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Advanced T-SQL Querying and Query Tuning

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Learning Pathway: Query Tuning

- Identify Poorly Performing Queries - Three Tools You Already Own
  - Grant Fritchey / level 100 / Wednesday Nov 10, 15:15 UTC
- Here's the Execution Plan … Now What?
  - Hugo Kornelis / level 200 / Wednesday Nov 10, 16:45 UTC
- Indexing for Performance
  - Kimberly Tripp / level 200 / Wednesday Nov 10, 21:15 UTC
- Demystifying Statistics in SQL Server
  - Erin Stellato / Level 200 / Thursday Nov 11, 14:30 UTC
- Query Tuning Tips Concerning Table Expressions
  - Itzik Ben-Gan / Level 300 / Thursday Nov 11, 16:45 UTC
- Tackling Monster Stored Procs
  - Allen White / Level 200 / Thursday Nov 11, 19:00 UTC

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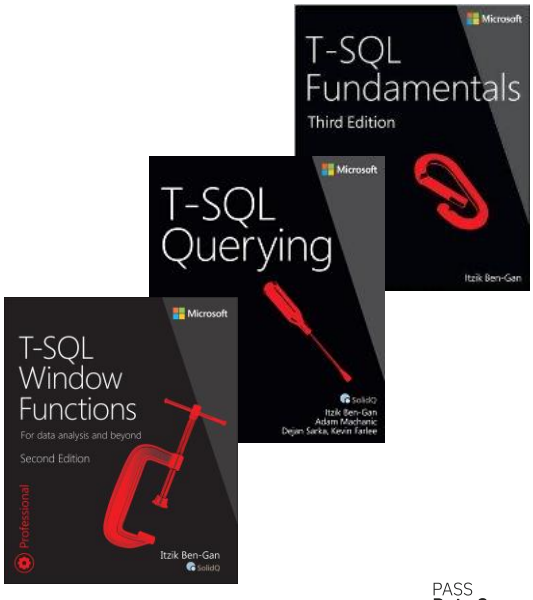

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sqlperformance.com/author/itzikbengan

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Agenda

- Search arguments
- Join ordering optimization
- Adaptive / Intelligent QP
  - Batch-mode processing and batch mode on rowstore
  - Adaptive joins
  - Interleaved execution and table variable deferred compilation
  - Scalar UDF inlining
  - Memory grant feedback
- APPLY
- Window functions
- OFFSET-FETCH

Search argument (SARG)

- SARG: filter predicate that enables the optimizer to rely on index order
  - No manipulation of filtered column (OK to manipulate other side)
  - Operator represents a consecutive range of keys
- Careful with NULLs!

```sql
-- Not SARG
SELECT orderid, shippeddate
FROM Sales.Orders
WHERE YEAR(shippeddate) = 2018;

-- SARG
SELECT orderid, shippeddate
FROM Sales.Orders
WHERE shippeddate >= '20180101'
  AND shippeddate < '20190101';
```

```sql
-- SARG, incorrect
SELECT orderid, shippeddate FROM Sales.Orders
WHERE shippeddate = @dt;

-- Correct, not SARG
SELECT orderid, shippeddate FROM Sales.Orders
WHERE ISNULL(shippeddate, '99991231') = ISNULL(@dt, '99991231');

-- Correct, ugly SARG
SELECT orderid, shippeddate FROM Sales.Orders
WHERE shippeddate = @dt
   OR (shippeddate IS NULL AND @dt IS NULL);

-- Correct, elegant SARG
SELECT orderid, shippeddate FROM Sales.Orders
WHERE EXISTS(SELECT shippeddate INTERSECT SELECT @dt);
```


Join ordering optimization

- Joins are commutative (A J B = B J A) and associative (A J B) J C = A J (B J C)
- Optimizer explores candidate plans with different orders
  - Limited transformations with outer joins: A LJ B = B RJ A
  - More flexibility with inner and cross joins; theoretically (2N - 2)!/(N - 1)! permutations
  - To reduce exploration space, certain layouts not considered by default, e.g., bushy
- Use FORCE ORDER query hint or SET FORCEPLAN option for troubleshooting

```sql
SELECT DISTINCT C.companyname AS customer,
  S.companyname AS supplier
FROM Sales.Customers AS C
  INNER JOIN Sales.Orders AS O
    ON O.custid = C.custid
  INNER JOIN Sales.OrderDetails AS OD
    ON OD.orderid = O.orderid
  INNER JOIN Production.Products AS P
    ON P.productid = OD.productid
  INNER JOIN Production.Suppliers AS S
    ON S.supplierid = P.supplierid
OPTION (FORCE ORDER);
```

Join ordering optimization

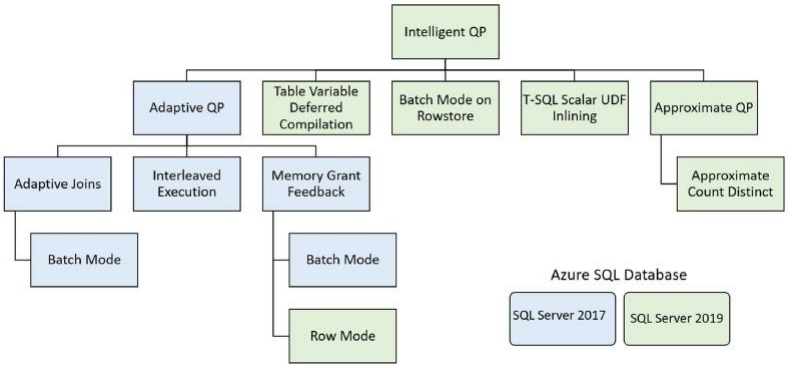
- ON-clause order defines logical join ordering (and physical w/FORCE ORDER)
- For query to be valid ON clause must appear below two units being joined

```
-- Join O with OD first, then C with result
-- Use as physical order
SELECT DISTINCT C.companyname AS customer,
  S.companyname AS supplier
FROM Sales.Customers AS C
  INNER JOIN
    ( Sales.Orders AS O
        INNER JOIN Sales.OrderDetails AS OD
          ON OD.orderid = O.orderid )
      ON O.custid = C.custid
  INNER JOIN Production.Products AS P
    ON P.productid = OD.productid
  INNER JOIN Production.Suppliers AS S
    ON S.supplierid = P.supplierid
OPTION (FORCE ORDER);
```

```
-- Include customers with no matches
SELECT DISTINCT C.companyname AS customer,
  S.companyname AS supplier
FROM Sales.Customers AS C
  LEFT OUTER JOIN
    ( Sales.Orders AS O
        INNER JOIN Sales.OrderDetails AS OD
          ON OD.orderid = O.orderid
        INNER JOIN Production.Products AS P
          ON P.productid = OD.productid
        INNER JOIN Production.Suppliers AS S
          ON S.supplierid = P.supplierid )
      ON O.custid = C.custid;
```


Adaptive / Intelligent QP

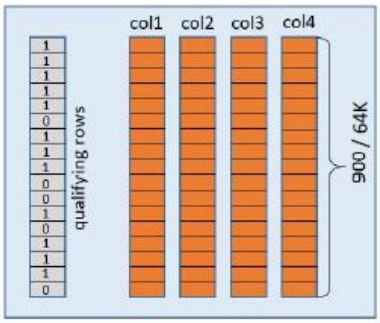
- SQL Server 2017 introduces adaptive query processing capabilities
- SQL Server 2019 enhances those to broader intelligent QP capabilities



Batch-mode processing and batch mode on rowstore

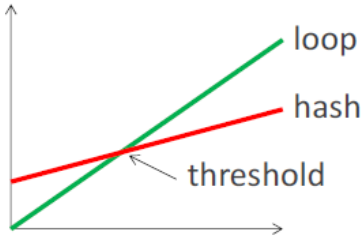
- Row mode: operator iterates once per row, metadata evaluated per row
- Batch mode: batch has vectorized representation of relevant columns, size 64KB/64-900 rows; operator iterates and evaluates metadata once per batch
- Considered automatically when columnstore indexes are present, even if not used
- Considered on rowstore starting with SQL Server 2019 Enterprise Edition under certain conditions (see queryprocessor.com/batch-mode-on-row-store)
- Backdoor: create dummy filtered columnstore index

```
CREATE NONCLUSTERED COLUMNSTORE INDEX idx_cs
  ON dbo.Orders(orderid)
  WHERE orderid = -1 AND orderid = -2;
```



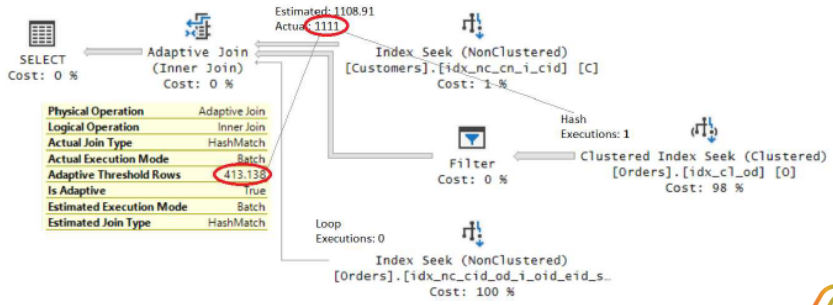
Adaptive joins

- Introduced in SQL Server 2017
- Supports both hash and loop joins, choice which to execute at run time based on threshold
- Same outer input
- One inner input for hash (middle branch)
- Another inner input for loop (bottom branch)
- >= threshold – hash, < threshold – loop
- Initially supported only in batch mode; can use dummy filtered columnstoreindex backdoor to enable



Adaptive joins

```
SELECT C.custid, C.custname,
  O.orderid, O.empid, O.shipperid, O.orderdate
FROM dbo.Customers AS C
  INNER JOIN dbo.Orders AS O
    ON O.custid = C.custid
WHERE C.custname LIKE @custprefix + N'%'
  AND O.orderdate BETWEEN @fromdate AND @todate;
```

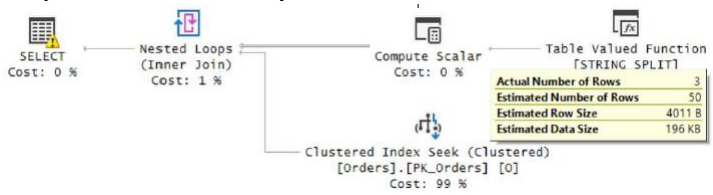


String splitting with the STRING_SPLIT function

- Introduced in SQL Server 2016

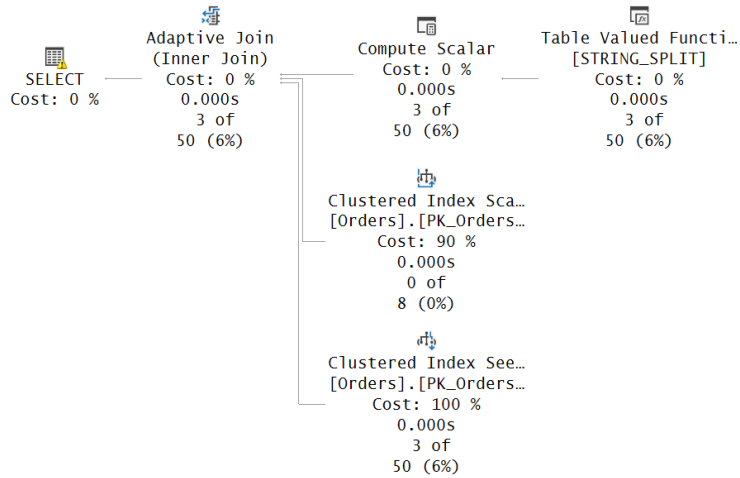
```
CREATE OR ALTER PROC dbo.GetOrders(@orderids AS VARCHAR(8000))
AS
SELECT O.orderid, O.orderdate, O.custid, O.empid
FROM Sales.Orders AS O
  INNER JOIN STRING_SPLIT(@orderids, ',') AS K
    ON O.orderid = CAST(K.value AS INT);
GO

EXEC dbo.GetOrders @orderids = '10248,10249,10250';
```

- Note: cardinality estimate always fixed 50



Adaptive join solves fixed cardinality issue

```
CREATE NONCLUSTERED COLUMNSTORE INDEX idx_dontworrybehappy
  ON Sales.Orders(orderid)
  WHERE orderid = -1 AND orderid = -2;
```



Interleaved execution

- Introduced in SQL Server 2017
- Used with queries involving multi-statement TVFs
- Initially optimize only until node representing table variable
- Once have actual number of rows, optimize remaining plan

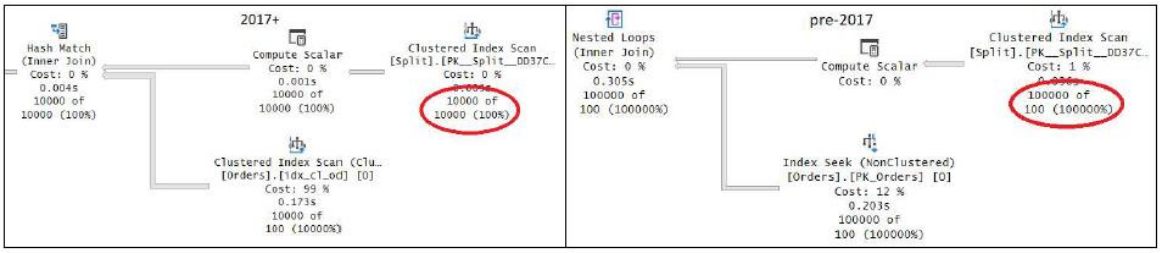
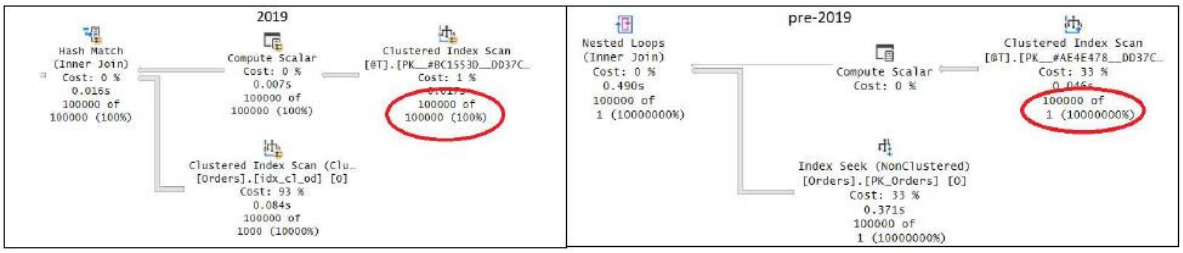


Table variable deferred compilation

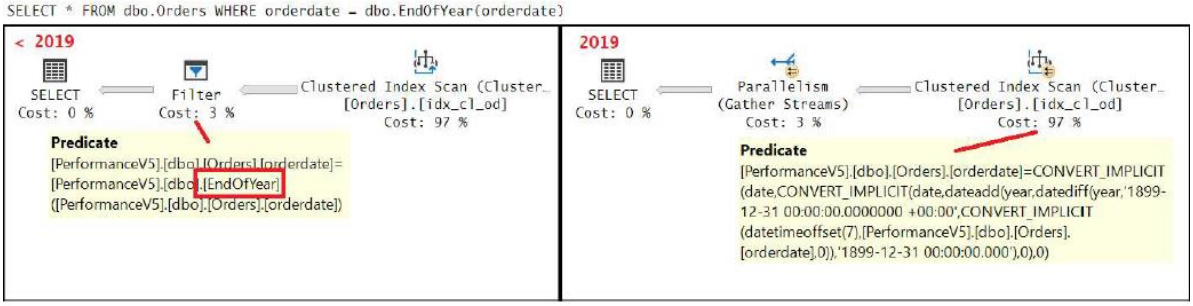
- Introduced in SQL Server 2019
- Similar to interleaved execution, but with regular table variables



Scalar UDF inlining

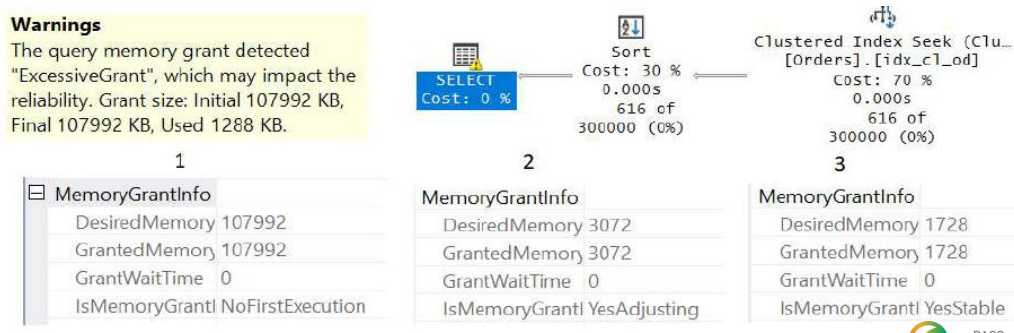
- Pre-2019 scalar UDFs did not get inlined and were a parallelism inhibitor
- SQL Server 2019 introduces scalar UDF inlining under certain conditions https://docs.microsoft.com/en-us/sql/relational-databases/user-defined-functions/scalar-udf-inlining
- Not just for RETURN <single expression>, also DECLARE, SET, IF get converted into relational counterparts such as CASE

```
SELECT * FROM dbo.Orders WHERE orderdate = dbo.EndOfYear(orderdate)
```



Memory grant feedback

- Memory grant correction over multiple executions for queries with cached plans
- 2017 introduces support for batch mode memory grant feedback
- 2019 adds support for row mode as well



APPLY

- Apply right table expression to each row from left table
- Table expression can have correlations (lateral/correlated join), can be TVF
- Left rows with no matches: discarded by CROSS APPLY, preserved by OUTER APPLY

```
SELECT C.custid, A.orderid, A.orderdate, A.empid
FROM Sales.Customers AS C
  CROSS APPLY ( SELECT TOP (3) orderid, orderdate, empid
                FROM Sales.Orders AS O
                WHERE O.custid = C.custid
                ORDER BY orderdate DESC, orderid DESC ) AS A;
```

Converting scalar UDFs to inline TVFs

- When scalar UDF does not get inlined

```
SELECT *
FROM dbo.Orders
WHERE orderdate = dbo.EndOfYear(orderdate);
```

- Convert to inline TVF if possible, and execute with APPLY

```
SELECT O.*
FROM dbo.Orders AS O
  CROSS APPLY dbo.EndOfYear(orderdate) AS F
WHERE O.orderdate = F.endofyear;
```


Using APPLY to get a seek-based strategy

- Example with MIN/MAX aggregate per group; normally you get a scan

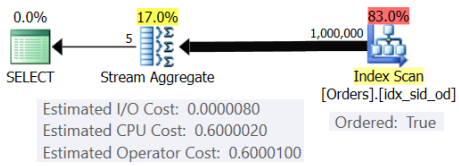
```
SELECT empid, MAX(orderdate) AS maxod
FROM dbo.Orders
GROUP BY empid;
```

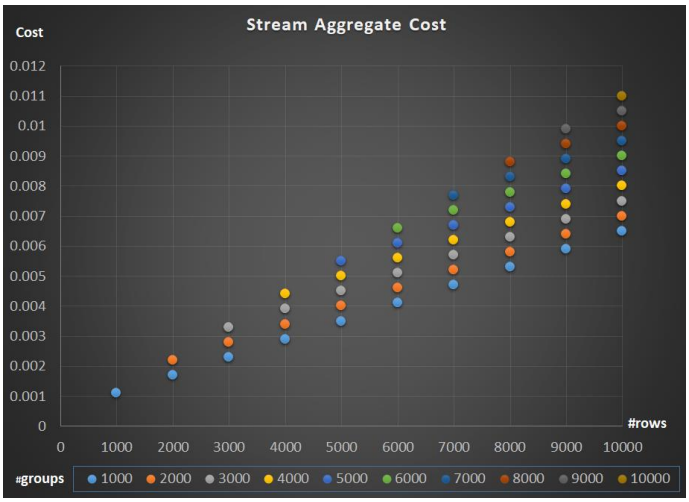
- Normal choices for grouped query:
  - Preordered Stream Aggregate
  - Sort + Stream Aggregate
  - Hash Aggregate

** For details see Optimization Thresholds Parts 1 – 5 at sqlperformance.com/author/itzikbengan*

Preordered Stream Aggregate

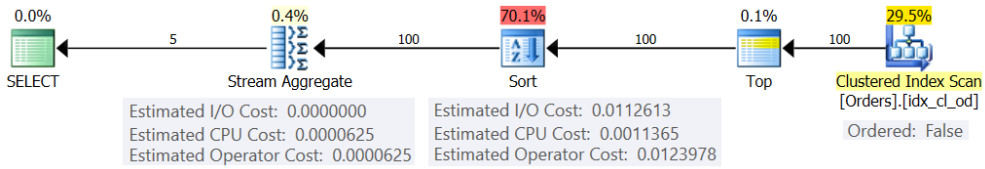
- I/O cost: negligible
- CPU cost:
  #rows * 0.0000006
  + #groups * 0.0000005
- Scaling: linear
- Used when supporting index exists





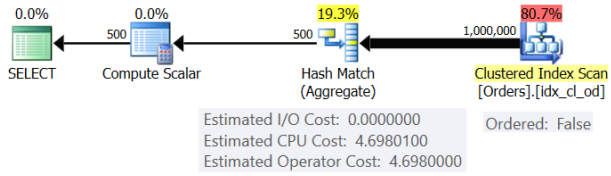
Sort + Stream Aggregate

- Scaling: n log n, negligible startup cost
- Used when:
  - no supporting index
  - small number of rows



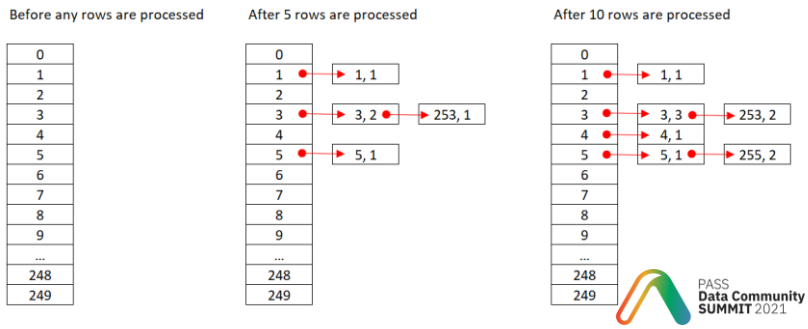
Hash Aggregate

- Scaling: linear, higher startup cost than Sort + SA
- Used when:
  - no supporting index
  - large number of rows

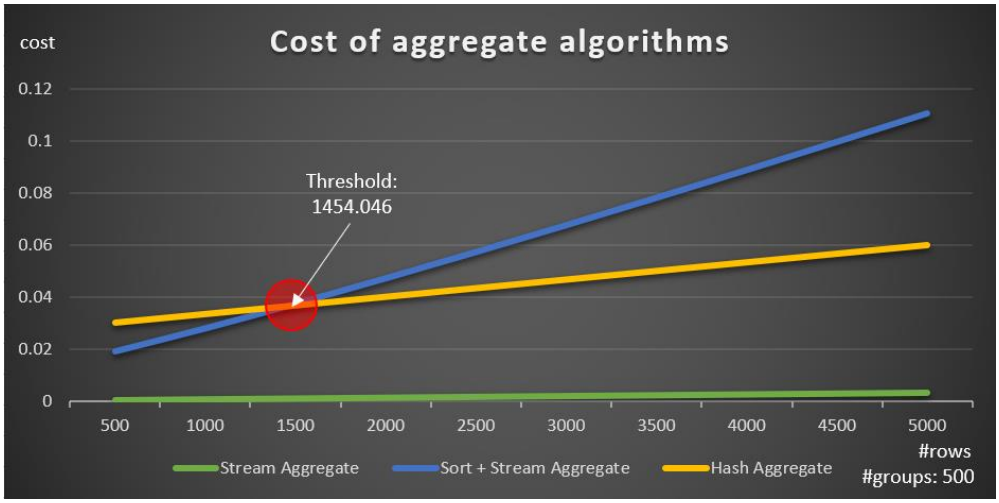


orderid	empid
320	3
30	5
660	253
820	3
850	1
1000	255
700	3
1240	253
350	4
400	255

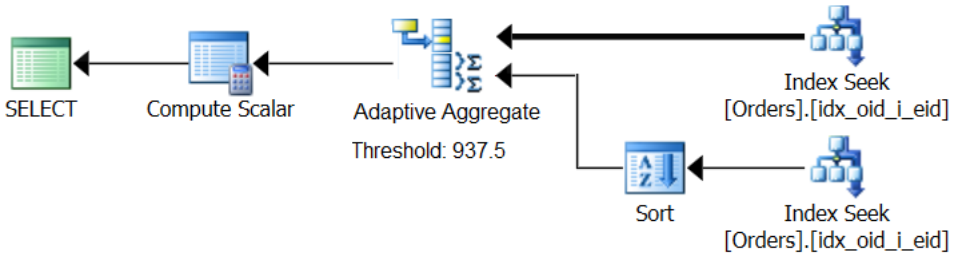
hash function:
empid % 250



Optimization threshold



Potential for Adaptive Aggregate operator

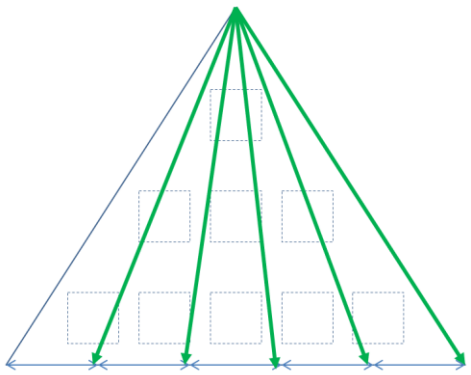


Wishful thinking

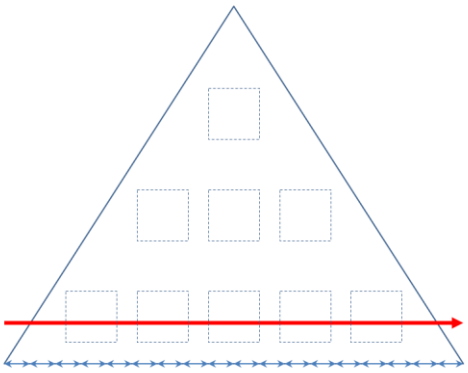
Scan versus seeks in grouped query

- Which is better?

High density: seeks



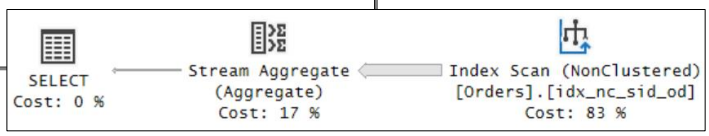
Low density: scan



Scan versus seeks in grouped query

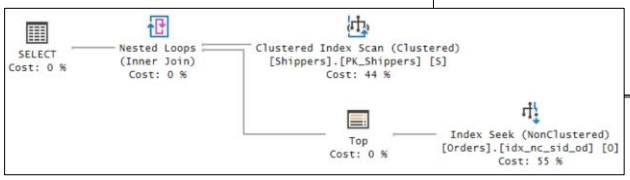
- Grouped query: scan

```
SELECT shipperid, MAX(orderdate) AS maxod
FROM dbo.Orders
GROUP BY shipperid;
```



- APPLY query: seeks

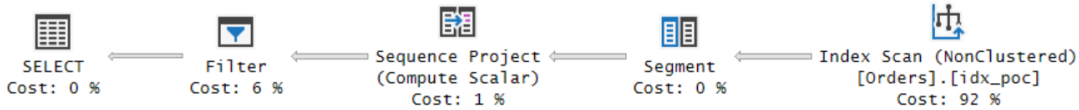
```
SELECT S.shipperid, O.maxod
FROM dbo.Shippers AS S
  CROSS APPLY ( SELECT TOP (1) O.orderdate
                FROM dbo.Orders AS O
                WHERE O.shipperid = S.shipperid
                ORDER BY O.orderdate DESC ) AS O(maxod);
```



Top N per group

- To get a scan use ROW_NUMBER

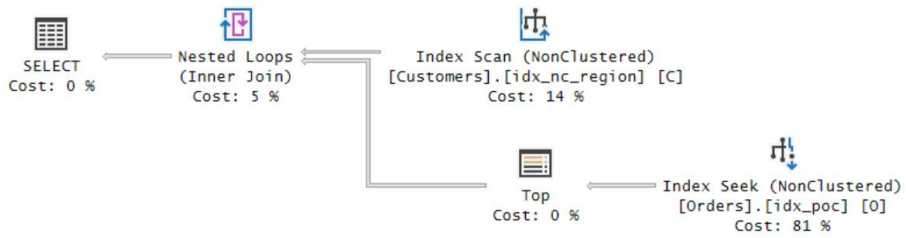
```
WITH C AS
(
  SELECT
    ROW_NUMBER() OVER(
      PARTITION BY custid
      ORDER BY orderdate DESC, orderid DESC) AS rownum,
    orderid, orderdate, custid, empid
  FROM Sales.Orders
)
SELECT custid, orderdate, orderid, empid
FROM C
WHERE rownum <= 3;
```



Top N per group

- To get seeks use APPLY

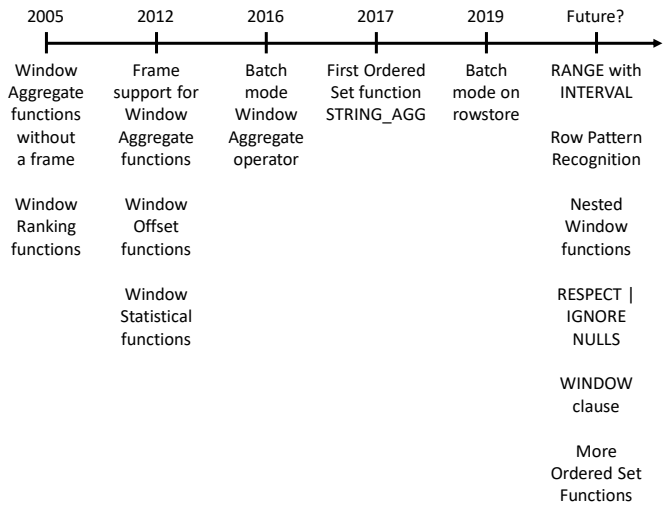
```
SELECT C.custid, A.*
FROM Sales.Customers AS C
  CROSS APPLY ( SELECT TOP (3) orderid, orderdate, empid
                FROM Sales.Orders AS O
                WHERE O.custid = C.custid
                ORDER BY orderdate DESC, orderid DESC ) AS A;
```



Many other uses of APPLY

- Reuse of column aliases
- Aggregate over columns (alternative to GREATEST/LEAST)
- Flexible unpivoting with multiple measures and control over NULLs
- MIN/MAX over partitioned tables
- And many others…

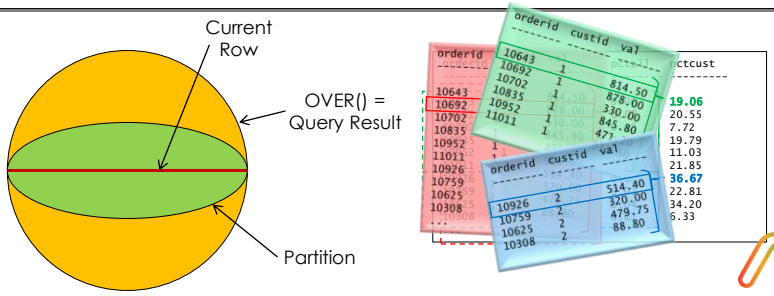
Window functions



Frameless aggregates

- Support optional window partition clause
- Do not involve a window order clause
- Not very optimal under row mode, but very optimal under batch mode

```
SELECT orderid, custid, val,
  CAST(100. * val / SUM(val) OVER()                    AS NUMERIC(5, 2)) AS pctall,
  CAST(100. * val / SUM(val) OVER(PARTITION BY custid) AS NUMERIC(5, 2)) AS pctcust
FROM Sales.OrderValues;
```



Ranking

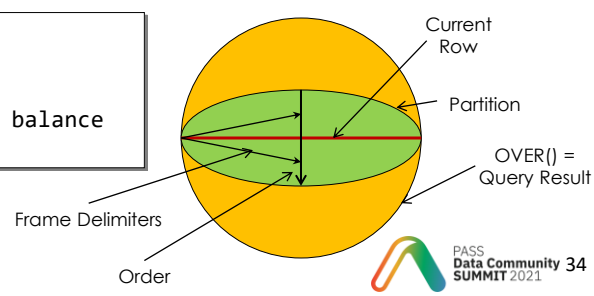
- Provide ranking values to rows in target partition
- Supported functions: ROW_NUMBER, RANK, DENSE_RANK, NTILE
- Support optional window partition clause and mandatory window order clause
- Benefit from POC index to avoid sort (relevant to all window functions)

```
SELECT orderid, qty,
  ROW_NUMBER() OVER(ORDER BY qty) AS rownum,
  RANK()       OVER(ORDER BY qty) AS rnk,
  DENSE_RANK() OVER(ORDER BY qty) AS densernk,
  NTILE(4)     OVER(ORDER BY qty) AS ntile4
FROM dbo.Orders;
```


Framed aggregates

- A frame is a restricted portion of a partition
- Use window order clause to define order in partition
- Use ROWS or RANGE to define delimiters
- Optimization of RANGE under row mode uses an on-disk spool
- When window order clause specified without unit, defaults to RANGE!

```
SELECT actid, tranid, val,
  SUM(val) OVER(PARTITION BY actid
                ORDER BY tranid
                ROWS UNBOUNDED PRECEDING) AS balance
FROM dbo.Transactions;
```



Offset

- Apply offset calculation to retrieve element from previous (LAG), next (LEAD) first (FIRST_VALUE), last (LAST_VALUE) row
- Support optional window partition clause and mandatory window order clause
- Warning: FIRST_VALUE and LAST_VALUE work with a frame; absent an explicit frame specification, you get RANGE UNBOUNDED PRECEDING by default

```
SELECT custid, orderid, orderdate, qty,
  LAG(qty)  OVER(PARTITION BY custid ORDER BY orderdate, orderid) AS prevqty,
  LEAD(qty) OVER(PARTITION BY custid ORDER BY orderdate, orderid) AS nextqty
FROM dbo.Orders;
```

```
SELECT custid, orderid, orderdate, qty,
  FIRST_VALUE(qty) OVER(PARTITION BY custid ORDER BY orderdate, orderid
                        ROWS BETWEEN UNBOUNDED PRECEDING AND CURRENT ROW) AS firstqty,
  LAST_VALUE(qty)  OVER(PARTITION BY custid ORDER BY orderdate, orderid
                        ROWS BETWEEN CURRENT ROW AND UNBOUNDED FOLLOWING) AS lastqty
FROM dbo.Orders;
```


Statistical

- Apply statistical calculations like percentiles and percentile ranks
- Support optional partitioning and mandatory within group ordering
- Not very optimal under row mode, but very optimal under batch mode

```
SELECT DISTINCT empid,
  PERCENTILE_CONT(0.5) WITHIN GROUP(ORDER BY qty) OVER(PARTITION BY empid) AS median_cont,
  PERCENTILE_DISC(0.5) WITHIN GROUP(ORDER BY qty) OVER(PARTITION BY empid) AS median_disc
FROM dbo.Orders;
```

Batch mode Window Aggregate

- Introduced in SQL Server 2016
- Improves many inefficiencies beyond supporting optimal batch mode
- Pre-2019 requires a columnstore index to be present even if not used
- Can use backdoor with dummy filtered columnstore index to enable

Row mode

Batch mode

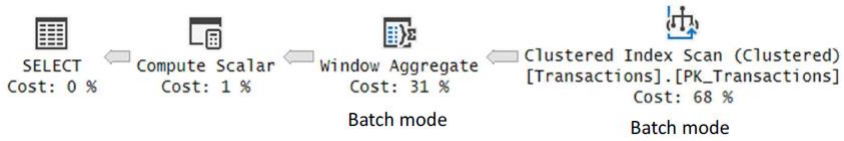
String concatenation

- Introduced in SQL Server 2017, as ordered set function

```
SELECT custid,
  STRING_AGG(CAST(orderid AS VARCHAR(10)), ',')
    WITHIN GROUP(ORDER BY orderdate DESC, orderid DESC) AS orderids
FROM Sales.Orders
GROUP BY custid;
```

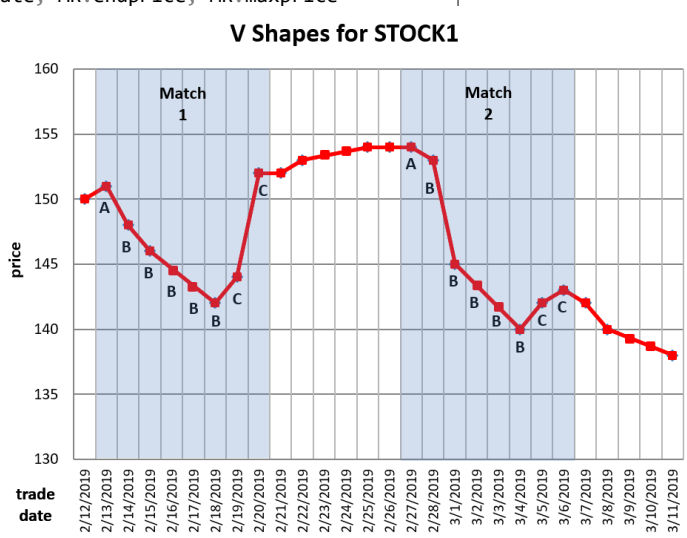
Batch mode on rowstore (covered earlier)

- Introduced in SQL Server 2019
- Doesn't require columnstore indexes to be present
- Allows scanning of rowstore data to happen natively in batch mode with no adapters
- Requires EE and certain conditions based on heuristics to be met (see queryprocessor.com/batch-mode-on-row-store), so backdoor could still be useful!



Missing, row pattern recognition (RPR)

```
SELECT
  MR.symbol, MR.matchnum, MR.startdate, MR.startprice,
  MR.bottomdate, MR.bottomprice, MR.enddate, MR.endprice, MR.maxprice
FROM dbo.Ticker
  MATCH_RECOGNIZE
  (
    PARTITION BY symbol
    ORDER BY tradedate
    MEASURES
      MATCH_NUMBER() AS matchnum,
      A.tradedate AS startdate,
      A.price AS startprice,
      LAST(B.tradedate) AS bottomdate,
      LAST(B.price) AS bottomprice,
      LAST(C.tradedate) AS enddate,
      LAST(C.price) AS endprice,
      MAX(price) AS maxprice
    PATTERN (A B+ C+)
    DEFINE
      -- A defaults to True
      B AS B.price < PREV(B.price),
      C AS C.price > PREV(C.price)
  ) AS MR;
```



Missing, nested window functions

- Interact with points in window as an argument of an aggregate function:
  BEGIN_PARTITION, BEGIN_FRAME, CURRENT_ROW, FRAME_ROW, END_FRAME, END_PARTITION

```
-- cur value minus average without first and last orders for customer
SELECT orderid, custid, orderdate, val,
  val - AVG( CASE
               WHEN ROW_NUMBER(FRAME_ROW) NOT IN ( 1, ROW_NUMBER(END_PARTITION) ) THEN val
             END )
          OVER( PARTITION BY custid ORDER BY orderdate, orderid
                ROWS BETWEEN UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING ) AS diff
FROM Sales.OrderValues;

-- cur value minus average without cur order date for customer
SELECT orderid, custid, orderdate, val,
  val - AVG( CASE WHEN orderdate <> VALUE OF orderdate AT CURRENT_ROW THEN val END )
          OVER( PARTITION BY custid ) AS diff
FROM Sales.OrderValues;
```


Missing, NULL treatment clause

- Available in SQL standard to offset window functions (LAG, LEAD, FIRST_VALUE, LAST_VALUE)
- IGNORE NULLs means keep going until a non-NULL value found

```
SELECT id, col1, COALESCE(col1, LAG(col1) IGNORE NULLS OVER(ORDER BY id)) AS lastval
FROM dbo.T1;
```

- Workaround

```
WITH C AS
(
  SELECT id, col1,
    MAX(CASE WHEN col1 IS NOT NULL THEN id END)
      OVER(ORDER BY id ROWS UNBOUNDED PRECEDING) AS grp
  FROM dbo.T1
)
SELECT id, col1,
  MAX(col1) OVER(PARTITION BY grp ORDER BY id ROWS UNBOUNDED PRECEDING)
FROM C;
```

Solutions using window functions

- Gaps
- Islands
- Creating auxiliary table of numbers (see GetNums function)
- Identifying maximum number of concurrent intervals
- Packing intervals
- And many others…

OFFSET-FETCH

- Similar to TOP but with skipping capability
- Useful for paging, but also tasks like median with high density groups
- Connected entirely to the ORDER BY
- OFFSET: rows to skip, FETCH: rows to filter

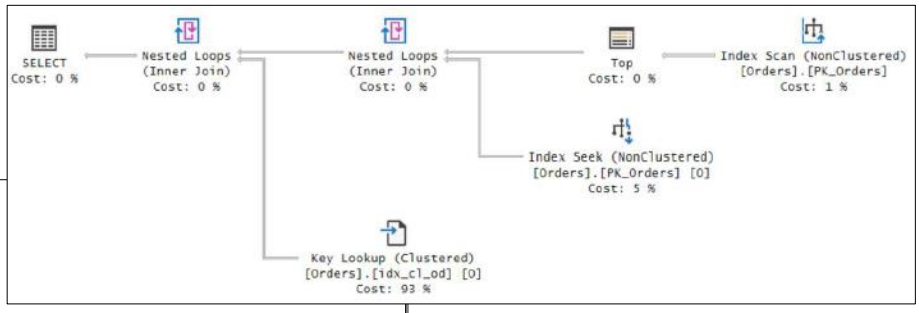
```
SELECT orderid, orderdate, custid, empid
FROM Sales.Orders
ORDER BY orderdate DESC, orderid DESC
OFFSET 50 ROWS FETCH NEXT 25 ROWS ONLY;
```

OFFSET-FETCH

- Optimized with enhanced Top operator
- #rows scanned in index = Offset exp + Top exp

```
SELECT orderid, orderdate, custid, empid
FROM dbo.Orders
ORDER BY orderid
OFFSET (@pagenum - 1) * @pagesize ROWS FETCH NEXT @pagesize ROWS ONLY;
```

OFFSET-FETCH




```
WITH Keys AS
(
  SELECT orderid
  FROM dbo.Orders
  ORDER BY orderid
  OFFSET (@pagenum - 1) * @pagesize ROWS
  FETCH NEXT @pagesize ROWS ONLY
)
SELECT O.orderid, O.orderdate, O.custid, O.empid
FROM dbo.Orders AS O
  INNER JOIN Keys AS K
    ON O.orderid = K.orderid;
```

- Use CTE+join to avoid unnecessary lookups

Review

- Search arguments
- Join ordering optimization
- Adaptive / Intelligent QP
  - Batch-mode processing and batch mode on rowstore
  - Adaptive joins
  - Interleaved execution and table variable deferred compilation
  - Scalar UDF inlining
  - Memory grant feedback
- APPLY
- Window functions
- OFFSET-FETCH

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SQL is all you need

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