

IBM System z Technology Summit



DB2 9 & DB2 10 for z/OS Optimizer

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Agenda

- **Bind/Prepare**
 - Plan management
 - Hints/Bind options
 - Explain
 - Dynamic Statement Caching
 - REOPT
- **Optimizer costing**
- **Runtime query performance**
- **Indexing**
- **Complex queries**

Plan Management Overview

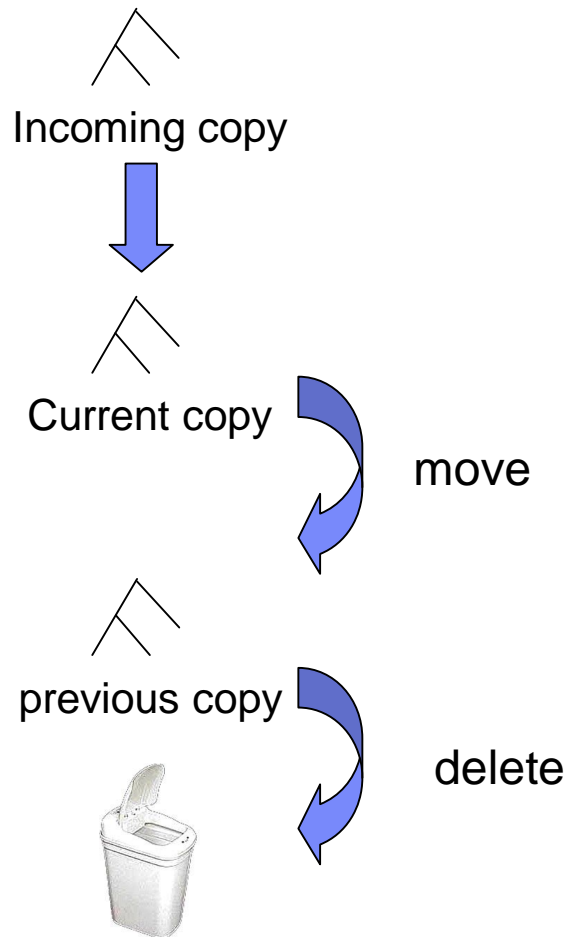
- **Ability to backup your static SQL packages (DB2 9)**

- **At REBIND**
 - Save old copies of packages in Catalog/Directory
 - Switch back to previous or original version

- **Two flavors**
 - BASIC
 - 2 copies: Current and Previous
 - EXTENDED
 - 3 copies: Current, Previous, Original
 - Default controlled by a ZPARM
 - Also supported as REBIND options

Plan Management - BASIC support

REBIND ... PLANMGMT(BASIC)



REBIND ... SWITCH(PREVIOUS)

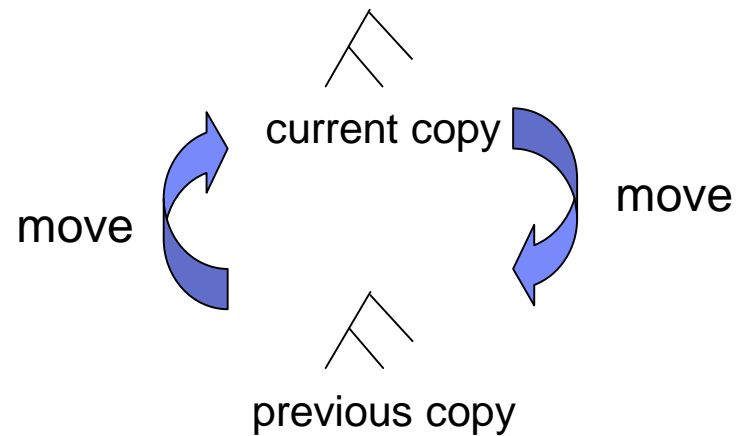
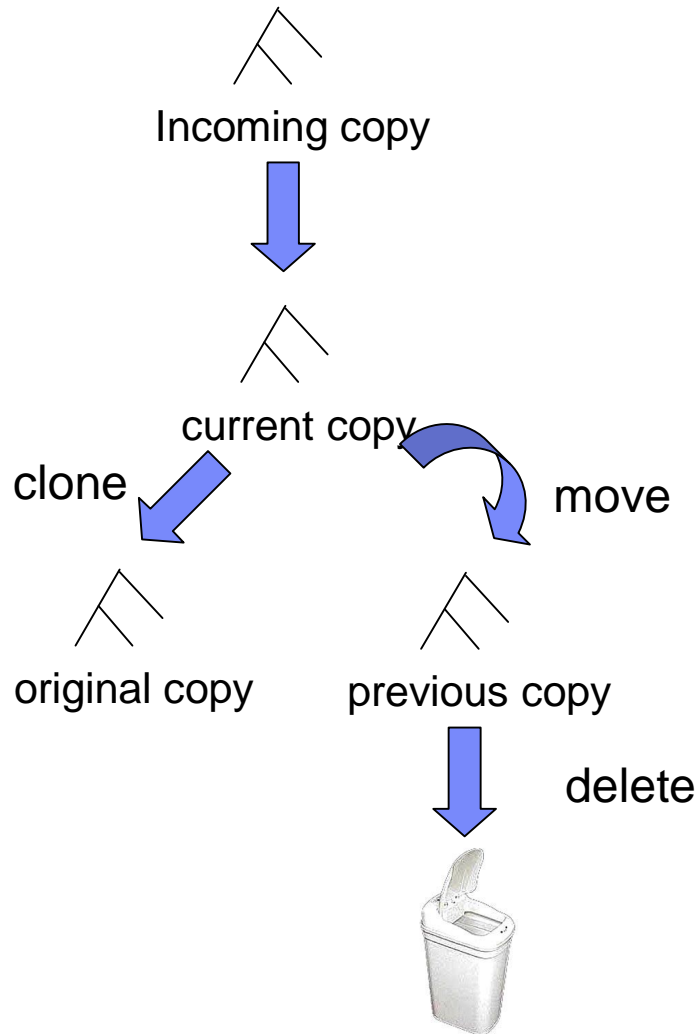


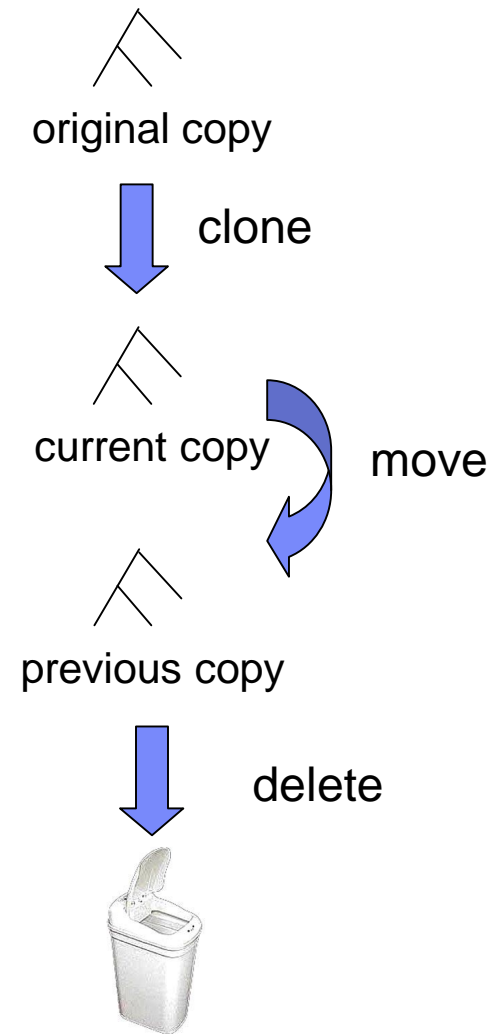
Chart is to be read from bottom to top

Plan Management - EXTENDED support

REBIND ... PLANMGMT(EXTENDED)



REBIND ... SWITCH(ORIGINAL)



DB2 10 Updates to Plan Management

▪ **SYSIBM.SYSPACKCOPY**

- New catalog table
- Hold SYSPACKAGE-style metadata for any previous or original package copies
- No longer need to SWITCH to see information on inactive copies
 - Complaint from DB2 9

▪ **APRETAINDUP option of REBIND**

- Default YES
 - Retain duplicate for BASIC or EXTENDED
- Optional NO
 - Do not retain duplicate access path as PREVIOUS or ORIGINAL
 - PREVIOUS/ORIGINAL must be from DB2 9 or later

What-if? BIND

- **BIND package to see what new**
- **Bind package EXPLAIN(ONLY) and/or SQLERROR(CHECK)**
 - Existing package copies are not overwritten
 - Performs explain or syntax/semantic error checks on SQL
 - Requires BIND, BINDAGENT, or EXPLAIN privilege.
 - Supported for BIND only
 - Not REBIND
 - Targeted to application changes
 - Eg. Development environment is DB2 LUW, production DB2 for z/OS

Retrieving Access Path with EXPLAIN(NO)

▪ EXPLAIN PACKAGE

– Extract existing PLAN_TABLE information for packages 

- NOT a new explain
- The package/copy must be created on DB2 9 or later

– Useful if you didn't BIND with EXPLAIN(YES)

- Or PLAN_TABLE entries are lost

```
>>-EXPLAIN----PACKAGE----->
```

```
>>----COLLECTION--collection-name--PACKAGE--package-name----->
```

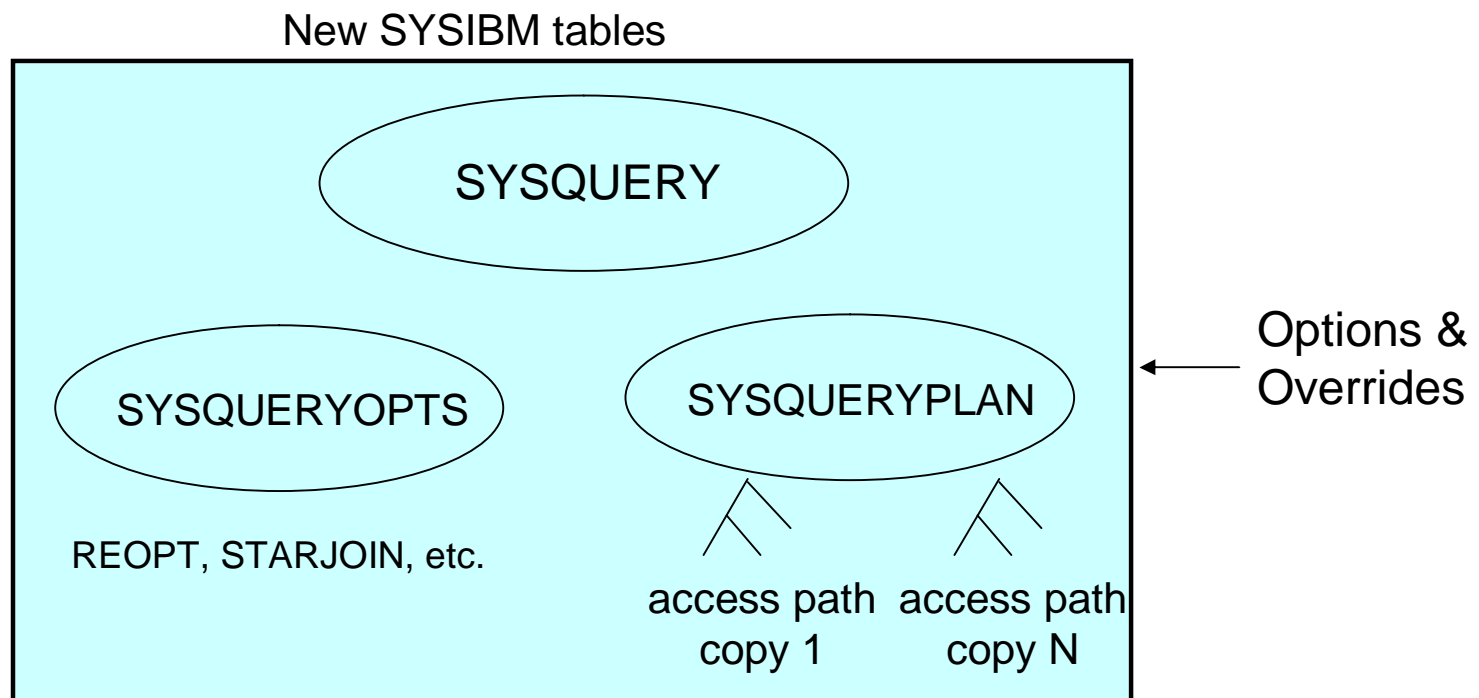
```
>---+-----+-----+-----+----->
      |               |               |               |
      +---VERSION-version-name---+   +---COPY--copy-id---+
      |               |               |               |
```

- COPY-ID can be 'CURRENT', 'PREVIOUS', 'ORIGINAL'

Access Path Stability with statement level hints

- **Current limitations in hint matching**
 - QUERYNO is used to link queries to their hints – a bit fragile
 - For dynamic SQL, require a change to apps – can be impractical
- **New mechanisms:**
 - Associate query text with its corresponding hint ... more robust
 - Hints enforced for the entire DB2 subsystem
 - irrespective of static vs. dynamic, etc.
 - Hints integrated into the access path repository
- **PLAN_TABLE isn't going away**
- **Only the “hint lookup” mechanism is being improved.**

Access Path Repository – Hints/Statement level




Statement level hints (cont.)

▪ Steps to use new hints mechanism

- Populate a user table DSN_USERQUERY_TABLE with query text
- Populate PLAN_TABLE with the corresponding hints
- Run new command BIND QUERY
 - To integrate the hint into the repository.
- FREE QUERY can be used to remove the hint.

Statement-level BIND options

- **Statement-level granularity may be required rather than:**
 - Subsystem level ZPARMs (STARJOIN, SJTABLES, MAX_PAR_DEGREE)
 - Package level BIND options (REOPT, DEF_CURR_DEGREE)
- **For example**
 - Only one statement in the package needs REOPT(ALWAYS) 
- **New mechanism for statement-level bind options:**
 - Similar to mechanism used for hints
 - DSN_USERQUERY_TABLE can also hold per-statement options

Literal Replacement

- **Dynamic SQL with literals can now be re-used in the cache**
 - Literals replaced with &
 - Similar to parameter markers but not the same
- **To enable either you:-**
 - Put CONCENTRATE STATEMENTS WITH LITERALS in the PREPARE ATTRIBUTES clause
 - Or set LITERALREPLACEMENT in the ODBC initialization file
 - Or set the keyword enableLiteralReplacement='YES' in the JCC Driver
- **Lookup Sequence**
 - Original SQL with literals is looked up in the cache
 - If not found, literals are replaced and new SQL is looked up in the cache
 - Additional match on literal usability
 - Can only match with SQL stored with same attribute, not parameter marker
 - If not found, new SQL is prepared and stored in the cache

Literal Replacement ...

- **Example:**

```
WHERE ACCOUNT_NUMBER = 123456
```

– This would be replaced by

```
WHERE ACCOUNT_NUMBER = &
```

- **Performance Expectation**

- Using parameter marker still provides best performance
- Biggest performance gain for repeated SQL with different literals
- NOTE: Access path is not optimized for literals
 - True for parameter markers/host variables today
 - Need to use REOPT for that purpose

Agenda

- **Bind/Prepare**
- **Optimizer costing**
 - RUNSTATS
 - Cost model enhancements
 - Subquery costing
- **Runtime query performance**
- **Indexing**
- **Complex queries**

Histogram Statistics

- **RUNSTATS will produce equal-depth histogram**
 - Each quantile (range) will have approx same number of rows
 - Not same number of values
 - Another term is range frequency

- **Example**

- 1, 3, 3, 4, 4, 6, 7, 8, 9, 10, 12, 15 (sequenced)
- Lets cut that into 3 quantiles.

- 1, 3, 3, 4, 4 6,7,8,9 10,12,15

Seq No	Low Value	High Value	Cardinality	Frequency
1	1	4	3	5/12
2	6	9	4	4/12
3	10	15	3	3/12

Histogram Statistics Notes

▪ RUNSTATS

- Maximum 100 quantiles for a column
- Same value columns WILL be in the same quantile
- Quantiles will be similar size but:
 - Will try to avoid big gaps inside quantiles
 - Highvalue and lowvalue may have separate quantiles
 - Null WILL have a separate quantile

▪ Supports column groups as well as single columns

▪ Think “frequencies” for high cardinality columns

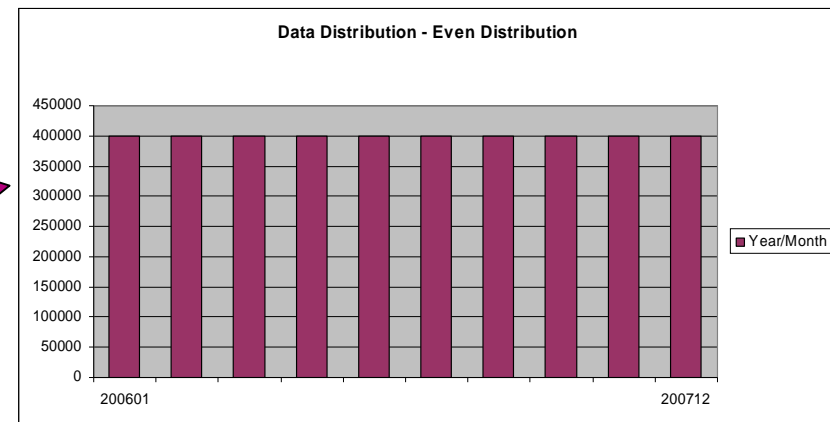
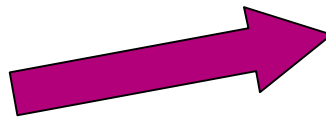
Histogram Statistics Example

- **SAP uses INTEGER (or VARCHAR) for YEAR-MONTH**

WHERE YEARMONTH BETWEEN 200601 AND 200612

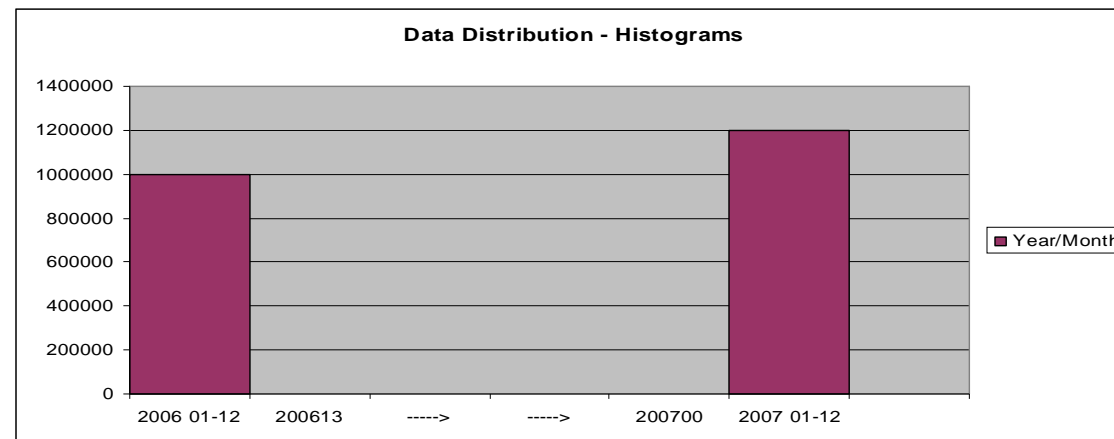
- Assuming data for 2006 & 2007
 - $FF = (\text{high-value} - \text{low-value}) / (\text{high2key} - \text{low2key})$
 - $FF = (200612 - 200601) / (200711 - 200602)$
 - **10% of rows estimated to return**

Data assumed as evenly distributed between low and high range



Histogram Statistics Example

- Example (cont.)
 - Data only exists in ranges 200601-12 & 200701-12
 - Collect via histograms
 - 45% of rows estimated to return



No data between
200613 & 200700

WHERE YEARMONTH BETWEEN 200601 AND 200612

Autonomic Statistics Solution Overview

- **Autonomic Statistics is implemented through a set of Stored Procedures**

- *Stored procedures are provided to enable administration tools and packaged applications to automate statistics collection.*

- ADMIN_UTL_MONITOR
- ADMIN_UTL_EXECUTE
- ADMIN_UTL_MODIFY

- Working together, these SP's


- Determine what stats to collect
- Determine when stats need to be collected
- Schedule and Perform the stats collection
- Records activity for later review

- *See Chapter 11 "Designing DB2 statistics for performance" in the DB2 10 for z/OS Performance Monitoring and Tuning Guide for details on how to configure autonomic monitoring directly within DB2.*

RUNSTATS Simplification/Performance Overview

▪ RUNSTATS options to SET/UPDATE/USE a stats profile

– Integrate specialized statistics into generic RUNSTATS job

- RUNSTATS ... TABLE tbl COLUMN(C1)... **SET PROFILE** 
 - Alternatively use **SET PROFILE FROM EXISTING STATS**
- RUNSTATS ... TABLE tbl COLUMN(C5)... **UPDATE PROFILE**
- RUNSTATS ... TABLE tbl **USE PROFILE**

▪ New option for page-level sampling

– But what percentage of sampling to use?

- RUNSTATS ... TABLE tbl **TABLESAMPLE SYSTEM AUTO** 

Optimizer Validation with Realtime Stats

- **Index Probing & RTS lookup**



- Estimate # of rids within a given start/stop index key range at bind/prepare

- **Exploited when these two conditions are met.**

- Query has matching index-access local predicate
- Predicate contain literals, or REOPT(ALWAYS|ONCE|AUTO)

- **And 1 of the following is also true**

- Predicate is estimated to qualify no rows
- Stats indicate the table contains no rows
- Table is defined as VOLATILE or qualifies for NPGTHRS

- **New EXPLAIN table to externalize runtime estimates**

- User managed DSN_COLDIST_TABLE

DB2 10 - Minimizing Optimizer Challenges

- **Potential causes of sub-optimal plans**

- Insufficient statistics
- Unknown literal values used for host variables or parameter markers


- **DB2 10 Optimizer will evaluate the risk for each predicate**



- For example: WHERE BIRTHDATE < ?
 - Could qualify 0-100% of data depending on literal value used
- As part of access path selection
 - Compare access paths with close cost and choose lowest risk plan

Extending VOLATILE TABLE usage

- **VOLATILE TABLE support added in DB2 V8**
 - Targeted to SAP Cluster Tables
 - Use Index access whenever possible
 - **Avoids list prefetch**
 - Can be a problem for OR predicates or UPDATES at risk of loop

- **DB2 10 provides VOLATILE to general cases**
 - Tables matching SAP cluster tables will maintain original limitations
 - Table with 1 unique index
 - Tables with > 1 index will follow NPGTHRSH rules
 - Use Index access whenever possible
 - **No limitation on list prefetch** 
 - Less chance of getting r-scan when list-prefetch plan is only alternative

Global Optimization - Problem Scenario 1

- **V8, Large Non-correlated subquery is materialized***

```
SELECT * FROM SMALL_TABLE A
WHERE A.C1 IN
      (SELECT B.C1 FROM BIG_TABLE B)
```

- “BIG_TABLE” is scanned and put into workfile
- “SMALL_TABLE” is joined with the workfile

- **V9 may rewrite non-correlated subquery to correlated**

- Much more efficient if scan / materialisation of BIG_TABLE was avoided
- Allows matching index access on BIG_TABLE

```
SELECT * FROM SMALL_TABLE A
WHERE EXISTS
      (SELECT 1 FROM BIG_TABLE B WHERE B.C1 = A.C1)
```

Global Optimization - Problem Scenario 2

- **V8, Large outer table scanned rather than using matching index access***

```
SELECT * FROM BIG_TABLE A
```

```
WHERE EXISTS
```

```
(SELECT 1 FROM SMALL_TABLE B WHERE A.C1 = B.C1)
```

- “BIG_TABLE” is scanned to obtain A.C1 value
- “SMALL_TABLE” gets matching index access

- **V9 may rewrite correlated subquery to non-correlated**

```
SELECT * FROM BIG_TABLE A
```

```
WHERE A.C1 IN
```

```
(SELECT B.C1 FROM SMALL_TABLE B)
```

- “SMALL_TABLE” scanned and put in workfile
- Allows more efficient matching index access on BIG_TABLE

Global Optimization

- **Global opt internally represent subqueries as virtual tables**
 - Allows subquery to be considered in different join sequences
 - May or may not represent a physical workfile
 - Additional row added to PLAN_TABLE for non-correlated subq
 - PM30425 adds this new row for correlated
 - Apply only to subqueries that cannot be transformed to joins
 - SELECT only (not INSERT/SELECT, UPDATE, DELETE)

Correlated or non-correlated?.....I shouldn't have to care!

Agenda

- **Bind/Prepare**
- **Optimizer costing**
- **Runtime query performance**
 - Sort/sort avoidance
 - Sparse index
 - Predicate application
- **Indexing**
- **Complex queries**

GROUP BY Sort Avoidance

- **Improved sort avoidance for GROUP BY**

- Reorder GROUP BY columns to match available index

```
SELECT ... FROM T1
GROUP BY C2, C1    ← GROUP BY in C2, C1 sequence
Index 1 (C1, C2) ← Index in C1, C2 sequence
```

- Remove 'constants' from GROUP BY ordering requirement

```
SELECT ... FROM T1
WHERE C2 = 5      ← C2 Constant
GROUP BY C2, C1
```

- ordering requirement reduced to just C1

GROUP BY Sort Avoidance Implications

- **Implications of improved sort avoidance for GROUP BY**
 - May improve query performance!!!

 - Data may be returned in a different order
 - Always been true in any DB2 release
 - Also true in other DBMSs

 - **Relational theory states that order is NOT guaranteed without ORDER BY**

Sort Performance Enhancements

▪ **FETCH FIRST n ROWS ONLY (FFnR) and Sort**

- DB2 9 added in-memory replacement for FFnR to avoid sort
 - Provided $(n * (\text{sort key} + \text{data})) < 32\text{K}$
- DB2 10 extends this to 128K

▪ **Avoid workfile usage for small sorts**



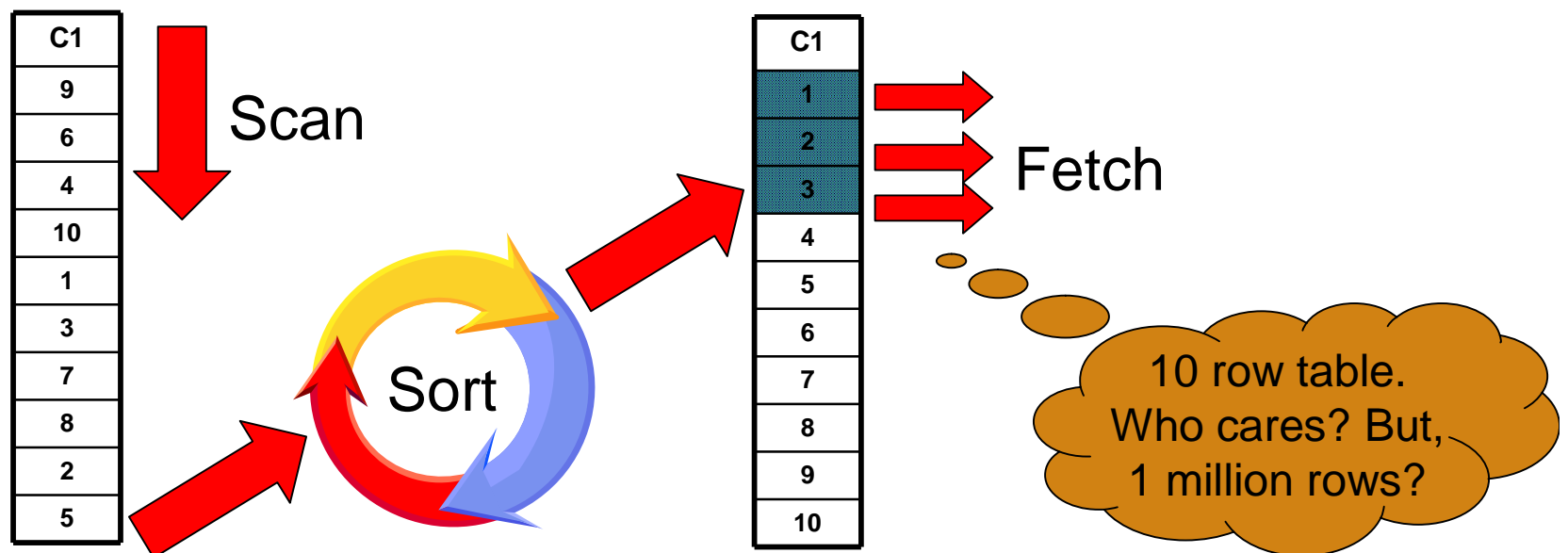
- DB2 9 avoided allocating WF for final sort only
 - If ≤ 255 rows and result $< 32\text{K}$ (sort key + data)
- DB2 10 extends this to intermediate sorts also
 - Except for parallelism or SET function

Improving sort with FETCH FIRST

▪ DB2 V8 example

- Sort is not avoided via index
 - Must sort all qualified rows

```
SELECT C1
FROM T
ORDER BY C1
FETCH FIRST 3 ROWS ONLY
```

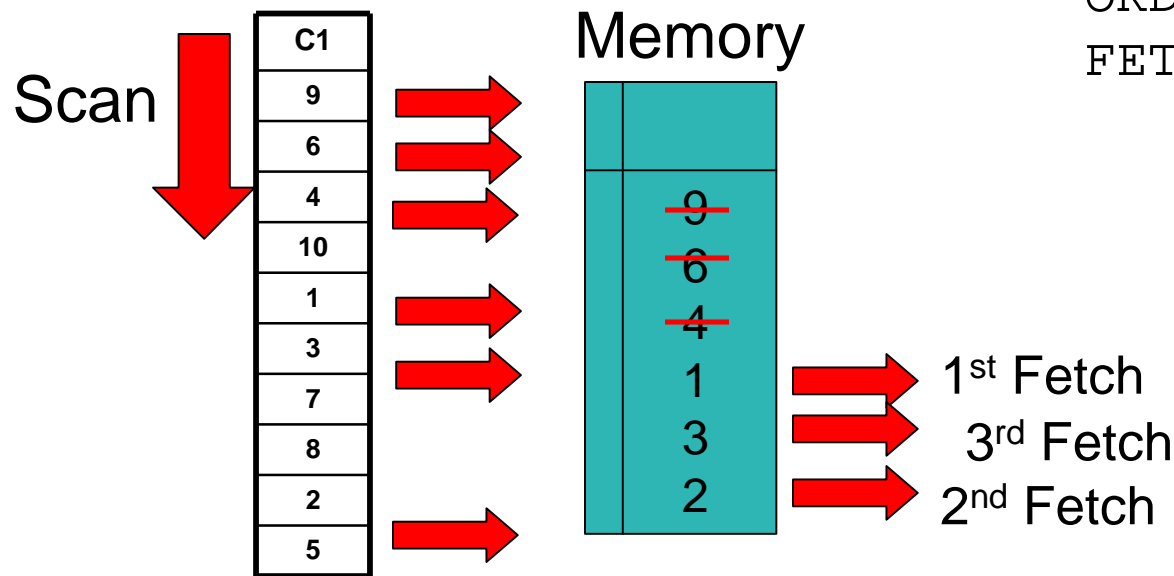


Improving sort with FETCH FIRST

- **DB2 9 example**

- New algorithm for in-memory swap avoids (traditional) sort
 - Pointers maintain order

```
SELECT C1
FROM T
ORDER BY C1
FETCH FIRST 3 ROWS ONLY
```



Suggestion: Add
FETCH FIRST
when subset is
required.

Improvements to predicate application



- **Major enhancements to OR and IN predicates**
 - Improved performance for AND/OR combinations and long IN-lists
 - General performance improvement to stage 1 predicate processing
 - IN-list matching
 - Matching on multiple IN-lists
 - Transitive closure support for IN-list predicates
 - List prefetch support
 - Trim IN-lists from matching when preceding equals are highly filtering
 - SQL pagination
 - Single index matching for complex OR conditions

- **Many stage 2 expressions to be executed at stage 1**
 - Stage 2 expressions eligible for index screening
 - Not applicable for list prefetch
 - Externalized in DSN_FILTER_TABLE column PUSHDOWN



IN-list Table - Table Type 'I' and Access Type 'IN'

- The IN-list predicate will be represented as an in-memory table if:
 - **List prefetch is chosen, OR**
 - **More than one IN-list is chosen as matching.**
- **The EXPLAIN output associated with the in-memory table will have:**
 - **New Table Type: TBTYP – 'I'**
 - **New Access Type: ACTYP – 'IN'**

```
SELECT *
FROM T1
WHERE T1.C1 IN (?, ?, ?);
```

QBNO	PLANNO	METHOD	TNAME	ACTYPE	MC	ACNAME	QBTYPE	TBTYP	PREFETCH
1	1	0	DSNIN001(01)	IN	0		SELECT	I	
1	2	1	T1	I	1	T1_IX_C1	SELECT	T	L

IN-list Predicate Transitive Closure (PTC)

```
SELECT *  
FROM T1, T2  
WHERE T1.C1 = T2.C1  
      AND T1.C1 IN (?, ?, ?)
```

**AND T2.C1 IN (?, ?, ?) ← Optimizer can generate
this predicate via PTC**

- **Without IN-list PTC (DB2 9)**

- Optimizer will be unlikely to consider T2 is the first table accessed

- **With IN-list PTC (DB2 10)**

- Optimizer can choose to access T2 or T1 first.

SQL Pagination

- **Targets 2 types of queries**

- Cursor scrolling (pagination) SQL
 - Retrieve next n rows
 - Common in COBOL/CICS and any screen scrolling application
 - Not to be confused with “scrollable cursors”
- Complex OR predicates against the same columns
 - Common in SAP

- **In both cases:**

- The OR (disjunct) predicate refers to a single table only.
- Each OR predicate can be mapped to the same index.
- Each disjunct has at least one matching predicate.


Simple scrolling – Index matching and ORDER BY

- Scroll forward to obtain the next 20 rows
 - Assumes index is available on (LASTNAME, FIRSTNAME)
 - WHERE clause may appear as:

```
WHERE ( LASTNAME=' JONES ' AND FIRSTNAME>' WENDY ' )
```

```
OR ( LASTNAME>' JONES ' )
```

```
ORDER BY LASTNAME , FIRSTNAME ;
```

- DB2 10 supports
 - Single matching index access with sort avoided 
- DB2 9 requires
 - Multi-index access, list prefetch and sort
 - OR, extra predicate (AND LASTNAME >= 'JONES') for matching single index access and sort avoidance

Complex OR predicates against same index

- Given WHERE clause
 - And index on one or both columns

```
WHERE ( LASTNAME='SMITH' AND FIRSTNAME='JOHN' )
      OR ( LASTNAME='JONES' ) ;
```

QBlockno	Planno	Accessname	Access_Type	Matchcols	Mixopseq
1	1	IX1	NR	2	1
1	1	IX1	NR	1	2

Minimizing impact of RID failure

- **RID overflow can occur for**
 - Concurrent queries each consuming shared RID pool
 - Single query requesting > 25% of table or hitting RID pool limit

- **DB2 9 will fallback to tablespace scan***

- **DB2 10 will continue by writing new RIDs to workfile**
 - Work-file usage may increase
 - Mitigate by increasing RID pool size (default increased in DB2 10).
 - MAXTEMPS_RID zparm for maximum WF usage for each RID list



* Hybrid join can incrementally process. Dynamic Index ANDing will use WF for failover.

Agenda

- **Bind/Prepare**
- **Optimizer costing**
- **Runtime query performance**

- **Indexing**

- Index on expression
- Tracking index use
- Sparse index
- Include columns

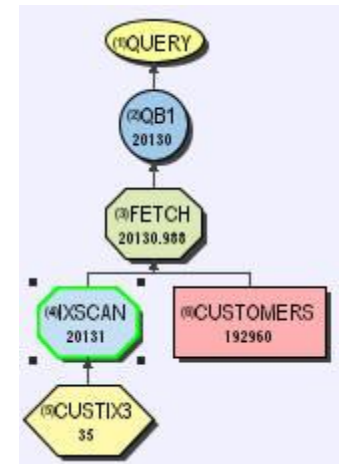
- **Complex queries**

Index on Expression

- **DB2 9 supports “index on expression”**
 - Can turn a stage 2 predicate into indexable

```
SELECT *
FROM CUSTOMERS
WHERE YEAR(BIRTHDATE) = 1971
```

```
CREATE INDEX ADMF001.CUSTIX3
ON ADMF001.CUSTOMERS
(YEAR(BIRTHDATE) ASC)
```



Previous FF = 1/25
 Now, RUNSTATS collects frequencies. Improved FF accuracy

Name	Value
Input RIDs	192960
Index Leaf Pages	241
Matching Predicates	Filter Factor
ADMF001.CUSTOMERS.= CAST(1971 AS INTEGER)	0.1043
Scanned Leaf Pages	26
Output RIDs	20131
Total Filter Factor	0.1043
Matching Columns	1

Data Caching and Sparse Index

▪ Data Caching

- Built at runtime
 - Is a runtime enhancement to sparse index
- Extended to non-star join in DB2 9

▪ New ZPARM MXDTCACH

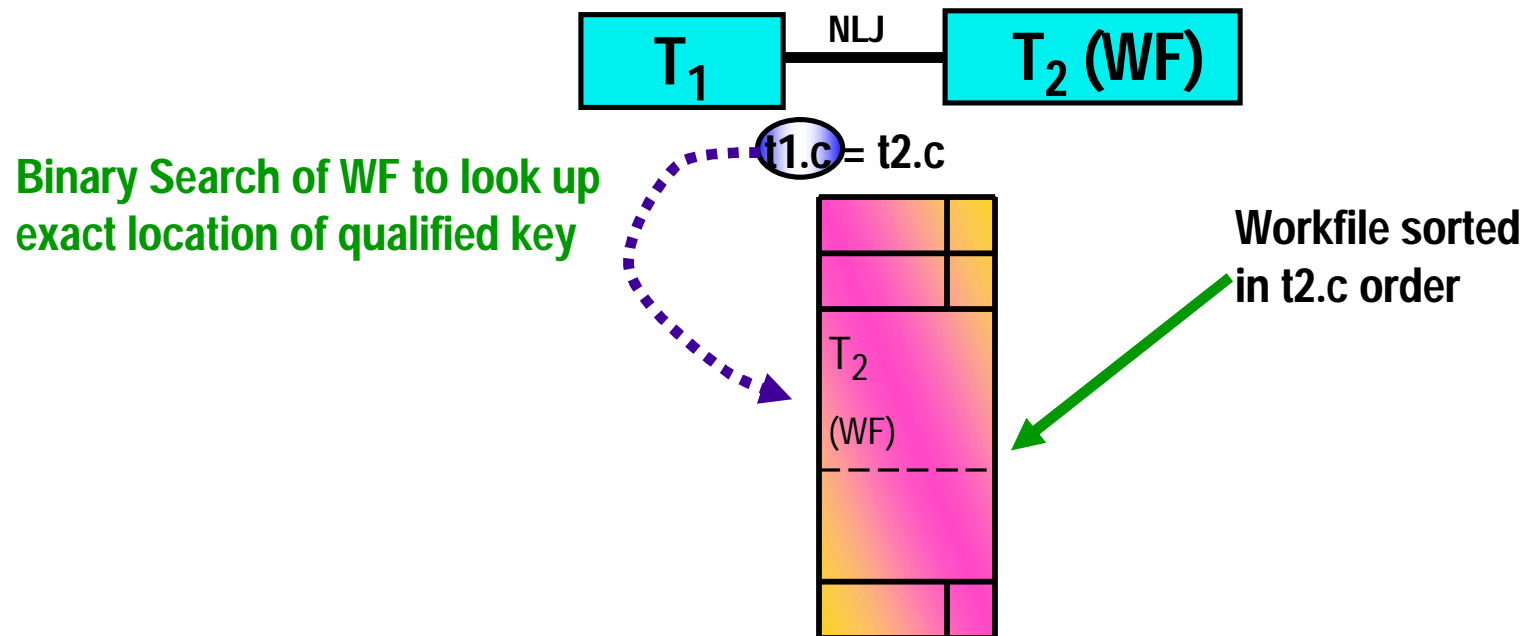
- Maximum extent in MB, for data caching per thread
- If memory is insufficient
 - Fall-back to sparse index at runtime

▪ Considered when lacking an index on join column(s):

- Temporary tables
- Subqueries converted to joins
-any table

How does Data Caching WF work?

- Data Cache contains the full result of materialized result
 - Sparse index will be a subset of WF entries
- Example, WF may have 10,000 entries
 - Cache is “binary searched” to find target location of search key



Index Include Columns

▪ Index **INCLUDE** columns



- Create an Index as **UNIQUE**, and add additional columns
- Ability to consolidate redundant indexes

```
INDEX1 UNIQUE (C1)  
INDEX2 (C1,C2)
```



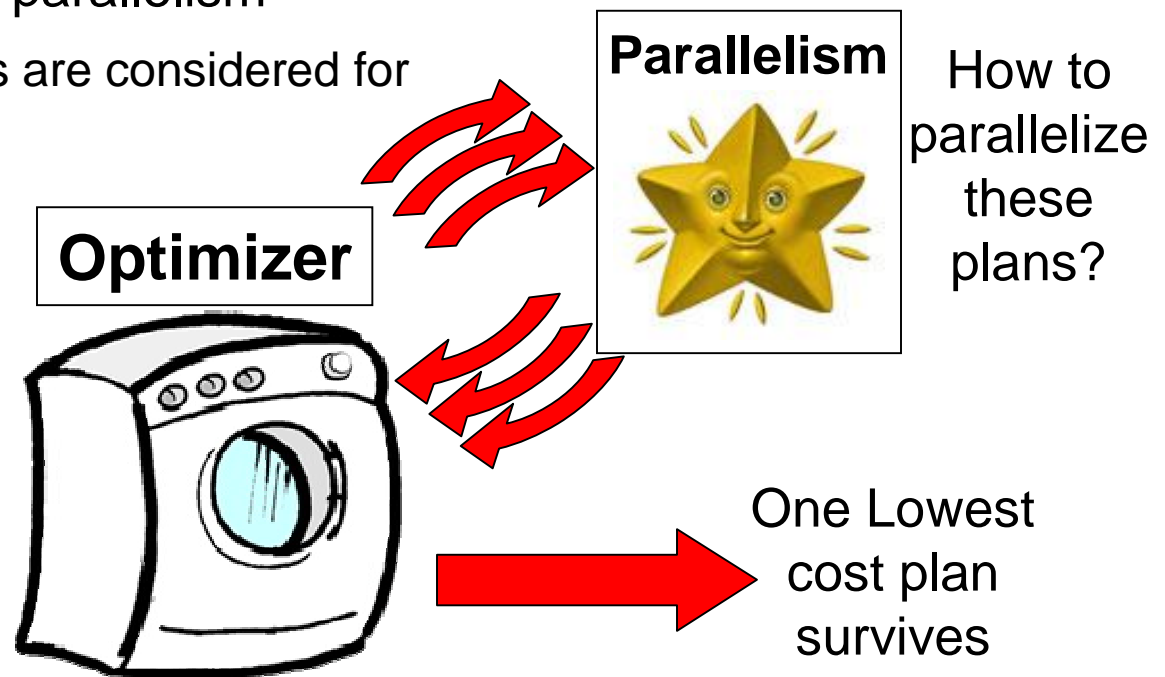
```
Consolidate to  
INDEX1 UNIQUE (C1) INCLUDE (C2)
```

Agenda

- **Bind/Prepare**
- **Optimizer costing**
- **Runtime query performance**
- **Indexing**
- **Complex queries**
 - Parallelism
 - BI/DW

Parallelism Enhancements

- In V8
 - Lowest cost is BEFORE parallelism
- In DB2 9
 - Lowest cost is AFTER parallelism
 - Only a subset of plans are considered for parallelism



Parallelism Enhancements - Effectiveness

- **Previous Releases of DB2 may use Key Range Partitioning**

- Key Ranges Decided at Bind Time
- Based on Statistics (low2key, high2key, column cardinality)
 - Assumes uniform data distribution
 - Histograms can help
 - But rarely collected
- If Statistics are outdated or data is not uniformly distributed what happens to performance?



Key range partition - Today

```

SELECT *
FROM   Medium_T M,
       Large_T  L
WHERE  M.C2 = L.C2
      AND M.C1 BETWEEN (CURRENTDATE-90) AND CURRENTDATE
    
```

Medium_T
10,000 rows
C1 C2

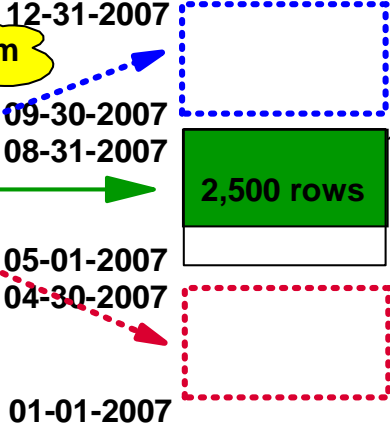
25%

SORT ON C2

3-degree parallelism



Partition the records according to the key ranges



Large_T
10,000,000 rows
C2 C3

5,000,000 rows

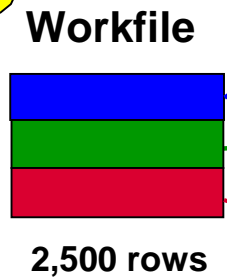
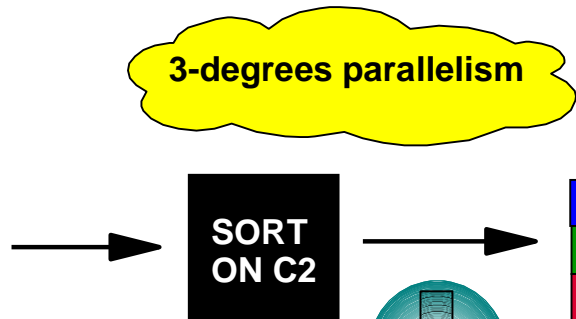
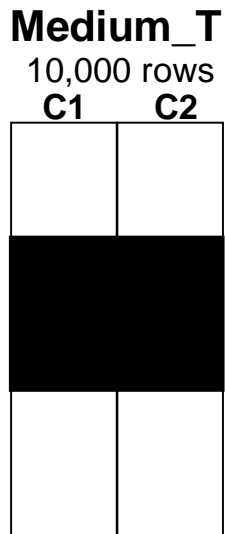
M.C1 is date column, assume currentdate is 8-31-2007, after the between predicate is applied, only rows with date between 06-03-2007 and 8-31-2007 survived, but optimizer chops up the key ranges within the whole year after the records are sorted :-)

Parallelism Effectiveness – Record range

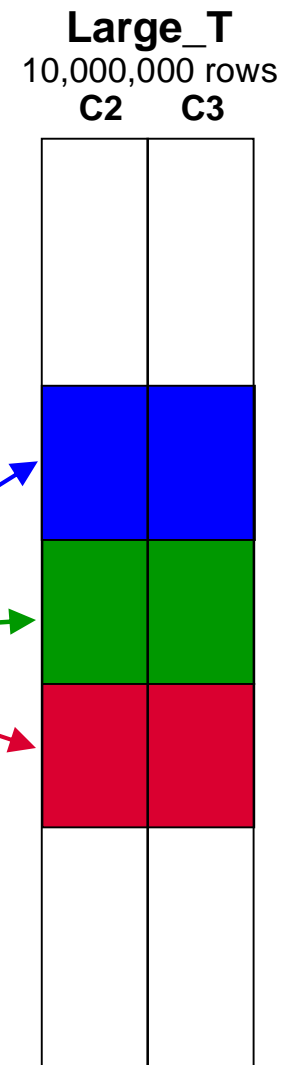
- **DB2 10 can use** Dynamic record range partitioning
 - Materialize the intermediate result in a sequence of join processes
 - Results divided into ranges with equal number of records
 - Division doesn't have to be on the key boundary
 - Unless required for group by or distinct function
 - Record range partitioning is dynamic
 - no longer based on the key ranges decided at bind time
 - Now based on number of composite records and parallel degree
 - Data skew, out of date statistics etc. will not have any effect on performance

Dynamic record range partition

```
SELECT *  
FROM Medium_T M,  
     Large_T L  
WHERE M.C2 = L.C2  
      AND M.C1 BETWEEN (CURRENTDATE-90) AND CURRENTDATE
```



Partition the records -
each range has same
number of records



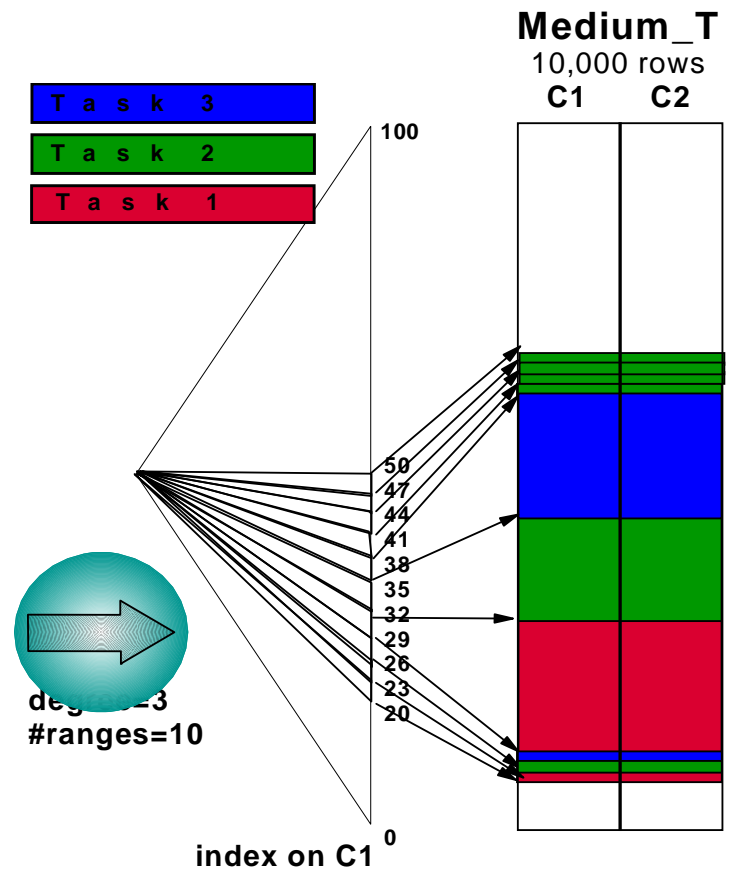
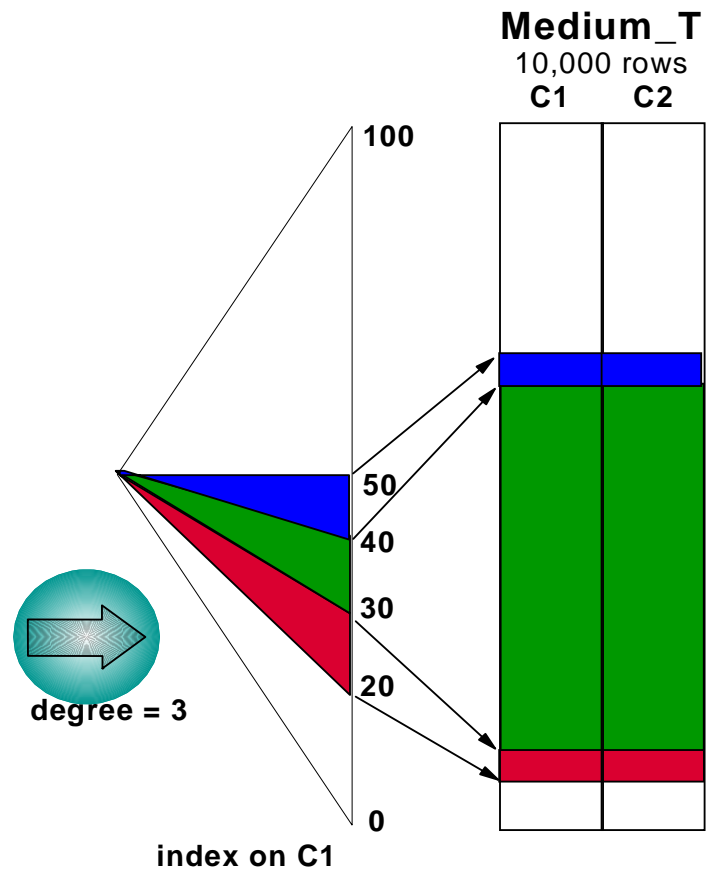
Parallelism Effectiveness - Straw Model

- **Previous releases of DB2 divide the number of keys or pages by the number representing the parallel degree**
 - One task is allocated per degree of parallelism
 - The range is processed and the task ends
 - Tasks may take different times to process

- **DB2 10 can use the Straw Model workload distribution method**
 - More key or page ranges will be allocated than the number of parallel degrees
 - The same number of tasks as before are allocated (same as degree)
 - Once a task finishes it's smaller range it will process another range
 - Even if data is skewed this new process should make processing faster

STRAW Model

```
SELECT *
FROM Medium_T M
WHERE M.C1 BETWEEN 20 AND 50
```

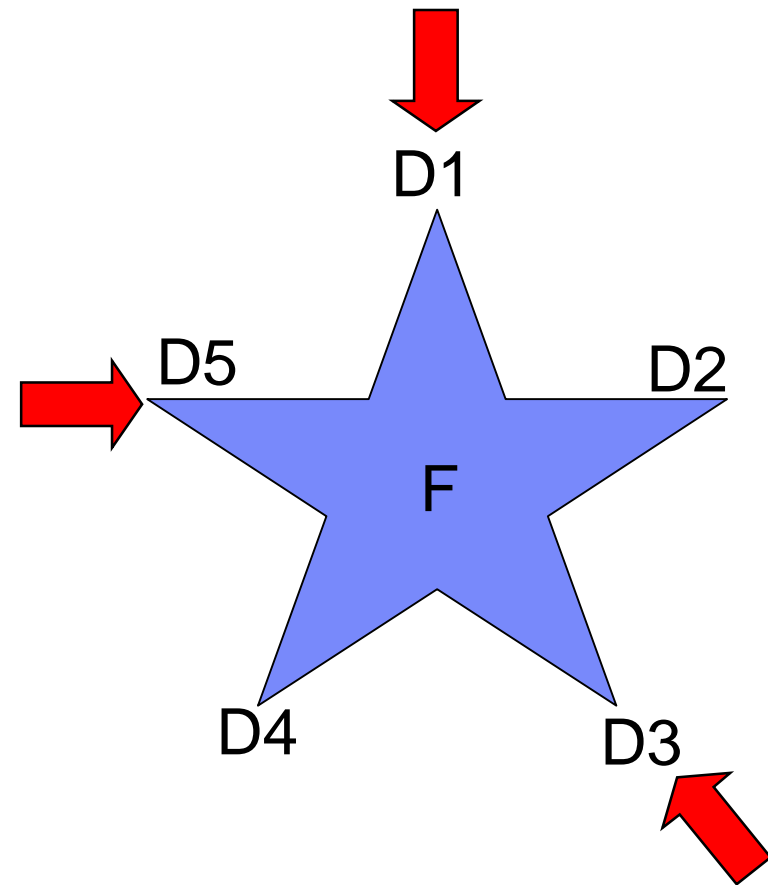


Divided in key ranges before DB2 10

Divided in key ranges with Straw Model

Dynamic Index ANDing Challenge

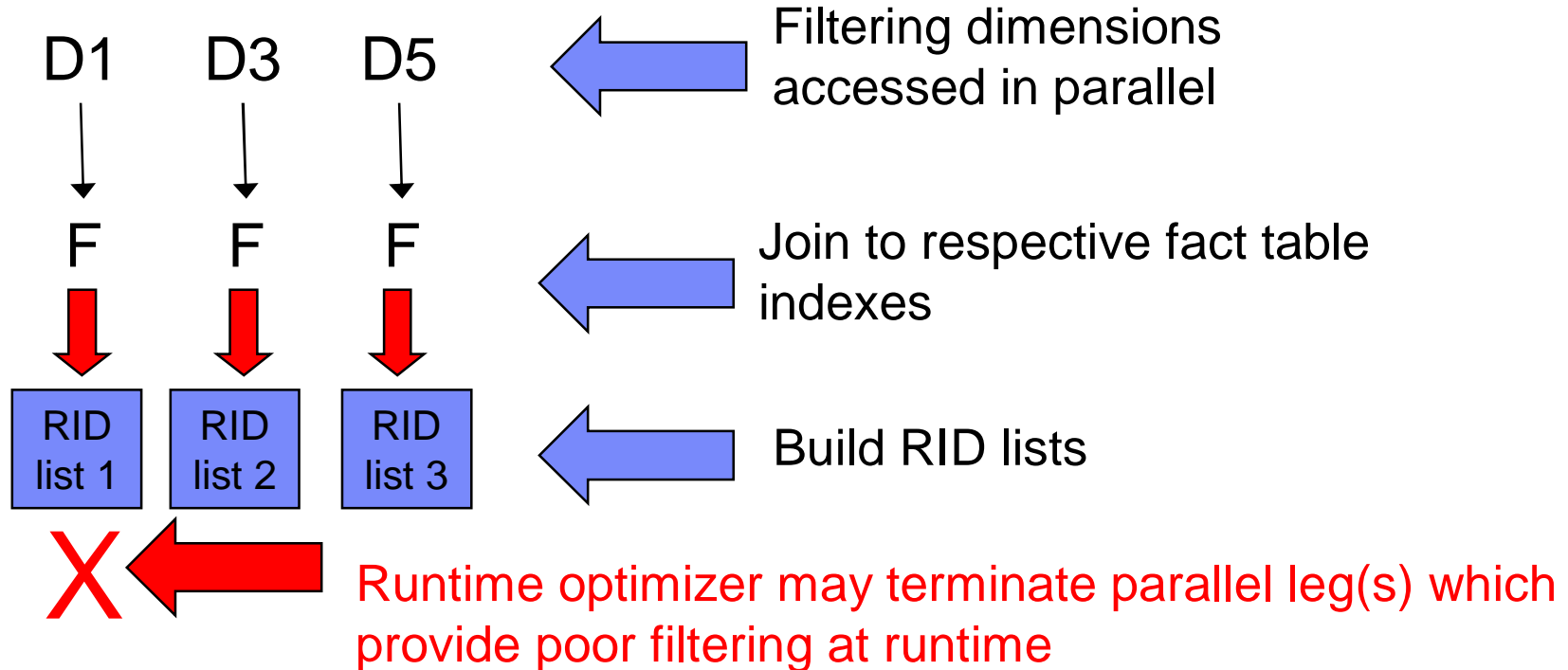
- **Filtering may come from multiple dimensions**
 - Creating multi-column indexes to support the best combinations is difficult



Index ANDing – Pre-Fact

- **Pre-fact table access**

- Filtering may not be (truly) known until runtime



Index ANDing – Fact and Post-Fact

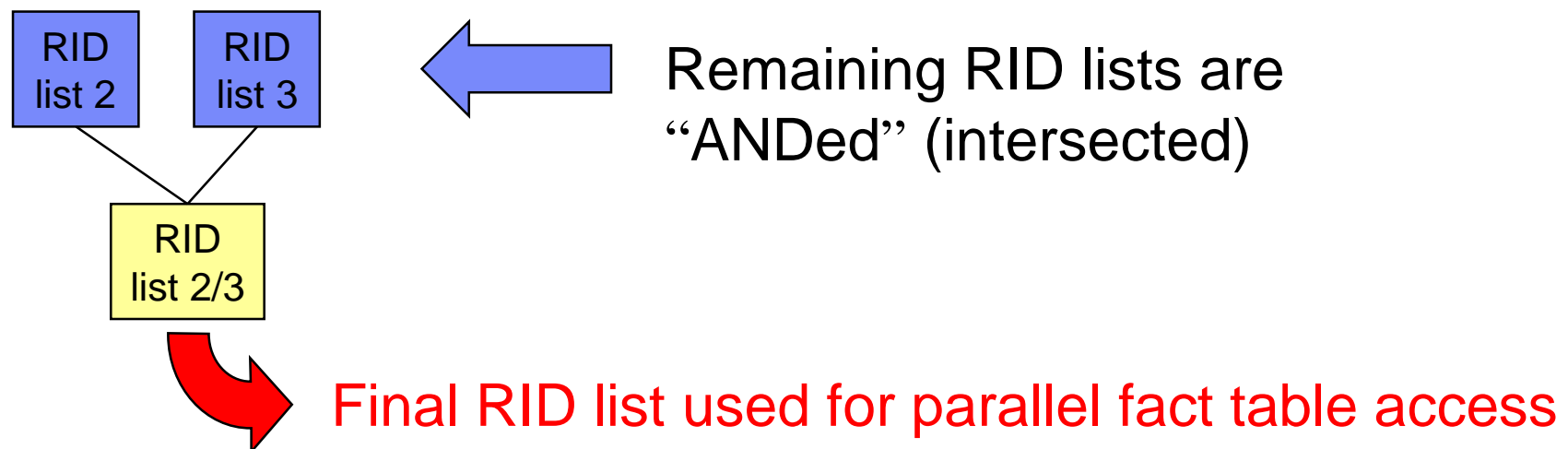
- **Fact table access**

- Intersect filtering RID lists
- Access fact table
 - From RID list

- **Post fact table**

- Join back to dimension tables

Using parallelism



Dynamic Index Anding Highlights

- **Pre-fact table filtering**
 - Filtering dimensions accessed concurrently

- **Runtime optimization**
 - Terminate poorly filtering legs at runtime

- **More aggressive parallelism**

- **Fallback to workfile for RID pool failure**
 - Instead of r-scan

APAR PK76100 – zparm to enable EN_PJSJ