Optimize Query Performance in Azure SQL

Introduction to Query Store, Execution Plans, Indexes, and Query Tuning

Objectives

- Analyze query plans and identify problem areas
- Evaluate potential query improvements
- Review table and index design
- Determine whether query or design changes have had a positive effect

Explore Query Performance Optimization

Objectives

- Generate and save execution plans
- Compare the different types of execution plans
- Understand how and why query plans are generated
- Understand the purpose and benefits of the Query Store

What are execution plans?

Every time you execute a query, the query optimizer uses a path of operations to process your query and retrieve any results.

The optimizer also collects statistics about the operation and execution of this plan.

How are query plans generated?

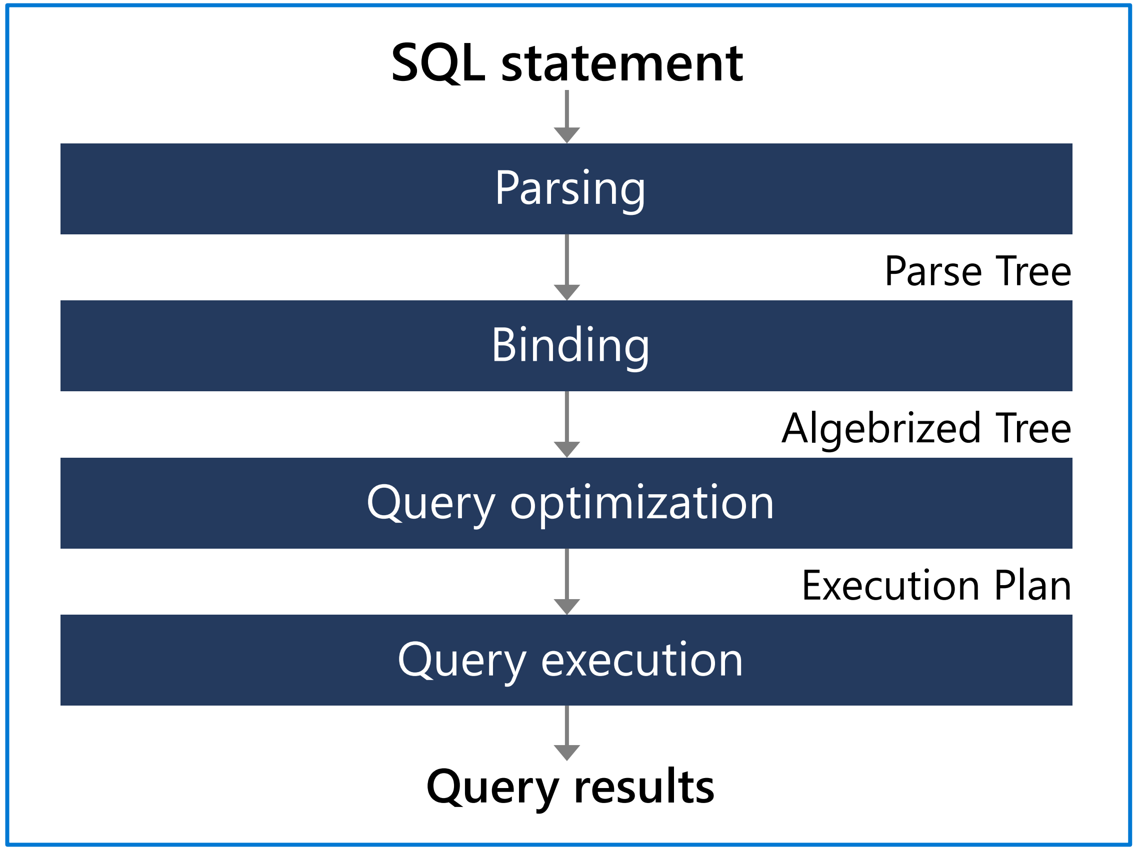
The first time you run a given query, the optimizer generates several plans and chooses the one with the lowest overall cost.

The Query Optimizer

The Query Optimizer takes a query and returns a query plan

Will attempt several plans to choose the 'best guess'

Generating a plan has a high CPU cost, so SQL Server® caches plans



Types of execution plans

Estimated execution plans

The path the database engine plans to take to retrieve the data to answer your query

Actual execution plans

The estimated execution plan, but also including actual statistics from the execution of the query

Live query statistics

An animated view of query execution showing progress and order of operations

More about actual vs. estimated execution plans

Actual execution plans

vs.

Estimated execution plans

The plans shape will nearly always be the same

The actual execution plan will have additional information about row counts and runtime stats

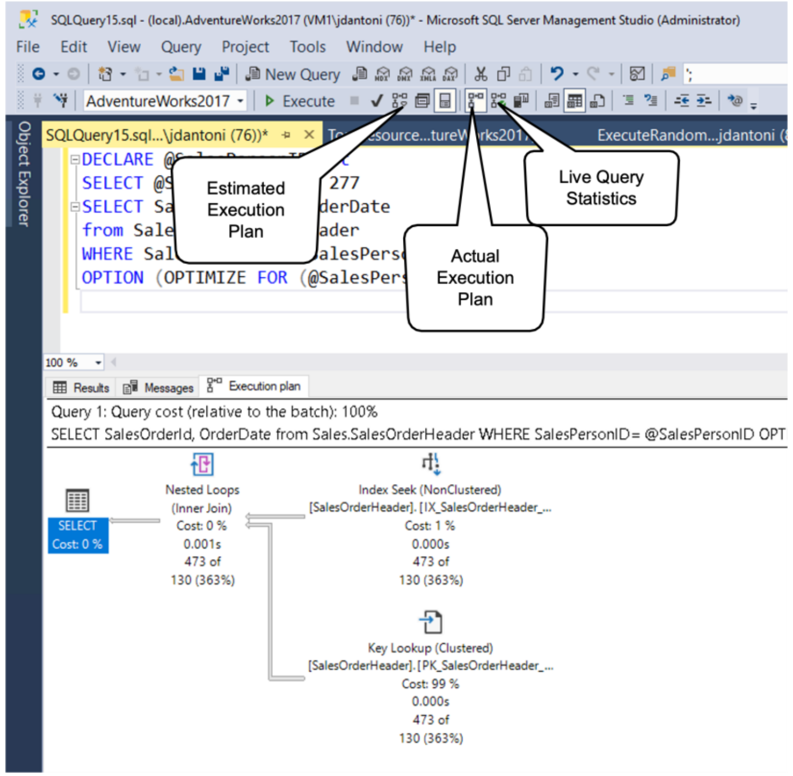
The actual execution traditionally has **significant overhead** to capture

Capturing plans in Management Studio

SQL Server Management Studio allows you to capture both estimated and actual execution plans, and Live Query Statistics

Plan capture can also be enabled by keyboard commands

You can capture a text query plan by using the SET SHOWPLAN ON option



Lightweight query profiling

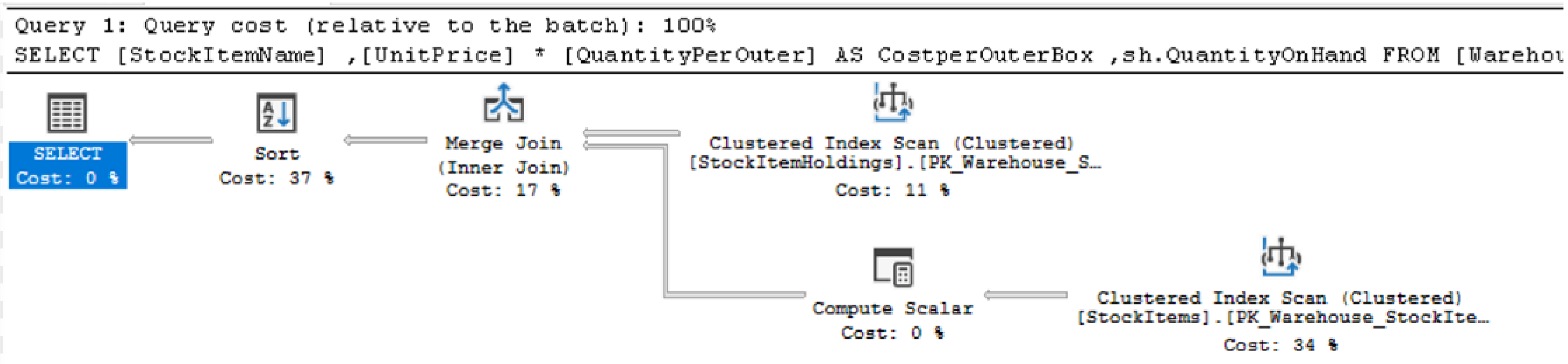
- Supported by Azure SQL Database
- Required trace flag 7412 to be enabled globally, prior to SQL Server 2019
- Newer releases allow it to be enabled at the query level
- Provides additional statistics to help close gap to actual execution plan data

How to read an execution plan

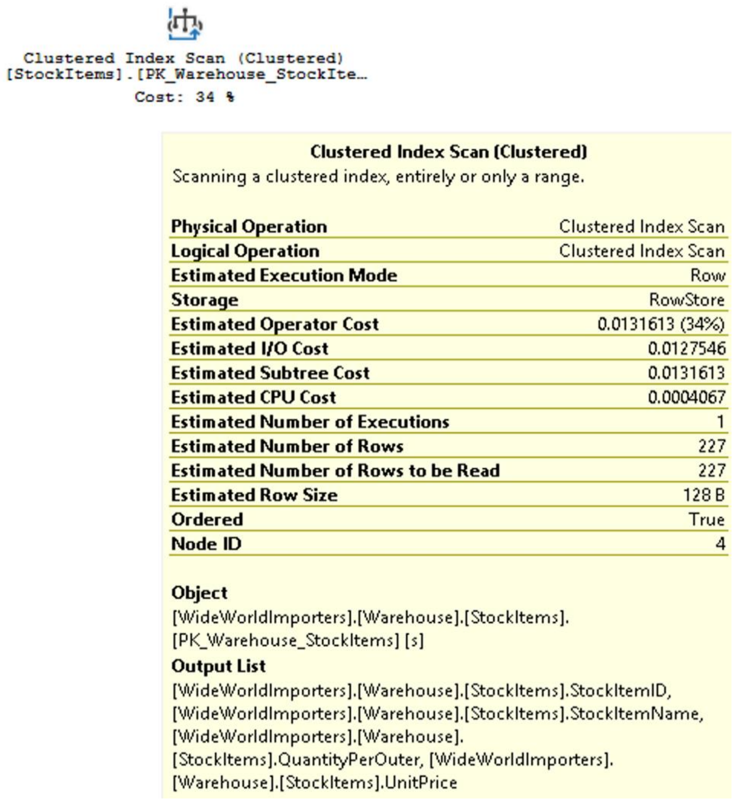
- Plans should be read from right to left and top to bottom
- The **size** of the arrows connecting the objects is representative of the amount of data flowing to the next operator
- Each operator contains a lot of metadata in its properties and tool tip. This is where you can learn how the decisions were made
- All operators are assigned a cost
- Even operators that have a 0% cost have some degree of cost—nothing is free in SQL Server query execution

Example: SQL query with a JOIN clause

```
SELECT   [stockItemName],
         [UnitPrice] * [QuantityPerOuter] AS CostPerOuterBox,
         [QuantityonHand]
FROM [Warehouse].[StockItems] s
         JOIN [Warehouse].[StockItemHoldings] sh ON s.StockItemID = sh.StockItemID
ORDER BY CostPerOuterBox;
```



Tool tips and properties



Clustered Index Scan (Clustered)
[StockItems].[PK_Warehouse_StockIte…
Cost: 34 %

Clustered Index Scan (Clustered)

Scanning a clustered index, entirely or only a range.

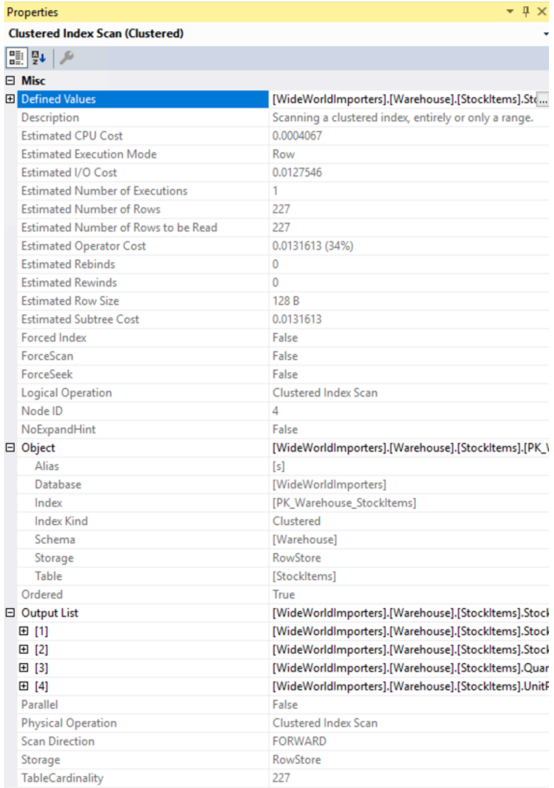
Physical Operation	Clustered Index Scan
Logical Operation	Clustered Index Scan
Estimated Execution Mode	Row
Storage	RowStore
Estimated Operator Cost	0.0131613 (34%)
Estimated I/O Cost	0.0127546
Estimated Subtree Cost	0.0131613
Estimated CPU Cost	0.0004067
Estimated Number of Executions	1
Estimated Number of Rows	227
Estimated Number of Rows to be Read	227
Estimated Row Size	128 B
Ordered	True
Node ID	4

Object

[WideWorldImporters].[Warehouse].[StockItems].[PK_Warehouse_StockItems] [s]

Output List

[WideWorldImporters].[Warehouse].[StockItems].StockItemID, [WideWorldImporters].[Warehouse].[StockItems].StockItemName, [WideWorldImporters].[Warehouse].[StockItems].QuantityPerOuter, [WideWorldImporters].[Warehouse].[StockItems].UnitPrice



Properties

Clustered Index Scan (Clustered)

Misc	
Defined Values	[WideWorldImporters].[Warehouse].[StockItems].St…
Description	Scanning a clustered index, entirely or only a range.
Estimated CPU Cost	0.0004067
Estimated Execution Mode	Row
Estimated I/O Cost	0.0127546
Estimated Number of Executions	1
Estimated Number of Rows	227
Estimated Number of Rows to be Read	227
Estimated Operator Cost	0.0131613 (34%)
Estimated Rebinds	0
Estimated Rewinds	0
Estimated Row Size	128 B
Estimated Subtree Cost	0.0131613
Forced Index	False
ForceScan	False
ForceSeek	False
Logical Operation	Clustered Index Scan
Node ID	4
NoExpandHint	False
Object	[WideWorldImporters].[Warehouse].[StockItems].[PK_\
Alias	[s]
Database	[WideWorldImporters]
Index	[PK_Warehouse_StockItems]
Index Kind	Clustered
Schema	[Warehouse]
Storage	RowStore
Table	[StockItems]
Ordered	True
Output List	[WideWorldImporters].[Warehouse].[StockItems].Stock
[1]	[WideWorldImporters].[Warehouse].[StockItems].Stock
[2]	[WideWorldImporters].[Warehouse].[StockItems].Stock
[3]	[WideWorldImporters].[Warehouse].[StockItems].Quar
[4]	[WideWorldImporters].[Warehouse].[StockItems].UnitF
Parallel	False
Physical Operation	Clustered Index Scan
Scan Direction	FORWARD
Storage	RowStore
TableCardinality	227

Common plan operators: Finding data

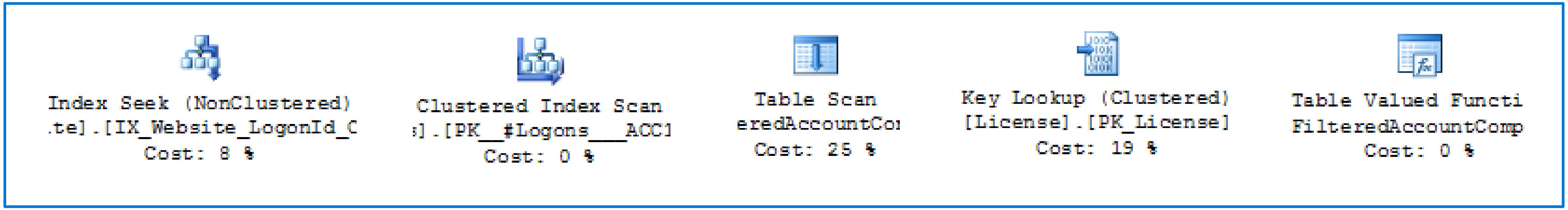
Index Seek
Reads the portion of the index which contains the needed data

Index Scan
Reads the entire index for the needed data

Table Scan
Reads the entire table for the needed data

Key Lookup
Looks up values row by row for values which are missing from the index used

Table Valued Function
Executes a table valued function within the database



Common plan operators: Filtering & sorting

Nested Loops

Performs inner, outer, semi and anti semi joins. Performs search on the inner table for each row of the outer table

Hash Match

Creates a hash for required columns for each row. Then creates a hash for second table and finds matches

TOP

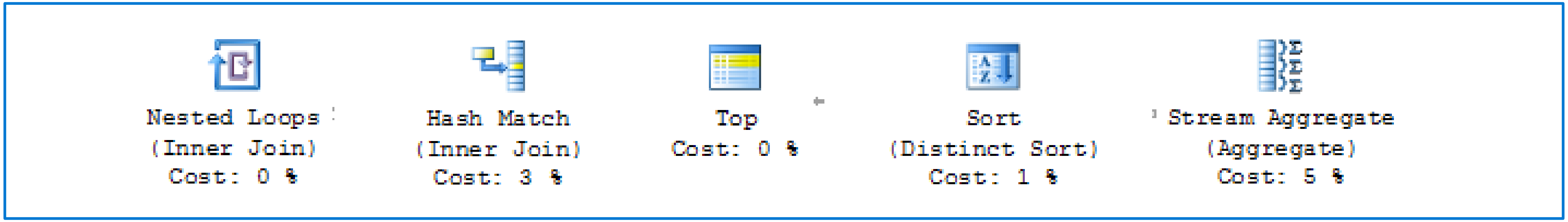
Returns the specified top number of rows

Sort

Sorts the incoming rows

Stream Aggregate

Groups rows by one or more columns and calculates one or more aggregate expressions



Dynamic management objects

- Dynamic Manage Views and Functions supply data about database performance and state
- These objects may be scoped at the database or server level
- Azure SQL Database has some of its own DMVs to provide Azure specific data at the database level
- All objects are in the sys schema and following the naming convention *sys.dm_**

Query Store

Introduced in SQL Server 2016, this data collection tool tracks query execution plans and runtime statistics

- Can help you quickly identity queries that have regressed in performance
- Allows you to easily identity the most expensive queries in your database
- Available in Azure SQL Database and Azure SQL Managed Instances
- A version of the Query Store is available in Azure Database for MySQL and Azure Database for PostgreSQL

Query Store cont'd

Common scenarios

- Detecting regressed queries
- Determining the number of times a query was executed in a given time window
- Comparing the average execution time of a query across time windows to see large deltas

Enabled by default for new Azure SQL Database databases, not enabled for

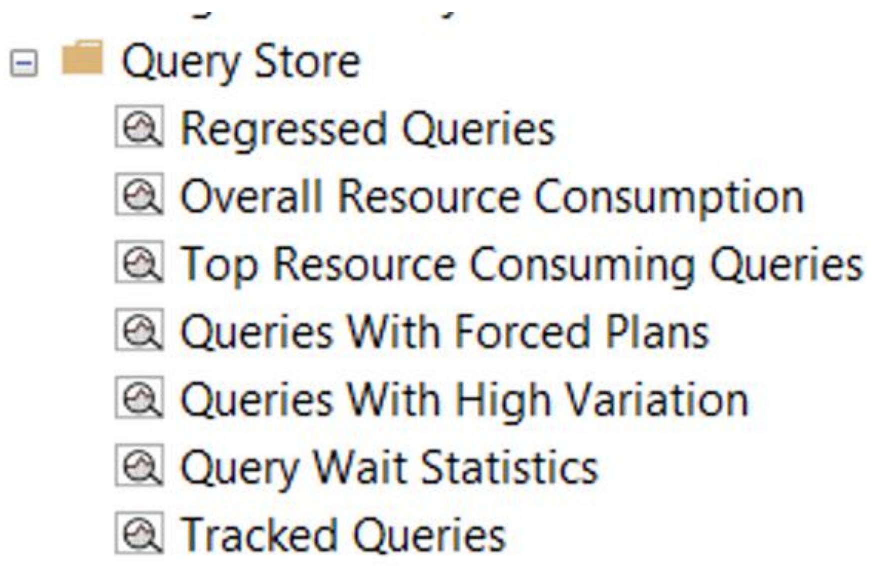
```
ALTER DATABASE <dbname> SET QUERY_STORE = ON (OPERATION_MODE = READ_WRITE);
```

Query Store reports

The Query Store includes several reports built into SQL Server Management Studio

These reports can be filtered by a range of time, allowing you to identity performance issues that happened in the past

These reports can also help you identity a problematic change in execution plans leading to a performance regression



Performance overhead of Query Store

- Any monitoring system has some degree of observer overhead to capture data
- The query store has been developed with performance in mind and has relatively low overheard
- The query store allows adjusting of collection parameters to reduce data collection on particularly busy systems

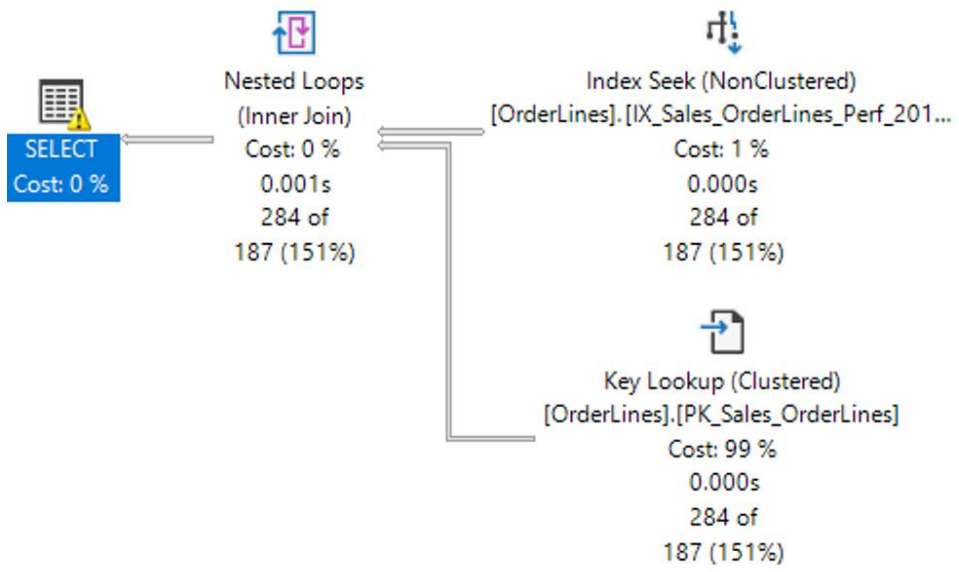
Plan forcing in the Query Store

- This feature allows you to force the database engine to use a specific execution plan for a given query
- Plan forcing is typically used as a temporary fix for a sudden query plan regression
- The full fix is to fix the query and/or indexes to ensure plan stability
- The Automatic Tuning feature in Azure SQL uses this feature

Identifying problematic execution plans

This query has a few problems:

- There is a warning that can be identified by the yellow triangle on the SELECT operation
- There is also an expensive Key Lookup that is using 99.6% of the query's execution cost



SARGarbility

This is a term that refers to a Search Arguable query predicate that can use an index to improve the performance of a query

Predicates that are not SARGs include some of the following examples:

WHERE LastName LIKE '%SMITH%'

WHERE CONVERT(CHAR(10), CreateDate,121) = '2020-03-22'

- **Functions can influence the SARGability of predicates, so you should be careful with their use**

Missing indexes

- SQL Server includes missing index warnings in execution plans
- Look for queries that may **scan a clustered index** to return a **small** amount of records from a **large table**
- SQL Server stores missing index information and index utilization information in the database (***sys.dm_db_missing_index_details***)
- Indexes can **impact write** performance and **consume space**, yet the performance gains offset the additional resource costs many times over
- Drop an index that is not used by any queries in the database

Hardware constraints

- Typically manifested through **wait statistics**
- SOS_SCHEDULER_YIELD and CXPACKET wait types can be associated with **CPU pressure**, but can also point to **improper parallelism** settings or **missing indexes**
- PAGEIOLATCH_* wait types can be indicative of **storage performance issues**
- Detect CPU contention with '% Processor Time'
- SQL Server will write to its error log if disk I/O takes longer than 15 seconds to complete
- Storage system performance is best tracked at the operating system level with **'Disk Seconds/Read'** and **'Disk Seconds/Write'**

Statistics

- Having up to date column and index statistics allows for the query optimizer to make the **best possible execution plan decisions**
- SQL Server, Azure SQL Database and Managed Instance **default** to auto-updating statistics
- In some cases, you may want to update statistics **more frequently** to ensure consistent performance for your queries
- Use ***sys.dm_db_stats_properties*** to see the last time statistics were updated and the number of modifications that have been made since the last update
- **Auto-update** statistics uses a dynamic percentage, which as the table grows, the percentage of row modifications that was required to trigger a statistics update gets smaller

Blocking and locking in SQL Server

Databases lock records and block other transactions as part of their normal behavior and their consistency model

SQL Server uses a process called lock escalation to reduce the impact of these locks, taking low level locks and only escalating as needed

Blocking activity can be problematic in two main scenarios:

- Poor transaction handling in application code (leaving transactions open for too long)
- Transactions taking too long to complete because of poor indexing or external operations like linked server queries

Isolation levels

SQL Server offers multiple isolation levels to allow for a balance of concurrency and data quality

Isolation levels are specified at the session level, but may be overridden by the query

Lower isolation like **Read Uncommitted** may allow for more users to read the data, but increase the chance that the queries return incorrect results

Monitoring for blocking problems

The *Sys.dm_tran_locks* DMV contains all active locks, and can be joined with the *sys.dm_exec_requests* in order to provide statements holding locks

Querying DMVs is good for identifying a problem in real-time

For longer term monitoring creating an extended events session to monitor for blocking issues

What is parameter sniffing?

Parameter Sniffing

Default behavior in SQL Server

Optimizer makes decisions based on statistics, using initial parameter values

Reduces recompilations and CPU load

Local variables get standard assumption

Instructor led labs: Identify and resolve blocking issues

Run blocked queries report

Enable Read Commit Snapshot isolation level

Evaluate performance improvements

Explore Performance-based Database Design

Objectives

- Explore normal forms and how they affect database design
- Choose appropriate datatypes for your data
- Evaluate appropriate index types

Normalization (First Normal Form)

Create a separate table for each set of related data

Eliminate repeating groups in individual tables

Identify each set of related data with a primary key

First Normal Form eliminates repeating groups, each row refers to a particular product, and there is a ProductID to be used a primary key

ProductID	ProductName	Price	ProductionCountry	ShortLocation
1	Widget	15.95	United States	US
2	Foop	41.95	United Kingdom	UK
3	Glombit	49.95	United Kingdom	UK
4	Sorfin	99.99	Republic of the Philippines	RepPhil
5	Stem Bolt	29.95	United States	US

Normalization (Second Normal Form)

If a table does not have a composite key, first and second normal form are the same

Same requirements as first normal form, plus..

If the table has a composite key, all attributes must depend on the complete key, not just part of it

ProductID	ProductName	Price	ProductionCountry	ShortLocation
1	Widget	15.95	United States	US
2	Foop	41.95	United Kingdom	UK
3	Glombit	49.95	United Kingdom	UK
4	Sorfin	99.99	Republic of the Philippines	RepPhil
5	Stem Bolt	29.95	United States	US

Normalization (Third Normal Form)

Same requirements as second normal form, plus..

All non-key relationships are non-transitively dependent on the primary key

Most OLTP databases should be in third normal form or as it is commonly abbreviated 3NF

ProductID	ProductName	Price	ProductionCountry	ShortLocation
1	Widget	15.95	United States	US
2	Foop	41.95	United Kingdom	UK
3	Glombit	49.95	United Kingdom	UK
4	Sorfin	99.99	Republic of the Philippines	RepPhil
5	Stem Bolt	29.95	United States	US

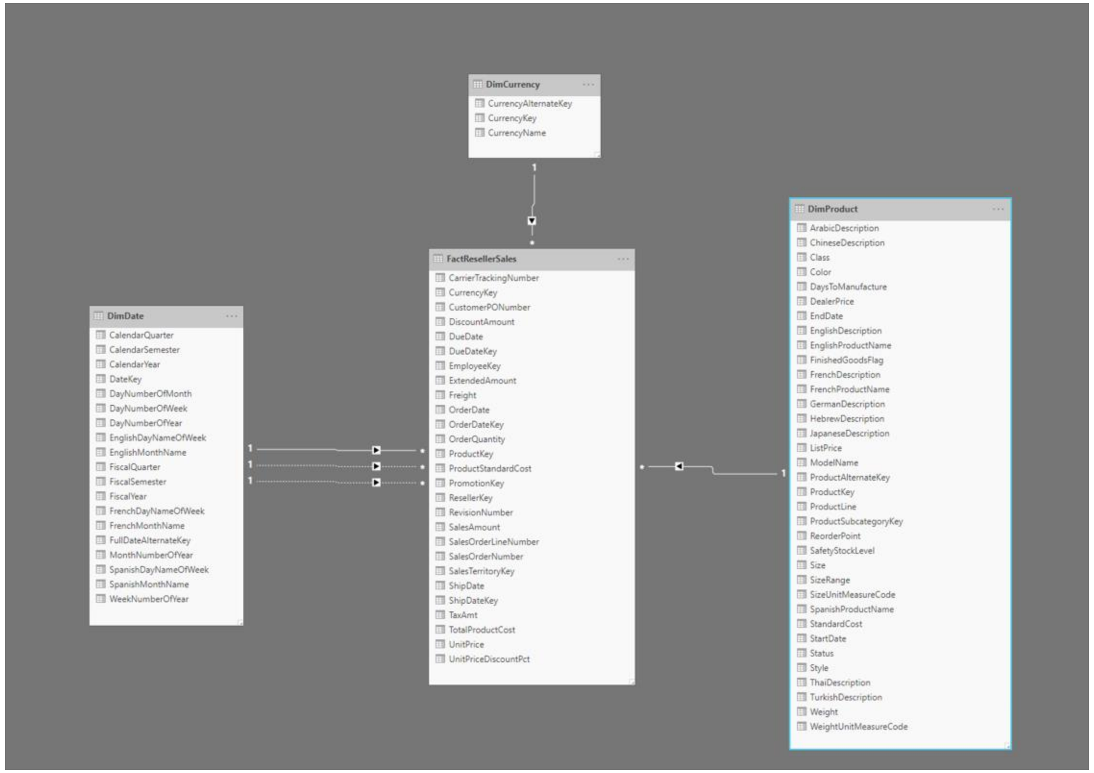
This table is NOT in 3rd normal form because ShortLocation depends on ProductionCountry, and not just on the primary key

Denormalization

Denormalized database designs are commonly used in data warehouses and data mart

This is helpful for reducing the number of joins required for reporting, but is less effective for updates

Two examples of denormalized structures are star (shown below) and snowflake schemas



Understand data types for performance

- Importantly, ensure that the data types in your application code match the data types in your database tables
- Conversions are expensive, and can cause much more expensive execution plans
- In general, smaller data types are better where possible
- Data compression can help with this

Unicode data

Normal data types use **1 byte** per character

The problem with this is that the data type can only represent about **256 characters**

Unicode types use 2 bytes per character and can support up to **65,536 patterns**

Unicode data is needed for Cyrillic languages, Asian languages and many symbols

Types of indexes

- Clustered Indexes
- Nonclustered Indexes
- Columnstore Indexes
- Rowstore Indexes

Designing indexes

- Cluster key values can help minimize page splits and improve data locality and help to decrease disk seek time
- Clustered Indexes should be as narrow (minimal columns) as possible
- In nonclustered index keys, the most selective column should be the leftmost column in the key
- Use included columns in your nonclustered indexes where possible, to keep keys narrower
- You should not create redundant indexes and avoid creating unused indexes on your tables

Clustered indexes

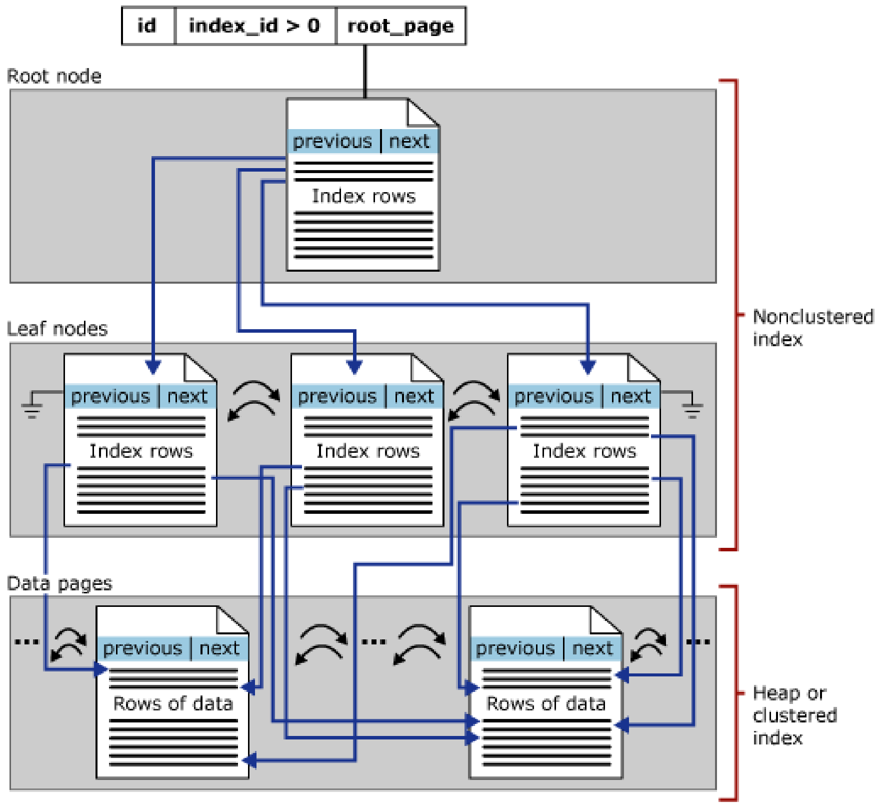
- A clustered index sorts and stores the data in a table based on key values
- There can only be one clustered index per table, since rows can only be stored in one order
- Clustered indexes are frequently the primary key for a table
- Clustered indexes have no uniqueness requirement

What are nonclustered indexes?

- **Nonclustered indexes** are secondary indexes used to help the performance of queries not served by the clustered index
- You can create multiple nonclustered indexes on a table
- You can also create filtered indexes, for tables with large data skew
- The cost of nonclustered indexes is space and data modification operations

Nonclustered indexes

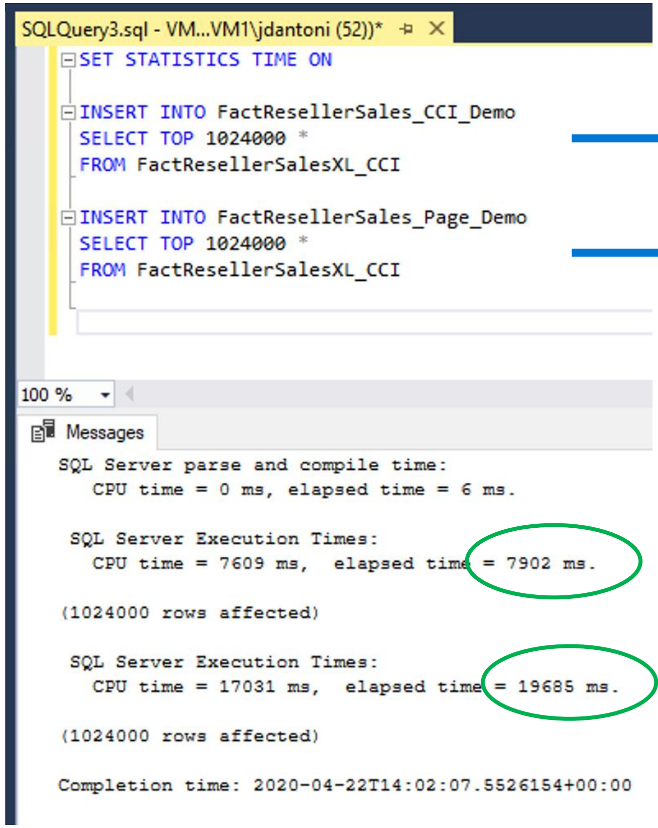
- Each page in an index b-tree is a called an index node, and the top node of b-tree is called the root node.
- The bottom nodes in an index are called leaf nodes and the collection of leaf nodes is the leaf level.



Columnstore indexes

- Data is stored in columns, not rows
- This allows for higher levels of compression, which reduces storage and memory footprint of data
- Columns that are not referenced in a query are not scanned, giving reducing the amount of I/O needed
- Best used in large tables (e.g., data warehouse fact tables, temporal history tables)
- Clustered columnstore must include all columns of the table
- Use **clustered columnstore index** for fact tables and large dimension tables for DW workloads. Use **nonclustered columnstore index** to perform analysis in real time on an OLTP workloads

Columnstore indexes – data load performance comparison



Clustered columnstore index

Clustered index with page compression

8 secs

20 secs

Instructor led labs: Identify database design issues

Examine the query and identify the problem

Identify ways to fix the warning message

Improve the code

Evaluate Performance Improvements

Objectives

- Describe wait statistics
- Understand important aspects when tuning indexes
- Explore when to use query hints

Wait statistics

- Analysis of wait statistics is a holistic method of evaluating server performance
- The database engine tracks what each thread is waiting on
- This wait data is logged into memory and then persisted to disks
- This can be helpful to isolate hardware, code, and configuration problems
- Stored in *sys.dm_os_waits_stats* and in *sys.dm_db_wait_stats* in Azure SQL Database

Examples of wait statistics

High **RESOURCE_ SEMAPHORE** waits	This is indicative of **queries waiting on memory to become available**, and may indicate excessive memory grants to some queries
High **LCK_M_X** waits	This can indicate a **blocking problem** that can be solved by either changing to the READ COMMITTED SNAPSHOT isolation level, or making changes in indexing to reduce transaction times, or possibly better transaction management within T-SQL code
High **PAGEIOLATCH_ SH** waits	This can indicate a **problem with indexes**, where SQL Server is scanning too much data, or if the wait count is low, but the wait time is high, can indicate storage performance problems
High **SOS_ SCHEDULER_YIELD** waits	This can indicate **high CPU utilization** - very high workloads, or missing indexes

Demo: Query wait statistics

Querying sys.dm_os_wait_stats

Reviewing Query Store Wait report

Index tuning methodology

1. Identify expensive queries, using the Query Store or Extended Events profiling
2. Examine the query plans for those queries
3. Test changes to indexes to evaluate improvements in I/O and elapsed time
4. Implement changes in production

Index tuning

The goal is faster queries using the fewest indexes and IOs

Common tuning approach:

- Evaluate existing index usage - *sys.dm_db_index_operational_stats* and *sys.dm_db_index_usage_stats*
- Eliminate unused and duplicate indexes
- Review and evaluate expensive queries from the Query Store or Extended Events and refactor where appropriate
- Create the index(s) in a non-production environment and test query execution and performance
- Deploy the changes to production

Index maintenance

Over time, inserts, updates and deletes can cause fragmentation in an index

- Fragmentation causes the data to occupy more pages than it otherwise would
- Fragmentation can cause query performance degradation
- Indexes should be regularly **reorganized** or **rebuilt**
- SQL Server and Azure SQL Database allow for indexes to rebuilt **online**
- Newer versions of SQL Server allow **resumable** index operations
- Stored in the DMV *Sys.dm_db_index_physical_stats*

Index maintenance

Reorganization

- Defragments an index by physically reordering the leaf-level index pages to match the logical sorted order of the leaf nodes
- Compacts the index pages based on the index's fill factor setting
- It is an online process

Rebuilding

- Drops and recreates the pages of the index
- Causes the statistics to be updated
- Use when fragmentation is greater than 30%
- It can be either online or offline

Columnstore index maintenance

Columnstore indexes also require maintenance due to fragmentation

- If 20% or more of the rows are deleted, you should consider **reorganizing** your index
- Fragmentation is caused when deletes and updates happen as they both leave deleted rows in the columnstore index
- These deleted records are not included in query results, but are scanned in each query
- Fragmentation is measured by looking for deleted rows in the *sys.dm_dm_colum_store_row_group_physical_stats* DMV

Query hints

Query hints specify that the indicated behavior should be used throughout the query

They affect all the operators in the query

Some common use cases for query hints include:

- Limit the amount of memory granted to query
- Force the use of a specific index
- Control join behavior

Instructor led labs: Isolate problem areas in poorly performing queries in a SQL Database

Generate actual execution plan

Resolve a suboptimal query plan

Use Query Store to detect and handle regression

Examine Top Resource Consuming Queries report

Force a better execution plan

Use query hints to impact performance

Summary

Explore query performance optimization:

- Understand how plans are generated
- Understand query plan warnings and guidance
- Explore the Query Store
- Types of query execution plans

Explore performance-based database design:

- Learn the concepts of database normalization
- Choosing the proper data types for your database
- Understand the types of indexes in SQL Server

Evaluating performance improvements:

- Capturing data from dynamic management views and functions
- Understand wait statistics
- Understand index and statistics maintenance