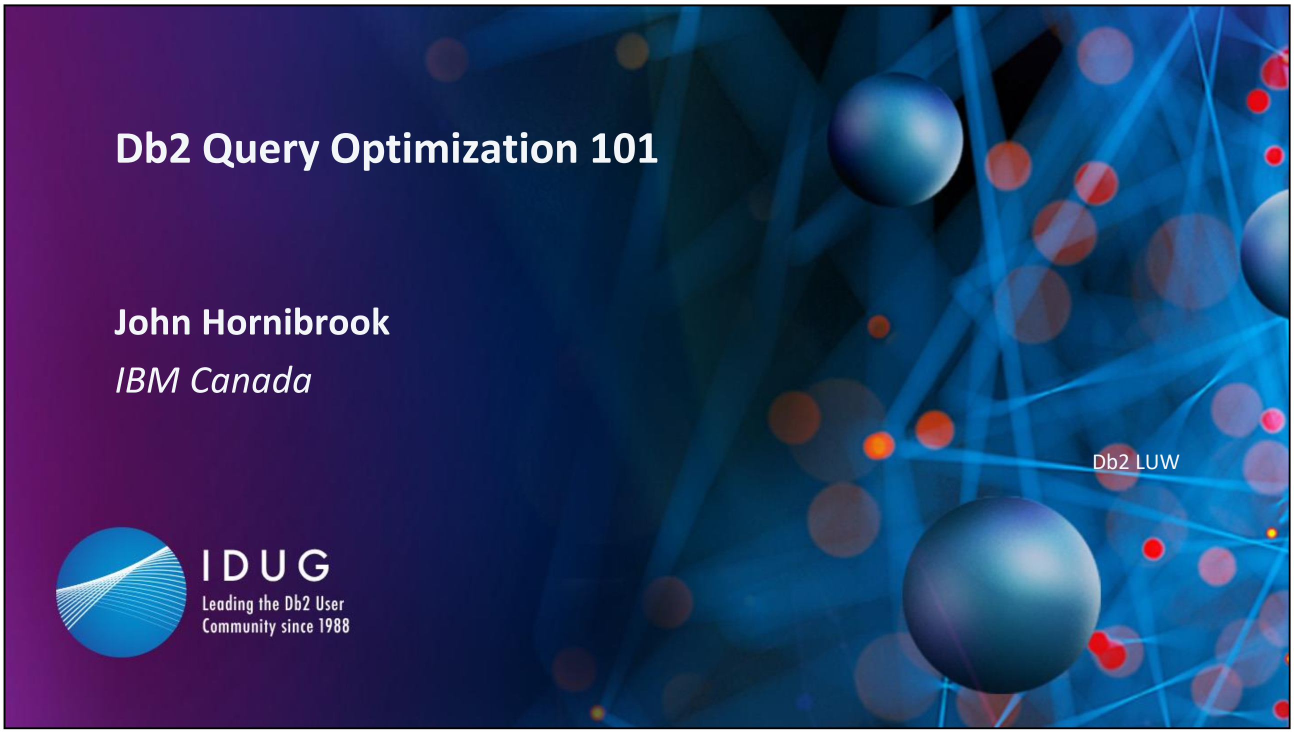


Db2 Query Optimization 101

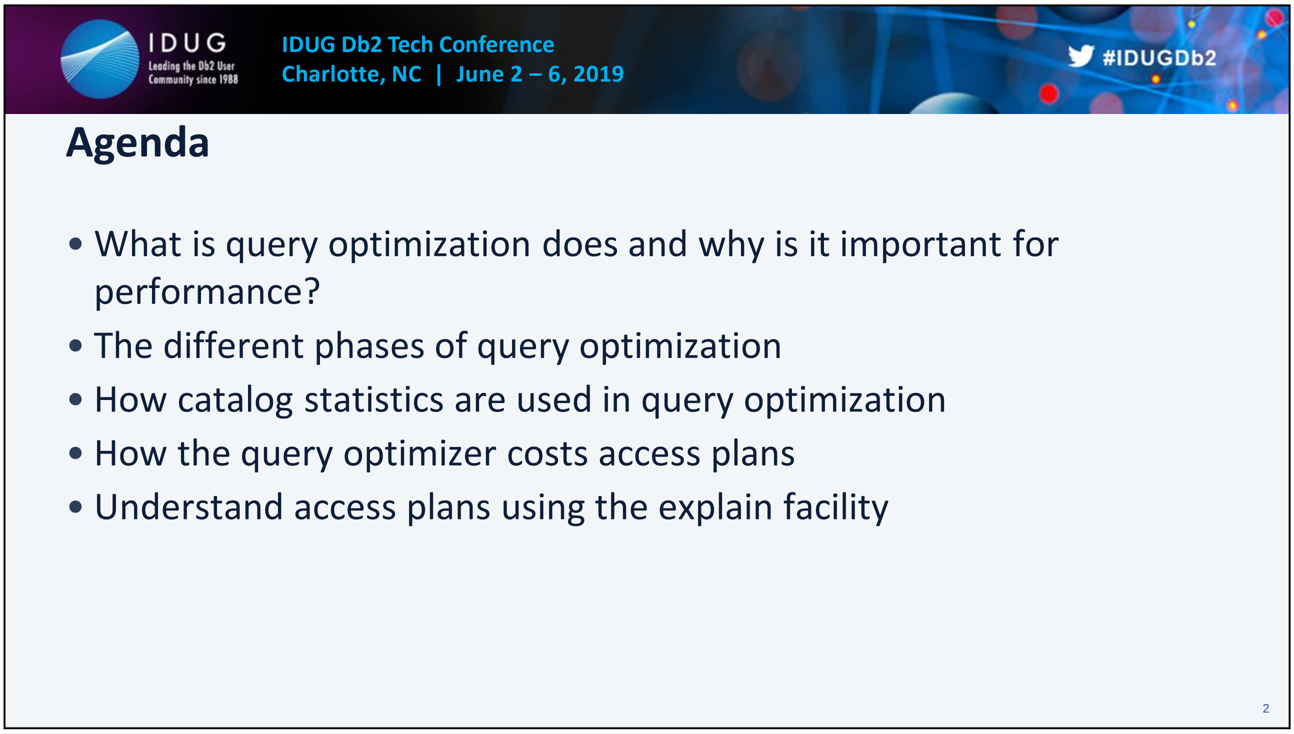
John Hornibrook

IBM Canada

Db2 LUW

IDUG
Leading the Db2 User Community since 1988

Optimal query access plans are essential for good data server performance and it is the Db2 query optimizer's job to choose the best access plan. The optimizer is a very sophisticated component of the data server, tasked with the challenging job of choosing good access paths for the variety of features and table organizations supported by Db2. The optimizer can automatically rewrite complex SQL resulting in huge performance improvements. It models various aspects of Db2 runtime so that it can choose the best access plan out of hundreds of thousands of possible options. Attend this session to get an overview of how the optimizer works and to get some tips on how to understand its decisions and control its behavior.



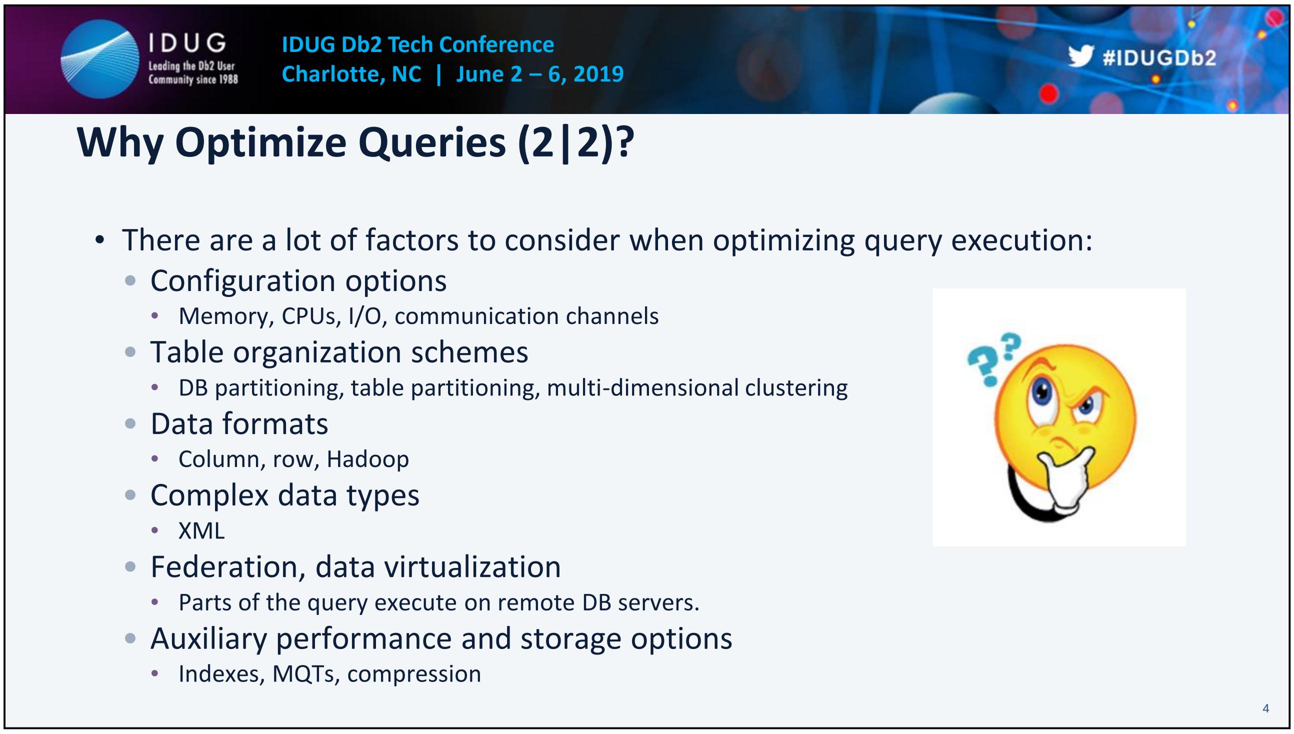
Agenda

- What is query optimization does and why is it important for performance?
- The different phases of query optimization
- How catalog statistics are used in query optimization
- How the query optimizer costs access plans
- Understand access plans using the explain facility

Why Optimize Queries (1|2)?

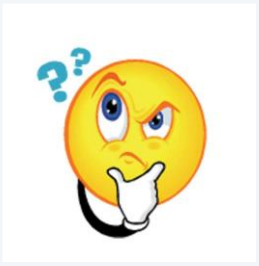
- Performance
  - Improvement can be orders of magnitude for complex queries

- Lower total cost of ownership
  - Query tuning requires deep skill
    - Complex DB designs
    - SQL/XQuery generated by query generators, naive users
    - Fewer skilled administrators available
    - Various configuration and physical implementation



Why Optimize Queries (2|2)?

- There are a lot of factors to consider when optimizing query execution:
  - Configuration options
    - Memory, CPUs, I/O, communication channels
  - Table organization schemes
    - DB partitioning, table partitioning, multi-dimensional clustering
  - Data formats
    - Column, row, Hadoop
  - Complex data types
    - XML
  - Federation, data virtualization
    - Parts of the query execute on remote DB servers.
  - Auxiliary performance and storage options
    - Indexes, MQTs, compression

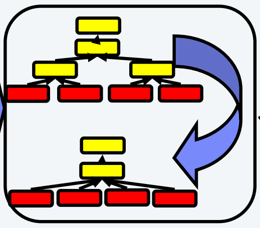


What is Query Optimization?

- SQL compilation:
  - In: SQL statement, Out: access section
  - Query optimization is 2 steps in the Db2 SQL statement compilation process
    - Query transformation (rewrite)
    - Access plan generation

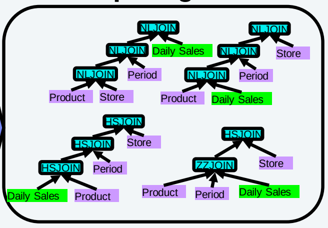
```
SELECT ITEM_DESC, SUM(QUANTITY_SOLD),
     AVG(PRICE), AVG(COST)
   FROM PERIOD, DAILY_SALES, PRODUCT, STORE
WHERE
   PERIOD.PERKEY=DAILY_SALES.PERKEY AND
   PRODUCT.PRODKEY=DAILY_SALES.PRODKEY
    AND
   STORE.STOREKEY=DAILY_SALES.STOREKEY AND
   CALENDAR_DATE BETWEEN AND
     '01/01/2012' AND '04/28/2012' AND
   STORE_NUMBER='03' AND
   CATEGORY=72
GROUP BY ITEM_DESC
```

Query transformation



Dozens of query transformations

Access plan generation

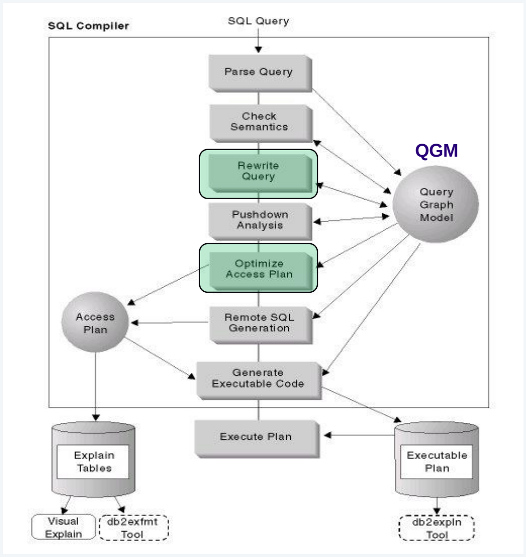


Hundreds or thousands of access plan options

Access section

```
Thread 0
DSS
TQA (tq1)
AGG (complete)
BNO
EXT
Thread 1
TA (Product)
NLJN (Daily Sales)
NLJN (Period)
NLJN (Store)
AGG (partial)
TQB (tq1)
EXT
Thread 2
TA (DS_IX7)
EXT
Thread 3
TA (PER_IX2)
EXT
Thread 4
TA (ST_IX1)
EXT
```

Phases of SQL Compilation



- Sometimes references to “**optimization”** really mean **SQL compilation**
- There is a lot more involved to SQL compilation

Parsing
- Catch syntax errors
- Generate internal representation of query

Semantic checking
- Determine if query makes sense
- Incorporate view definitions
- Add logic for constraint checking and triggers

Query optimization
- **Modify query to improve performance (Query Rewrite)**
- **Choose the most efficient "access plan"**

Pushdown Analysis
- Federation “optimization”

Threaded code generation
- Generate efficient "executable" code
- “Access section”

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Query Optimization

- SQL compilation:
  - **Query transformation (rewrite)**
  - Access plan generation

```
SELECT ITEM_DESC, SUM(QUANTITY_SOLD),
    AVG(PRICE), AVG(COST)
  FROM PERIOD, DAILY_SALES, PRODUCT, STORE
WHERE
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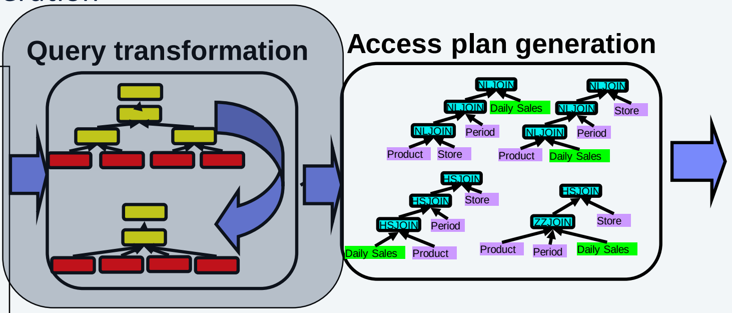
    PRODUCT.PRODKEY=DAILY_SALES.PRODKEY
     AND
    STORE.STOREKEY=DAILY_SALES.STOREKEY AND
    CALENDAR_DATE BETWEEN AND
      '01/01/2012' AND '04/28/2012' AND
    STORE_NUMBER='03' AND
    CATEGORY=72
GROUP BY ITEM_DESC
```



Dozens of query transformations

Hundreds or thousands of access plan options

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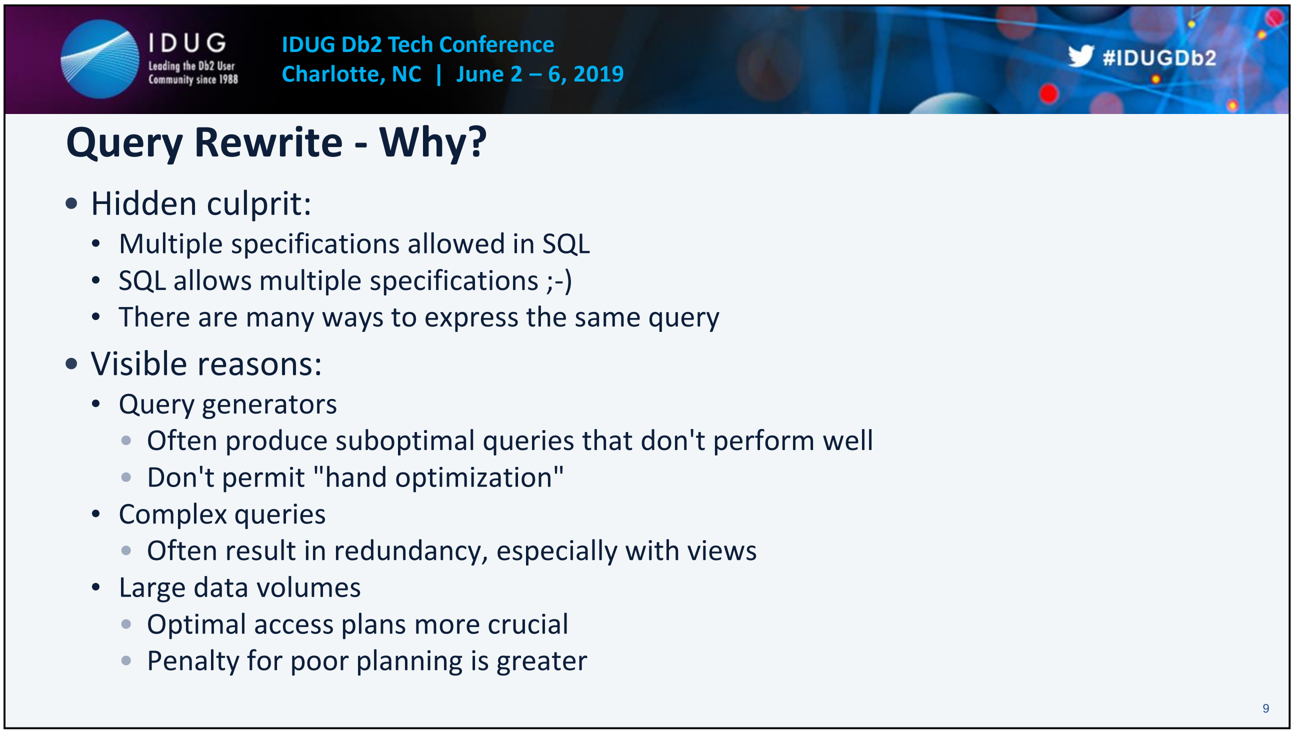
EXT
Thread 2
TA (DS_IX7)
EXT
Thread 3
TA (PER_IX2)
EXT
Thread 4
TA (ST_IX1)
EXT
```

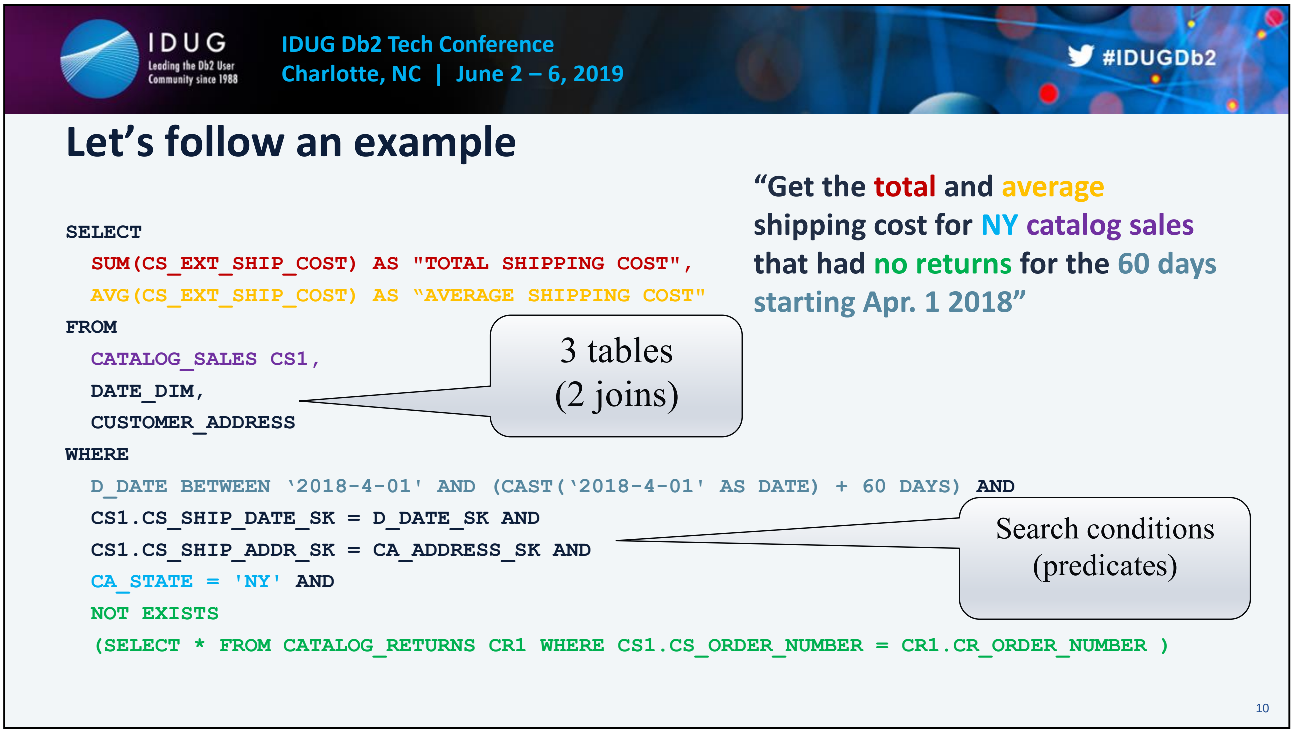
Query Rewrite - An Overview

- What is Query Rewrite?
  - Rewriting a given SQL query into a semantically equivalent form that may be processed more efficiently
- Example:
  - Original query:
    ```
    SELECT DISTINCT CUSTKEY, NAME FROM CUSTOMER
    ```
  - After Query Rewrite:
    ```
    SELECT CUSTKEY, NAME FROM CUSTOMER
    ```
  - Rationale:
    - CUSTKEY is unique, distinct is redundant



Query Rewrite - Why?

- Hidden culprit:
  - Multiple specifications allowed in SQL
  - SQL allows multiple specifications ;-)
  - There are many ways to express the same query
- Visible reasons:
  - Query generators
    - Often produce suboptimal queries that don't perform well
    - Don't permit "hand optimization"
  - Complex queries
    - Often result in redundancy, especially with views
  - Large data volumes
    - Optimal access plans more crucial
    - Penalty for poor planning is greater



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Let's follow an example

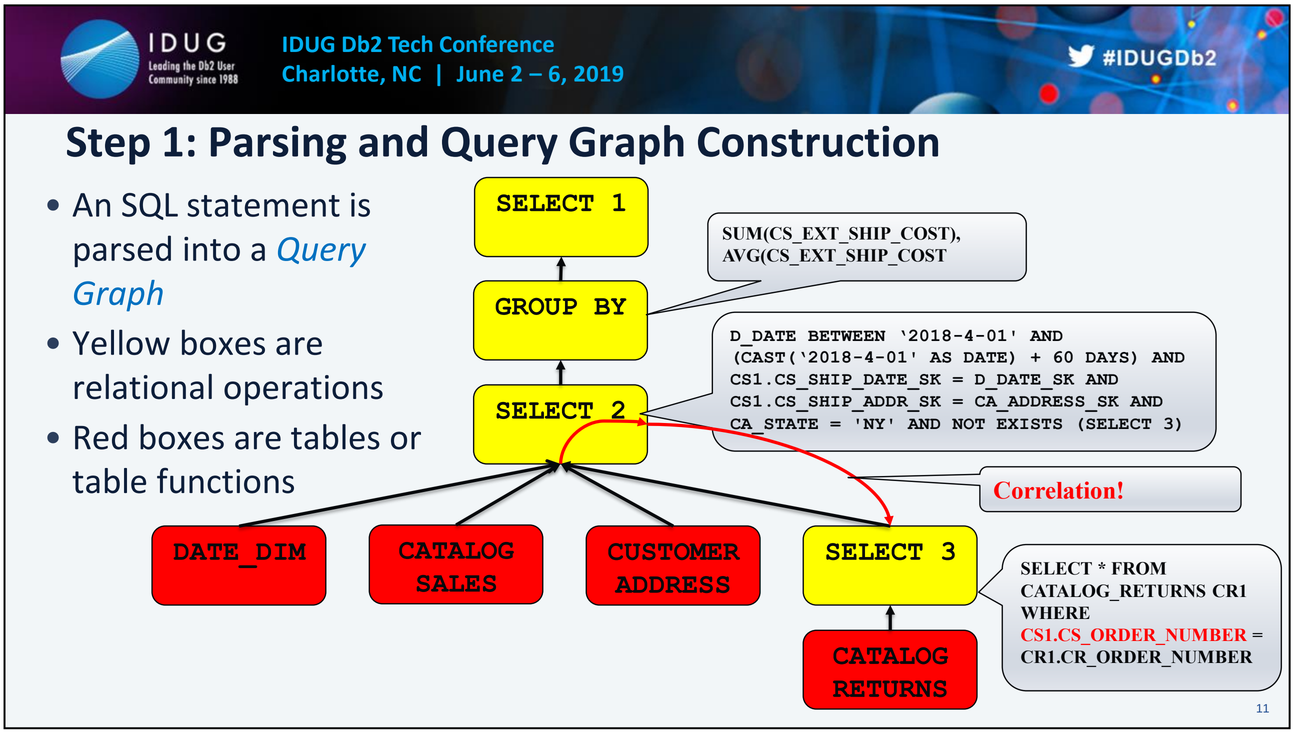
"Get the total and average shipping cost for NY catalog sales that had no returns for the 60 days starting Apr. 1 2018"

```
SELECT
  SUM(CS_EXT_SHIP_COST) AS "TOTAL SHIPPING COST",
  AVG(CS_EXT_SHIP_COST) AS "AVERAGE SHIPPING COST"
FROM
  CATALOG_SALES CS1,
  DATE_DIM,
  CUSTOMER_ADDRESS
WHERE
  D_DATE BETWEEN '2018-4-01' AND (CAST('2018-4-01' AS DATE) + 60 DAYS) AND
  CS1.CS_SHIP_DATE_SK = D_DATE_SK AND
  CS1.CS_SHIP_ADDR_SK = CA_ADDRESS_SK AND
  CA_STATE = 'NY' AND
  NOT EXISTS
  (SELECT * FROM CATALOG_RETURNS CR1 WHERE CS1.CS_ORDER_NUMBER = CR1.CR_ORDER_NUMBER )
```

3 tables
(2 joins)

Search conditions
(predicates)

10



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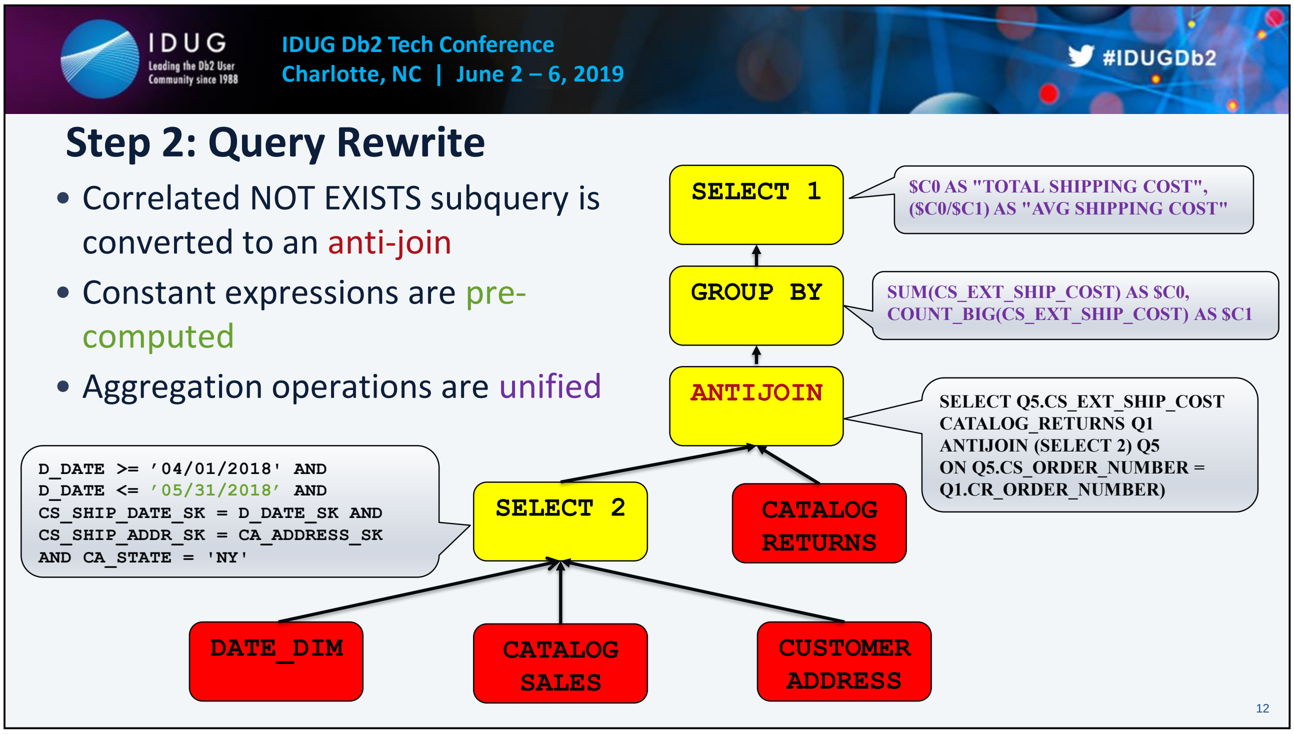
Step 1: Parsing and Query Graph Construction

- An SQL statement is parsed into a *Query Graph*
- Yellow boxes are relational operations
- Red boxes are tables or table functions

SELECT 1
GROUP BY
SUM(CS_EXT_SHIP_COST), AVG(CS_EXT_SHIP_COST
SELECT 2
D_DATE BETWEEN '2018-4-01' AND (CAST('2018-4-01' AS DATE) + 60 DAYS) AND CS1.CS_SHIP_DATE_SK = D_DATE_SK AND CS1.CS_SHIP_ADDR_SK = CA_ADDRESS_SK AND CA_STATE = 'NY' AND NOT EXISTS (SELECT 3)
Correlation!
DATE_DIM
CATALOG SALES
CUSTOMER ADDRESS
SELECT 3
SELECT * FROM CATALOG_RETURNS CR1 WHERE CS1.CS_ORDER_NUMBER = CR1.CR_ORDER_NUMBER
CATALOG RETURNS
11

The SQL statement is first parsed and the relational operations are represented as nodes in a query graph. The yellow nodes represent relational operations such as selection, aggregation (group by), union, insert, update, delete, etc.. The red nodes are leaf nodes representing data sources such as tables or table functions. The edges represent the flow of rows. Rows can flow in both directions. A downward flow represents a correlated reference in a lower sub-select, such as the correlated NOT EXISTS subquery in this example. Correlation requires that the lower sub-select be re-evaluated for each row provided by the downward edge.

A SELECT node can have multiple input edges which can either represent joins or subquery predicates. SELECT nodes also include SELECT list items including expressions and WHERE clause predicates.



Step 2: Query Rewrite

- Correlated NOT EXISTS subquery is converted to an anti-join
- Constant expressions are pre-computed
- Aggregation operations are unified

```
$C0 AS "TOTAL SHIPPING COST",
($C0/$C1) AS "AVG SHIPPING COST"
```

```
SUM(CS_EXT_SHIP_COST) AS $C0,
COUNT_BIG(CS_EXT_SHIP_COST) AS $C1
```

```
SELECT Q5.CS_EXT_SHIP_COST
CATALOG_RETURNS Q1
ANTIJOIN (SELECT 2) Q5
ON Q5.CS_ORDER_NUMBER =
Q1.CR_ORDER_NUMBER)
```

```
D_DATE >= '04/01/2018' AND
D_DATE <= '05/31/2018' AND
CS_SHIP_DATE_SK = D_DATE_SK AND
CS_SHIP_ADDR_SK = CA_ADDRESS_SK
AND CA_STATE = 'NY'
```

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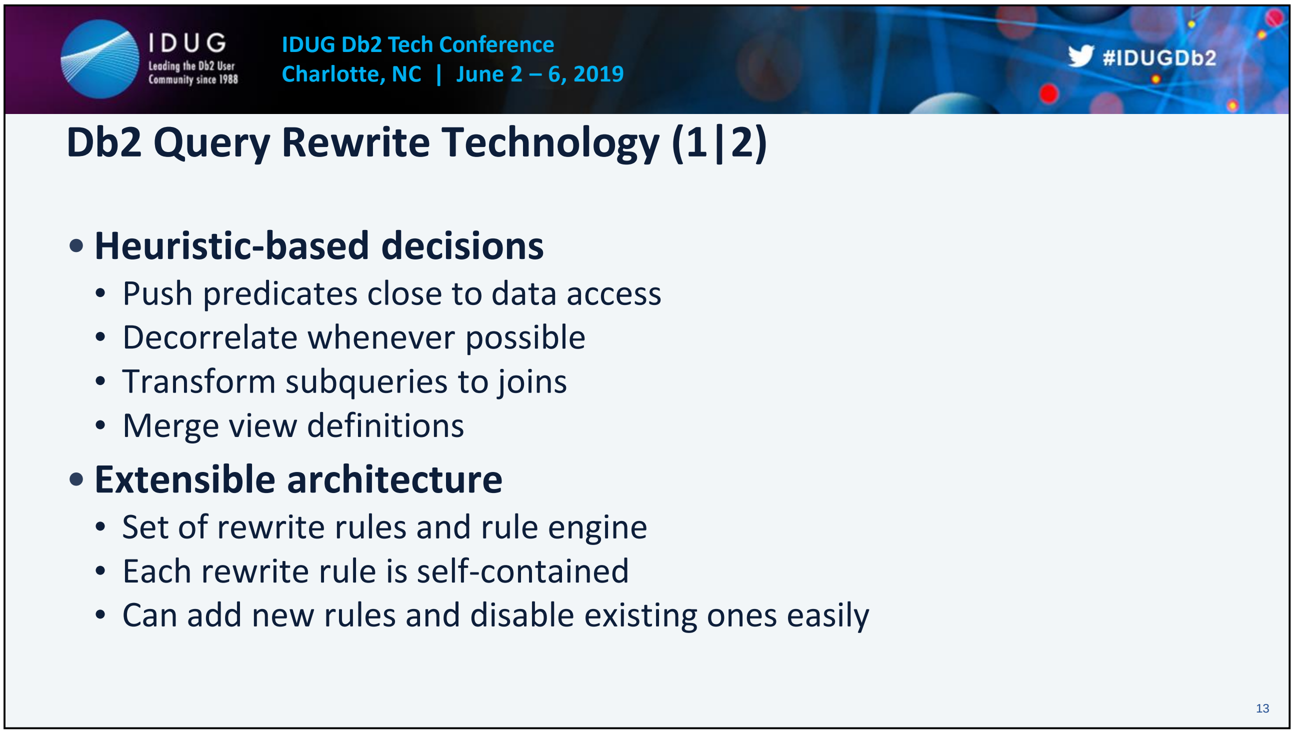
3 important query rewrites have occurred:

1) The correlated NOT EXISTS subquery has been rewritten as an anti-join. An anti-join is a type of join where only the rows that don’t match are returned. The Db2 query runtime engine supports a efficient native anti-join.
2) The date expression “CAST(‘2018-4-01' AS DATE) + 60 DAYS” has been pre-computed as ’05/31/2018’. This allows the optimizer to compute a more accurate selectivity estimate in a later phase.
3) The AVG aggregation function can be replaced with SUM/COUNT, re-using the existing SUM result

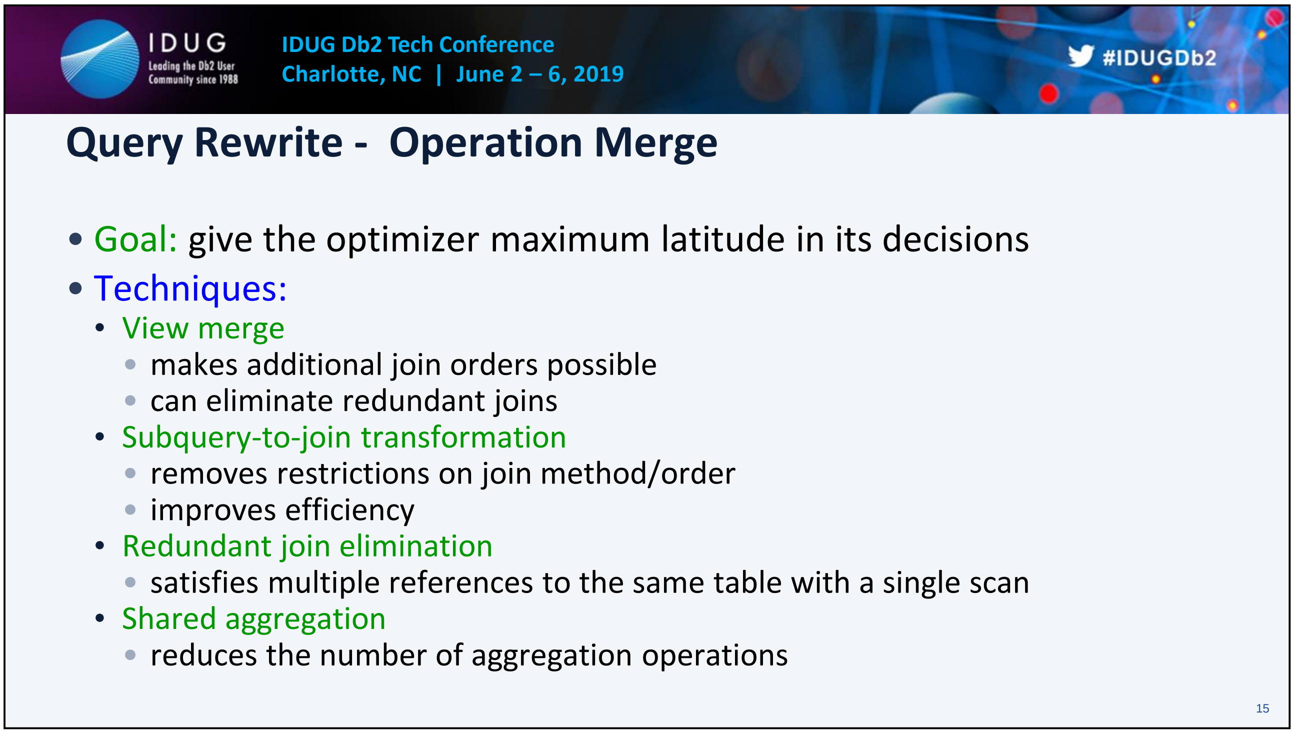


Db2 Query Rewrite Technology (1|2)

- **Heuristic-based decisions**
  - Push predicates close to data access
  - Decorrelate whenever possible
  - Transform subqueries to joins
  - Merge view definitions
- **Extensible architecture**
  - Set of rewrite rules and rule engine
  - Each rewrite rule is self-contained
  - Can add new rules and disable existing ones easily

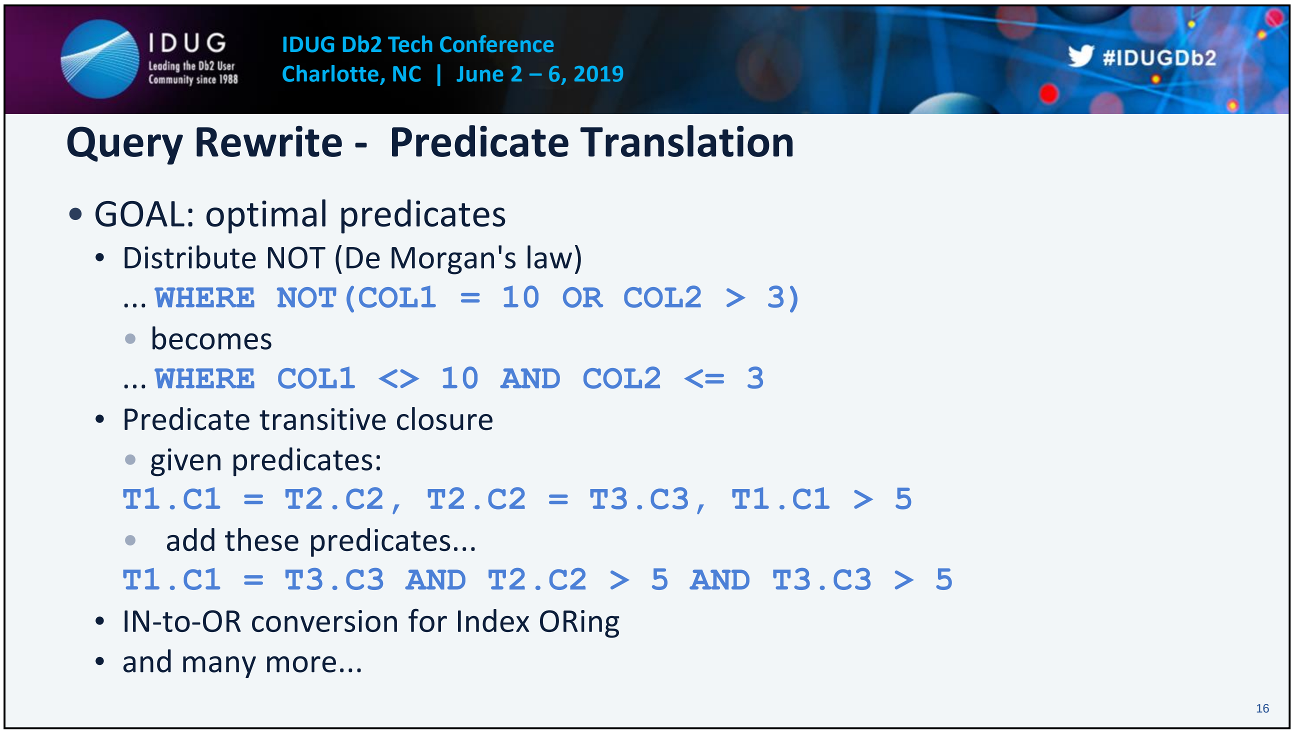
Db2 Query Rewrite Technology (2|2)

- Rule engine with local cost-based decisions
- Rule engine iteratively transforms query until the query graph reaches a steady-state
- ~140 rules
- This presentation shows only a few examples



Query Rewrite - Operation Merge

- Goal: give the optimizer maximum latitude in its decisions
- Techniques:
  - View merge
    - makes additional join orders possible
    - can eliminate redundant joins
  - Subquery-to-join transformation
    - removes restrictions on join method/order
    - improves efficiency
  - Redundant join elimination
    - satisfies multiple references to the same table with a single scan
  - Shared aggregation
    - reduces the number of aggregation operations



Query Rewrite - Predicate Translation

- GOAL: optimal predicates
  - Distribute NOT (De Morgan's law)

    ...`WHERE NOT(COL1 = 10 OR COL2 > 3)`
    - becomes

    ...`WHERE COL1 <> 10 AND COL2 <= 3`
  - Predicate transitive closure
    - given predicates:

    `T1.C1 = T2.C2, T2.C2 = T3.C3, T1.C1 > 5`
    - add these predicates...

    `T1.C1 = T3.C3 AND T2.C2 > 5 AND T3.C3 > 5`
  - IN-to-OR conversion for Index ORing
  - and many more...

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Query Optimization

- SQL compilation:
  - Query transformation (rewrite)
  - **Access plan generation**

```
SELECT ITEM_DESC, SUM(QUANTITY_SOLD),
     AVG(PRICE), AVG(COST)
    FROM PERIOD, DAILY_SALES, PRODUCT, STORE
WHERE
    PERIOD.PERKEY=DAILY_SALES.PERKEY AND
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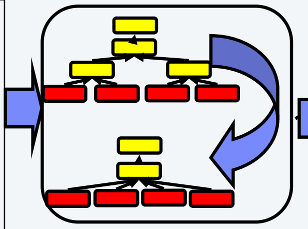
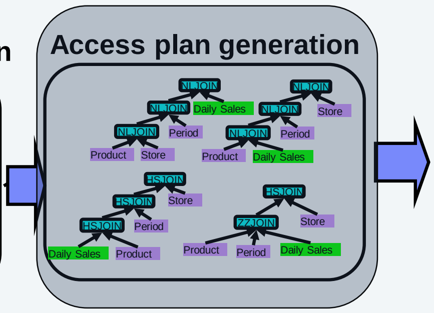
     AND
    STORE.STOREKEY=DAILY_SALES.STOREKEY AND
    CALENDAR_DATE BETWEEN AND
      '01/01/2012' AND '04/28/2012' AND
    STORE_NUMBER='03' AND
    CATEGORY=72
GROUP BY ITEM_DESC
```

Query transformation



Dozens of query transformations

Access plan generation



Hundreds or thousands of access plan options

Access section

```
Thread 0
DSS
TQA (tq1)
AGG (complete)
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AGG (partial)
TQB (tq1)
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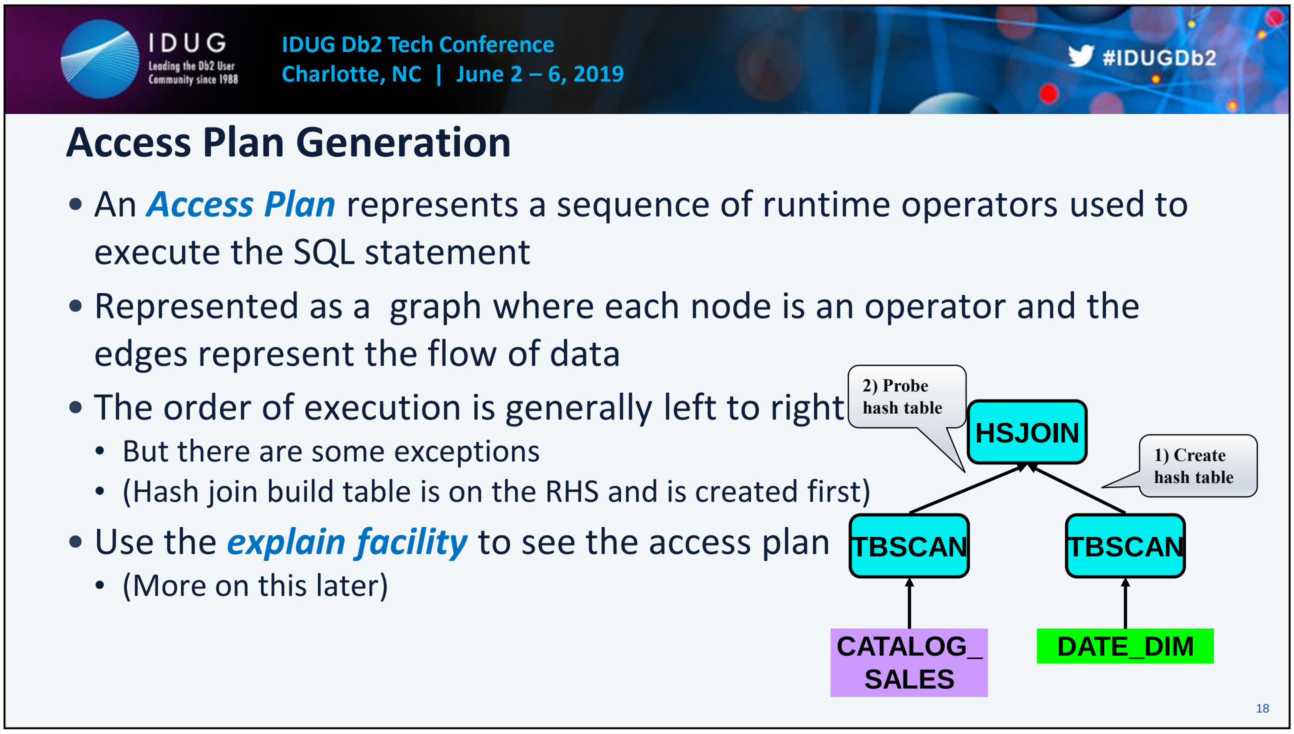
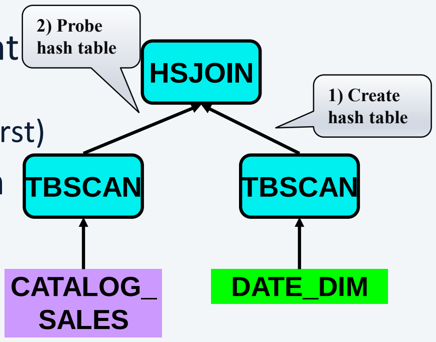
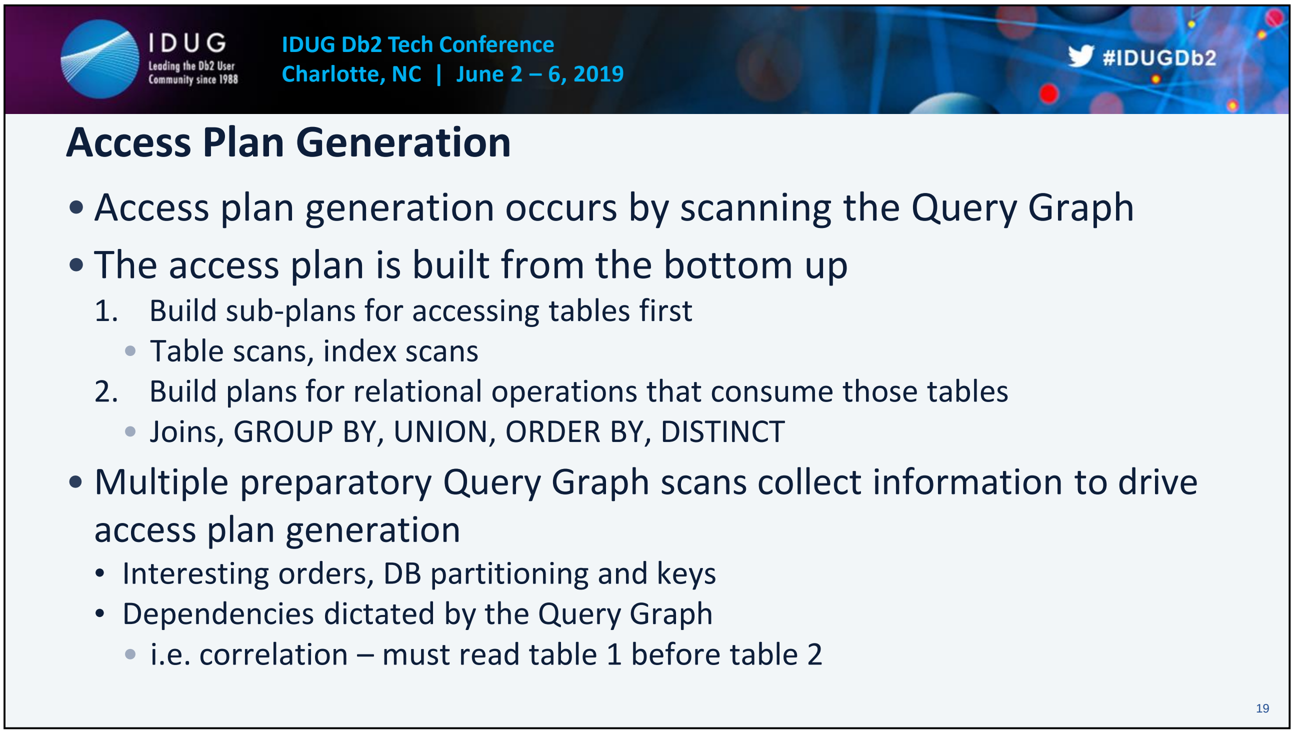
Thread 2
TA (DS_IX7)
EXT
Thread 3
TA (PER_IX2)
EXT
Thread 4
TA (ST_IX1)
EXT
```



Access Plan Generation

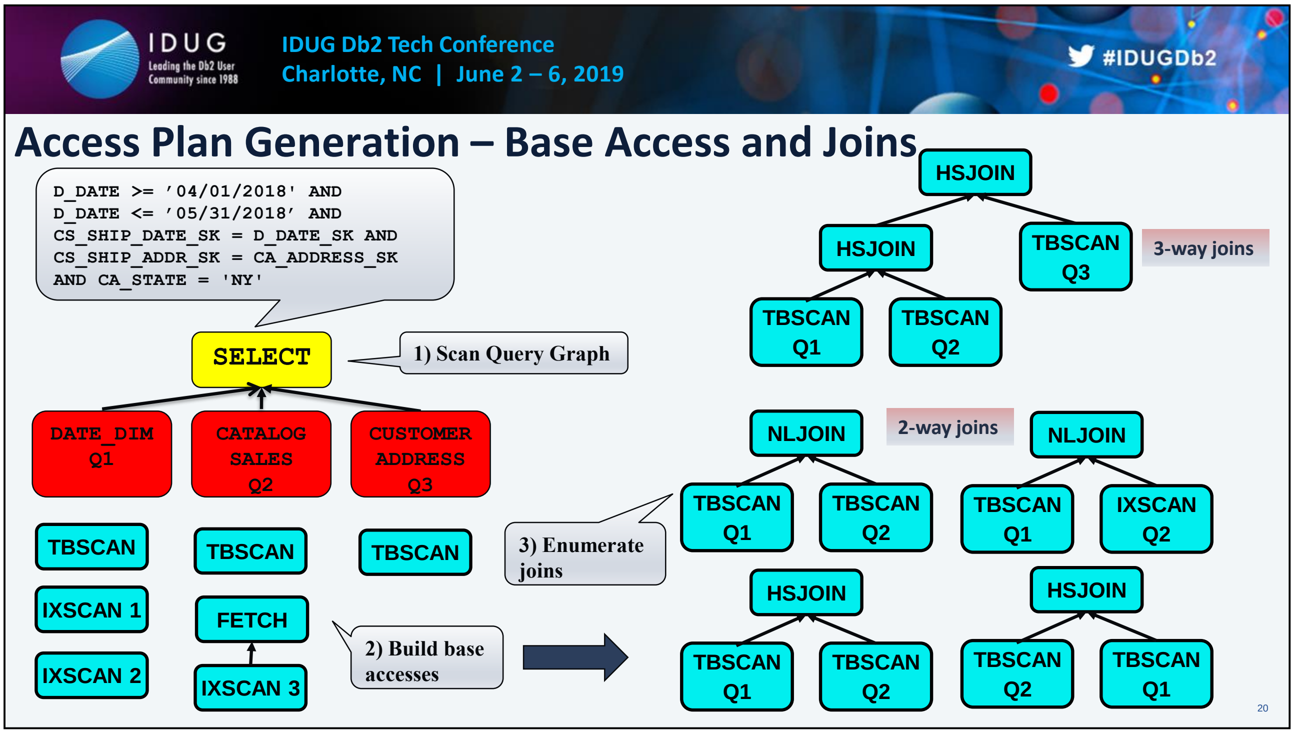
- An ***Access Plan*** represents a sequence of runtime operators used to execute the SQL statement
- Represented as a graph where each node is an operator and the edges represent the flow of data
- The order of execution is generally left to right
  - But there are some exceptions
  - (Hash join build table is on the RHS and is created first)
- Use the ***explain facility*** to see the access plan
  - (More on this later)





Access Plan Generation

- Access plan generation occurs by scanning the Query Graph
- The access plan is built from the bottom up
  1. Build sub-plans for accessing tables first
     - Table scans, index scans
  2. Build plans for relational operations that consume those tables
     - Joins, GROUP BY, UNION, ORDER BY, DISTINCT
- Multiple preparatory Query Graph scans collect information to drive access plan generation
  - Interesting orders, DB partitioning and keys
  - Dependencies dictated by the Query Graph
    - i.e. correlation – must read table 1 before table 2



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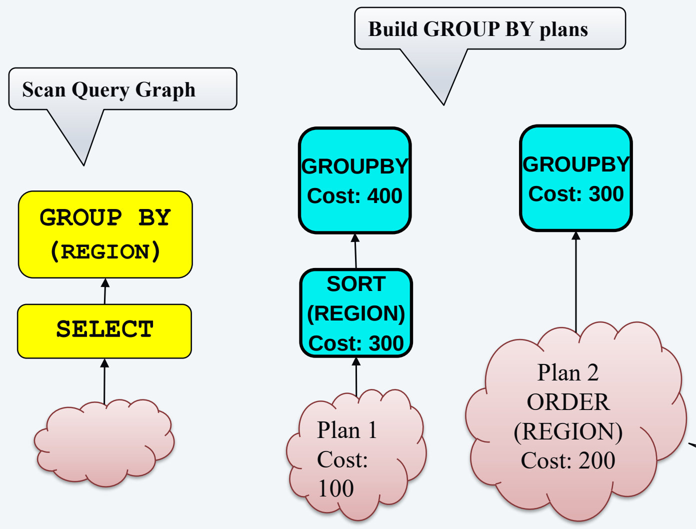
Access Plan Generation – Base Access and Joins

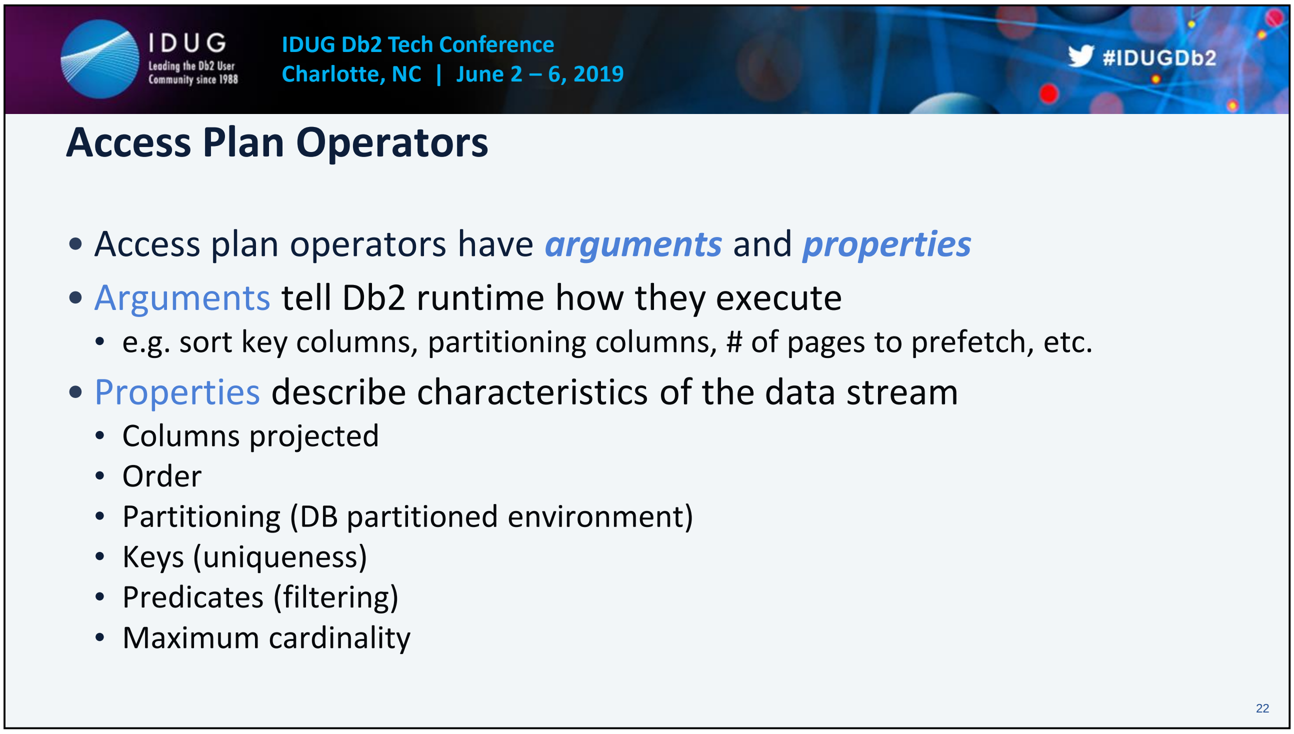
```
D_DATE >= '04/01/2018' AND
D_DATE <= '05/31/2018' AND
CS_SHIP_DATE_SK = D_DATE_SK AND
CS_SHIP_ADDR_SK = CA_ADDRESS_SK
AND CA_STATE = 'NY'
```

- For each relational operation in the query graph, evaluate runtime alternatives
  - Operation order
    - joins
    - predicate application – where?
    - aggregation – can be staged
  - Implementation to use:
    - table scan vs. index scan
    - nested-loop join vs. sort-merge join vs. hash join vs. zig-zag join

Access Plan Generation – GROUP BY

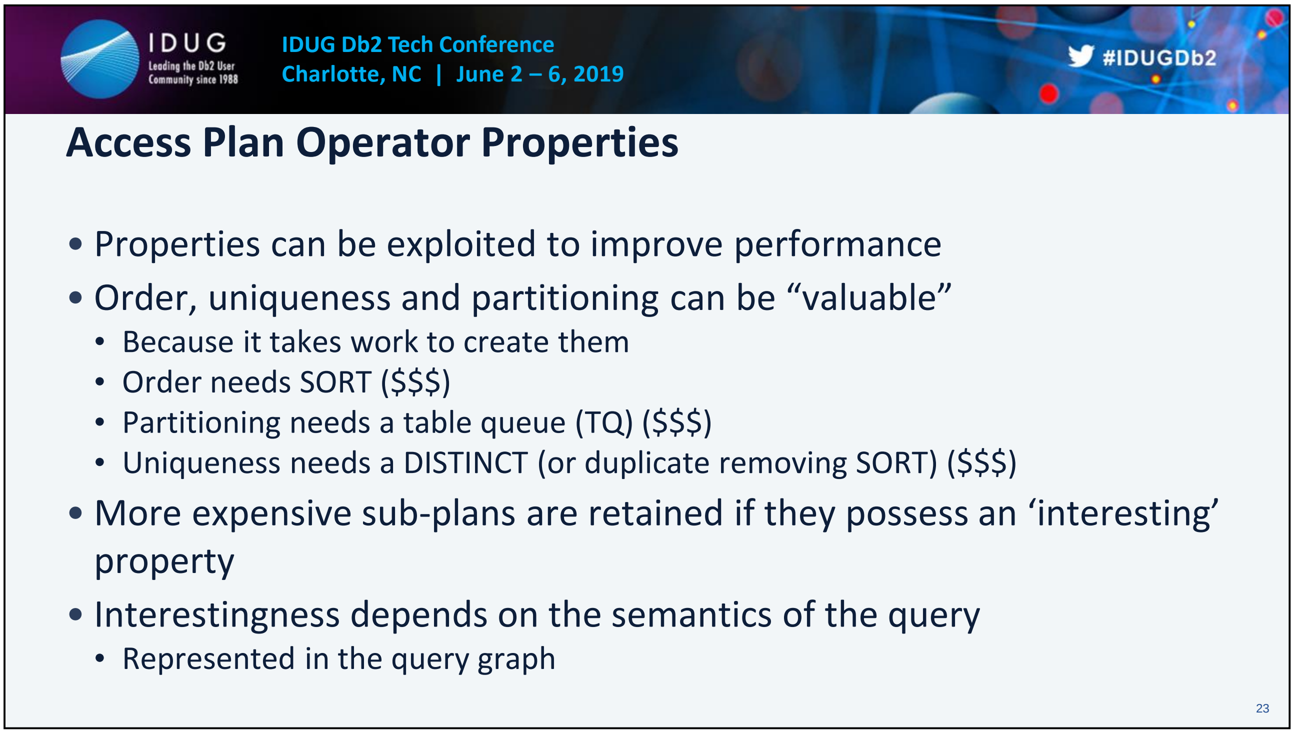


- Db2 runtime has different ways to execute GROUP BY
- One method requires order on grouping columns
- Some sub-plans might have the needed order, others require a SORT
- In general, only the cheapest sub-plans are kept
- Except if they have an ‘interesting’ property, like order
  - (Costs are cumulative)



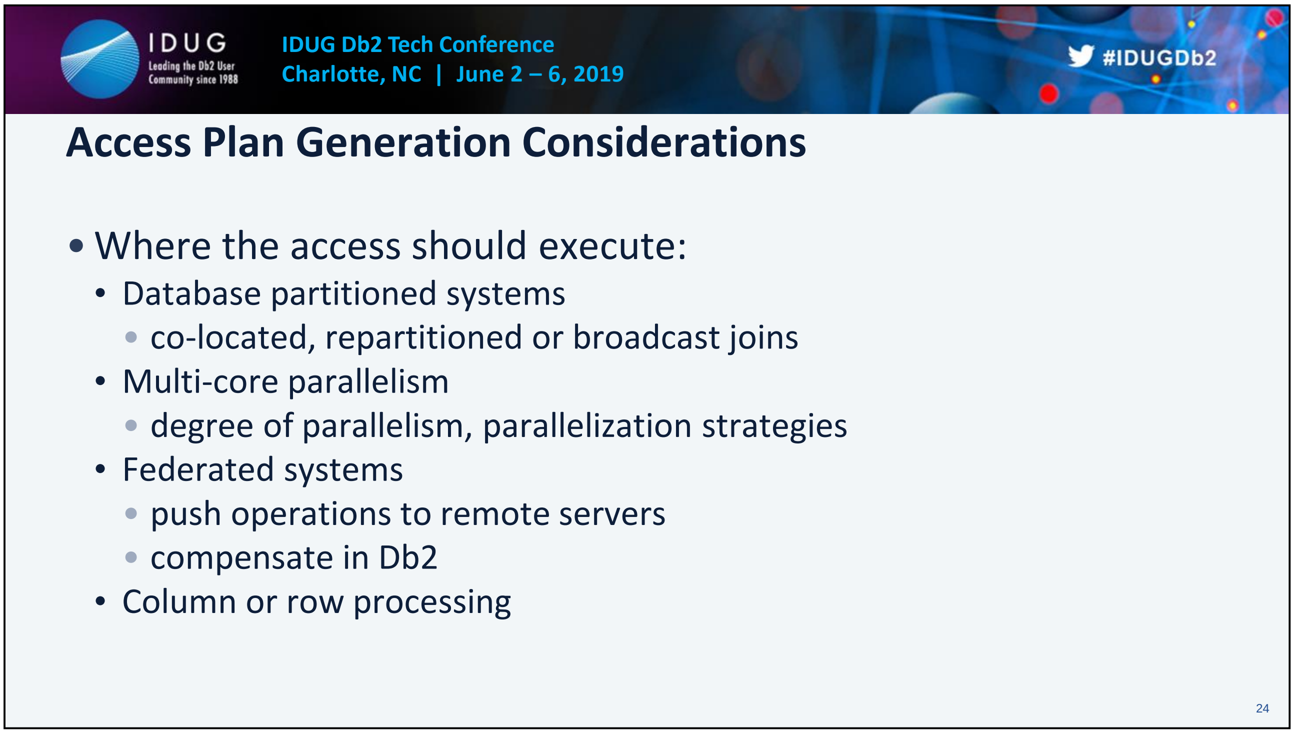
Access Plan Operators

- Access plan operators have ***arguments*** and ***properties***
- Arguments tell Db2 runtime how they execute
  - e.g. sort key columns, partitioning columns, # of pages to prefetch, etc.
- Properties describe characteristics of the data stream
  - Columns projected
  - Order
  - Partitioning (DB partitioned environment)
  - Keys (uniqueness)
  - Predicates (filtering)
  - Maximum cardinality



Access Plan Operator Properties

- Properties can be exploited to improve performance
- Order, uniqueness and partitioning can be "valuable"
  - Because it takes work to create them
  - Order needs SORT ($$$)
  - Partitioning needs a table queue (TQ) ($$$)
  - Uniqueness needs a DISTINCT (or duplicate removing SORT) ($$$)
- More expensive sub-plans are retained if they possess an 'interesting' property
- Interestingness depends on the semantics of the query
  - Represented in the query graph



Access Plan Generation Considerations

- Where the access should execute:
  - Database partitioned systems
    - co-located, repartitioned or broadcast joins
  - Multi-core parallelism
    - degree of parallelism, parallelization strategies
  - Federated systems
    - push operations to remote servers
    - compensate in Db2
  - Column or row processing

Join Enumeration

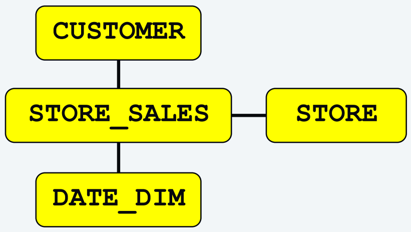
- The search algorithm used to plan joins
- Search complexity depends on how tables are connected by predicates
- 2 methods:
  - Greedy
    - Most efficient, but not exhaustive
    - Could miss some good plans
  - Dynamic
    - Exhaustive, but expensive for large or highly connected join graphs

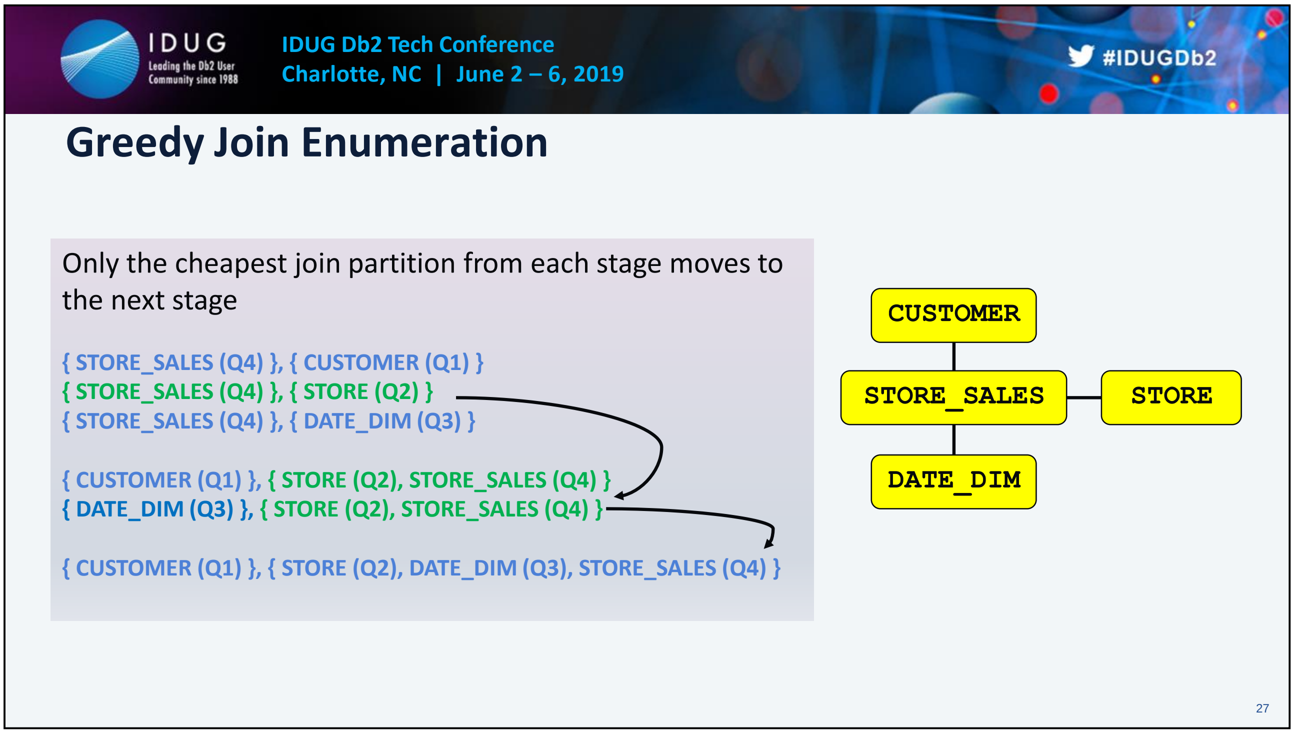
Dynamic Join Enumeration

{ CUSTOMER (Q1) }, { STORE_SALES (Q4) }
{ STORE (Q2) }, { STORE_SALES (Q4) }
{ DATE_DIM (Q3) }, { STORE_SALES (Q4) }

{ CUSTOMER (Q1) }, { DATE_DIM (Q3), STORE_SALES (Q4) } P4
{ CUSTOMER (Q1) }, { STORE (Q2), STORE_SALES (Q4) } P5
{ STORE (Q2) }, { DATE_DIM (Q3), STORE_SALES (Q4) } P6
{ STORE (Q2) }, { CUSTOMER (Q1), STORE_SALES (Q4) } P5
{ DATE_DIM (Q3) }, { STORE (Q2), STORE_SALES (Q4) } P6
{ DATE_DIM (Q3) }, { CUSTOMER (Q1), STORE_SALES (Q4) } P4

{ CUSTOMER (Q1) }, { STORE (Q2), DATE_DIM (Q3), STORE_SALES (Q4) }
{ STORE (Q2) }, { CUSTOMER (Q1), DATE_DIM (Q3), STORE_SALES (Q4) }
{ DATE_DIM (Q3) }, { CUSTOMER (Q1), STORE (Q2), STORE_SALES (Q4) }





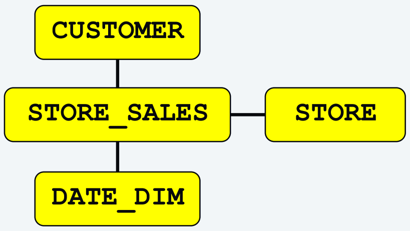
Greedy Join Enumeration

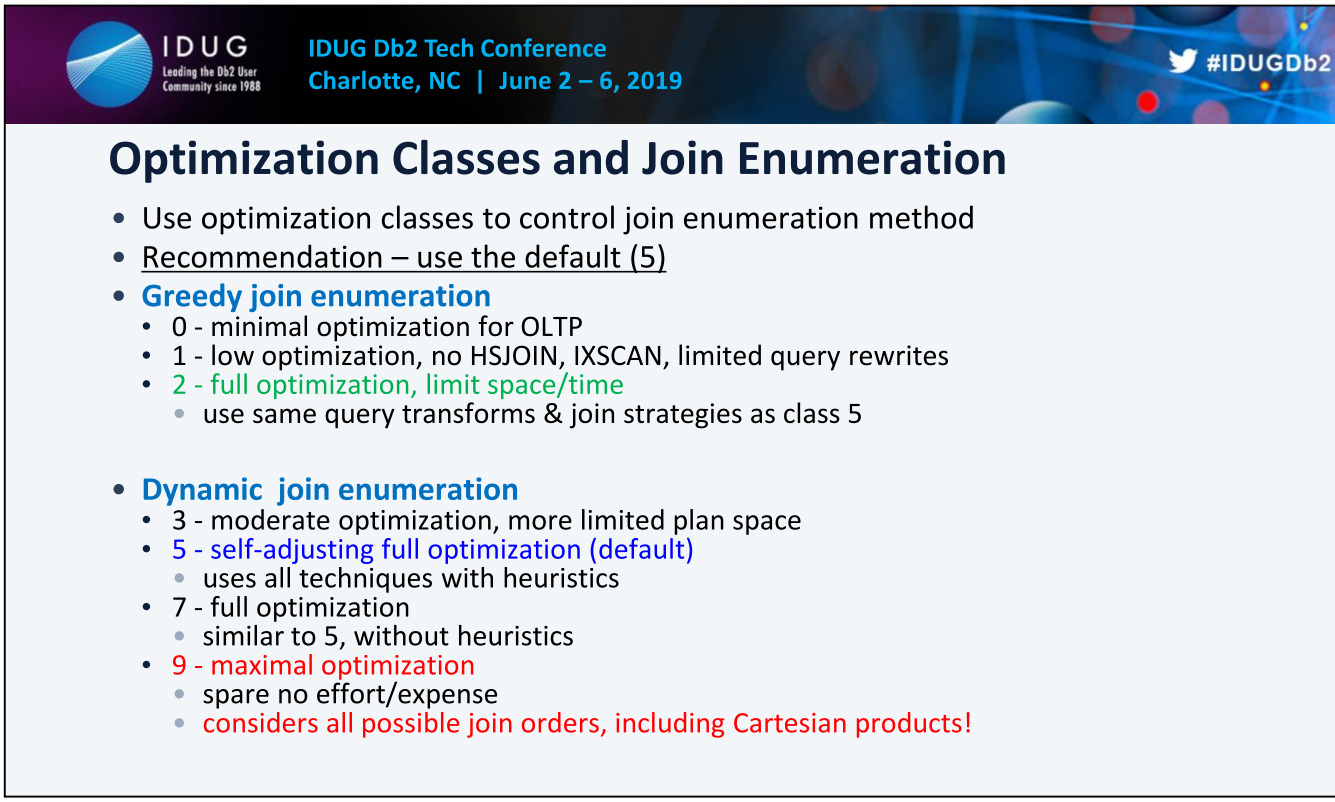
Only the cheapest join partition from each stage moves to the next stage

{ STORE_SALES (Q4) }, { CUSTOMER (Q1) }
{ STORE_SALES (Q4) }, { STORE (Q2) }
{ STORE_SALES (Q4) }, { DATE_DIM (Q3) }

{ CUSTOMER (Q1) }, { STORE (Q2), STORE_SALES (Q4) }
{ DATE_DIM (Q3) }, { STORE (Q2), STORE_SALES (Q4) }

{ CUSTOMER (Q1) }, { STORE (Q2), DATE_DIM (Q3), STORE_SALES (Q4) }

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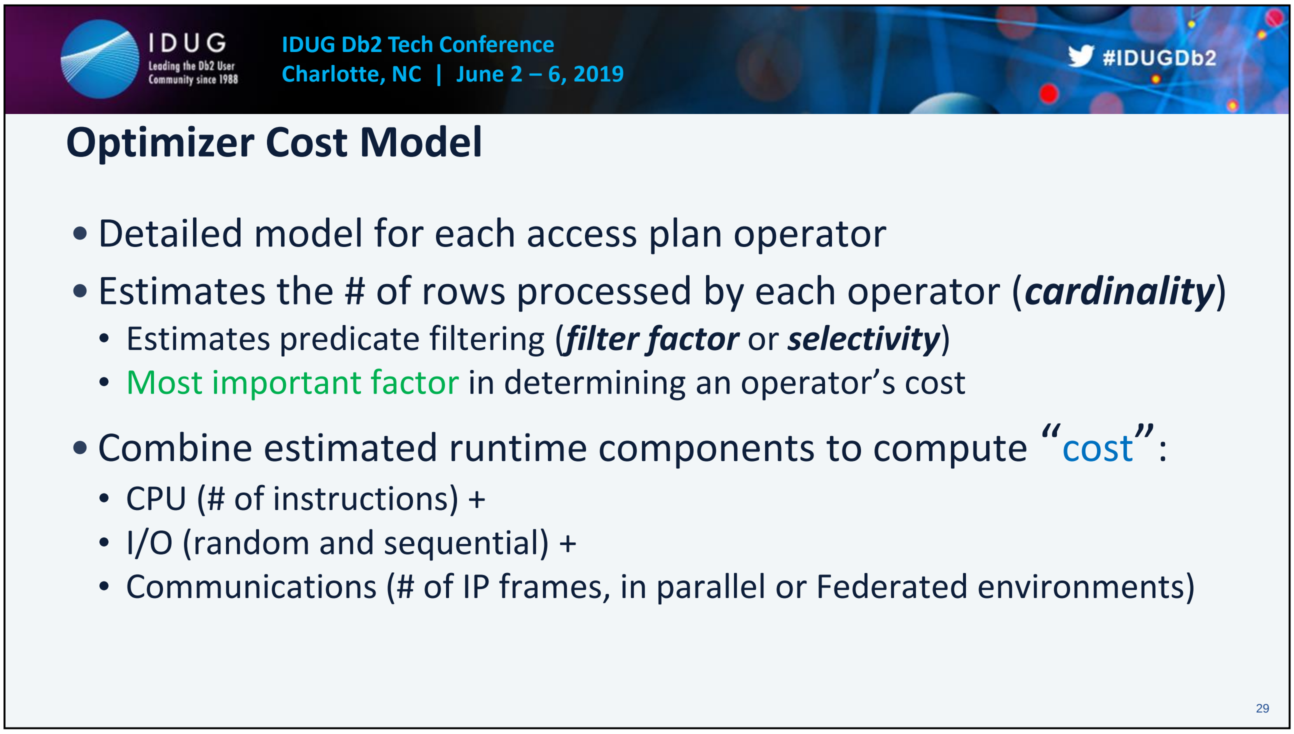
Optimization Classes and Join Enumeration

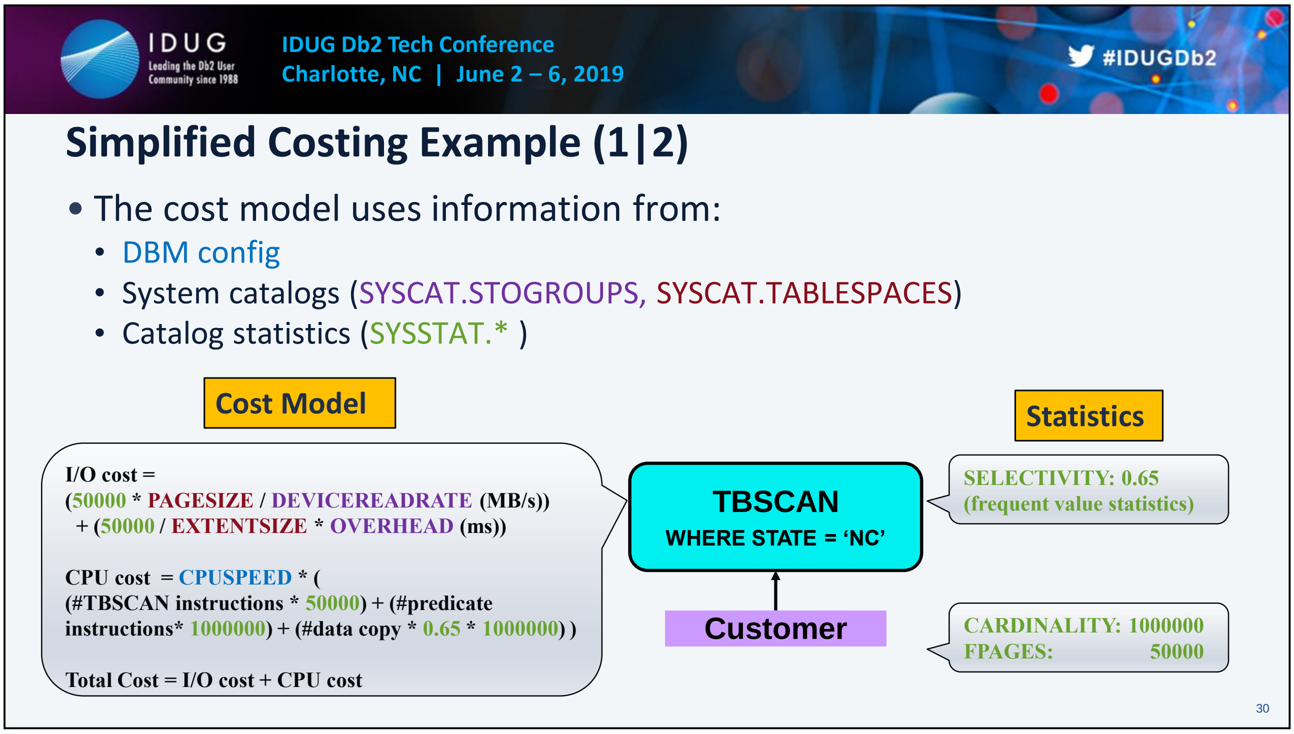
- Use optimization classes to control join enumeration method
- Recommendation – use the default (5)
- **Greedy join enumeration**
  - 0 - minimal optimization for OLTP
  - 1 - low optimization, no HSJOIN, IXSCAN, limited query rewrites
  - 2 - full optimization, limit space/time
    - use same query transforms & join strategies as class 5
- **Dynamic join enumeration**
  - 3 - moderate optimization, more limited plan space
  - 5 - self-adjusting full optimization (default)
    - uses all techniques with heuristics
  - 7 - full optimization
    - similar to 5, without heuristics
  - 9 - maximal optimization
    - spare no effort/expense
    - considers all possible join orders, including Cartesian products!

- Optimization requires processing time and memory
  - You can control resources applied to query optimization
  - (similar to the -O flag in a C compiler)
  - Special register, for dynamic SQL
    - SET CURRENT QUERY OPTIMIZATION = 1
  - Bind option, for static SQL
    - BIND YOURAPP.BND QUERYOPT 1
  - Database configuration parameter, for default
    - UPDATE DB CFG FOR <DB> USING DFT_QUERYOPT <N>
  - Static & dynamic SQL may use different values



Optimizer Cost Model

- Detailed model for each access plan operator
- Estimates the # of rows processed by each operator (***cardinality***)
  - Estimates predicate filtering (***filter factor*** or ***selectivity***)
  - Most important factor in determining an operator's cost
- Combine estimated runtime components to compute "cost":
  - CPU (# of instructions) +
  - I/O (random and sequential) +
  - Communications (# of IP frames, in parallel or Federated environments)



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Simplified Costing Example (1|2)

- The cost model uses information from:
  - DBM config
  - System catalogs (SYSCAT.STOGROUPS, SYSCAT.TABLESPACES)
  - Catalog statistics (SYSSTAT.*)

Cost Model
Statistics
TBSCAN
WHERE STATE = 'NC'
Customer
SELECTIVITY: 0.65 (frequent value statistics)
CARDINALITY: 1000000
FPAGES: 50000

I/O cost =
(50000 * PAGESIZE / DEVICEREADRATE (MB/s))
+ (50000 / EXTENTSIZE * OVERHEAD (ms))

CPU cost = CPUSPEED * (
(#TBSCAN instructions * 50000) + (#predicate instructions* 1000000) + (#data copy * 0.65 * 1000000))

Total Cost = I/O cost + CPU cost

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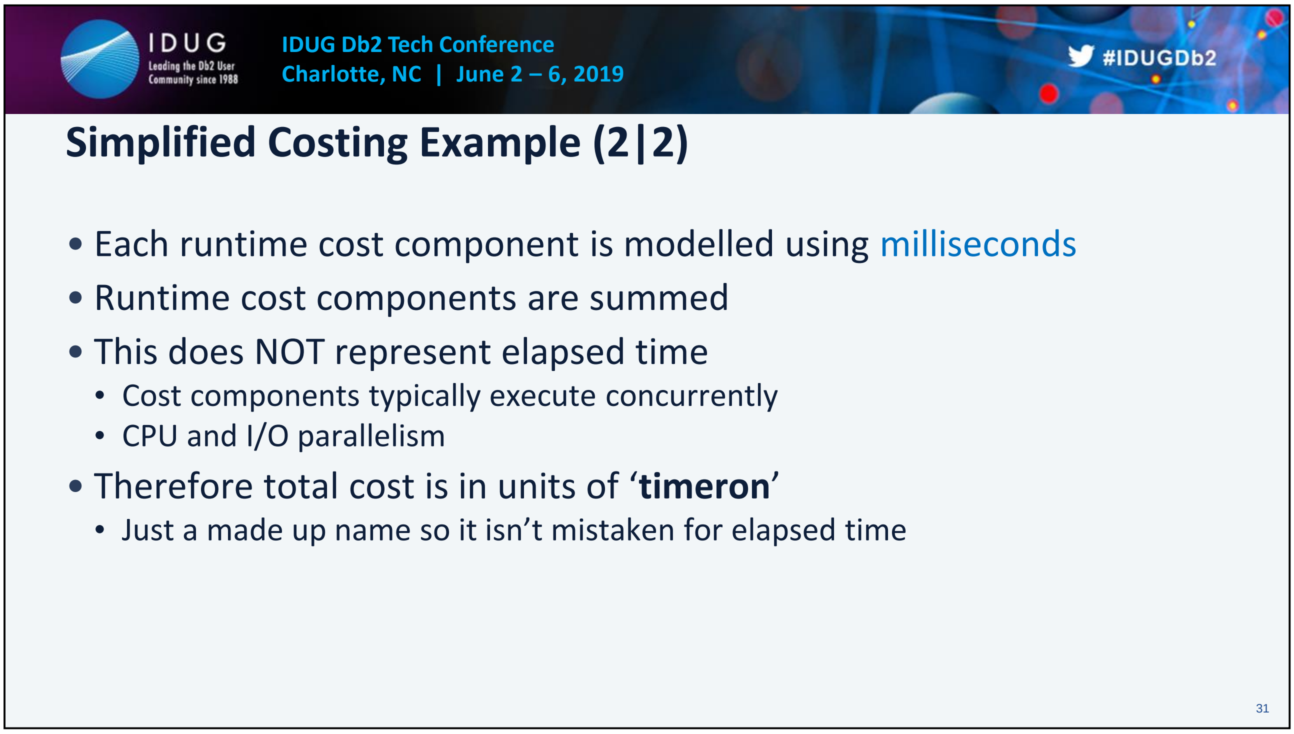
OVERHEAD

This attribute specifies the I/O controller time and the disk seek and latency time in milliseconds.

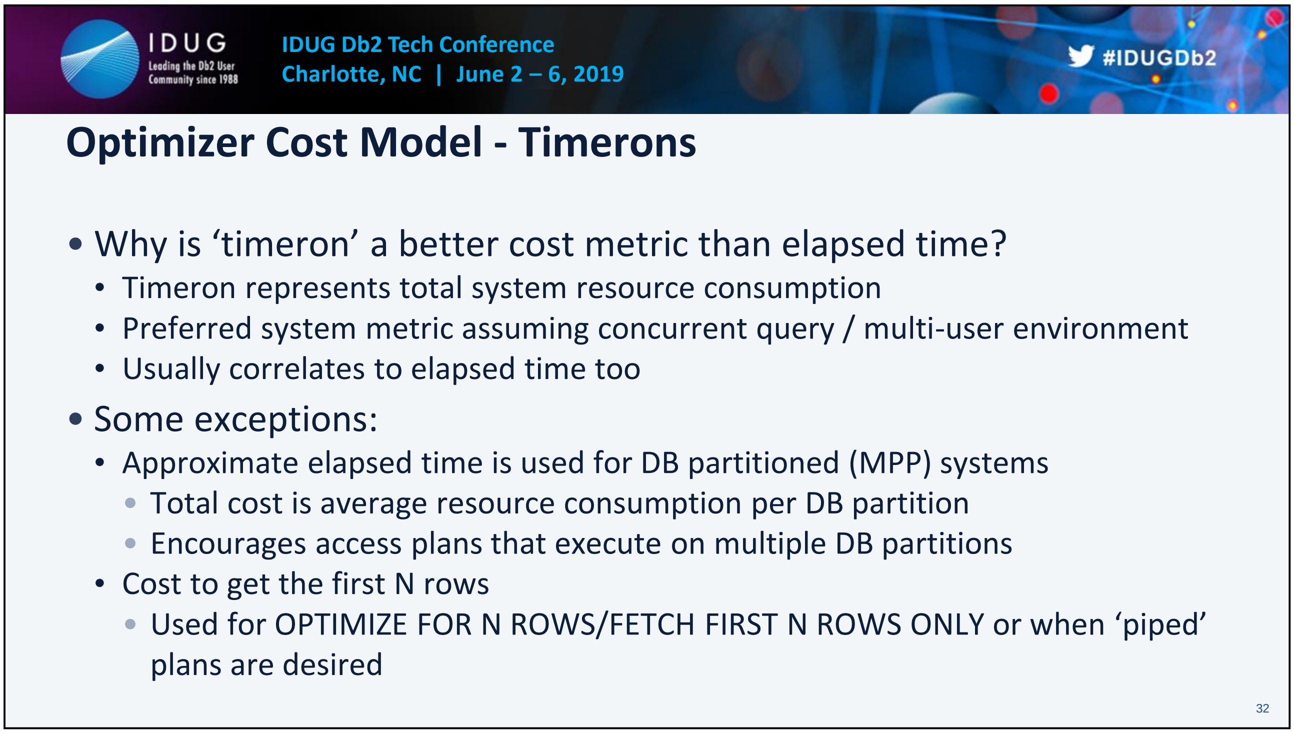
DEVICE READ RATE

This attribute specifies the device specification for the read transfer rate in megabytes per second. This value is used to determine the cost of I/O during query optimization. If this value is not the same for all storage paths, the number should be the average for all storage paths that belong to the storage group.



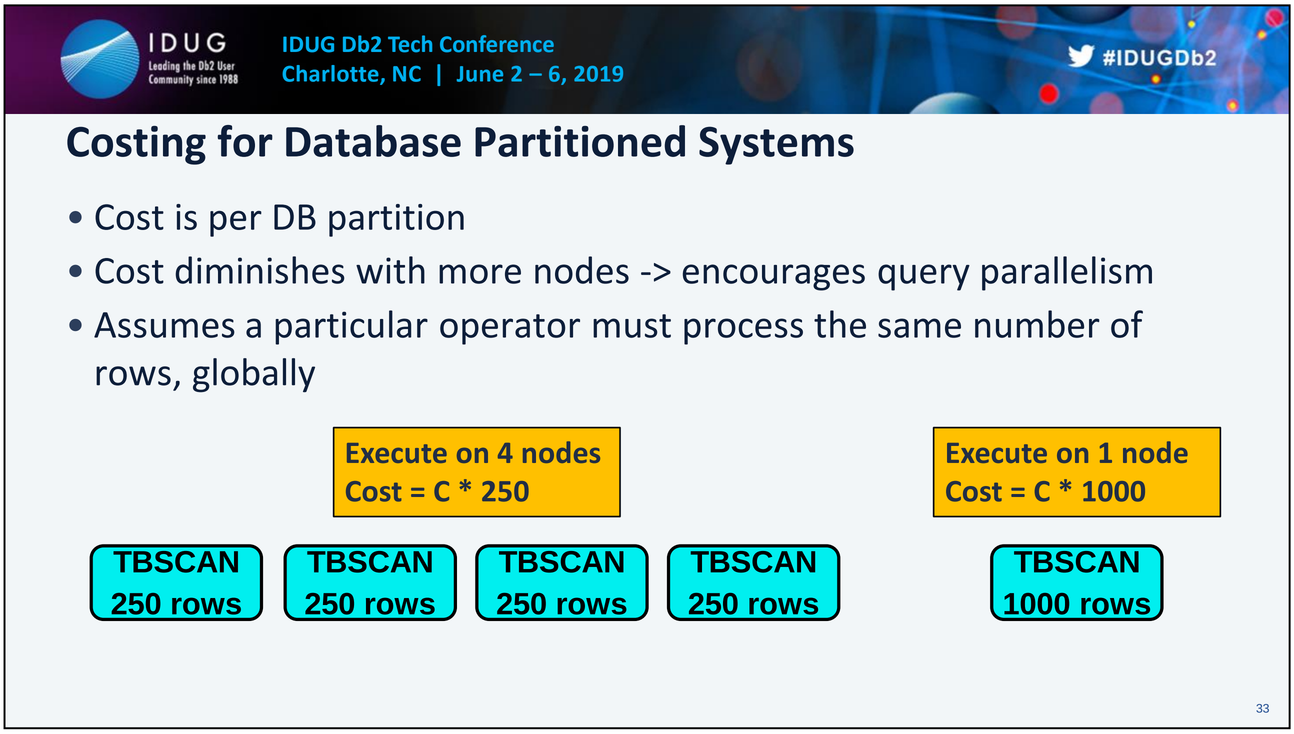
Simplified Costing Example (2|2)

- Each runtime cost component is modelled using milliseconds
- Runtime cost components are summed
- This does NOT represent elapsed time
  - Cost components typically execute concurrently
  - CPU and I/O parallelism
- Therefore total cost is in units of ‘**timeron**’
  - Just a made up name so it isn’t mistaken for elapsed time



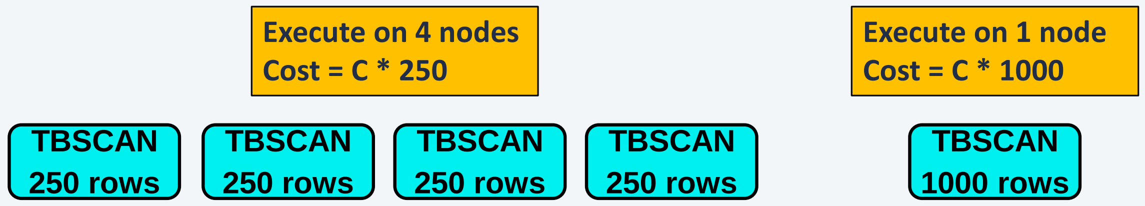
Optimizer Cost Model - Timerons

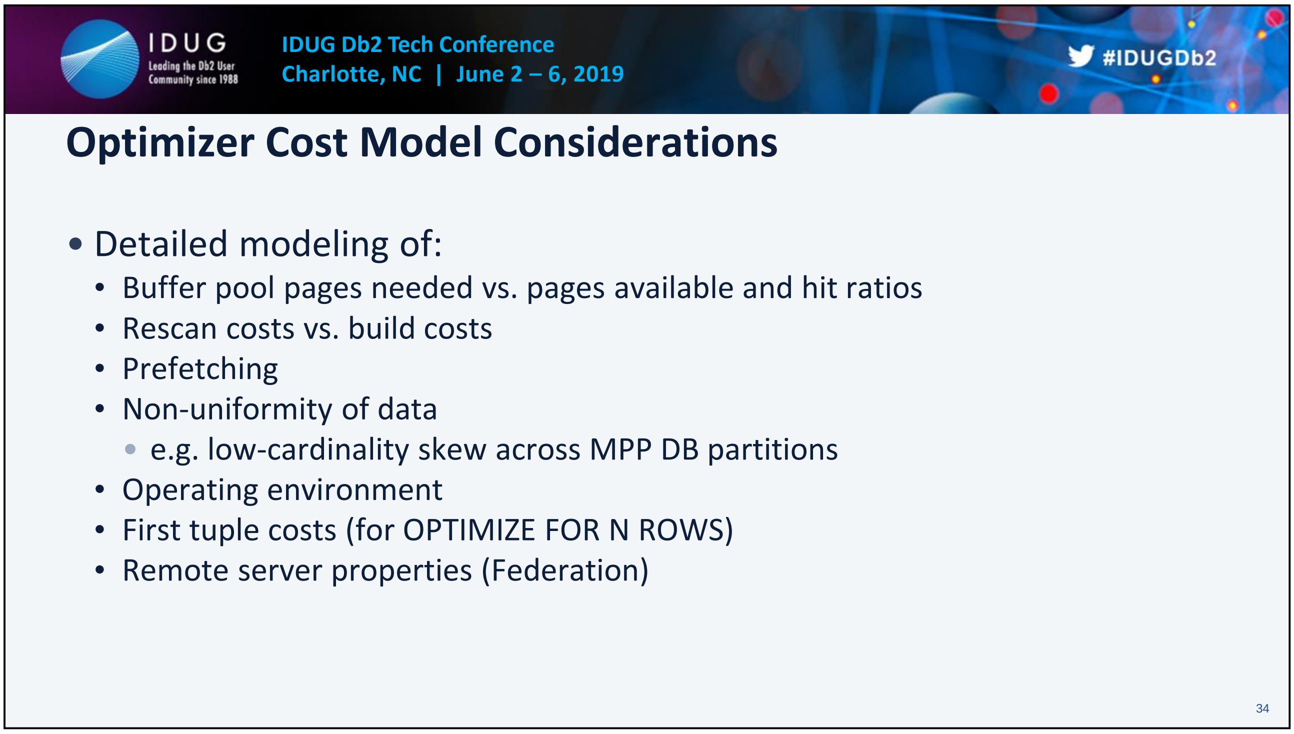
- Why is ‘timeron’ a better cost metric than elapsed time?
  - Timeron represents total system resource consumption
  - Preferred system metric assuming concurrent query / multi-user environment
  - Usually correlates to elapsed time too
- Some exceptions:
  - Approximate elapsed time is used for DB partitioned (MPP) systems
    - Total cost is average resource consumption per DB partition
    - Encourages access plans that execute on multiple DB partitions
  - Cost to get the first N rows
    - Used for OPTIMIZE FOR N ROWS/FETCH FIRST N ROWS ONLY or when ‘piped’ plans are desired



Costing for Database Partitioned Systems

- Cost is per DB partition
- Cost diminishes with more nodes -> encourages query parallelism
- Assumes a particular operator must process the same number of rows, globally



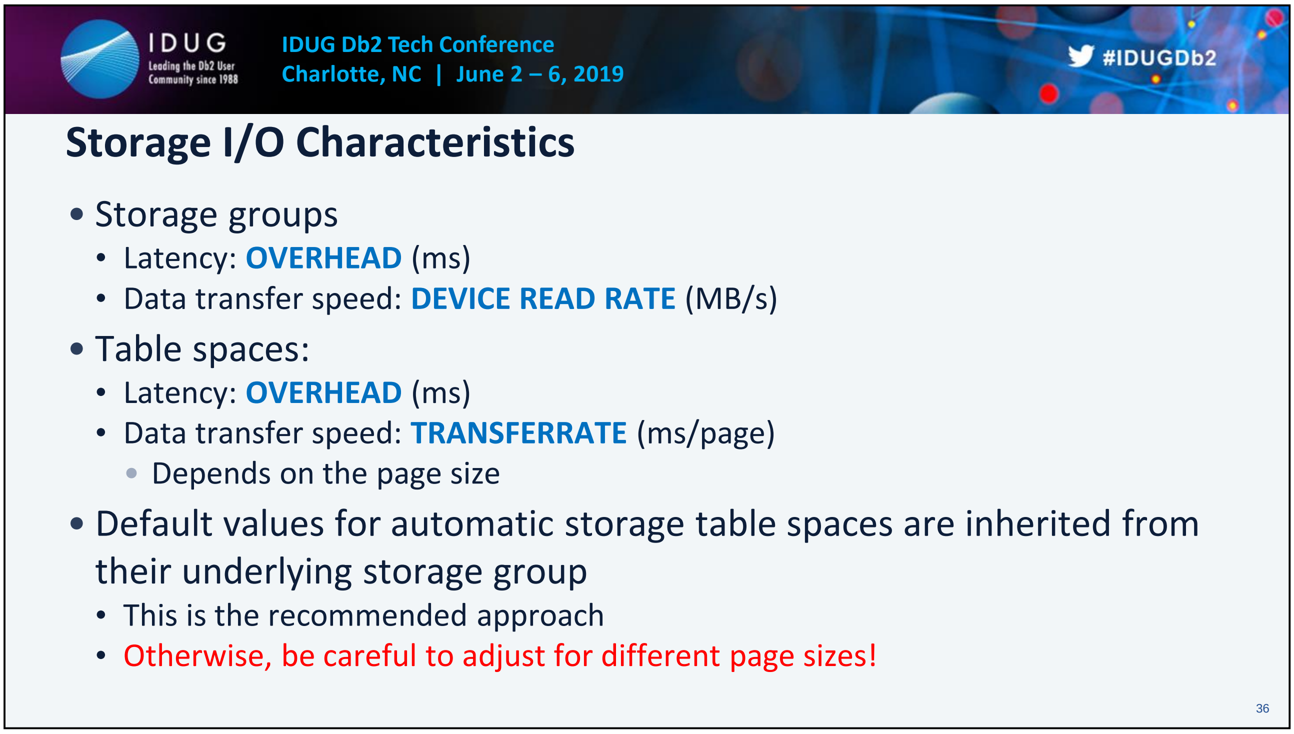


Optimizer Cost Model Considerations

- Detailed modeling of:
  - Buffer pool pages needed vs. pages available and hit ratios
  - Rescan costs vs. build costs
  - Prefetching
  - Non-uniformity of data
    - e.g. low-cardinality skew across MPP DB partitions
  - Operating environment
  - First tuple costs (for OPTIMIZE FOR N ROWS)
  - Remote server properties (Federation)

Optimizer Environment Awareness

- Speed of CPU
  - Determined automatically at instance creation time
  - Runs a timing program
  - Can be set manually (CPUSPEED DBM configuration parameter)
- Storage device characteristics
  - Used to model random and sequential I/O costs
  - I/O speed is based on :
    - I/O subsystem latency
    - Time to transfer data
  - Parameters are represented at the storage group and table space level
  - They are not set automatically by the DB2 server



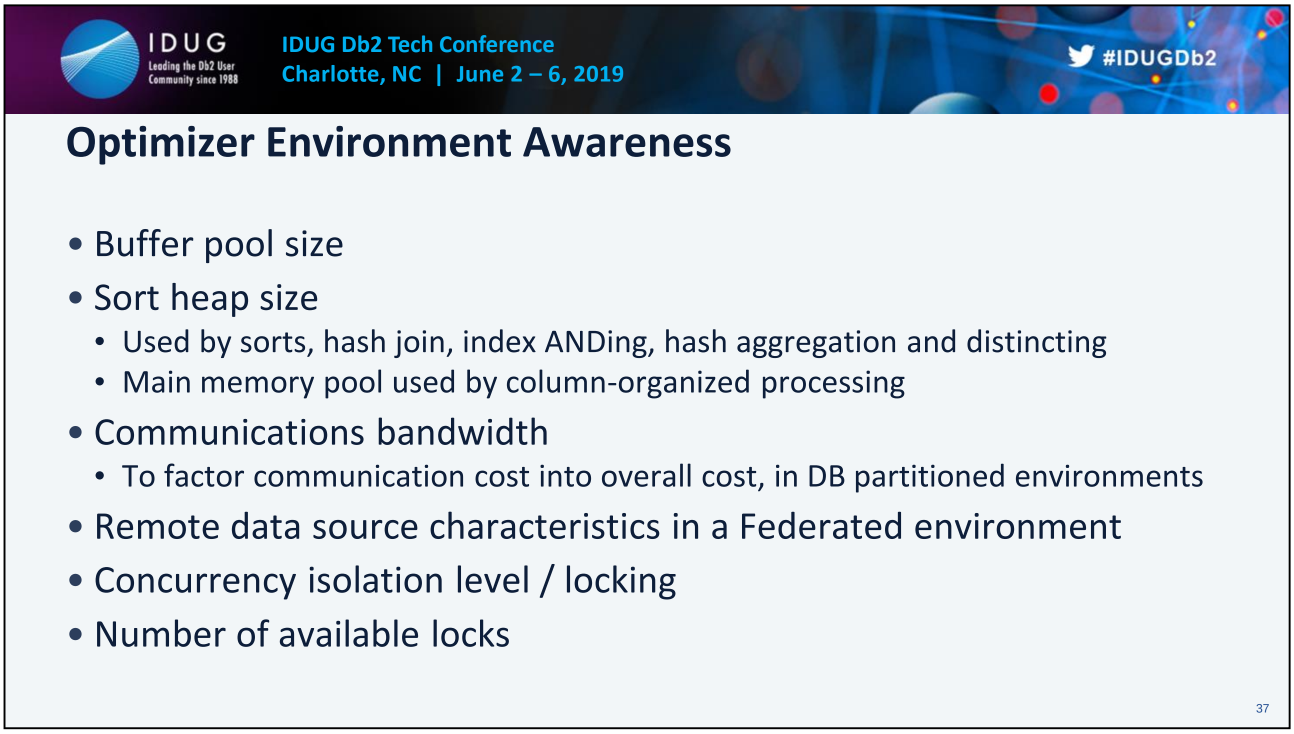
Storage I/O Characteristics

- Storage groups
  - Latency: **OVERHEAD** (ms)
  - Data transfer speed: **DEVICE READ RATE** (MB/s)
- Table spaces:
  - Latency: **OVERHEAD** (ms)
  - Data transfer speed: **TRANSFERRATE** (ms/page)
    - Depends on the page size
- Default values for automatic storage table spaces are inherited from their underlying storage group
  - This is the recommended approach
  - Otherwise, be careful to adjust for different page sizes!

https://www.ibm.com/support/knowledgecenter/en/SSEPGG_11.1.0/com.ibm.db2.luw.admin.perf.doc/doc/c0005051.html

OVERHEAD number-of-milliseconds Specifies the I/O controller usage and disk seek and latency time. This value is used to determine the cost of I/O during query optimization. The value of number-of-milliseconds is any numeric literal (integer, decimal, or floating point). If this value is not the same for all storage paths, set the value to a numeric literal which represents the average for all storage paths that belong to the storage group.If the OVERHEAD clause is not specified, the OVERHEAD will be set to 6.725 milliseconds.

DEVICE READ RATE number-megabytes-per-second Specifies the device specification for the read transfer rate in megabytes per second. This value is used to determine the cost of I/O during query optimization. The value of number-megabytes-per-second is any numeric literal (integer, decimal, or floating point). If this value is not the same for all storage paths, set the value to a numeric literal which represents the average for all storage paths that belong to the storage group. If the DEVICE READ RATE clause is not specified, the DEVICE READ RATE will be set to the built-in default of 100 megabytes per second.

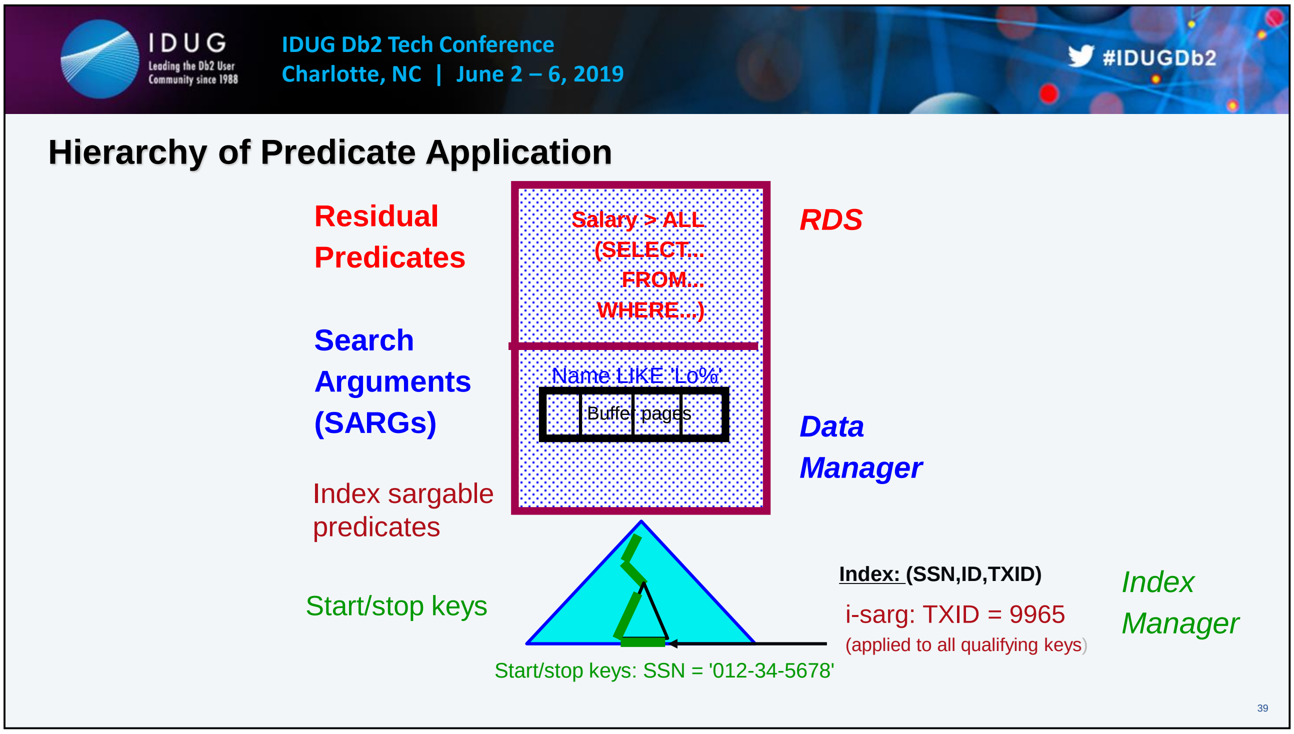


Optimizer Environment Awareness

- Buffer pool size
- Sort heap size
  - Used by sorts, hash join, index ANDing, hash aggregation and distincting
  - Main memory pool used by column-organized processing
- Communications bandwidth
  - To factor communication cost into overall cost, in DB partitioned environments
- Remote data source characteristics in a Federated environment
- Concurrency isolation level / locking
- Number of available locks

Planning and Modelling Predicate Application

- In general, optimizer tries to apply predicates as early as possible
  - Filter rows from stream to avoid unnecessary work
- However, some types of predicates can only be applied in certain locations during query execution
- There is a hierarchy of predicate application
- The explain facility shows where predicates are applied



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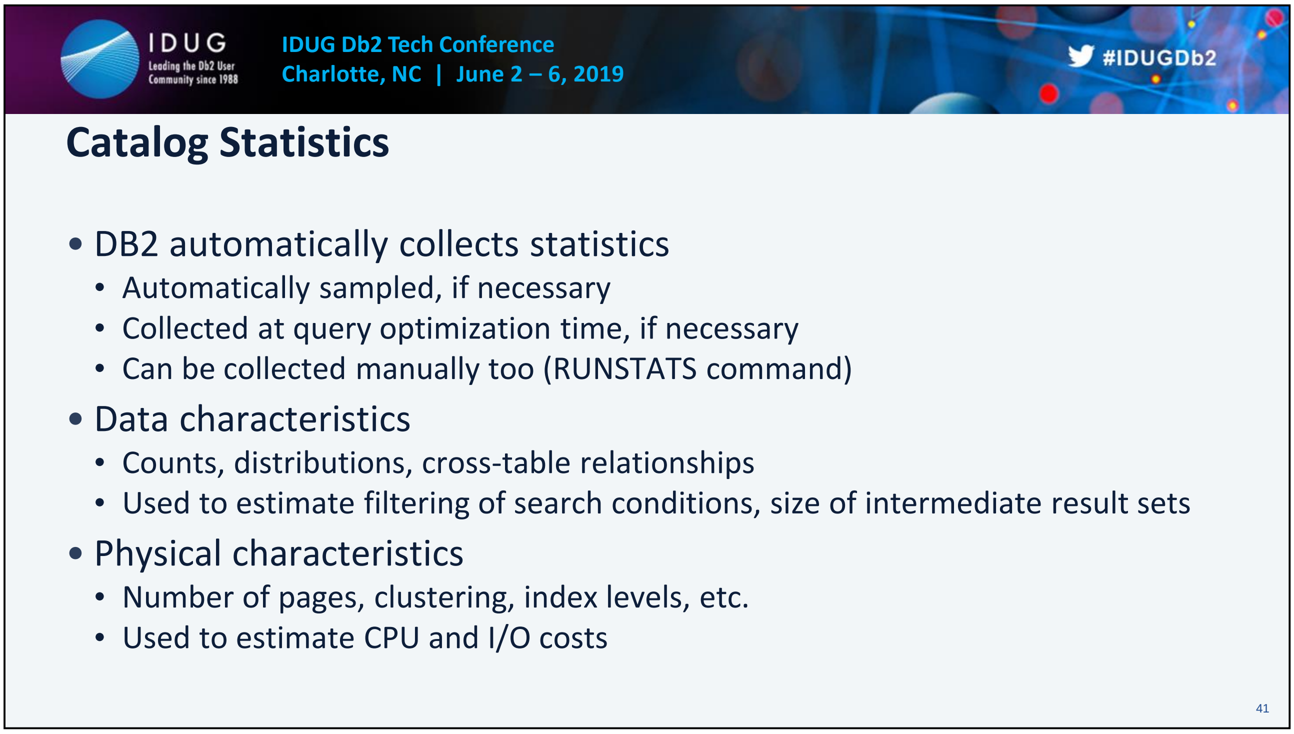
Hierarchy of Predicate Application

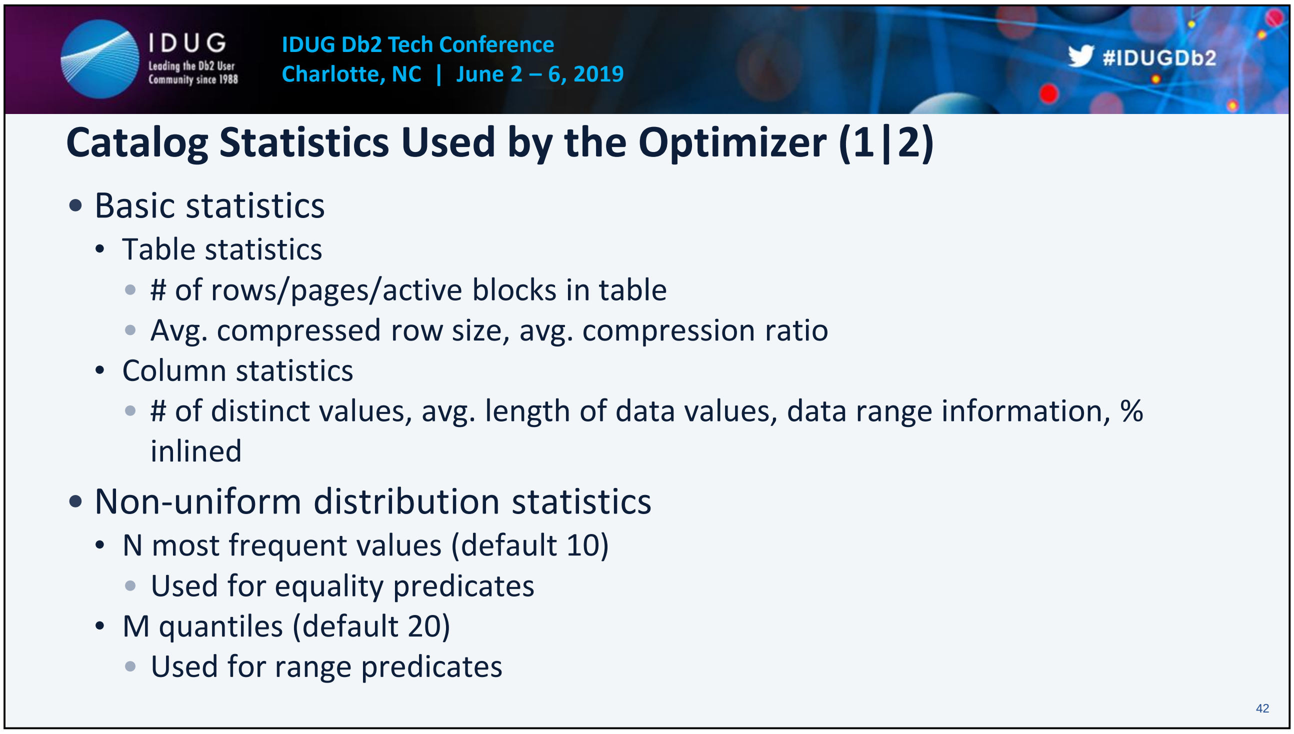
Cardinality Estimation

- *Cardinality* = number of rows
- The optimizer estimates the number of rows processed by each access plan operator
- Based on the number of rows in the table and the *filter factors* of applied predicates.
- This is the biggest impact on estimated cost!
- Catalog statistics are used to estimate filter factors and cardinality



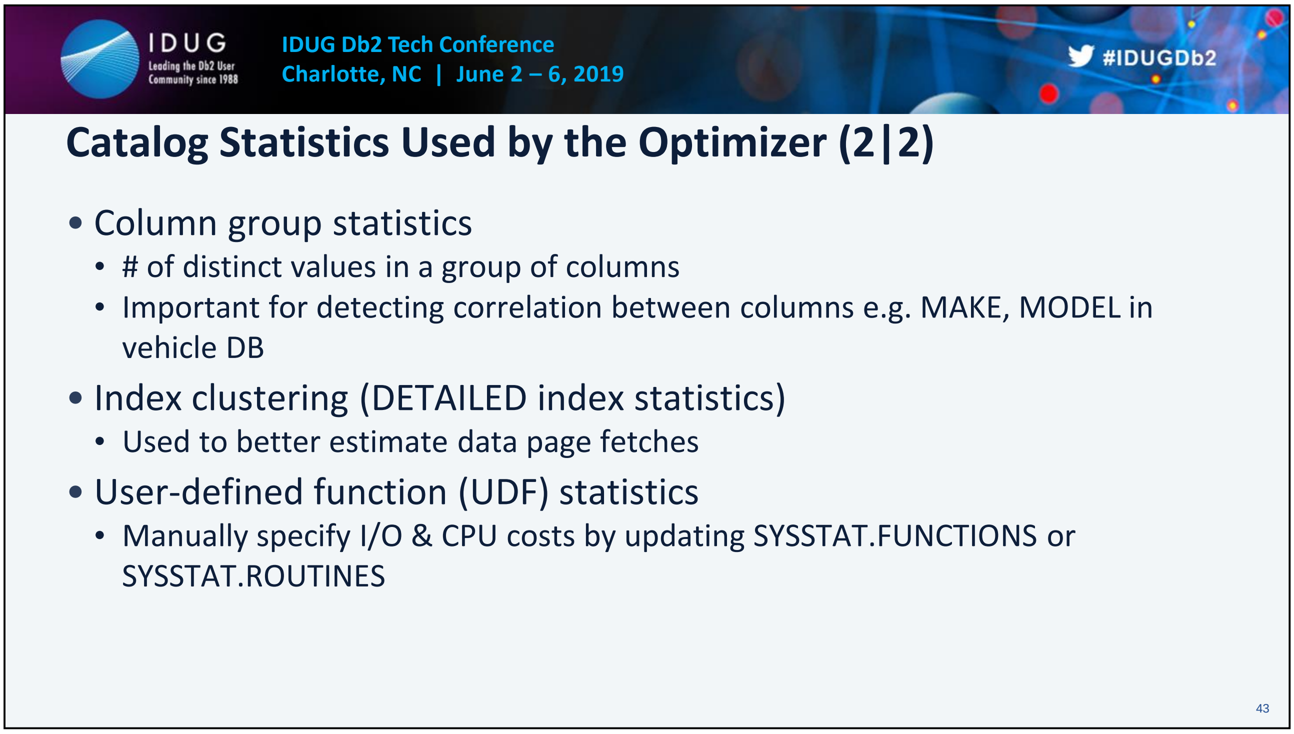
Catalog Statistics

- DB2 automatically collects statistics
  - Automatically sampled, if necessary
  - Collected at query optimization time, if necessary
  - Can be collected manually too (RUNSTATS command)
- Data characteristics
  - Counts, distributions, cross-table relationships
  - Used to estimate filtering of search conditions, size of intermediate result sets
- Physical characteristics
  - Number of pages, clustering, index levels, etc.
  - Used to estimate CPU and I/O costs



Catalog Statistics Used by the Optimizer (1|2)

- Basic statistics
  - Table statistics
    - # of rows/pages/active blocks in table
    - Avg. compressed row size, avg. compression ratio
  - Column statistics
    - # of distinct values, avg. length of data values, data range information, % inlined
- Non-uniform distribution statistics
  - N most frequent values (default 10)
    - Used for equality predicates
  - M quantiles (default 20)
    - Used for range predicates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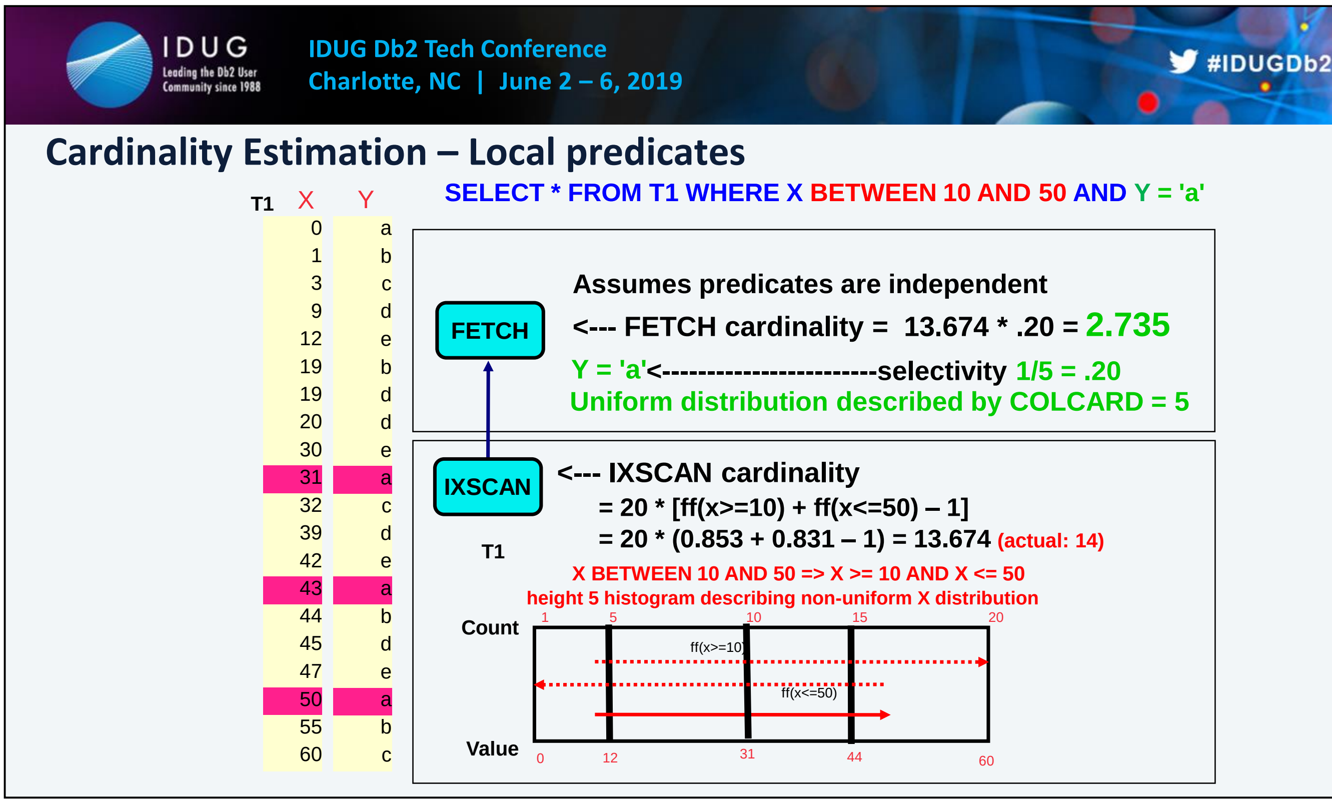
Catalog Statistics Used by the Optimizer (2|2)

- Column group statistics
  - # of distinct values in a group of columns
  - Important for detecting correlation between columns e.g. MAKE, MODEL in vehicle DB
- Index clustering (DETAILED index statistics)
  - Used to better estimate data page fetches
- User-defined function (UDF) statistics
  - Manually specify I/O & CPU costs by updating SYSSTAT.FUNCTIONS or SYSSTAT.ROUTINES

https://www.ibm.com/support/knowledgecenter/en/SSEPGG_11.1.0/com.ibm.db2.luw.admin.perf.doc/doc/c0005114.html

To create statistical information for user-defined functions (UDFs), update the SYSSTAT.ROUTINES catalog view.

The runstats utility does not collect statistics for UDFs. If UDF statistics are available, the optimizer can use them when it estimates costs for various access plans. If statistics are not available, the optimizer uses default values that assume a simple UDF.



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Cardinality Estimation – Local predicates

SELECT * FROM T1 WHERE X BETWEEN 10 AND 50 AND Y = 'a'

T1

X	Y
0	a
1	b
3	c
9	d
12	e
19	b
19	d
20	d
30	e
31	a
32	c
39	d
42	e
43	a
44	b
45	d
47	e
50	a
55	b
60	c

FETCH

Assumes predicates are independent

<--- FETCH cardinality = 13.674 * .20 = 2.735

Y = 'a'<-------------------------selectivity 1/5 = .20

Uniform distribution described by COLCARD = 5

IXSCAN

T1

<--- IXSCAN cardinality

= 20 * [ff(x>=10) + ff(x<=50) – 1]

= 20 * (0.853 + 0.831 – 1) = 13.674 (actual: 14)

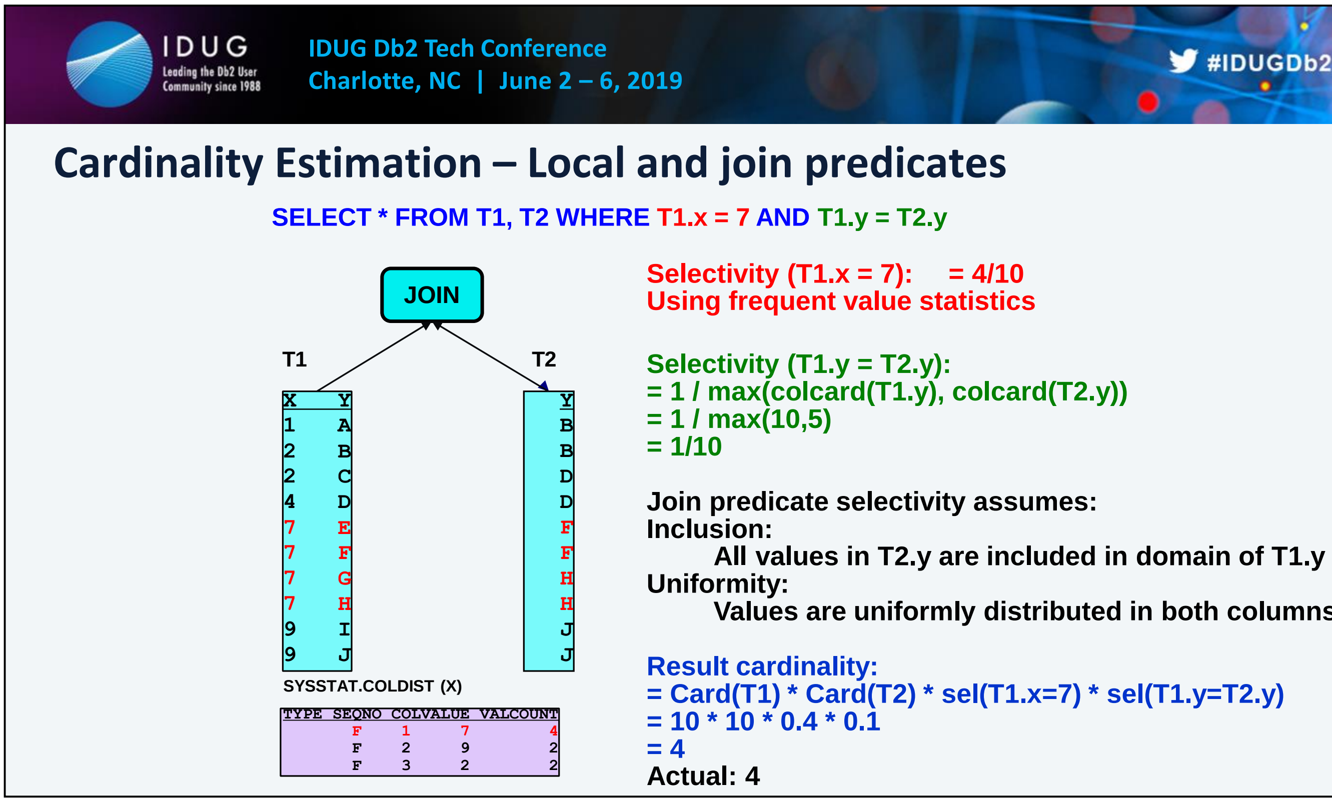
X BETWEEN 10 AND 50 => X >= 10 AND X <= 50

height 5 histogram describing non-uniform X distribution

The histogram example would actually be computed using the following approach, assuming 5 quantiles are collected:

```
Histogram Descriptor :
      Count    Distcount    Value_len    Value
      ----------------------------------------
      1        0            4            0
      5        0            4            12
      10       0            4            31
      15       0            4            44
      20       0            4            60
```

```
ff1  = ff(x<=50)
     = total count of 1st 3 histogram/total cardinality +
       (interpolate into 4th histogram) *
        (count of 4th histogram/total cardinality)
     = 15/20 + (50-44+1)/(60-44+1) * 0.25 = 0.852941
ff2  = ff(x>=10) = ( 1 - ff(x<10))
     = (use same method as ff(x<=50)
     = 1 - (10-0+1)/(12-0+1) * 0.20 = 0.830769
ff = ff1+ff2-1 = 0.68371
Cardinality = 20 * 0.68371 = 13.6742
```



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Cardinality Estimation – Local and join predicates

SELECT * FROM T1, T2 WHERE T1.x = 7 AND T1.y = T2.y

JOIN

T1

X	Y
1	A
2	B
2	C
4	D
7	E
7	F
7	G
7	H
9	I
9	J

T2

Y
B
B
D
D
F
F
H
H
J
J

SYSSTAT.COLDIST (X)

TYPE	SEQNO	COLVALUE	VALCOUNT
F	1	7	4
F	2	9	2
F	3	2	2

Selectivity (T1.x = 7): = 4/10
Using frequent value statistics

Selectivity (T1.y = T2.y):
= 1 / max(colcard(T1.y), colcard(T2.y))
= 1 / max(10,5)
= 1/10

Join predicate selectivity assumes:
Inclusion:
All values in T2.y are included in domain of T1.y
Uniformity:
Values are uniformly distributed in both columns

Result cardinality:
= Card(T1) * Card(T2) * sel(T1.x=7) * sel(T1.y=T2.y)
= 10 * 10 * 0.4 * 0.1
= 4
Actual: 4

Cardinality of T1: C(T1) = 10
Cardinality of T2: C(T2) = 10
Column cardinality of T1.Y: CC(T1.Y) = 10
Column cardinality of T2.Y: CC(T2.Y) = 5

Assuming even data distribution, there are the same number of duplicate values for each distinct value.

DC1 = C(T1)/CC(T1.Y) = 1
DC2 = C(T2)/CC(T2.Y) = 2

The column cardinality of the join result is min(CC(T1.Y),CC(T2.Y)). i.e. the number of distinct values that can occur in T1.Y and T2.Y after the join predicate is applied.
The number of rows returned by the join is the minimal join column cardinality times the number of duplicate values that can occur for each distinc
value for each join column.

```
 min(CC(T1.Y),CC(T2.Y)) * DC1 * DC2 =

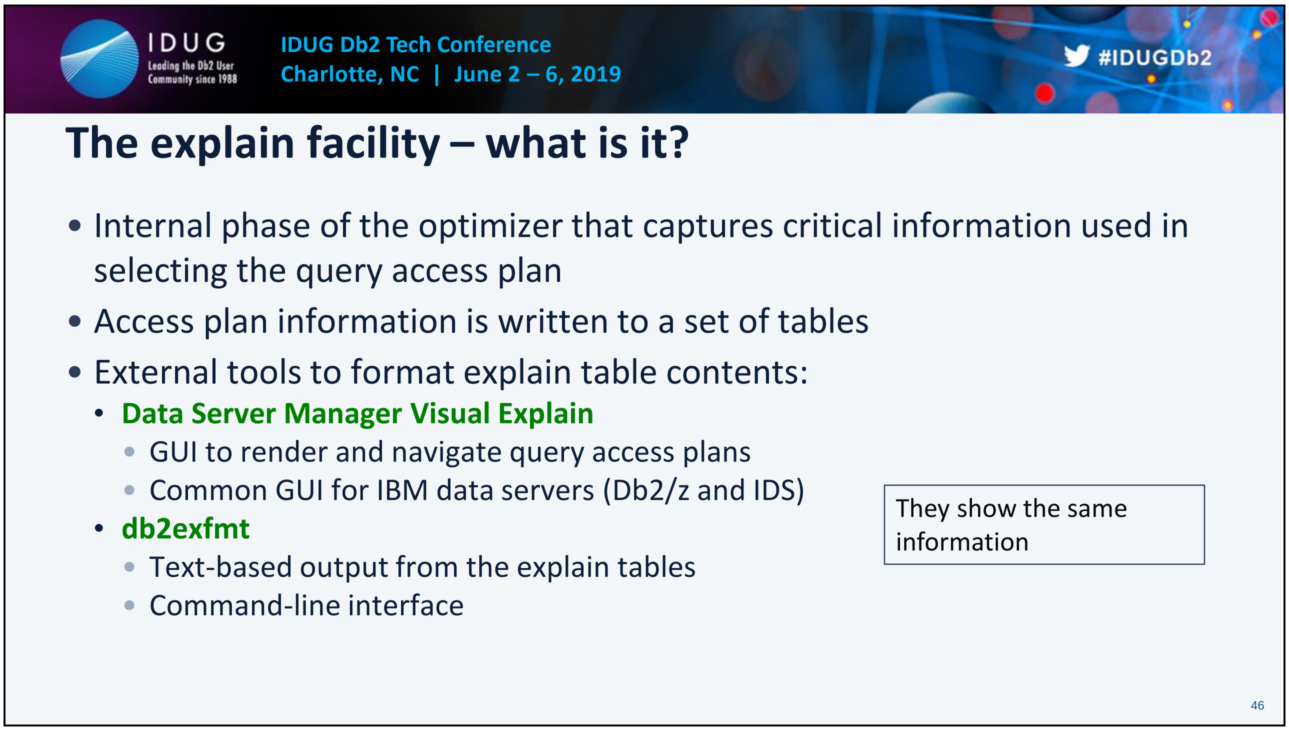
  min(CC(T1.Y),CC(T2.Y)) * (C(T1)/CC(T1.Y)) * (C(T2)/CC(T2.Y)) =

  min(CC(T1.Y) ,CC(T2.Y))
  ----------------------------- * C(T1) * C(T2) =
   CC(T1.Y) * CC(T2.Y)

      1
  ----------------------------  * C(T1) * C(T2)
  max(CC(T1.Y),CC(T2.Y))


  C(T1) * C(T2) = cardinality of Cartesian product of T1 and T2

     1
  ------------------------------- = selectivity of join predicate
```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The explain facility – what is it?

- Internal phase of the optimizer that captures critical information used in selecting the query access plan
- Access plan information is written to a set of tables
- External tools to format explain table contents:
  - **Data Server Manager Visual Explain**
    - GUI to render and navigate query access plans
    - Common GUI for IBM data servers (Db2/z and IDS)
  - **db2exfmt**
    - Text-based output from the explain tables
    - Command-line interface

They show the same information

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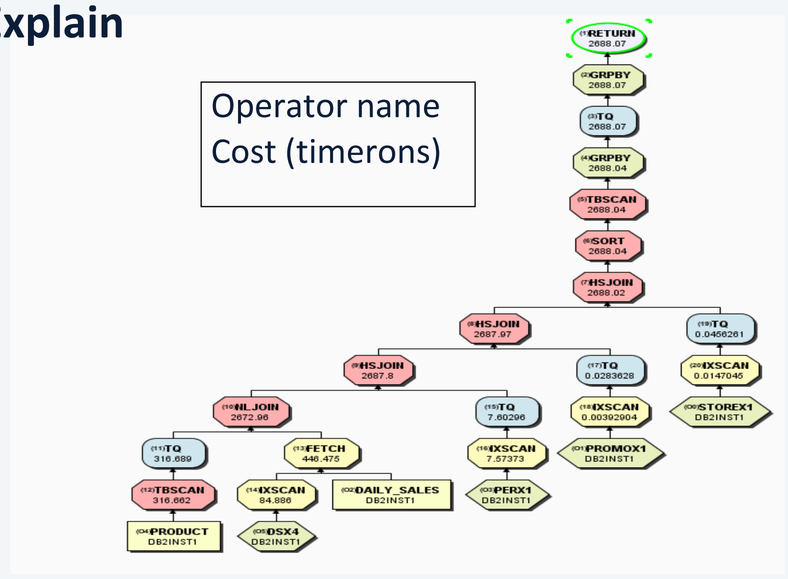
The explain facility is used to display the query access plan chosen by the query optimizer to run an SQL statement. It contains extensive details about the relational operations used to run the SQL statement such as the plan operators, their arguments, order of execution, and costs. Since the query access plan is one of the most critical factors in query performance, it is important to be able to understand the explain facility output in order to diagnose query performance problems.

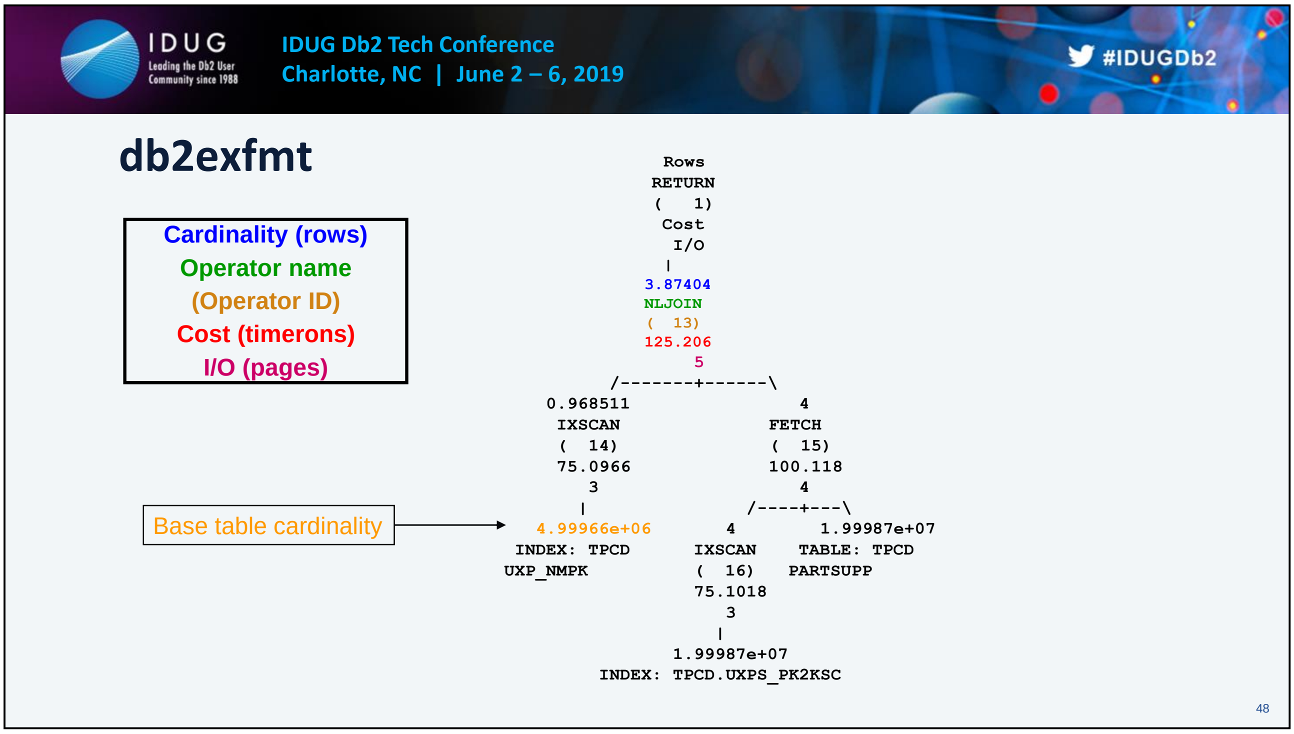
Explain information is typically used to:

- understand why application performance has changed
- evaluate performance tuning efforts

Visual Explain

Operator name
Cost (timerons)



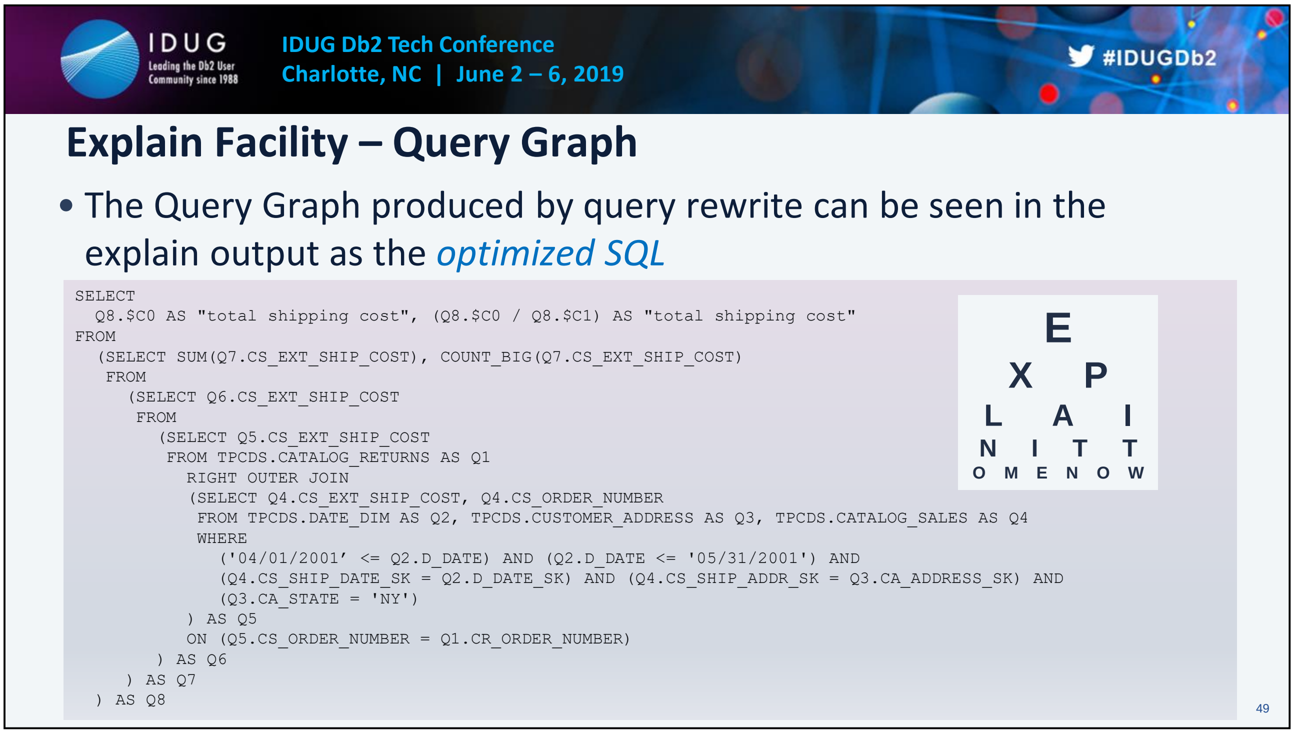


db2exfmt

Cardinality (rows)
Operator name
(Operator ID)
Cost (timerons)
I/O (pages)

Base table cardinality

```
                  Rows
                 RETURN
                 (   1)
                  Cost
                   I/O
                  |
                3.87404
                NLJOIN
                (  13)
                125.206
                   5
           /-------+------\
     0.968511              4
      IXSCAN             FETCH
      (  14)             (  15)
      75.0966            100.118
         3                  4
        |               /----+---\
    4.99966e+06        4        1.99987e+07
  INDEX: TPCD       IXSCAN    TABLE: TPCD
 UXP_NMPK           (  16)   PARTSUPP
                    75.1018
                       3
                      |
                  1.99987e+07
         INDEX:  TPCD.UXPS_PK2KSC
```



Explain Facility – Query Graph

- The Query Graph produced by query rewrite can be seen in the explain output as the *optimized SQL*

```
SELECT
  Q8.$C0 AS "total shipping cost", (Q8.$C0 / Q8.$C1) AS "total shipping cost"
FROM
  (SELECT SUM(Q7.CS_EXT_SHIP_COST), COUNT_BIG(Q7.CS_EXT_SHIP_COST)
   FROM
     (SELECT Q6.CS_EXT_SHIP_COST
      FROM
        (SELECT Q5.CS_EXT_SHIP_COST
         FROM TPCDS.CATALOG_RETURNS AS Q1
           RIGHT OUTER JOIN
           (SELECT Q4.CS_EXT_SHIP_COST, Q4.CS_ORDER_NUMBER
            FROM TPCDS.DATE_DIM AS Q2, TPCDS.CUSTOMER_ADDRESS AS Q3, TPCDS.CATALOG_SALES AS Q4
            WHERE
              ('04/01/2001' <= Q2.D_DATE) AND (Q2.D_DATE <= '05/31/2001') AND
              (Q4.CS_SHIP_DATE_SK = Q2.D_DATE_SK) AND (Q4.CS_SHIP_ADDR_SK = Q3.CA_ADDRESS_SK) AND
              (Q3.CA_STATE = 'NY')
           ) AS Q5
           ON (Q5.CS_ORDER_NUMBER = Q1.CR_ORDER_NUMBER)
        ) AS Q6
     ) AS Q7
  ) AS Q8
```

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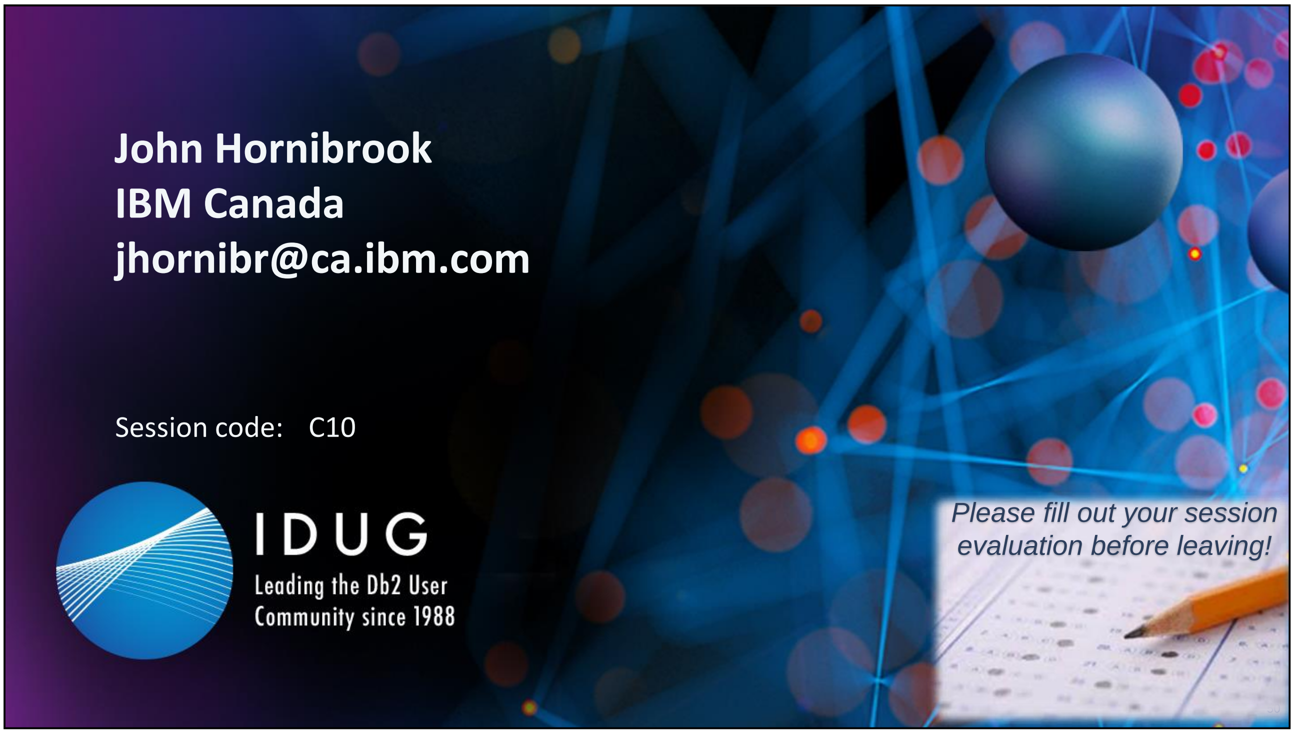
```
SELECT
  Q8.$C0 AS "total shipping cost", (Q8.$C0 / Q8.$C1) AS "total shipping cost"
FROM
  (SELECT SUM(Q7.CS_EXT_SHIP_COST), COUNT_BIG(Q7.CS_EXT_SHIP_COST)
   FROM
     (SELECT Q6.CS_EXT_SHIP_COST
      FROM
        (SELECT Q5.CS_EXT_SHIP_COST
         FROM TPCDS.CATALOG_RETURNS AS Q1
           RIGHT OUTER JOIN
           (SELECT Q4.CS_EXT_SHIP_COST, Q4.CS_ORDER_NUMBER
            FROM TPCDS.DATE_DIM AS Q2, TPCDS.CUSTOMER_ADDRESS AS Q3,
TPCDS.CATALOG_SALES AS Q4
            WHERE
              ('04/01/2001' <= Q2.D_DATE) AND (Q2.D_DATE <= '05/31/2001') AND
              (Q4.CS_SHIP_DATE_SK = Q2.D_DATE_SK) AND (Q4.CS_SHIP_ADDR_SK =
Q3.CA_ADDRESS_SK) AND
              (Q3.CA_STATE = 'NY')
           ) AS Q5
           ON (Q5.CS_ORDER_NUMBER = Q1.CR_ORDER_NUMBER)
        ) AS Q6
     ) AS Q7
  ) AS Q8
```



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Session code: C10

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John is a Senior Technical Staff Member responsible for relational database query optimization on IBM's distributed platforms. This technology is part of Db2 for Linux, UNIX and Windows, Db2 Warehouse, Db2 on Cloud, IBM Integrated Analytics System (IIAS) and Db2 Big SQL. John also works closely with customers to help them maximize their benefits from IBM's relational DB technology products.