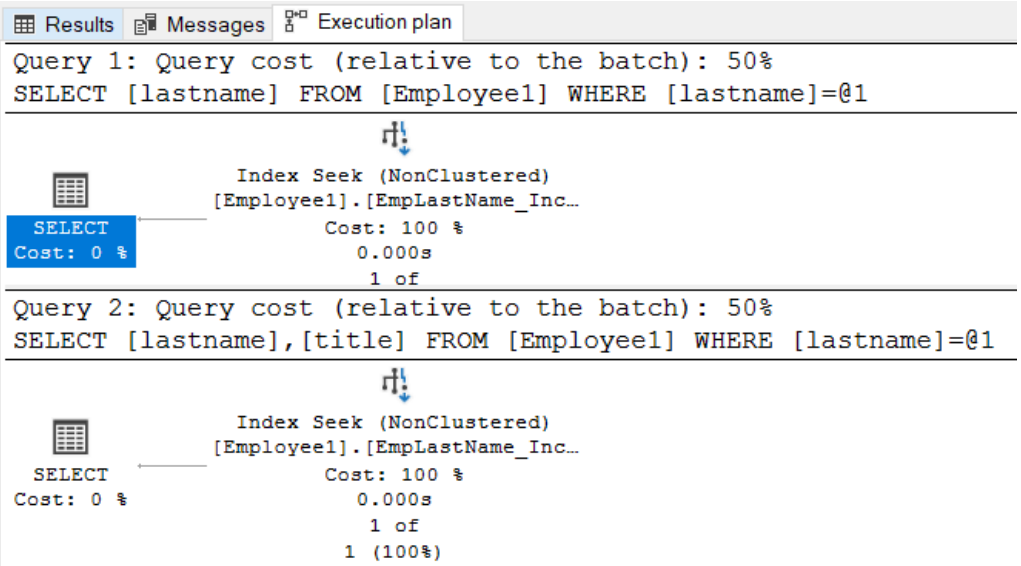
Covering index

- Solution: covering index via INCLUDE

```
create nonclustered index EmpLastName_Incl_Title
ON Employee1(lastname) INCLUDE (title);
```

Covering index

```
SELECT lastname FROM Employee1 WHERE lastname = 'Duffy'

SELECT lastname, title FROM Employee1 WHERE lastname = 'Duffy'
```

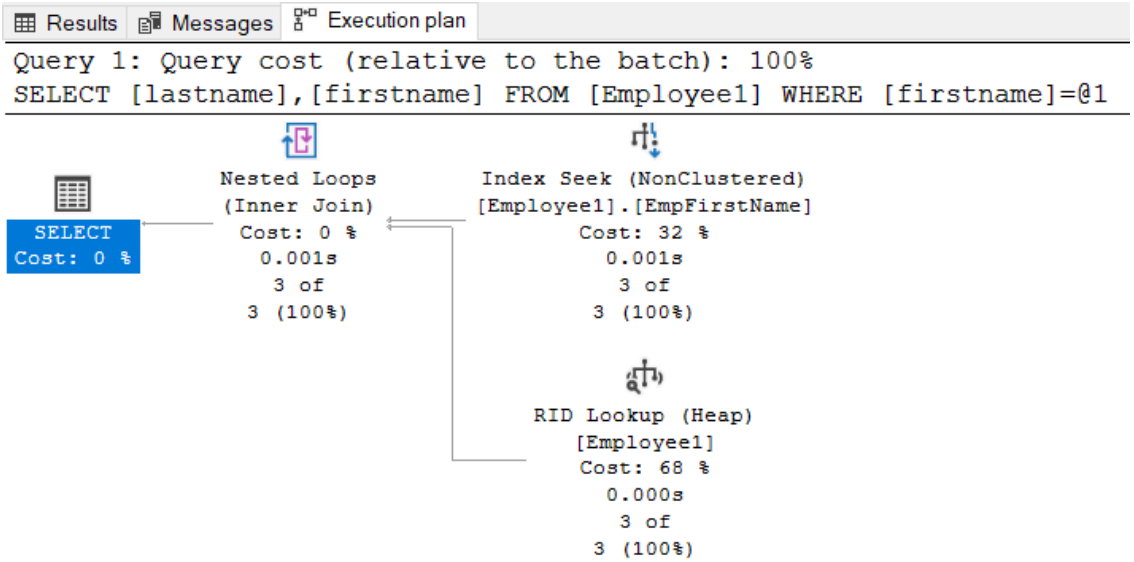


1 index with several columns vs. several indexes with 1 column

```
CREATE NONCLUSTERED INDEX EmpLastName ON Employee1(lastname);
 +
CREATE NONCLUSTERED INDEX EmpFirstname ON Employee1(firstname);

OR?

CREATE NONCLUSTERED INDEX EmpLastNameFirstname ON Employee1(lastname, firstname);
```

1 index with several columns vs. several indexes with 1 column

```
SELECT lastname, firstname FROM Employee1
WHERE firstname = 'Chris';
```

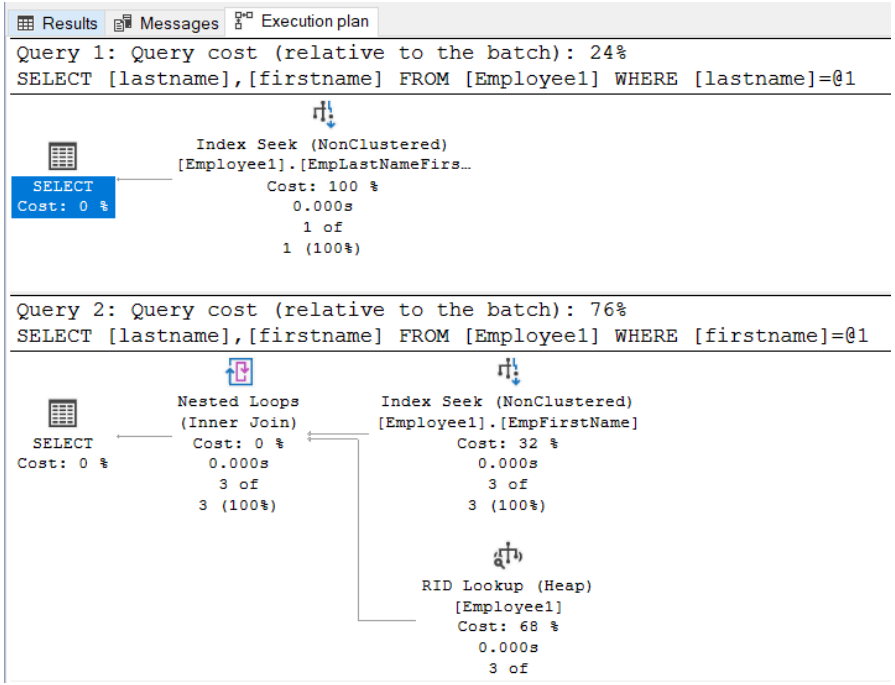


1 index with several columns vs. several indexes with 1 column

- When querying (e.g. in WHERE-clause) only 2nd and or 3th, … field of index, the index is not used. This directly follows from the B-tree table structure of the composed index
- Make your indexes according to the most commonly used queries.

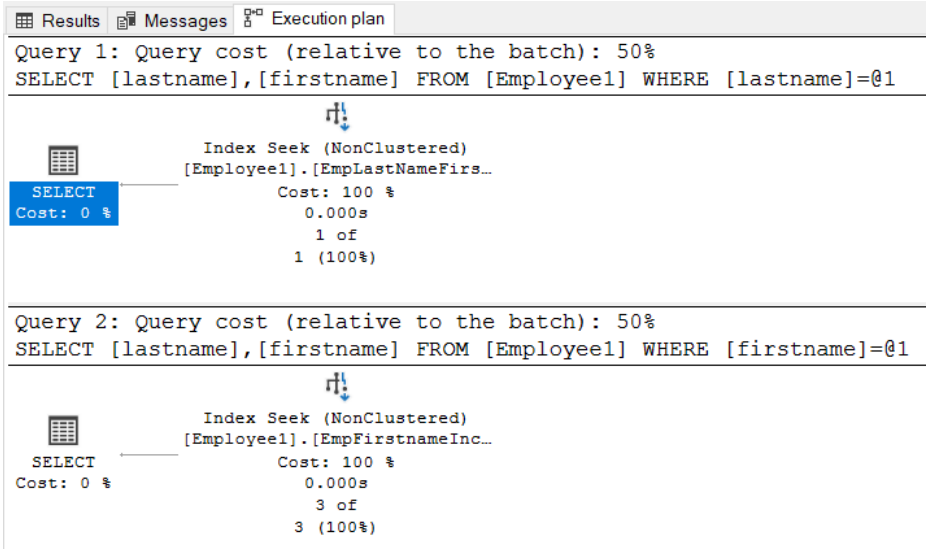
1 index with several columns vs. several indexes with 1 column

```
-- Test: Only combined index on lastname and
firstname
DROP INDEX EmpLastName ON Employee1;

SELECT lastname, firstname FROM Employee1
WHERE lastname = 'Preston'

SELECT lastname, firstname FROM Employee1
WHERE firstname = 'Chris';
```



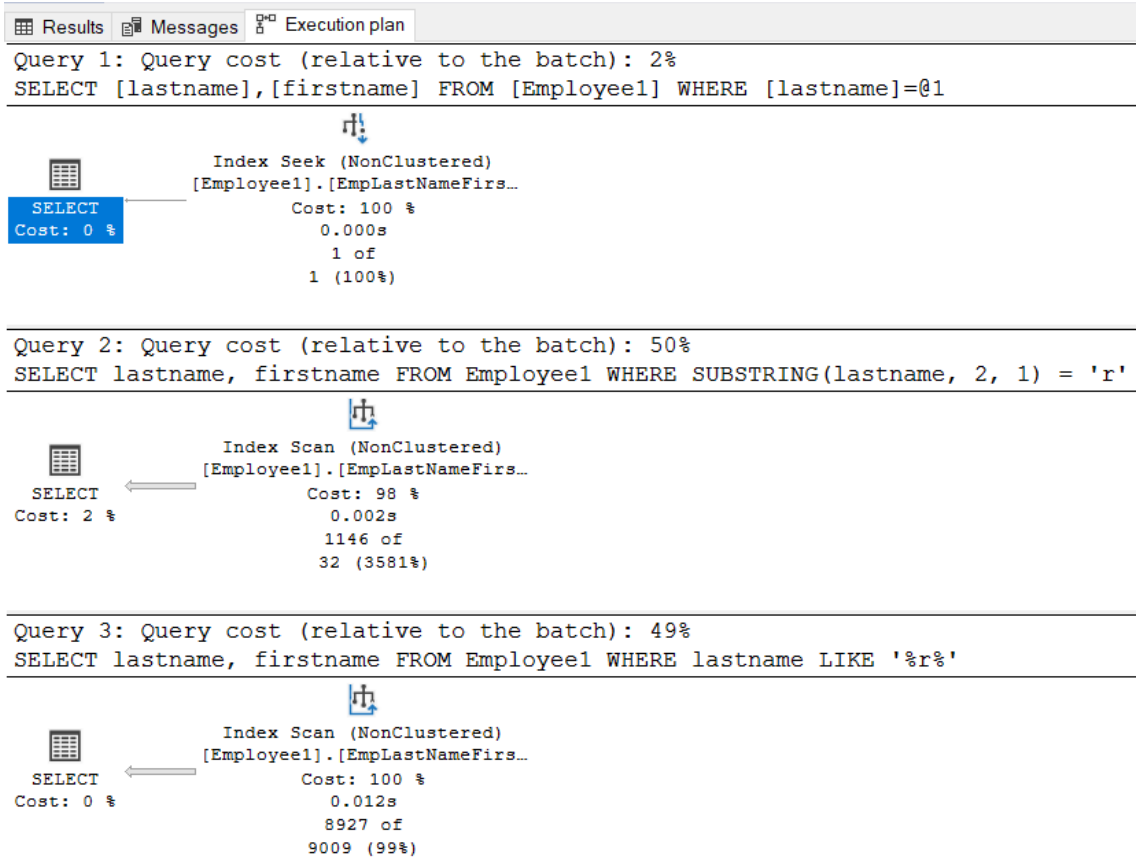
1 index with several columns vs. several indexes with 1 column

```
-- With extra index on firstname and covering of
lastname
create nonclustered index EmpFirstnameIncLastname
ON employee1(firstname)
INCLUDE (lastname);

SELECT lastname, firstname FROM Employee1
WHERE lastname = 'Preston'

SELECT lastname, firstname FROM Employee1
WHERE firstname = 'Chris';
```



Use of indexes with functions and wildcards

```sql
SELECT lastname, firstname
FROM Employee1
WHERE lastname = 'Preston'

SELECT lastname, firstname
FROM Employee1
WHERE SUBSTRING(lastname, 2, 1) = 'r'

SELECT lastname, firstname
FROM Employee1
WHERE lastname LIKE '%r%'
```



Index seek vs Index scan

- Index Seek: tree structure of index is used, resulting in very fast data retrieval.
- Index Scan: index is used but it is scanned from the start till the searched records are found.

When to use an index?

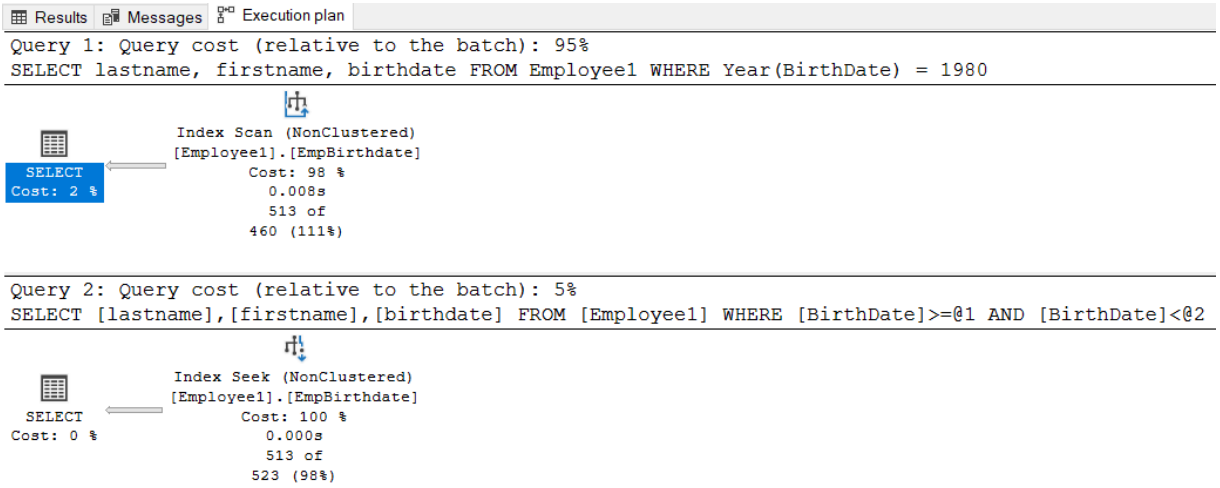
- Which columns should be indexed?
  - primary and unique columns are indexed automatically
  - foreign keys often used in joins
  - columns often used in search conditions (WHERE, HAVING, GROUP BY) or in joins
  - columns often used in the ORDER BY clause

When to use an index?

- Which columns should be not indexed?
  - columns that are rarely used in queries
  - columns with a small number of possible values (e.g. gender)
  - columns in small tables
  - columns of type bit, text or image

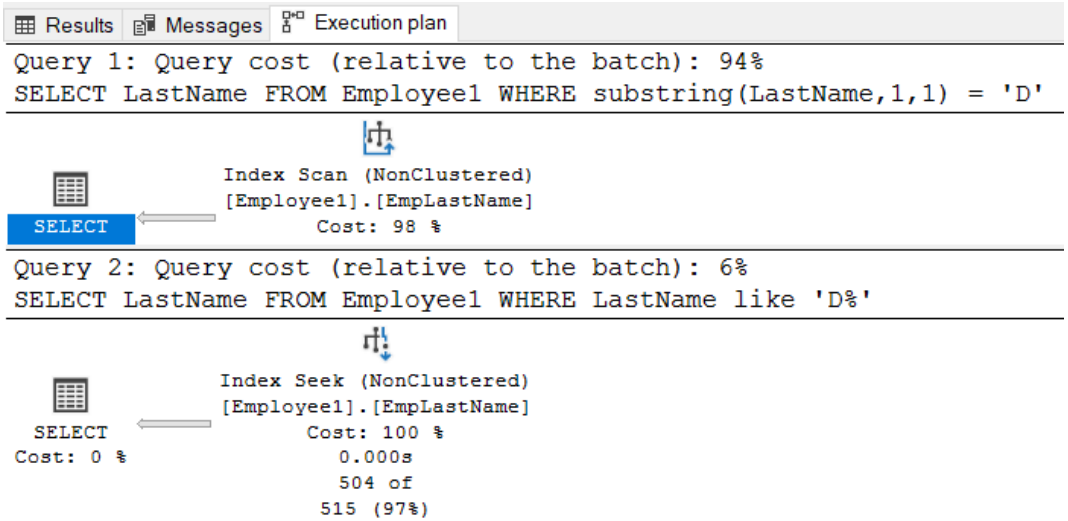
Tips & Tricks: (1) Avoid the use of functions

```sql
-- BAD
SELECT FirstName, LastName, Birthdate
FROM Employee1
WHERE Year(BirthDate) = 1980;

-- GOOD
SELECT FirstName, LastName, Birthdate
FROM Employee1
WHERE BirthDate >= '1980-01-01' AND
BirthDate <  '1981-01-01';
```



Tips & Tricks: (2) Avoid the use of functions

```sql
-- BAD
SELECT LastName
FROM Employee1
WHERE substring(LastName,1,1) = 'D';

-- GOOD
SELECT LastName
FROM Employee1
WHERE LastName like 'D%';
```



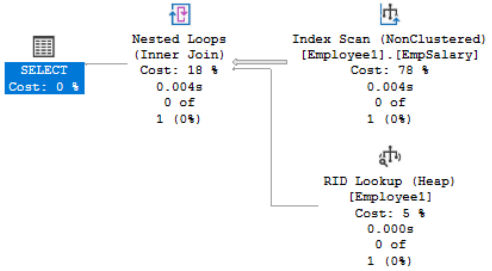
Tips & Tricks: (3) avoid calculations, isolate columns

```
-- BAD
SELECT EmployeeID, FirstName, LastName
FROM Employee1
WHERE Salary*1.10 > 100000;

-- GOOD
SELECT EmployeeID, FirstName, LastName
FROM Employee1
WHERE Salary > 100000/1.10;
```

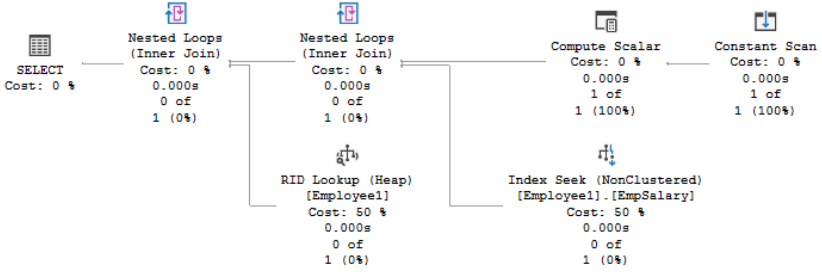
Tips & Tricks: (3) avoid calculations, isolate columns

Results | Messages | Execution plan

```
Query 1: Query cost (relative to the batch): 92%
SELECT [EmployeeID],[FirstName],[LastName] FROM [Employee1] WHERE [Salary]*@1>@2
```




```
Query 2: Query cost (relative to the batch): 8%
SELECT [EmployeeID],[FirstName],[LastName] FROM [Employee1] WHERE [Salary]>@1/@2
```



Key lookup:

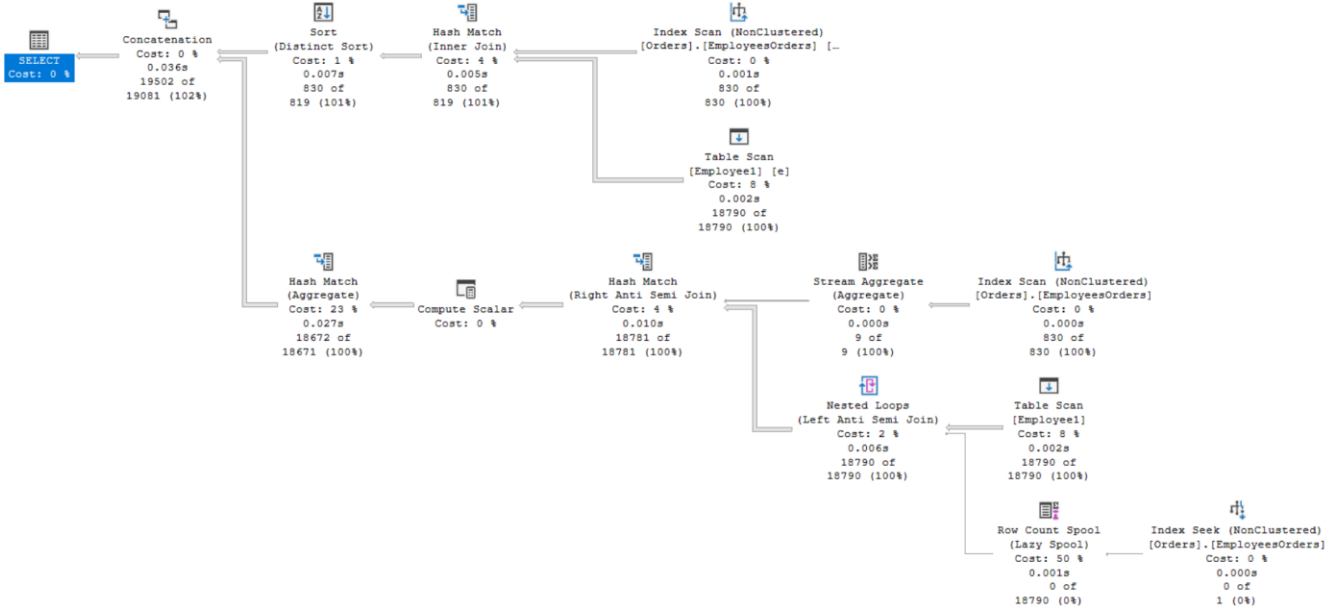
The non-clustered index EmpSalary, holds in each leaf a reference to the location of the total record in the clustered index. Following this reference is called “key lookup”.

Tips & Tricks: (4) prefer OUTER JOIN above UNION

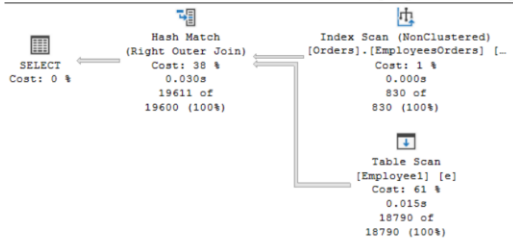
```
-- BAD
SELECT lastname, firstname, orderid
from Employee1 e join Orders o on e.EmployeeID = o.employeeid
union
select lastname, firstname, null
from Employee1
where EmployeeID not in (select EmployeeID from Orders)

-- GOOD
SELECT lastname, firstname, orderid
from Employee1 e left join Orders o on e.EmployeeID = o.employeeid;
```

Results | Messages | Execution plan

Query 1: Query cost (relative to the batch): 89%
SELECT lastname, firstname, orderid from Employee1 e join Orders o on e.EmployeeID = o.employeeid union select lastname, firstname, null from Employee1 wh
Missing Index (Impact 11.6844): CREATE NONCLUSTERED INDEX [<Name of Missing Index, sysname,>] ON [dbo].[Employee1] ([EmployeeID]) INCLUDE ([LastName],[Fir



Query 2: Query cost (relative to the batch): 11%
SELECT lastname, firstname, orderid from Employee1 e left join Orders o on e.EmployeeID = o.employeeid



Tips & Tricks: (5) avoid ANY and ALL

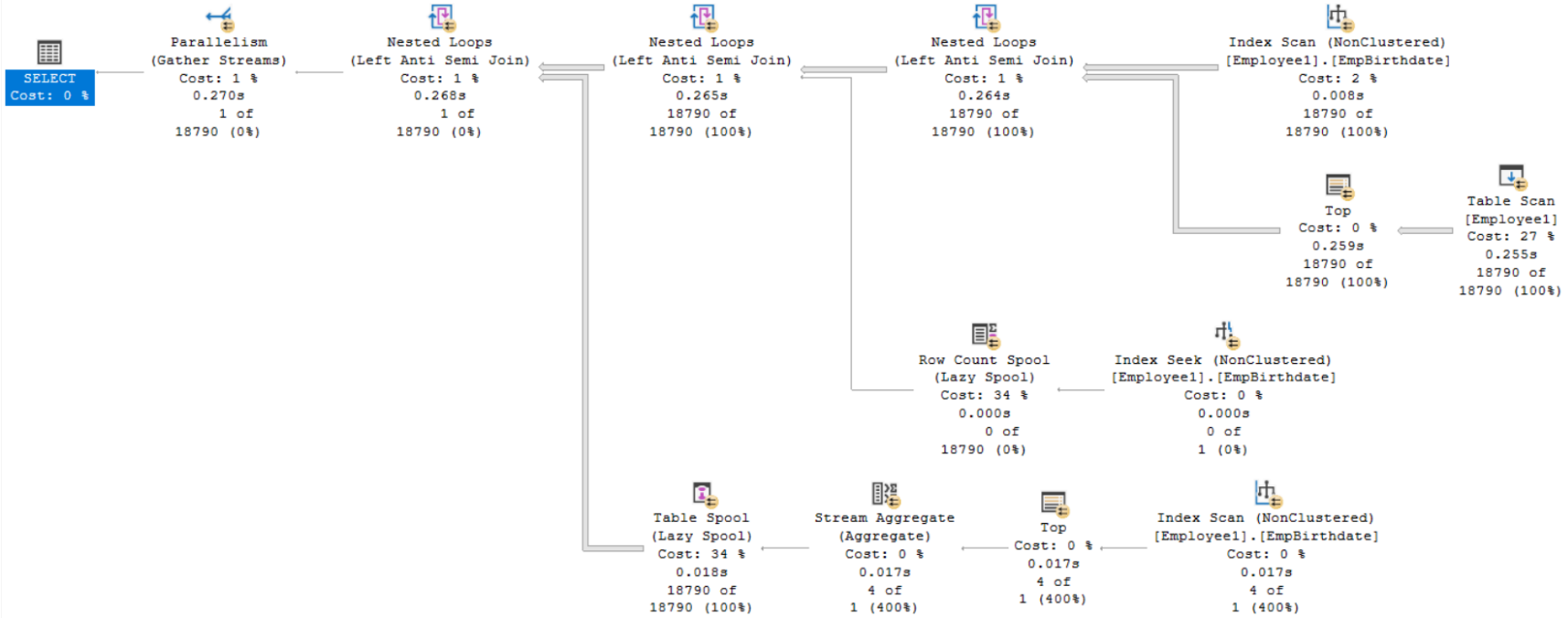
```
-- BAD
SELECT lastname, firstname, birthdate
from Employee1
where BirthDate >= all(select BirthDate from Employee1)

-- GOOD
SELECT lastname, firstname, birthdate
from Employee1
where BirthDate = (select max(BirthDate) from Employee1)
```

Tips & Tricks: (5) avoid ANY and ALL

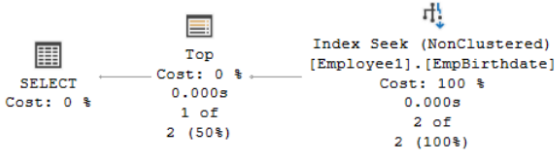
```
-- BAD
SELECT lastname, firstname, birthdate
from Employee1
where BirthDate >= all(select BirthDate from Employee1)

-- GOOD
SELECT lastname, firstname, birthdate
from Employee1
where BirthDate = (select max(BirthDate) from Employee1)
```

Results | Messages | Execution plan

Query 1: Query cost (relative to the batch): 100%
SELECT lastname, firstname, birthdate from Employee1 where BirthDate >= all(select BirthDate from Employee1)



Query 2: Query cost (relative to the batch): 0%
SELECT lastname, firstname, birthdate from Employee1 where BirthDate = (select max(BirthDate) from Employee1)



Quiz 1 / 5

- Is the following index a good fit for the query?
  - A: Good fit: No need to change anything
  - B: Bad fit: Changing the index or query could improve performance

```
CREATE INDEX tbl_idx ON tbl (date_column);

SELECT * FROM tbl
WHERE YEAR(date_column) = 2017;
```

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Quiz 2 / 5

- Is the following index a good fit for the query?
  - A: Good fit: No need to change anything
  - B: Bad fit: Changing the index or query could improve performance

```
CREATE INDEX tbl_idx ON tbl (a, date_column);

SELECT TOP 1 * FROM tbl
WHERE a = 12
ORDER BY date_column DESC;
```

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Quiz 3 / 5

- Is the following index a good fit for the query?
  - A: Good fit: No need to change anything
  - B: Bad fit: Changing the index or query could improve performance

```
CREATE INDEX tbl_idx ON tbl (a, b);

SELECT * FROM tbl
WHERE a = 123 AND b = 1;

SELECT * FROM tbl WHERE b = 123;
```

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Quiz 4 / 5

- Is the following index a good fit for the query?
  - A: Good fit: No need to change anything
  - B: Bad fit: Changing the index or query could improve performance

```
CREATE INDEX tbl_idx ON tbl (text);

SELECT * FROM tbl
WHERE text LIKE 'TJ%';
```

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Quiz 5 / 5

```
CREATE INDEX tbl_idx ON tbl (a, date_column);

SELECT date_column, count(*)
FROM tbl
WHERE a = 123
GROUP BY date_column;
```

```
SELECT date_column, count(*)
FROM tbl
WHERE a = 123 AND b = 1
GROUP BY date_column;
```

- First consider the following index and query:
- Let's say this query returns at least a few rows.
  To implement a new functional requirement, another condition (b = 1) is added to the WHERE clause. How wil the change affect performance?
  - A: Same: Query performance stays about the same
  - B: Not enough information: Definite answer cannot be given
  - C: Slower: Query takes more time
  - D: Faster: Query take less time

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