Data-driven systems

Query optimization

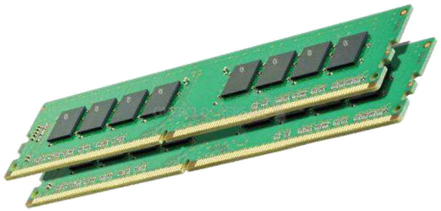
Automatizálási és
Alkalmazott
Informatikai Tanszék

Contents

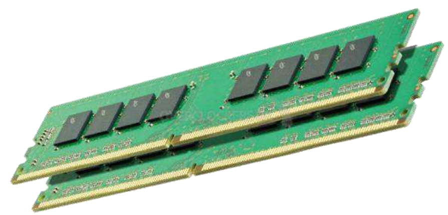
- Purpose of query optimization
- Microsoft SQL Server
  - Execution plans
  - Join and table access options
  - General recommendation
- MongoDB
  - Indices and execution plans

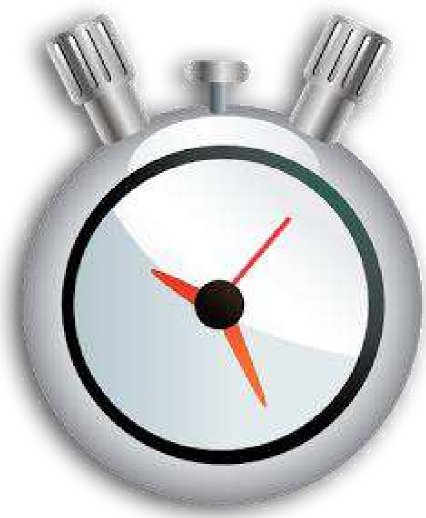
What is the purpose of query optimization?

What is the purpose of query optimization?



What is the purpose of query optimization?





Response time is affected by

- I/O cost
  - Most prominent in data bases
  - Does not improve according to Moore's law
  - Needs special tricks
- CPU usage
  - Complex queries
  - Complex computations
- Memory usage
  - Cache effect

Microsoft SQL Server

General concepts

Basics of the optimization

- Evaluates based on statistics
  - Cost = response time (CPU + I/O time)
- Trivial plan
  - Unambiguous for simple queries
  - Rule-based
- When no trivial plan is available
  - Complex queries
  - Three phase optimization

Three phase optimization

- No trivial plan
- 0. Phase
  - Simple optimizations
  - Preferred hash join
  - If cost < X → execute
- 1. Phase
  - Complex optimizations
  - If cost < Y → execute
- 2. Phase
  - Parallel execution

Process of executing a query

- Analyzer
  - Compiler
  - Logical plan
- Optimization
  - Physical execution plan
  - Read tables
  - Joining tables
- Row executor
  - Mapping physical plan to I/O operations
- Executor
  - Executes the operations

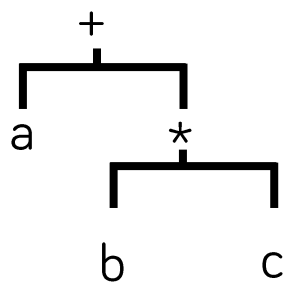
Microsoft SQL Server

Logical execution plan

Elements of the logical execution plan

- Parser tree
  - Relations (leaf)
  - Operations (node)
  - Data flow from bottom to top
- Relational algebra operations
  - Cartesian-join ($R \times S$)
  - Projection ($\pi_L(R)$)
  - Selection ($\sigma_F(R)$)
  - Join ($R \bowtie S$)
  - Filtering duplicates ($\delta(R)$)
  - Grouping ($\gamma_L(R)$)
  - Sorting ($\tau_L(R)$)

a + b * c

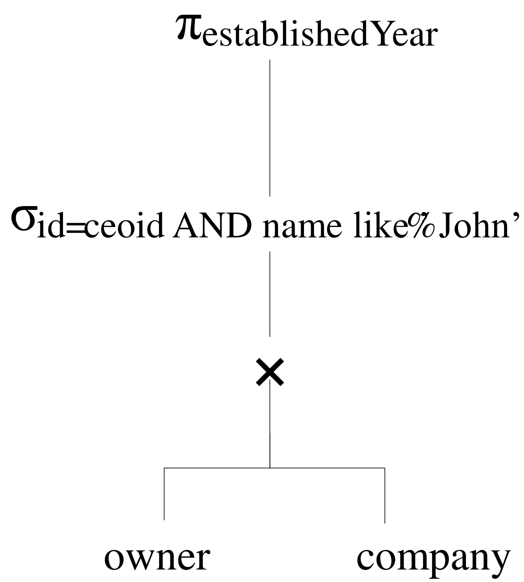


Parser tree

select establishedYear

from owner o, company c

where o.id = c.ceoid AND name like '%John'



Refactoring the parser tree - 1

- Create an optimal logical execution plan
- Reduce possible physical execution options
- Basic concept
  - Move selection (where) down in the three
  - Using joins
    - Cartesian join only when explicitly specified
  - One side of a join should be a table

Refactoring the parser tree - 2

- Selection
  - Can be re-ordered: $\sigma_{F1}(\sigma_{F2}(R)) = \sigma_{F2}(\sigma_{F1}(R))$
  - Can be re-written:
    - $\sigma_{F \text{ and } G}(R) = \sigma_F(\sigma_G(R))$
    - $\sigma_{F \text{ or } G}(R) = \sigma_F(R) \text{ UNION } \sigma_G(R)$
- Join
  - $R \bowtie_F S = \sigma_F(R \times S)$
  - $R \bowtie S = S \bowtie R$
  - $(R \bowtie S) \bowtie U = R \bowtie (S \bowtie U)$

Refactoring the parser tree - 3

- Joining and selection
  - $\sigma_F(R \bowtie S) = \sigma_F(R) \bowtie S$
    - If R has all attributes of F
  - $\sigma_F(R \bowtie S) = R \bowtie \sigma_F(S)$
    - If S has all attributes of F
  - $\sigma_F(R \bowtie S) = \sigma_F(R) \bowtie \sigma_F(S)$
    - If both R and S has attributes of F
- Duplicates
  - $\delta(\gamma_L(R)) = \gamma_L(R)$
  - $\delta(R \times S) = \delta(R) \times \delta(S)$ (similarly for joins)

Microsoft SQL Server

Physical execution plan

Physical plan

- Elements of the physical plan
  - Operators for reading the table
    - Logical plan leaf reading operations
  - Executing relational algebra operations
- Creating plans
  - Rule-based
  - Cost-based
    - Table seek methods
    - Implementation of joins
    - Order of joins

Nested loop join

- Two embedded for cycles
- I/O cost
  - *O(num_block_1 * num_block_2)*
- Works in all cases
  - In case of large tables: keep only partitions of the tables in memory

Hash join

- First pass
  - Read the smaller table
  - Build a hash table in memory
    - Key is the column used for joining
- Second pass
  - Read the larger table
  - Search for matching records in the hash table
- I/O cost
  - *O(num_block_1 + num_block_2)*

Sort Merge Join

- Reads both tables into memory
- Sorts based on the joined columns
- Merge the two sorted lists
  - While "walking" the two sorted lists
- For small tables
- Index due to sorting
- I/O cost
  - $O(num\_block\_1 + num\_block\_2)$

Table scan methods - 1

- Generally there are two ways
  - Full scan
    - For small tables
    - When most rows are needed
  - Index scan
    - When using filtering
      - If there is an index covering the filter criteria
    - Sorting

Table scan methods - 2

- Table scan
  - No index
  - Evaluates the filtering condition
- Clustered index scan
  - Clustered reading
  - Data blocks ordered by index
  - Clustered index created along primary key
  - Preferred over table scan

Table scan methods - 3

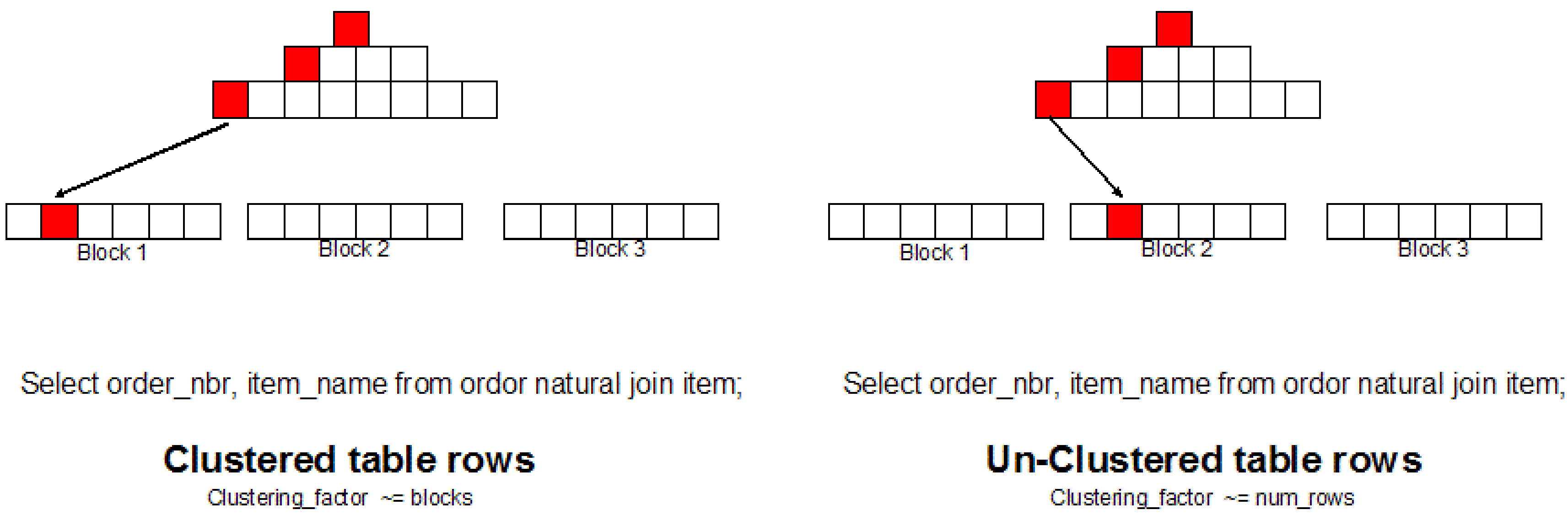
- Nonclustered index scan
  - Similar to clustered index scan
  - Mostly for evaluating =
- Clustered/Nonclustered index seek
  - Similar to index scan
  - Walks the index from a starting point
    - >, between, < operators

MS SQL Server indexes

- B* tree
  - Simple
  - Compound indexes
    - Hierarchical
  - Clustered
    - Data blocks orderes by index
    - One for each table
    - Automatically created for the primary key

MS SQL Server indexes

- Clustered / non-clustered



Source: http://www.dba-oracle.com/t_table_row_resequencing.htm

Indexes - 1

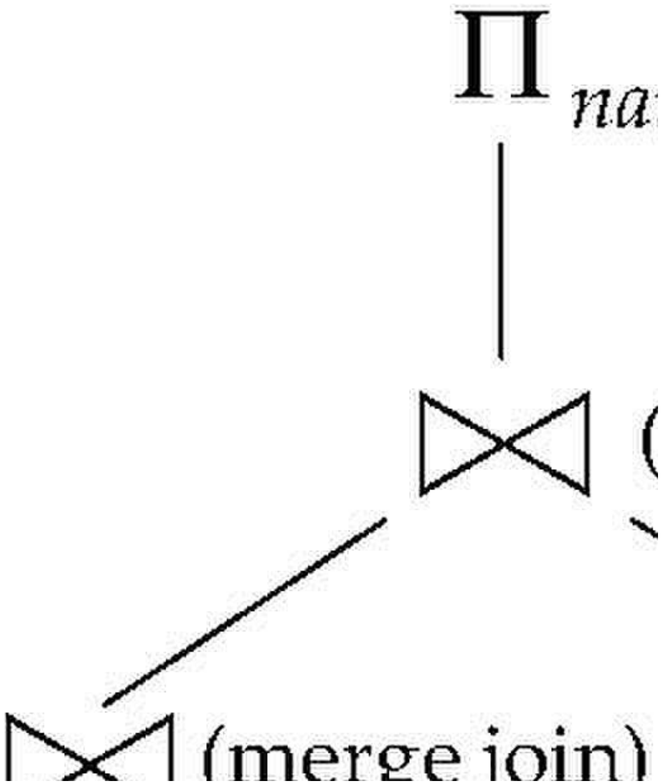
- Cover index (included column)
  - Adding further data into the B* tree leaf nodes
  - The row data does not need to be accessed
- Using clustered and non clustered indices together
  - Nonclustered index leaf
    - Does not contain a physical address
    - Points to the clustered index
  - Double index read

Indexes - 2

- Indexed views
  - The view result is stored
  - Index can be defined, works as for tables

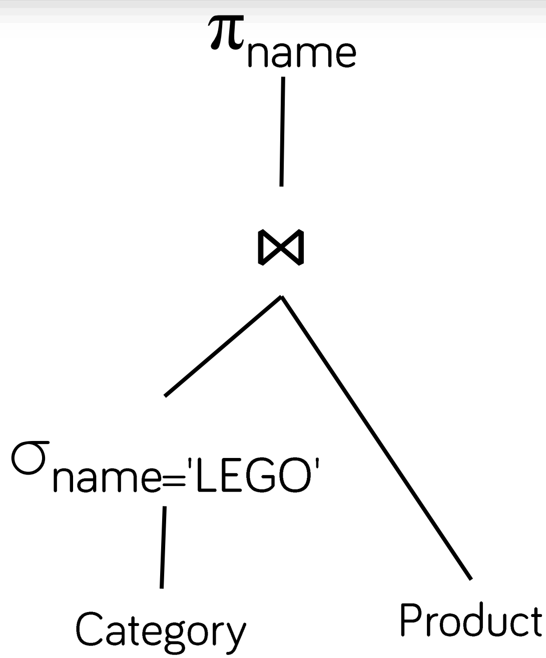
Execution plan

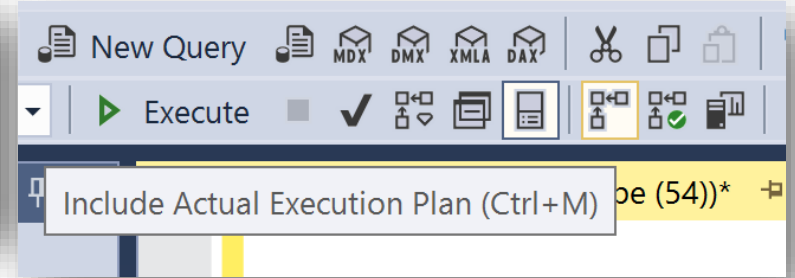
- It defines exactly what action is performed on each node

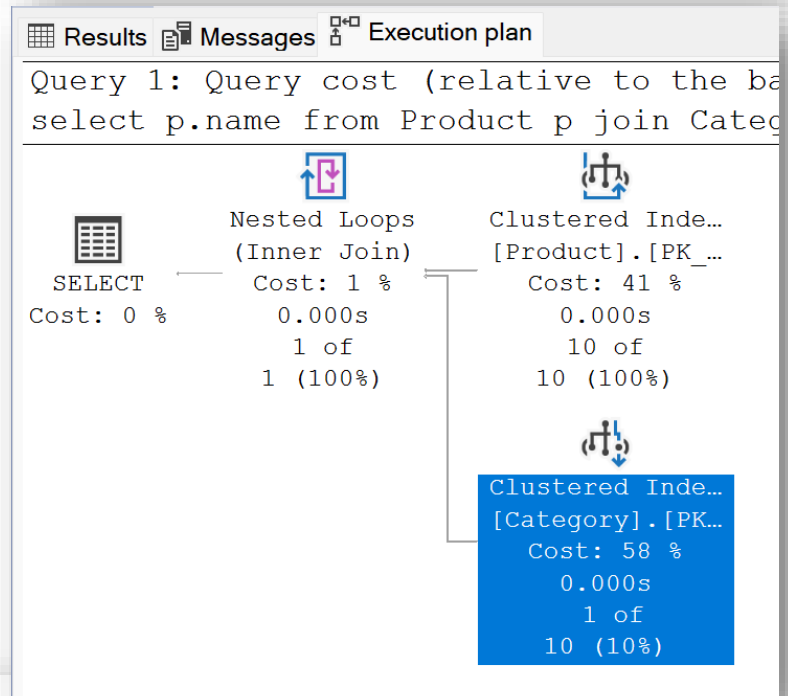


Végrehajtási terv megnézése

```sql
select p.name from Product p
join Category c on p.CategoryID = c.ID
where c.Name = 'LEGO'
```





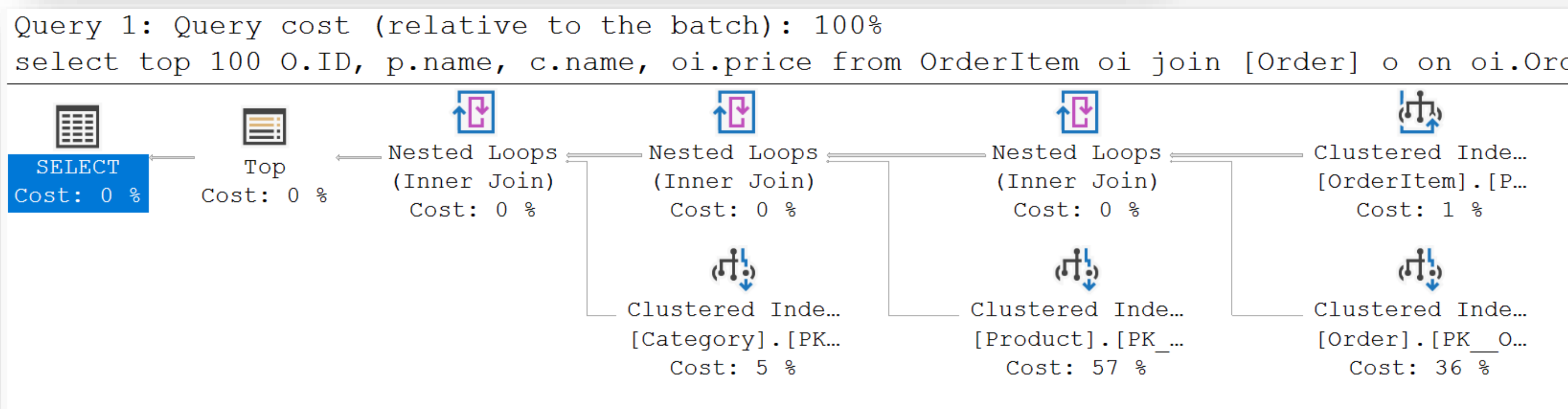


Parallel	False
Physical Operation	Clustered Index Seek
Predicate	[M22XDS].[dbo].[Category].[Name] as [c].[Name]=N'LEGO'
Scan Direction	FORWARD

Query plan in SQL Server

- Press CTRL+L after executing the query

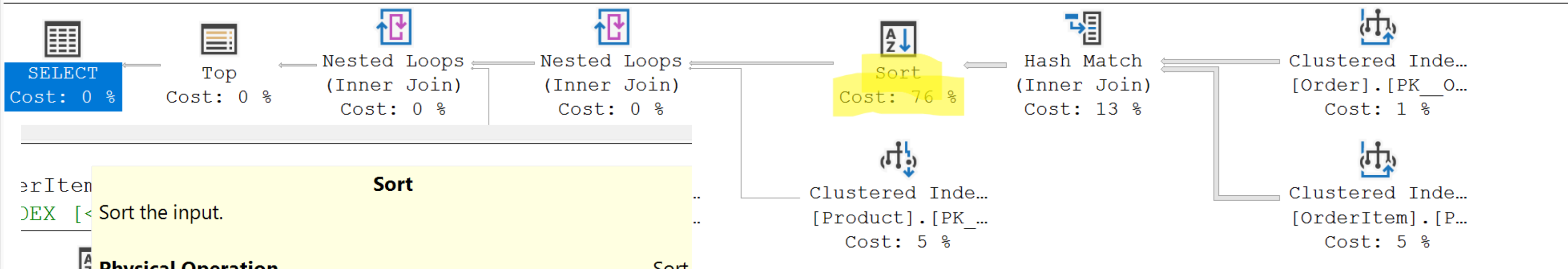
```sql
select top 100 O.ID, p.name, c.name, oi.price
from
    OrderItem oi join [Order] o on oi.OrderID = o.ID
    join Product p on oi.ProductID = p.ID
    join Category c on p.CategoryID = c.ID
```



Index hints

```
select top 100 O.ID, p.name, c.name, oi.price
from
    OrderItem oi join [Order] o on oi.OrderID = o.ID
    join Product p on oi.ProductID = p.ID
    join Category c on p.CategoryID = c.ID
order by o.Deadline desc
```

Query 1: Query cost (relative to the batch): 100%
select top 100 O.ID, p.name, c.name, oi.price from OrderItem oi join [Order] o on oi.OrderID = o.ID joi…
Missing Index (Impact 17.5168): CREATE NONCLUSTERED INDEX [<Name of Missing Index, sysname,>] ON [dbo].…



Sort

Sort the input.

Physical Operation	Sort
Logical Operation	Sort
Estimated Execution Mode	Row
Estimated I/O Cost	0,0112613
Estimated Operator Cost	3,40483 (76%)
Estimated CPU Cost	3,39357
Estimated Subtree Cost	4,24715
Estimated Number of Executions	1
Estimated Number of Rows for All Executions	100
Estimated Number of Rows Per Execution	100
Estimated Row Size	31 B
Node ID	4

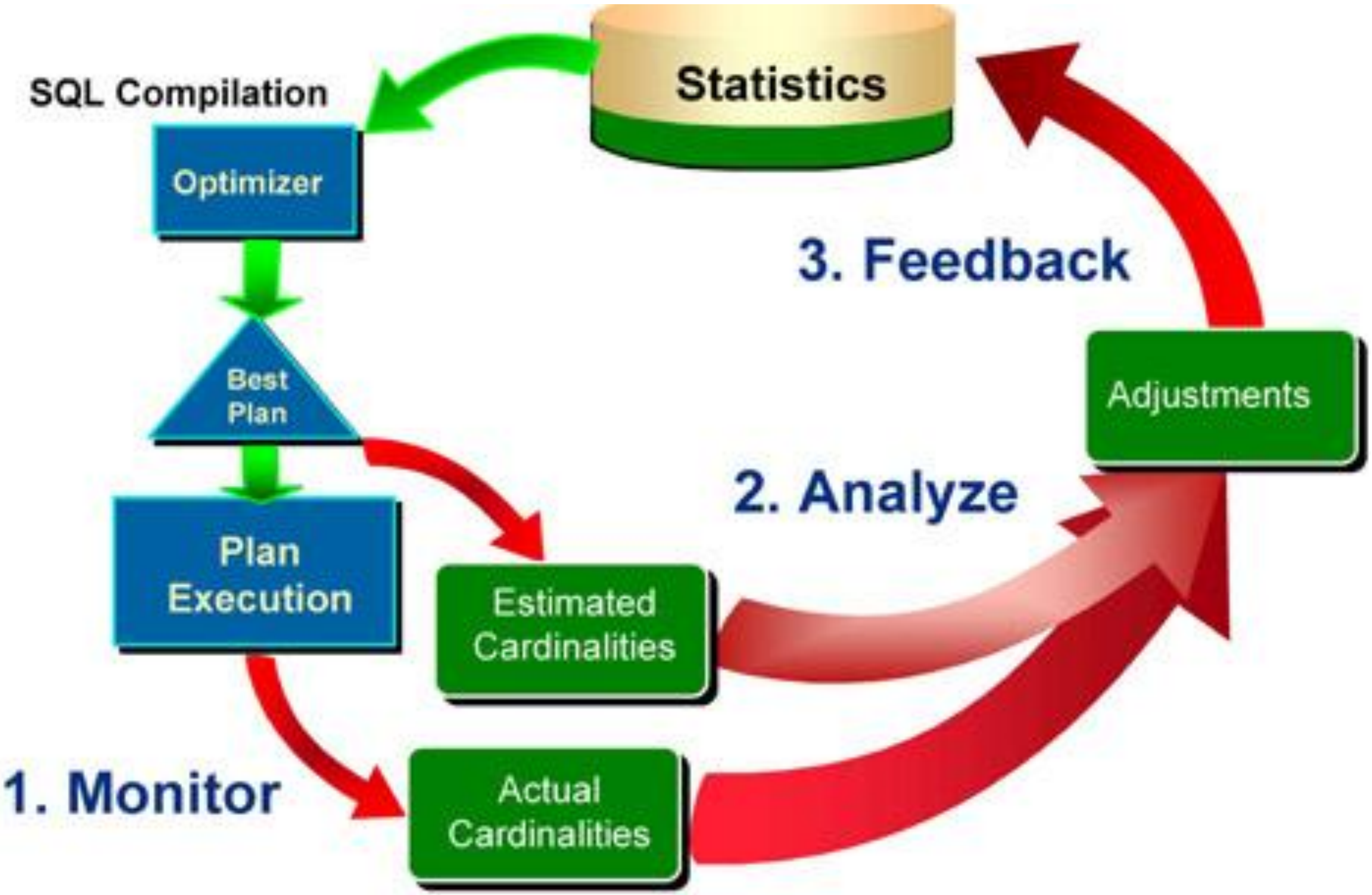
Output List
[M22XDS].[dbo].[OrderItem].Price; [M22XDS].[dbo].[OrderItem].ProductID; [M22XDS].[dbo].[Order].ID; [M22XDS].[dbo].[Order].Deadline

Order By
[M22XDS].[dbo].[Order].Deadline Descending

Execution plan alternatives

- There can be several plan alternatives, which one is optimal?
  - Huge differences: seconds or days
  - The cost depends on how many lines are the result for each phase
  - The system estimates this based on statistics
    - -> Self-tuning database, redesigns if necessary, during execution
- Plan cache
  - Execution plan cache
  - Used when for queries with the same structure
  - Statistics have not changed
    - You may need to update the cache manually!
    - The statistics maintenance must be setup!

Self-tuning



Statistics
SQL Compilation
Optimizer
Best Plan
Plan Execution
3. Feedback
Adjustments
2. Analyze
Estimated Cardinalities
1. Monitor
Actual Cardinalities

Microsoft SQL Server

General recommendation

Best practices - 1

- Keep statistics up to date
  - Deprecated statistics →suboptimal execution plan
  - (This is the default unless turned off)
- Structure of the query
  - SQL is declarative
    - Keep procedural execution in mind
  - Same result can be obtained multiple ways
  - Make it simple
  - Avoid select *
  - Good structure is advantageous
    - Use hints as a last resort

Best practices - 2

- Prefer join over
  - In / Not in
  - Exists / Not exists
- Prefer In over Exists
- Views
  - Avoid if possible
  - Do not join them
- Avoid Or clauses →Union all
- Union all if possible

Best practices - 3

```
select *
from Invoice i
where not exists
(
    select 1
    from InvoiceItem ii
    where i.Id=ii.InvoiceID
)
```

```
select i.*
from Invoice i
where i.id not in
(
        select InvoiceID
        from InvoiceItem
)
```

```
select i.*
from Invoice i left outer join InvoiceItem ii
on i.Id=ii.InvoiceID
where ii.id is null
```

Does not matter in simple cases

Best practices - 4

- Using indexes
  - Usually one can be used for one table in a query
    → Join may use it up
  - Compound indexes
    - Hierarchy matters
  - If the key is used in an expression, the optimizer cannot use it
    - E.g., key+0 (← Optimizer may handle this though)

Best practices - 5

- Using functions
  - No problem in a select
    - Does not affect the execution plan
  - Avoid in a where clause
    - Has to be evaluated for each record
    - Hard to move in the query tree
    - No statistics are available for its output → hard to optimize

Further reading material

- Grant Fritchey: SQL Server Execution Plans, Simple Talk Publishing, 2012
  - pdf: http://www.red-gate.com/community/books/sql-server-execution-plans-ed-2

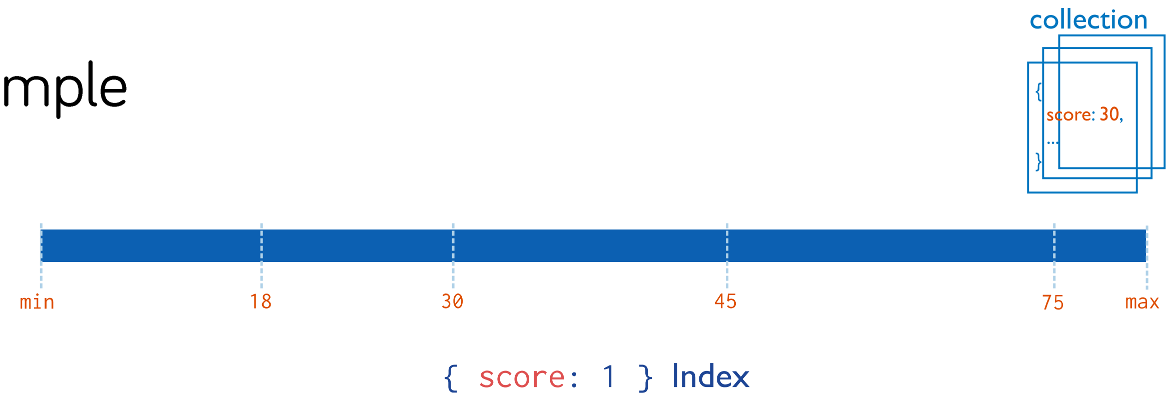
MongoDB

Indices in MongoDB

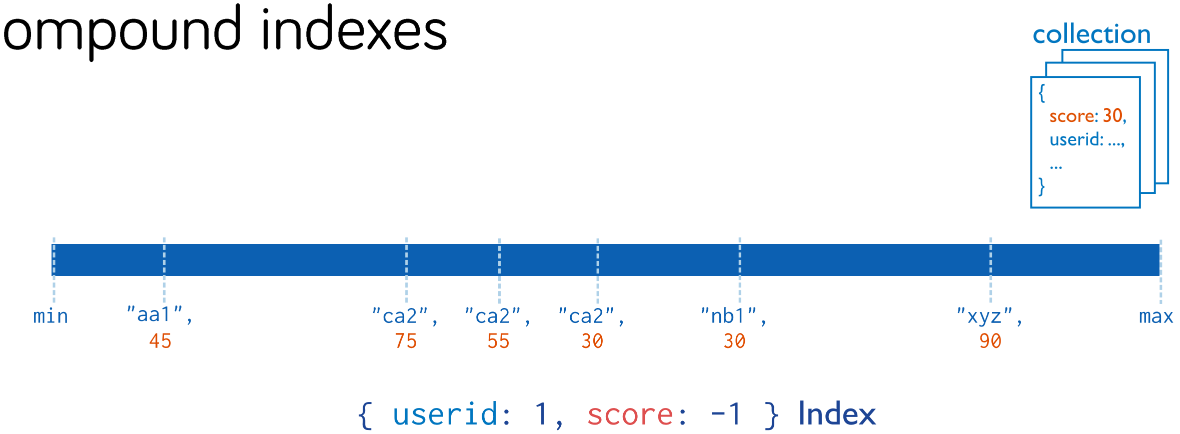
- Index “only” for lookup
  - (As there is no join operation)
- Types of indices
  - Simple and compound
  - Unique index
    - Can be used to ensure a primary key-like attribute
  - Indexes content of arrays too
  - Indexes nested objects too
  - TTL, Geospatial, full text
- Index must be defined
  - Except: _id unique

Types of indices

Simple



Compound indexes



Images source: https://docs.mongodb.com/manual/indexes/

Basics of the optimization

- Does **not** use statistics
- Choice between multiple possible plans
  - Starts execution all, whichever yields the first 101 results, is the best
- How can there be multiple plans?
  - There are multiple indices covering the query

Optimization steps

- Move filtering ahead of other steps
  - Before projection, and if needed, split the filtering into two
  - Before sorting
- Move skip and limit ahead
  - Projection
- Merge
  - Limit + limit, skip + skip

Plan cache

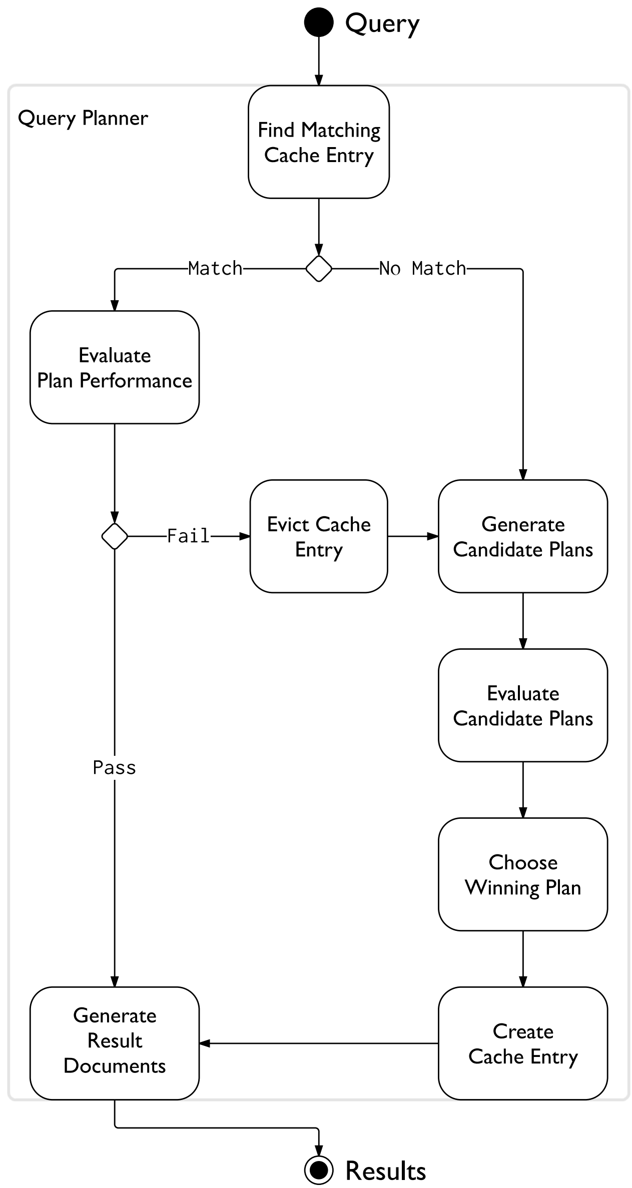


Image source:
https://docs.mongodb.com/manual/core/query-plans/

Plan cache

- Plan cache
  - Structurally similar plans
  - Pass/fail evaluation
- *Query shape*
  - Filters, sorting, etc. used
  - No values
    - E.g. for filtering only the filtered field name is present

Explain

- query.explain()

```
"winningPlan" : {
   "stage" : <STAGE1>,
   ...
   "inputStage" : {
      "stage" : <STAGE2>,
      ...
      "inputStage" : {
         "stage" : <STAGE3>,
         ...
      }
   }
},
"rejectedPlans" : [
   <candidate plan 1>,
   ...
]
```

Stage-ek

- *COLLSCAN*
- *IXSCAN*
- *FETCH*
- *…*