BROADCOM
MAINFRAME SOFTWARE

Db2 for z/OS

Performance Handbook

Reference Manual

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Chapter 1: About This Document

1.1 Introduction

With every release of Db2, IBM makes a significant effort to improve performance as well as introduce features that further automate performance tuning. The factors that database administrators (DBAs) were worried about just a few years ago now seem like distant memories. The focus must switch from micromanaging specific access paths, buffers, and DASD response times to designing proper tables and indexes, reducing SQL calls, coding SQL properly, and monitoring application performance. It is not that system monitoring and tuning are not important—they are—but there have been considerable advances in hardware performance and subsystem performance such that the former should no longer be the primary focus of DBAs. Given the proliferation of application development automation, the majority of a DBA's time must be focused on ensuring generic designs do not negatively impact the demands of high-performance processes. This is not an argument against development tools, as they are the norm. However, time-to-delivery demands must be balanced with performance, especially considering the high volumes of data and high transaction rates.

1.2 About Db2 Performance Content

Refer to the Db2 for z/OS Managing Performance Guide and Db2 for z/OS performance redbooks. These valuable and often under-utilized references are extremely important tools in day-to-day performance tuning efforts. This guide is not a rehash or condensation of that material, nor is it a replacement for that material. The intention of this guide is to complement the printed performance information that is part of the Db2 documentation and to give insight on particular situations where certain features are of benefit or detriment. Therefore, it is important to cross-reference and research each discussed feature and technique. Remember that nothing is free—the deployment of any technique or feature carries a cost. This guide attempts to balance these choices.

This guide is heavily focused on application, database, and SQL design and tuning. System tuning and performance are secondary to application and database tuning. Thus, this guide should be read from front to back, and not used to reference various features to learn something about performance. There are many features that are addressed in multiple sections of this guide, as well as settings, techniques, and features that have a relationship to each other and are not necessarily addressed in just one place. This guide may be used as a reference, but it is strongly recommended that it be read entirely.

This guide is very much slanted toward transaction processing as opposed to data warehousing and business analytics. Db2 for z/OS is an excellent data warehouse engine. Recent advancements both in query performance and the introduction of the IBM Db2 Analytics Accelerator (IDAA) make it a great and economically feasible database for data warehouses. It is encouraged to run both transaction processing and decision support against the same production database. However, most enterprises are utilizing Db2 for z/OS for transaction processing and not data warehousing. Thus, the majority of design and tuning techniques presented here are specifically in support of transaction processing systems. Many of the concepts can be applied to a data warehouse, especially the information included in Chapter 3, Chapter 4, and Chapter 5.

This document is intended as a performance guide. It is much more about performance than flexibility and availability. The concepts of performance, flexibility, and availability generally oppose each other, especially when implementation and operational costs are of concern. It is crucial to strike a balance in implementation that is appropriate for the enterprise and situation.

1.3 Purpose and Audience

The information provided in this guide is relevant through Db2 11 for z/OS. In most feature descriptions, no distinction is made between versions when discussing various features. Verify the Db2 manuals for version number to confirm the availability of specific features.

1.4 Authors

Dan Luksetich is an independent Db2 consultant specializing in high-performance database solutions, Db2 performance evaluations, and SQL training. Dan works on some of the largest and most complex database systems in the world on the z/OS, UNIX, Linux, and Windows platforms. Dan has taken the knowledge he has gained over the years and shared it at various International Db2 User Group (IDUG) technical conferences, IBM Information on Demand technical conferences, and various local user groups in North America, Europe, Africa, and the Middle East. Dan is an IBM Champion for Information Management, chairman of the IDUG Content Committee, co-author of two Db2 for z/OS certification guides, co-author of several Db2 certification tests, and author or co-author of numerous Db2 articles published over the course of many years. He has held positions in programming and database management including COBOL, Assembler, Db2, and IMS.

Denis Tronin is the Product Manager for Database Management Solutions for Db2 for z/OS Performance Tools at Broadcom. He is an experienced IT professional with expertise in product management and software development. Denis has led the development of products for mainframes in workload automation, Db2, and API management domains. He is an IBM Champion for Analytics since 2016, a regular speaker at user groups and conferences, a member of the IDUG Content Committee, and a core contributor to the Zowe open source project.

Aysen Solak started her career as an IMS Database Administrator and later focused on Db2 for z/OS. After 10+ years experience as a Database Administrator and System Programmer for Db2 for z/OS in various countries and mainframe companies, she joined the Mainframe Division at Broadcom as a Product Owner. Aysen is now mainly responsible for *SYSVIEW® for Db2 for Db2 for z/OS* (SYSVIEW for Db2)—a strong tool helpful in implementing the solutions recommended in this guide.

1.5 About the Mainframe Division at Broadcom®

The Mainframe Division at Broadcom® continues to drive the next horizon of open, cross-platform, enterprise solutions. We specialize in DevOps, security, AIOps, and infrastructure software solutions that allow customers to embrace open tools and technologies, make mainframe an integral part of their cloud, and enable innovation that drives business forward. We are committed to forging deep relationships with our clients at all levels. We go beyond products and technology to partner with you in creative ways that support your success.

Chapter 2: Performance and Performance Tuning Basics

Since DBAs are constantly striving for high performance, managers are constantly demanding high performance, and IBM is dedicated to delivering a higher level of performance with each release of Db2, this guide focuses first on the concept of high performance and what it means within the context of processing for each individual organization and/or situation.

2.1 System Tuning vs. Application Tuning

There has always been a division with regards to performance tuning. Many DBAs spend a significant amount of time monitoring and tuning Db2 configuration parameters in an attempt to achieve a higher level of performance for applications using Db2. Certain parameters such as buffer sizes can make a huge difference in performance if they are initially undersized. However, once most parameters are set within a reasonable threshold, any changes typically make little to no impact on performance.

Use the 80/20 rule when it comes to performance tuning: 20% of the focus should be on systems and 80% should be on database and applications. When it comes to application performance tuning examine either SQL or database design, or perhaps even both together. *Detector™ for Db2 for z/OS* (Detector) and *Subsystem Analyzer for Db2 for z/OS* (Subsystem Analyzer) provide the application and database object view of tuning.

2.2 Application Design for Performance and SQL Tuning

There are two major challenges when it comes to SQL tuning: the first and most important is the quantity of SQL statements issued. The second is the relative performance of each SQL statement.

The biggest challenge in today's fast-paced application development environment is keeping the number of SQL statements executed per transaction to a minimum. In many cases, the development utilizes a framework and service-oriented architecture. Often, database tables are mapped one-to-one with objects in the data services application layer. Repeated calls to a specific service can likewise result in repeated calls to populate an object from a database table. A greedy design where service calls are made repeatedly within a unit of work can result in extreme degradation in performance. Often the database is to blame, but database monitors show extreme quantities of reasonably performing SQL statements. There is very little system or database tuning that can be done in these situations. Hence, when designing a new database application there must be a more conscious approach to design for performance.

A performance-conscious approach must take two forms; the first focuses on calling the database only when necessary, and the second involves combining multiple calls into a single call. The first is conceptually easy; if a data object is already populated and there is no need to refresh it, then the database call should be avoided. This may require some additional tests within the application code, but the results can be very effective. The second may be a bit more dramatic, and it is best to do this only when performance is more of a concern versus speed of delivery and the flexibility of the code. Great success has been found in designing applications where the focus on multi-table SQL statements was concentrated on the high-performance component of the application, while normal development was in place for the majority of the application logic. For these high-performance components, examine which tables are being accessed during a unit of work, which columns from the tables are required (if at all), and the relationships between the tables. If application SQL complexity is too much for the application developers, or if there is no interest in placing the complexity within the application code, then stored procedures, triggers, and user-defined functions provide a nice alternative for bundling multiple SQL calls into one call. It is almost impossible to tune a simple statement against a single table with one predicate against a primary key column, but with multiple table access more tuning opportunities exist, and in general the more complex SQL statement will almost always outperform many simple statements providing the same functionality. This is especially true across a network: programmatic joins have been tested against equivalent SQL joins for two tables and realized a 30% performance gain for the SQL join.

More complex SQL statements offer additional opportunities for the tuning of these individual statements, but before looking into complex SQL tuning, step back and understand the overall performance of the application. This is where active monitoring of the production Db2 system is important. *SYSVIEW® for Db2* can be used to analyze the appropriate Db2 trace output to produce meaningful performance reports. There are also Db2 components, such as the dynamic statement cache, that can be utilized to produce performance metrics. Whatever the case may be, examine the performance of applications at the application level, user level, and then statement level. *Detector* collects all necessary application performance details. When tuning SQL, tune the element that consumes the most resources, or the element that exceeds a specified SLA, first. Regular monitoring should be part of application and SQL performance tuning, especially when changes are being implemented. The ability to show a real-world result is crucial to getting management support for tuning.

When tuning SQL statements, utilize two techniques to determine the potential savings to be realized from a database or SQL change; the EXPLAIN facility and benchmarking. EXPLAIN takes as input a SQL statement and externalizes the predicted access path within the database engine. There are several EXPLAIN tables that are populated when a statement is EXPLAINed, so utilize *Plan Analyzer for Db2 for z/OS* (Plan Analyzer) featuring advanced EXPLAIN services and streamlines analysis of the SQL access path. For an adventurous route, write a query against the EXPLAIN tables. There are various examples available on the Internet. In addition to providing access path information, EXPLAIN also provides statement cost information. This is internal cost information that Db2 uses to determine the access path and it is also information that can be used to compare the predicted cost of two different SQL statements that are logically equivalent.

While comparing the statement cost in EXPLAIN is a good start, it is not always the definitive guide to better SQL performance. Cost calculations are also used as part of the predicted savings of a SQL tuning change. Examine the access path and perform benchmark testing. Benchmark testing is usually performed using REXX, SPUFI, or Interactive SQL (ISQL) facility on the mainframe. If a test database is properly configured and database statistics are updated to match production statistics[1], a strong estimate of the potential performance savings can be determined by running a benchmark test and capturing the performance using a monitoring tool or the statement cache. Back up any proposed SQL performance change with both EXPLAIN and benchmark test results.

2.3 Database Design for Performance

There are a myriad of database tuning possibilities. Before jumping to any of the touted performance features of Db2, it is critical to first understand the problem that must be solved. If you want to partition a table, are you hoping that the partitioning results in a performance improvement or is it for data management or flexibility? Clustering of data is critical, but clustering has to reflect potential sequential access for single-table, and especially multi-table, access. Generic table keys are usable, but clustering is meaningless unless parent keys are used for clustering child table data when processing follows a key-based sequential pattern or when multiple tables are being joined. Natural keys may be preferred unless compound keys become exceedingly large. There are a number of choices of page sizes, and this can be especially important for indexes where page splitting may be a concern. Tables can also be specifically designed for high-volume inserts with such features as *append only* and *member cluster*.

Let the database itself influence the design. Set up test database designs and test conditions that mock the predicted application and database design. This usually involves generated data and statements run through Interactive SQL (ISQL) facility, SPUFI, REXX programs, db2batch, or shell scripts, all while performance information is gathered from monitors and compared. If this sounds complicated it is not. Most proof-of-concept tests do not last more than a week or two. The effort is minimal, but the reward can be dramatic.

2.4 Summary

This section has been a high-level review of Db2 performance tuning, hopefully serving as an inspiration to look for specific solutions to performance issues. Do not be afraid to test things and perform benchmarks.

1. Use Statistics Manager in *Plan Analyzer* and *SQL-Ease™ for Db2 for z/OS* (SQL-Ease) to view, calculate, manipulate, and migrate Db2 statistics.

Chapter 3: SQL Access Paths

The Db2 engine is becoming more sophisticated with each new release. The good news is this means that SQL statements usually execute with the highest level of performance and stability. The bad news is that in the infrequent situations where tuning SQL statements is required, a knowledge of statistics and access paths is required which is becoming significantly more complicated. Nonetheless, an understanding of catalog statistics and major access paths is a requirement for SQL performance tuning. The Db2 Administration Guide, Db2 for z/OS Managing Performance Guide, and Utilities Guide are all required reading to gain this knowledge. This section of the guide attempts to consolidate this information, as well as offer some advice on when various statistics and access paths are important for applications.

3.1 The Critical Importance of Appropriate Catalog Statistics

The Db2 engine is cost-based and access path selection is based upon statistics that are stored in the Db2 system catalog. Accurate statistics are a necessity to get the best level of performance for SQL statements. There are many different types and levels of statistics that can be gathered, but there are trade-offs to consider. The more statistics that are gathered, the more information that is available to the optimizer for calculating access paths. However, not all of these statistics are necessary for every type of query and data. Resist gathering all the available statistics for tables and indexes since the quantity of these statistics is going to influence the cost of binding or preparing SQL statements. An understanding of any special data or application requirements is required before gathering anything beyond the basic statistics.

When collecting statistics, do so for the complete set of objects related to a table space. That is, do not collect index statistics separate from table, column, and table space statistics. This can lead to conflicts, which can distort optimizer calculations and impact access path selection. Rarely gather statistics as part of the execution of other utilities, and never gather index statistics separate from other statistics.

3.1.1 Base Line Statistics

The RUNSTATS utility is used to gather statistics based upon the data stored in tables as well as the key values and entries in the indexes referencing those tables. The RUNSTATS utility collects statistics based upon parameters set for table space, tables, columns, and indexes. The following is an example of an extremely common RUNSTATS utility control statement that gathers the minimal base line statistics for a table space, associated table, and associated indexes.

```
RUNSTATS TABLE SPACE DB1.TS1 TABLE(ALL) INDEX(ALL
```

These base line statistics are important for transaction processing systems where the vast majority of the SQL statements are static embedded statements that use host variables in predicates or dynamic SQL statements where the vast majority of the SQL statements use parameter markers in predicates. Also, if the majority of statements in the application are very simple, single-table accesses, then there is probably not much need for any type of additional statistics. Typically, only base line statistics are utilized until a special situation occurs that may require additional statistics.

3.1.2 Frequency Distribution Statistics

Some performance problems can be attributed to skewed distribution of data. The optimizer assumes that the data is uniformly distributed. When this is not the case, the result can be poor join sequences, increased synchronous I/O, and longer application response times. These outcomes can occur if the optimizer chooses an incorrect access path because it has incorrectly estimated the number of matching rows for a qualified predicate. For a predicate such as this:

```
WHERE LASTNAME = 'RADY'
```

Db2, without frequency distribution statistics, uses a formula of 1/COLCARDF (1 divided by the column cardinality) to determine the percentage of time RADY is found in the table. If the cardinality is 1000, then the percentage of qualifying rows is 0.1%. If the values of the LASTNAME column are evenly distributed then this is an accurate estimate. However, assume that there is a high degree of nepotism at the company and about 200 Radys work for us. Then, the actual percentage of qualifying rows is 20%. In this case, the default filtering calculation is incorrect when compared to the actual data values. Since Db2 uses the filter factors it calculates to determine whether or not to use an index, as well as the table access sequence for multi-table statements, such a difference in filtering estimates can result in a less than efficient access path for the specific query and value. In a situation such as this, frequency distribution statistics should be considered for the table.

The RUNSTATS utility can collect any number of most and least frequently occurring values for a column or set of columns along with the frequency of occurrence for those values. Observe that the frequency distribution statistics are only meaningful, for the most part, if our queries are using embedded literals or runtime re-optimization.

For situations that may benefit from frequency distribution statistics, run some queries against the table with the suspected skewed data to make sure before collecting the statistics. In the case of the LASTNAME column, such a query appears like this:

```
SELECT LASTNAME, COUNT(*)
FROM EMP
GROUP BY LASTNAME
```

If the column counts in the result set show a significant level of variation, and the SQL statements against this table qualify in that predicates with literal values are coded against the column, then there is a benefit to gathering frequency distribution statistics.

3.1.3 Column Correlation Statistics

Db2 calculates a filter factor based upon formulas it uses to calculate the percentage of rows that will qualify for a given predicate. When there are multiple predicates coded against a table, Db2 determines column level filter factors for each column. It then uses filter factors coded for multiple predicates against a given table to calculate index and table-level filter factors. These ultimately contribute to decisions as to whether or not to use a certain index and/or the table access sequence for a given SQL statement. Filter factors in these situations can get distorted if the columns being referenced in a compound predicate are highly correlated. To understand column correlation, think of data values as they change in a table. If the value for one column changes, what is the likelihood that another column will change? If this is the case then those columns may be correlated and therefore predicates coded against both columns may inaccurately influence the filter factor. A classic example of correlated columns is city and state. If you examine the United States, chances are that if the value for the city column is Chicago there is a very good chance that the value for the state is Illinois, and if the value for the city column is Baltimore then there is a very good chance that the value for the state is Maryland. Assuming the following predicate:

```
WHERE CITY = ? AND STATE = ?
```

Db2 calculates multiple filter factors. For the predicate against city, assuming 10,000 different cities in our table, the filter factor is 1/10000 (or 0.0001), and for the predicate against the state column, the filter factor is 1/50 (or 0.02). Db2 then calculates the combined filter factor for the compound predicate 0.0001 × 0.02 = 0.000002. If the columns are correlated, then the filter factor is exaggerated by the percentage of the lesser occurring value, becoming in this case 2% of what it should be. This can have a significant impact when it comes to index selection and table access sequence, especially in more complex queries.

The RUNSTATS utility can collect statistics for combinations of columns. So the same statistics that are available for single columns are also available for combinations of columns. When these statistics are available, the Db2 optimizer considers the correlation statistics versus the single-column statistics for compound predicates. This results in a more accurate filter factor for these compound predicates and thus results in a more accurate index selection and table access sequence.

Before collecting column correlation statistics, ensure that they will benefit the applications. Perform the following to confirm:

- Determine if there are compound predicates coded against columns that can potentially be correlated by scanning the SQL statements in the application.
- Determine if the columns in question are actually correlated by running some queries against the suspected tables and columns

In the example of the table with the CITY and STATE columns, the analysis query looks like this[2]:

```
SELECT VALUE1, VALUE2,
       CASE WHEN VALUE1 > VALUE2 THEN 'COLUMNS CORRELATED'
       ELSE 'COLUMNS NOT CORRELATED' END
FROM ( SELECT COUNT (DISTINCT CITY) * COUNT (DISTINCT STATE),
        ( SELECT COUNT(*)
          FROM ( SELECT DISTINCT CITY, STATE
                 FROM TAB1 ) AS T2 )
       FROM TAB1) AS CORRELATION_COMPARE (VALUE1, VALUE2)
```

The query is comparing a multiplication of the counts of distinct values to the distinct combination of the two values. If the two values are close to equal then they are not correlated. However, if the first value is significantly greater than the second value then it is likely the two columns are correlated. Also, if the table is relatively small then it is more difficult to determine column correlation. The following is an example of a RUNSTATS utility to collect correlation statistics if the query above indicates that the correlation statistics were required.

```
RUNSTATS TABLESPACE DB1.TS1
TABLE(DANL.TAB1)
COLGROUP(CITY, STATE)
```

3.1.4 Histogram Statistics

Histogram statistics enable Db2 to improve access path selection by estimating predicate selectivity from value-distribution statistics that are collected over the entire range of values in a data set. This information aids filtering estimation when certain data ranges are heavily populated and others are sparsely populated.

Db2 chooses the best access path for a query based on predicate selectivity estimation, which in turn relies heavily on data distribution statistics. Histogram statistics summarize data distribution on an interval scale by dividing the entire range of possible values within a data set into a number of intervals.

Db2 creates equal-depth histogram statistics, meaning that it divides the whole range of values into intervals that each contain about the same percentage of the total number of rows. The following columns in a histogram statistics table define an interval:

- QUANTILENO: An ordinary sequence number that identifies the interval.
- HIGHVALUE: A value that serves as the upper bound for the interval.
- LOWVALUE: A value that serves as the lower bound for the interval.

Histogram statistics are most useful if queries against the skewed data include range, LIKE, and BETWEEN predicates. Histogram statistics could also be useful for equality predicates when a portion of the input values are expected to not match the data. As with frequency distribution statistics, the histogram statistics are most useful when predicates contain literal values or when using runtime reoptimization.

2. Use *SQL-Ease* for SQL text formatting and syntax checking.

3.1.5 Sampling

Executing a RUNSTATS utility can be an expensive endeavor, especially for extremely large tables. There is an option to use sampling when running a RUNSTATS utility. The sampling is not necessarily going to reduce the elapsed time of the utility, but will reduce the CPU time consumed, which is important when paying per CPU hour. The statistics produced via sampling are fairly accurate when sampling between 10% and 100% of the rows in the table. Do not specify less than 10% for a sample as experience has shown that the statistics produced can be highly inaccurate.

There are two choices for sampling: row level and page level. While page-level sampling is rarely used, it may be a promising alternative to row level from an elapsed time perspective.

3.1.6 When to Gather Statistics

There are three basic principles to gathering statistics:

- Gather statistics on a regular basis. This is quite a common practice, and it could be good or bad. This habit may also be a bit reckless. Since statistics can cause access path changes, the regular refreshing of statistics creates a certain level of unpredictability to access path changes. Some shops install a regular policy of the Three Rs: REORG, RUNSTATS, and REBIND. This is only a good practice for enterprises where DBA support is limited and the DBAs do not have a good relationship with development and know nothing about the applications that are using the data. In this case, all faith is on the Db2 engine; do not expect to do proactive SQL analysis and tuning and have a tuning strategy that involves simply fighting fires. If this is not the situation then it is strongly recommended to explore one of the other choices for gathering statistics. This may very well be a better policy for data warehouses.
- Gather statistics once and forget about it. This technique is most appropriate when the database and application is quite well known by the DBAs and plenty of proactive SQL performance analysis has taken place and is understood. This is also a good policy for transaction processing systems with extremely high data volume and extremely high transaction rates. In these situations, the access path should be understood and predictable. In these situations there is no need to gather statistics beyond what has been gathered to get the desired access paths. Understand that in this situation you are trading the CPU costs for running regular RUNSTATS and the unpredictability of production access path selection with the cost of DBA time and effort to fully understand the database and application. It does require that the application developers and DBAs have a strong relationship and that as changes are made to the application, database, or data, the developers and DBAs are communicating, testing, and documenting the impact. RUNSTATS must be executed when changes are implemented. This is the technique used in the vast majority of high volume, high transaction rate OLTP implementations.
- Gather statistics when something changes. This technique is pretty much a balance between the first two techniques. It requires an initial gathering of representative statistics and then a policy in place whereas if data, database, or processes change, the DBA is informed and a RUNSTATS is executed. This is a very common recommendation and a smarter option than the option of running regular RUNSTATS, but only when the DBA resources available to handle the coordination of change.

In addition to gathering statistics, the RUNSTATS utility can also reset the statistics. This is important when there is significant change to database, data, or processes, or a previously deployed flavor of statistics that is no longer desired. This is also recommended for test environments where you may want to try an assortment of different statistics when testing an application for performance. See the Db2 Utility Guide for details.

3.1.7 Real-Time Statistics and Object Reorganization

Catalog statistics are critical to performance and reflect the condition of the data at the moment they are gathered. The REORG utility is useful for organizing the data in tables and the keys in an index, and hopefully the organization of the data in the tables and the catalog statistics about those tables are in harmony. It is vital to gather catalog statistics when objects are properly organized in situations where there is a good policy of organization and expected application performance. If no good policy exists, then the Three Rs may be the best solution.

Db2 gathers and reports on object organization and activity in the real-time statistics catalog tables, SYSIBM.SYSTABLESPACESTATS and SYSIBM.SYSINDEXSPACESTATS. The gathering of these statistics is automatic and the population of the data in the tables is controlled by the STATSINT subsystem parameter. Force the externalization of these statistics for an object with the following command:

```
ACCESS DB(<database name>) SP(<pageset name>) MODE(STATS)
```

For high-volume transaction processing systems, take the *one and done* approach to collecting catalog statistics and then employ an intelligent policy of monitoring production objects for organization, executing REORGs on only the objects that require reorganization. Utilize the real-time statistics tables to determine when objects must be reorganized, and only reorganize those objects when required. With this type of analysis, you may be surprised at the reduction in REORGs from a regular REORG policy. It is likely that real-time statistics expose the need for index REORGs far more often than table space REORGs. *Database Analyzer™ for Db2 for z/OS* (Database Analyzer) leverages existing real-time statistics and collects new statistics on Db2 objects to intelligently automate Db2 housekeeping and utility scheduling/execution.

IBM supplies a stored procedure called DSNACCOX[3] that can interpret the data in real-time statistics. Since the installation and use of this stored procedure is optional, it may not be available at your installation. For this reason, there is a set of queries against the real-time statistics tables that can be executed on a regular basis. These queries determine which tables and indexes to reorganize. Below are examples of basic rules that run against the statistics gathered since the last REORG. These are not dissimilar from the default rules, but these rules can easily be adjusted to your preferences.

Table space:

- Indirect references greater than 5%.
- Inserts greater than 25%.
- Deletes greater than 25%.
- Unclustered inserts greater than 10% (watch for intentional unclustered inserts). The SQL seems to check for 5% and not 10%.
- Disorganized LOBs greater than 50%.
- Mass deletes.
- More than 30 extents.
- Table is unclustered or has poor clustering.

```
SELECT TBSP.DBNAME,
       TBSP.NAME,
       TB.NAME,
       TBSP.PARTITION,
       TBSP.NACTIVE,
       TBSP.NPAGES,
       TBSP.TOTALROWS,
       CASE WHEN (((TBSP.REORGNEARINDREF+TBSP
REORGFARINDREF)*100)/TBSP.TOTALROWS)>5
             THEN (((TBSP.REORGNEARINDREF+TBSP
REORGFARINDREF)*100)/TBSP.TOTALROWS)
             ELSE 0 END AS INDREF,
          CASE WHEN ((TBSP.REORGINSERTS*100)/TBSP.TOTALROWS)>25
          THEN ((TBSP.REORGINSERTS*100)/TBSP.TOTALROWS)
          ELSE 0 END AS INSERTS,
       CASE WHEN ((TBSP.REORGDELETES*100)/TBSP.TOTALROWS)>25
          THEN ((TBSP.REORGDELETES*100)/TBSP.TOTALROWS)
          ELSE 0 END AS DELETES,
       CASE WHEN ((TBSP.REORGUNCLUSTINS*100)/TBSP
TOTALROWS)>10
          THEN ((TBSP.REORGUNCLUSTINS*100)/TBSP.TOTALROWS)
          ELSE 0 END AS UNCLINS,
```

3. Database Analyzer provides a superset of the THRESHOLDS embedded in DSNACCOX.

```
        CASE WHEN ((TBSP.REORGDISORGLOB*100)/TBSP.TOTALROWS)>50
           THEN ((TBSP.REORGDISORGLOB*100)/TBSP.TOTALROWS)
           ELSE 0 END AS DLOB,
        CASE WHEN TBSP.REORGMASSDELETE>0
           THEN TBSP.REORGMASSDELETE
           ELSE 0 END AS MDEL,
        CASE WHEN TBSP.EXTENTS>30
           THEN TBSP.EXTENTS
           ELSE 0 END AS EXT,
        CASE WHEN IX.CLUSTERED = 'N'
           THEN IX.CLUSTERED
           ELSE ' ' END AS CLUS,
        CASE WHEN (IX.CLUSTERRATIOF*100) < 95
           THEN INT((IX.CLUSTERRATIOF*100))
           ELSE 0 END AS CLUSR,
        TBSP.EXTENTS,
        TBSP.LOADRLASTTIME,
        TBSP.REORGLASTTIME,
        TBSP.REORGINSERTS,
        TBSP.REORGDELETES,
        TBSP.REORGUPDATES,
        TBSP.REORGUNCLUSTINS,
        TBSP.REORGDISORGLOB,
        TBSP.REORGMASSDELETE,
        TBSP.REORGNEARINDREF,
        TBSP.REORGFARINDREF,
        TBSP.INSTANCE,
        TBSP.SPACE,
        TBSP.DATASIZE
FROM SYSIBM.SYSTABLESPACESTATS TBSP
INNER JOIN
       SYSIBM.SYSTABLES TB
ON TBSP.DBNAME = TB.DBNAME
AND TBSP.NAME = TB.TSNAME
LEFT OUTER JOIN
       SYSIBM.SYSINDEXES IX
ON     TB.CREATOR = IX.TBCREATOR
AND    TB.NAME = IX.TBNAME
AND    IX.CLUSTERING = 'Y'
WHERE  TBSP.DBNAME IN
('<dbname>','<dbname>')
AND    TB.CREATOR = '<creator>'
AND    TBSP.NACTIVE > 100
AND    TBSP.TOTALROWS > 0
AND    (
       ((((TBSP.REORGNEARINDREF+TBSP.REORGFARINDREF)*100)/
TBSP.TOTALROWS)>5)
       OR
       (((TBSP.REORGINSERTS*100)/TBSP.TOTALROWS)>25)
       OR
       (((TBSP.REORGDELETES*100)/TBSP.TOTALROWS)>25)
       OR
       (((TBSP.REORGUNCLUSTINS*100)/TBSP.TOTALROWS)>10)
       OR
       (((TBSP.REORGDISORGLOB*100)/TBSP.TOTALROWS)>50)
          OR
          (TBSP.REORGMASSDELETE>0)
          OR
          (TBSP.EXTENTS>30)
          OR
          (IX.CLUSTERED = 'N')
          OR
          ((IX.CLUSTERRATIOF*100) < 95)
          )
```

```
ORDER  BY TBSP.DBNAME,
       TBSP.NAME,
       TBSP.PARTITION
WITH UR
```

Index:

- Far away leaf pages greater than 10%.
- Extents greater than 30%.
- Inserts plus deletes greater than 20%.
- Pseudo-deletes greater than 10%.
- Appended inserts greater than 10% (be aware of potential intended appended inserts).
- Any mass deletes.
- Any change in number of levels.

```
SELECT SUBSTR(INDX.TBCREATOR,1,10) AS TBCREATOR,
       SUBSTR(INDX.TBNAME,1,20) AS TBNAME,
       SUBSTR(RTSI.CREATOR,1,10) AS CREATOR,
       SUBSTR(RTSI.NAME,1,20) AS NAME,
       RTSI.PARTITION,
       SUBSTR(RTSI.DBNAME,1,10) AS
DBNAME,NACTIVE,TOTALENTRIES,
       CASE WHEN ((((1+RTSI.REORGLEAFFAR)*100)-99)/RTSI
NACTIVE > 10)
          THEN ((((1+RTSI.REORGLEAFFAR)*100)-99)/RTSI
NACTIVE)
          ELSE 0 END AS LEAFFAR,
       CASE WHEN (RTSI.EXTENTS > 30)
          THEN (RTSI.EXTENTS)
          ELSE 0 END AS EXTENTS,
       CASE WHEN ((((1+RTSI.REORGINSERTS+RTSI
REORGDELETES)*100)-99)/RTSI.TOTALENTRIES > 20)
          THEN ((((1+RTSI.REORGINSERTS+RTSI
REORGDELETES)*100)-99)/RTSI.TOTALENTRIES)
          ELSE 0 END AS INS_DEL,
       CASE WHEN ((((1+RTSI.REORGPSEUDODELETES)*100)-99)/RTSI
TOTALENTRIES > 10)
          THEN ((((1+RTSI.REORGPSEUDODELETES)*100)-99)/RTSI
TOTALENTRIES)
          ELSE 0 END AS PDEL,
       CASE WHEN ((((1+RTSI.REORGAPPENDINSERT)*100)-99)/RTSI
TOTALENTRIES > 10)
          THEN ((((1+RTSI.REORGAPPENDINSERT)*100)-99)/RTSI
TOTALENTRIES)
          ELSE 0 END AS AINS,
       CASE WHEN (RTSI.REORGMASSDELETE > 0)
          THEN (RTSI.REORGMASSDELETE)
          ELSE 0 END AS MDEL,
       CASE WHEN (RTSI.REORGNUMLEVELS <> 0)
          THEN (RTSI.REORGNUMLEVELS)
          ELSE 0 END AS LEVELS,
       RTSI.REBUILDLASTTIME,
       RTSI.REORGLASTTIME,
   RTSI.REORGINSERTS,
   RTSI.REORGDELETES,
   RTSI.REORGAPPENDINSERT,
   RTSI.REORGPSEUDODELETES,
   RTSI.REORGMASSDELETE,
   RTSI.REORGLEAFNEAR,
   RTSI.REORGLEAFFAR,
   RTSI.REORGNUMLEVELS
FROM SYSIBM.SYSINDEXSPACESTATS RTSI
```

```
INNER JOIN
    SYSIBM.SYSINDEXES INDX
ON  RTSI.CREATOR = INDX.CREATOR
AND RTSI.NAME = INDX.NAME
WHERE RTSI.CREATOR = '<creator>'
AND RTSI.NACTIVE > 10
AND RTSI.TOTALENTRIES > 0
AND (
    ((((1+RTSI.REORGLEAFFAR)*100)-99)/RTSI.NACTIVE > 10)
    OR
    (RTSI.EXTENTS > 30)
    OR
    ((((1+RTSI.REORGINSERTS+RTSI.REORGDELETES)*100)-99)
RTSI.TOTALENTRIES > 20)
    OR
    ((((1+RTSI.REORGPSEUDODELETES)*100)-99)/RTSI
TOTALENTRIES > 10)
    OR
    ((((1+RTSI.REORGAPPENDINSERT)*100)-99)/RTSI
TOTALENTRIES > 10)
    OR
    (RTSI.REORGMASSDELETE > 0)
    OR
    (RTSI.REORGNUMLEVELS <> 0)
    )
ORDER BY INDX.TBCREATOR,
    INDX.TBNAME,
    RTSI.PARTITION
WITH UR
```

The output from these queries, as well as the stored procedure, is dependent upon populated and updated statistics in the RTS tables. In certain situations these statistics may not be populated. Check the real-time statistics for the objects of interest to make sure they are being populated before running these queries. Otherwise important REORGs may be missed. The index query does not take into account indexes that will be REORGed as part of a table space REORG resulting from the table space query. Easily add an exclusion to the index query for tables not in the table space query.

3.1.8 Db2 Reporting on Missing Statistics

As previously stated, it is important to collect accurate and consistent statistics on objects. If there are holes in statistics, Db2 collects and reports on the missing or conflicting statistics as part of the statement compile process (PREPARE or BIND) or as part of the EXPLAIN process. This missing information is documented in the SYSIBM.SYSSTATFEEDBACK system catalog table. The population of this table is controlled by the STATFDBK_SCOPE subsystem parameter.

There are two things that can be done if there is data in the SYSIBM.SYSSTATFEEDBACK: run a RUNSTATS utility to report on the statistics and/or update the statistics; or use a tool that analyzes the information in SYSIBM.SYSSTATFEEDBACK and make recommendations.

Missing statistics is also reported during EXPLAIN or BIND/REBIND/PREPARE. For additional information about this, see Chapter 5.

3.1.9 Invalidating the Dynamic Statement Cache

Executing RUNSTATS invalidates statements in the dynamic statement cache, which then goes through a long prepare and statement compilation at next execution. There may be situations in which it is desirable to refresh the monitoring statistics captured in the dynamic statement cache (see Chapter 10 for details about these statistics) without actually updating the system catalog statistics for an object. Do this with the following format of the RUNSTATS utility.

```
RUNSTATS TABLESPACE <database name>.<table space name>
REPORT NO UPDATE NONE
```

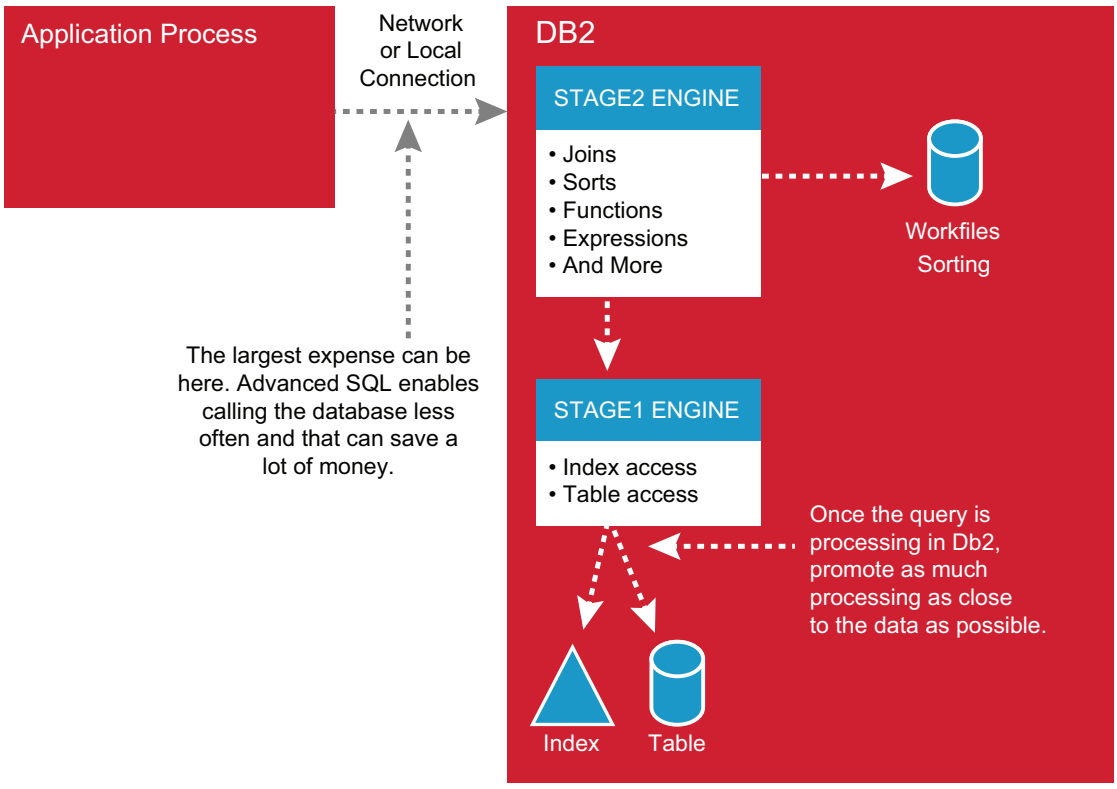
3.2 Db2 Engine Overview

Divide the relationship between Db2 for z/OS engine and SQL processing into three stages. This simplistic approach enables the correct frame of mind for constructing and tuning SQL statements for performance, and helps with understanding the golden rule of SQL performance: Filter as much as possible as early as possible.

- Stage 1: This part of the Db2 engine knows about tables and indexes. This is where the majority of filtering of data from tables and indexes must happen. It is the only place where the amount of data that is retrieved from mass storage (meaning disk) can be limited.
- Stage 2: This part of the Db2 engine processes, sorts, functions, expressions, and joins. It does not know about tables and indexes, so tables and indexes must be accessed and the data passed from Stage 1 to Stage 2 before any Stage 2 filters can be applied. Filtering performed in Stage 2 is not as efficient as filtering performed in Stage 1. However, it is significantly better than any filtering done in Stage 3.
- Stage 3: This is a fictitious step that has nothing to do with Db2 itself and everything to do with proper application development. It is filtering within the application process. To be more specific, it is when an application pulls data from the database only to discard that data upon further processing. Stage 3 predicates are wasteful and unnecessary 100% of the time. Any time a Stage 3 process is coded it is always a better decision to put that filtering into the database.

The following diagram illustrates the Db2 engine and the three stages.

Figure 1: The Db2 Engine in Three Stages



3.3 Predicate Types

The types of predicates and predicate processing are clearly documented in the Db2 for z/OS Managing Performance Guide. Read that section of the Db2 for z/OS Managing Performance Guide before proceeding.

From a performance perspective, the goal is to code Stage 1 indexable predicates (also known as index matching predicates). These are predicates that can match leading columns of indexes. Examine a collection of predicates in your queries when determining how to construct indexes to support them. Predicates of the form col=value are the most likely to be indexable; IN predicates are likely to be indexable as well; range and BETWEEN predicates are indexable; but any predicates that can potentially match on columns after the range predicate is applied cannot be indexable (except in situations where a query may get multiple index access).

Boolean term predicates are also important for index access. A Boolean term predicate is a simple or compound predicate that when evaluated false for a given row makes the entire WHERE clause false for that row. Code Boolean term predicates whenever possible to encourage index access. Examples of Boolean term predicates can be found in the section below on range-list access.

Db2 has the ability to transform predicates coded as Stage 2 into Stage 1 predicates, and is also capable of calling the Stage 2 engine while accessing indexes and tables in Stage 1. It is not always clear which predicates require the most focus. Db2 can also transform non-Boolean term predicates and has special access paths that can improve the indexability of non-Boolean term predicates. This is why the use of the EXPLAIN facility is critical in understanding how a predicate is interpreted, transformed, and processed by Db2. This is explained further in the next section on query transformation.

3.4 Query Transformation and Access Path Selection

The following are the major components to the Db2 engine as divided by roles within the Db2 development team:

- QST (query transformation)/parser
- APS (Access Path Selection, internally referred to as optimizer)
- Post-optimizer/parallelism
- ASLGEN
- Structure Gen
- Runtime

When most DBAs speak about the processing of Db2 SQL statements, they speak of the Db2 optimizer. What many do not realize is that before the query passes through the optimizer it first passes through something called query transformation. This component of the Db2 engine is critical to performance, and a vital part of query processing. It is important to understand query transformation because it is a separate piece of code from the optimizer, owned by a separate development team within Db2 development, and the first component to manage queries as they are processed.

Query transformation is responsible for this type of processing, amongst others:

- Parse the query
- Look up Db2 objects
- Read statistics
- Rewrite the query for submission to optimizer
- Transform queries to special Db2 objects
  - Materialized query table
  - Temporal table
  - View

To be a truly effective SQL performance specialist, take a moment to understand the role of query transformation in SQL processing. Some of the things that query transformation can do when processing a SQL query include:

- Transformation of subqueries. Table statistics are used to influence subquery transformation into either a subquery of a different type or a join. The subquery and join section in Chapter 4 describes the guidelines from which to code, and the transformations mostly follow these guidelines:
  - Correlated and non-correlated into joins
  - Correlated to non-correlated
  - Non-correlated to correlated
- Merging of table expressions with the outer query that references them. Read more about this in the nested table expression section of this chapter.
- Conversion of IN-list into a join. This utilizes the notion of relation division as a means of increasing the potential of matching index access. It also can eliminate the scanning of last IN-lists. See the comments on relation division in Chapter 4 in the sections on joins, nested table expressions, and common table expressions.
- Rewriting of ORDER OF clause. ORDER OF clauses are simply rewritten into ORDER BY clauses based upon the expression that they reference. There is no magic or increased potential for sort avoidance, just a simple cut and paste.
- Predicate transitive closure. If a=b and b=c, then a=c. Query transformation analyzes predicates in ON and WHERE clauses in statements that contain joins. If filtering is applied to a column that is used in a join predicate, then query transformation may generate an additional predicate to add that filtering to the other table of the join. This gives the optimizer (or the access path selection) more opportunities for considering table access sequence with the goal of accessing the table that returns the fewest rows first.
- CASTING of data types. If there are mismatched data types in filtering or join predicates, query transformation introduces CAST expressions to cast one side of the predicate to the other.
- Predicate and join distribution across a UNION or UNION ALL. Query transformation distributes predicates coded against a nested table expression or view that contains a UNION or UNION ALL across all blocks of the UNION or UNION ALL. It also distributes joins to these types of table expressions. There is more on this in the sections of this chapter on UNION and nested table expressions.
- Temporal query predicate generation and generation of UNION ALL for system-period temporal tables and archive tables. Time travel queries using a period-specification in a FROM clause results in the generation of range predicates in the WHERE clause to do the time travel. For system-period temporal tables and archive tables, query transformation generates UNION ALL in a nested table expression to enable access to history and archive tables. The rules and performance implications for these table expressions are the same as for normal table expressions that contain UNION ALL. See the sections in this chapter on UNION and nested table expressions and the section on temporal tables and archive tables in Chapter 7 for additional details.
- Transformation of some non-Boolean term predicates to Boolean terms. There is only benefit to this feature as it increases the index-ability of non-Boolean term predicates.
- Predicate pushdown into nested table expressions and views. There is only benefit to this feature.
- Predicate pruning for UNION in view or table expression and predicate pruning of some always true and always false predicates. When predicates are coded against a nested table expression that contains a UNION or UNION ALL those predicates can be distributed across all blocks of the UNION or UNION ALL. Those predicates within each block of the union are then interrogated and compared to already existing predicates in the block and if two predicates result in an always-false condition then that entire block of the union is eliminated from the query.
- ORDER BY pruning. Query transformation compares ORDER BY columns with columns that filter data in the WHERE clause predicate. If there is an equal's predicate against a leading ORDER BY column then that column is eliminated from the ORDER BY such that there is a greater chance of sort avoidance.
- Join simplification. If a local predicate is coded against the null supplying table of an outer join and that local predicate does not consider null values then the outer join is transformed into an inner join due to the fact that null values from the null supplying table would be eliminated anyway. By transforming the outer join to an inner join, access path selection has more options for table access sequence and higher performance. This also presents a challenge for developers, as often this type of predicate is incorrectly coded as an inner join rather than an outer join. Understanding this aspect of query transformation and being able to view the transformed query (Chapter 5) is a key component to understanding these types of problems.

With all of this potential for the query submitted to Db2 to be transformed to something that is logically equivalent, but significantly different physically, it is critical to have an understanding of the effects of query transformation. Researching query transformation is a difficult proposition. Read this section of this guide a few times, and then look up each of the features presented here in the Db2 for z/OS Managing Performance Guide. From there, write some test queries and use the EXPLAIN facility to expose the transformed queries. Chapter 5 details how transformed queries are exposed in the EXPLAIN tables.

3.5 Single-Table Access Paths

All table access paths are documented in the Db2 for z/OS Managing Performance Guide. This guide references the different types of access and discusses when this type of access is appropriate. Not all access paths are covered here as this is intended to be a compliment to the Db2 for z/OS Managing Performance Guide.

3.5.1 Matching Index Access

Matching index access is appropriate for all sorts of queries even when there are relatively small amounts of data in a table. Matching index access is great for OLTP queries and even certain warehouse-type queries. It may be less appropriate for queries that process large volumes of data sequentially, but the optimizer is less likely to choose an index in these situations unless it was to avoid a sort.

Index-only access is possible in situations in which an index supplies all of the columns required for the coded predicates and for the returned columns in the SELECT clause. It may be beneficial in some situations to add columns to an index to make the access index-only. Db2 allows for INCLUDE columns for unique indexes just for this purpose. Index-only access is a performance advantage in situations in which you cannot establish a common cluster between joined tables, and generally in situations in which extreme read access based upon a non-clustering key is required. Be cautious, however, when making indexes with lots of columns as this can seriously impact the performance of inserts and deletes against the index. To match on index columns of a single index, code Stage 1 indexable Boolean term predicates.

Db2 is also capable of multi-index access. This type of access path is utilized when there is a compound predicate coded against a table connected by ANDs or ORs. Multi-index access can use different indexes or the same index multiple times. Non-Boolean term predicates can qualify for Stage 1 multi-index access. Some non-Boolean term predicates can also qualify for range-list index access.

Index matching access is generally a good access path for transactions, as well as for report writing queries. It is especially good for transactions that return little or no data; as filtering is at the Stage 1 index matching level and undesired data is eliminated with the least amount of data access. DBAs generally strive towards index matching access, but are confused sometimes when index matching is expected but not found. The optimizer may consider alternate access paths when the amount of data qualifying, based upon statistics, is large and/or it is trying to avoid a sort.

Clustering and having well-clustered (organized) data can also play a role in which index Db2 selects for a query. Do not be alarmed when the level of index matching, or a good index matching index is not chosen. Instead, focus on figuring out the reason. Some of the reasons can include: another index eliminated a sort, a different table access sequence in a multi-table query eliminated more rows first, or too many rows qualified even when matching columns.

3.5.2 Range-List Index Access

Range-list index access is designed to support pagination-type queries that support result sets that can span more than one screen. These queries typically employ a specific style of non-Boolean term predicates to position a cursor on the next or previous page. The compound predicate form may look something like this:

```
WHERE LASTNAME > 'RADY'
OR (LASTNAME = 'RADY' AND FIRSTNAME > 'BOB')
```

Previously, the recommended coding technique was to rewrite the predicate as non-Boolean term by adding a redundant predicate:

```
WHERE LASTNAME >= 'RADY'
AND (LASTNAME > 'RADY'
OR (LASTNAME = 'RADY' AND FIRSTNAME > 'BOB'))
```

This technique is no longer needed (as of Db2 10 for z/OS) as it should be accommodated by range-list index access. However, if range-list is expected but not found then the predicates may not be indexable. In this case, add the redundant predicates if index access is desired for the predicates coded.

3.5.3 IN-List Access

IN-list access is a variation of matching index access and comes in two flavors; in-list index scan and in-list direct table access. These can support single and multiple in-list predicates, as well as predicate combinations involving in-lists and additional range or equality predicates. Do not fear a query with an in-list. Consider the indexability and filtering potential of in-list predicates. When performing an EXPLAIN against a query with multiple in-lists, observe that if in-list direct table access is selected then a nested loop join will be seen from the in-memory tables built from the in-lists to the table the predicates are coded against. Also, observe that if multiple predicates are coded against a table and use an in-list against one or more leading index columns, the remainder of the predicates may still be indexable. This can also be true for IN subqueries.

3.5.4 Non-Matching Index Access and Index Screening

Observe that even though an EXPLAIN may show an index being utilized, pay careful attention to the purpose of the index. Pay attention to the number of columns being matched to the index. If the number of columns matched is zero, then the access path is a non-matching index access. Db2 chooses this access path in situations where predicate filtering is poor, or if the use of the index is beneficial to avoiding a sort and the materialization of the result set. Db2 may also choose a non-matching index access because index screening may provide some filtering.

Index screening is filtering that Db2 can apply at the index level when matching is not possible on the leading columns of the index or when there is limited matching of the leading index columns. For example, if one predicate matches on the first column of the index and another predicate matches on the third column of the index but there is no matching predicate on the second column of the index, then Db2 can screen on the third column of the index. What this means is that even though the screen predicate does not limit the range of keys retrieved from the index, it can eliminate qualifying rows before data retrieval. This elimination results in reduced getpage count to the table.

How to determine that index screening is actually happening: The output of EXPLAIN can indicate that a predicate qualifies as an index screening predicate. However, that is not the ultimate way of determining whether or not index screening is being applied at execution. Assume, based upon the EXPLAIN output, that index screening is happening. However, EXPLAIN is not always correct in this regard. If the getpage count for table access appears higher than expected for a query in which index screening is expected, try running the query in a controlled test without the index screening predicate to see if the getpage count varies. If it does not then inquire with IBM why EXPLAIN indicates to expect index screening but it is not happening, or attempt to modify the query and/or indexes to promote a high level of matching index access.

Index screening is possible for many of the single and multi-table access paths, whether or not there is matching index access.

3.5.5 List Prefetch

As mentioned earlier, matching index access is great for queries that support transactions that return little or no data. When the matching predicates are predicted to return somewhat more than a relatively few rows, and the index being utilized is not the clustering index or is clustering but the table data is disorganized, then Db2 may elect to use the list prefetch access method. In other words, list prefetch is a desired access path when accessing a moderate amount of data that is not sequentially organized in the table. In this access path, one or more columns are matching, the index keys are retrieved and sorted in record identifier (RID) sequence which contains the page number, and then the pages of the table are accessed in a sequential or skip-sequential fashion. If the majority of queries against a table are using list prefetch in an OLTP application, consider changing the clustering of the table to the index being selected for list prefetch. Ensure all of the queries are monitored against the table.

Historically, some customers have been wary of list prefetch due to the potential for Db2 to exhaust RID storage for some queries that use list prefetch and revert to table space scans. This is no longer the case as the subsystem can be configured to overflow rid storage to workfiles.

3.6 Multi-Table Access Paths

The main focus in regards to the performance of queries against multiple tables should be the table access sequence. In general, eliminate the most data possible as early in the query as possible. So, the performance goal for a multi-table query is to have Db2 select the table that returns the fewest rows first.

3.6.1 Subquery Access

Because the Db2 engine (query transformation and access path selection) can transform subqueries, it is difficult to predict and control which table is accessed first when coding a subquery. In short, Db2 can do the following:

- Convert a correlated subquery into a join or non-correlated subquery
- Convert a non-correlated subquery into a join or correlated subquery

In general, the Db2 engine is attempting to either filter the most data first, take advantage of the best index matching, or make more table access sequences available (via join) within access path selection. The best solution in these situations is to understand the capabilities within the Db2 engine when dealing with subqueries, and to code the most efficient subqueries possible (see the section in Chapter 4 on coding efficient subqueries and joins).

3.6.2 Nested Loop Join

In a nested loop join, the outer table (the table accessed first) is either scanned or probed and for each qualifying row the inner table (the second table accessed) is then searched. This generally means that from a performance perspective the inner table can be accessed never, once, or many times during the join process. In a nested loop join it is important that the table that filters the most and returns the fewest rows is the first table accessed. A nested loop can be an extremely efficient access path for transactions that return little or no data, and is generally the preferred access path for joins supporting transactions.

Remember that when two tables are joined together and nested loop is the selected access path, the tables being joined should share a common cluster for the best performance. In this way, Db2 avoids random access to the inner table of the join and also takes advantage of such performance enhancers as sequential detection and index lookaside (discussed later in this section). For this reason, avoid system-generated keys in database design. However, if system-generated keys are used, at least let the child tables inherit the parent's primary key in an identifying relationship. That is, the parent key is the leading column of the child's primary key. In that way, a common cluster between tables that are commonly accessed in a join is established. When this happens, a nested loop join is an efficient access path.

If Db2 determines that the clustering between two tables does not support efficient access to the inner table for a non-trivial amount of data, then it may select an alternate access path. These alternates include hybrid and hash join.

3.6.3 Merge Scan Join

In a merge scan join, Db2 attempts to access both tables via a scan in the order of the joined columns. The inner table is always placed into a workfile. The outer table is placed into a workfile and sorted if there is no available index on the joined columns. Once in join column order, the tables are scanned and merged together. Merge scan can be an effective join method for tables in which one or both tables are not in clustering sequence relative to the join columns and both tables are going to qualify many rows of data, or when there are no indexes to support the join columns. This makes merge scan a more effective join method than nested loop for these types of queries. In general, merge scan is the report writing join method while nested loop is the transaction supporting join method. As always, it varies. Merge scan has outperformed nested loop for transactions and nested loop has outperformed merge scan for reports. Usually, the general rule applies.

3.6.4 Hybrid Join

A hybrid join can only be an inner join, and is an alternative to a nested loop join when the inner table is not in the same clustering sequence as the outer table. In a hybrid join, the outer table rows are joined to the index keys of the inner table and then sorted by inner table RID much like what happens with a list prefetch. Next, the inner table rows are accessed in a sequential or skip sequential fashion. A hybrid join, like list prefetch, is appropriate for a moderate quantity of rows when the tables are out of cluster and outperforms a nested loop join in these situations.

3.6.5 Hash Join, Sparse Index, and In-Memory Data Cache

There is another alternative to hybrid join and nested loop join for moderate amounts of data, typically accessed in transactions of an OLTP system. This technique is a form of hash join that enables a faster search of data to join when tables are not in common clustering sequence. While hash join is a named access path in Db2 for LUW, on Db2 for z/OS it appears as a nested loop join with intermediate sorts and workfiles. These in-memory files can either contain sparse indexes or hashes, with the hashes called in-memory data cache. This in-memory cache is just that—held in memory. They can overflow into actual workfiles if memory is short as controlled by the MXDTCACH subsystem parameter. Whether or not Db2 uses a sparse index or in-memory data cache, the objective is to improve the performance of the lookup into the inner table of the join.

While this hash join method exists to improve the response time of nested loop join in some situations, examine the situation in which this join technique is being used and consider the query for possible tuning. Typically the situation occurs in a transaction processing environment, and either adding indexes or changing the clustering of the tables involved to get a more efficient access for the transactions should be considered.

3.6.6 UNION and UNION ALL

For UNION and UNION ALL (as well as EXCEPT, EXCEPT ALL, INTERSECT, and INTERSECT ALL), table access is executed in separate blocks within the query access path. Db2 does not maintain state between the separate blocks. While UNION eliminates duplicates in the result set, it does also introduce a sort. The impact of UNION in a nested table expression or view can be significant, as discussed in the next section on nested table expression access.

3.7 Nested Table Expression Access

Nested table expressions refer to views as well. Common table expressions, scalar full-selects, and table functions are also forms of nested table expressions, however, the majority of this section addresses nested table expressions (or inline views) and views themselves.

3.7.1 Merge vs. Materialization

The key to understanding nested table expressions is merge versus materialization. Is the table expression merged with the outer portion of the statement that references it, or is it materialized into a workfile and then read a second time by the outer portion of the statement? When processing a nested table expression or view, the Db2 engine makes a decision about what to do with the nested table expression or view. The Db2 engine either merges the expression/view with the outer portion of the statement that references it or materializes it in a workfile before further processing. The Db2 for z/OS Managing Performance Guide clearly documents when a nested table expression or view is materialized, however, here are some simple examples where the nested table expression or view contains a GROUP BY (most times), a DISTINCT, or a non-deterministic function.

The following query contains a table expression that is merged with the outer statement that references it:

```
SELECT LAST_INIT
FROM (SELECT SUBSTR(LASTNAME,1,1) AS LAST_INIT
    FROM EMP) AS INIT_TBL(LAST_INIT)
```

The merged statement, seen as the transformed query in an EXPLAIN output, looks something like this:

```
SELECT SUBSTR(LASTNAME,1,1)
FROM EMP
```

The following query contains a table expression that is materialized due to the presence of a DISTINCT within the table expression:

```
SELECT LAST_INIT
FROM (SELECT DISTINCT SUBSTR(LASTNAME,1,1) AS LAST_INIT
    FROM EMP) AS INIT_TBL(LAST_INIT)
```

The following query contains a table expression that is materialized due to the presence of a non- deterministic function, the RAND() function, which is one of the most common ways to force the materialization of a table expression.

```
SELECT LAST_INIT
FROM (SELECT RAND() AS BOBRADY, SUBSTR(LASTNAME,1,1)
    AS LAST_INIT
    FROM EMP) AS INIT_TBL(BOBRADY, LAST_INIT)
```

What is the advantage of merge versus materialization? According to the Db2 for z/OS Managing Performance Guide, merge is always a better performance option than materialization. This is mostly true, but situations with one or more levels of nesting and embedded functions and expressions combined with multiple references to these generated columns in the outer portion of the query can result in excessive CPU consumption when compared to a materialized equivalent. In the following example, the SUBSTR function is actually executed twice per row rather than once per row due to the merging of the table expression:

```
SELECT MAX(LAST_INIT), MIN(LAST_INIT)
FROM (SELECT SUBSTR(LASTNAME,1,1) AS LAST_INIT
       FROM EMP) AS INIT_TBL(LAST_INIT)
```

In this example the difference in CPU consumed between a merged and materialized query may not make much difference, but in situations with many levels of nesting, functions, expressions, and multiple references to the columns resulting from the functions and expressions, it can be better to force materialization using a RAND() function. This has proved to be quite successful for large queries, saving hours of CPU time. Basically, for complex queries running for hours and consuming mostly CPU, consider forcing materialization.

Db2 11 for z/OS has introduced a potential performance improvement to repeated executions of expressions in merged nested table expressions with the introduction of a feature called expression sharing. This feature is currently activated via a hidden installation parameter, QUERY_REWRITE_ DEGREE, which is set to 1 by default. Setting the value to 2 enables expression sharing and enables the reuse of expression results in the outer portion of the query. This would, in effect, get all of the advantages of merge without the overhead of repeated expression execution. Note that this is a hidden installation parameter that applies to the entire subsystem and should be tested with extreme caution and under the guidance of IBM to determine if it will help the environment.

Another challenge in the performance of nested table expressions is the ability of Db2 to push predicates into a materialized table expression or view. Prior to Db2 11 for z/OS there is limited ability for Db2 to push predicates into table expressions, so it may have to be done manually. Check the transformed query that is part of EXPLAIN output to determine whether or not a table expression has been materialized and which predicates against it have been pushed down into the table expression. If redundant predicates are generated by predicate transitive closure, the process of predicate pushdown or predicate distribution is going to happen before transitive closure is applied. In this situation, if the predicates generated by transitive closure could be pushed down they will not and must be redundantly coded.

Db2 has the ability to merge some correlated nested table expressions with the outer portion of the statement that references them, and although correlated table expressions are recommended to force a nested loop access path (see Chapter 4), it may not always be effective.

3.7.2 Scalar Fullselect

Scalar fullselects are not merged with the referencing statement and are executed depending upon where they are coded in the SQL statement. In the following query, either correlated or non-correlated scalar fullselects are executed for every row processed within the SELECT clause. In the WHERE clause, the non-correlated scalar fullselect is evaluated only once and the result is be used in the predicate as Stage 1; but for a correlated reference it would be evaluated for each row as a Stage 2 predicate.

```
SELECT  EMPNO
      , ( SELECT COUNT ( * )
          FROM  EMP SE
          WHERE SE.WORKDEPT = E.WORKDEPT ) AS DEPT_HEAD_COUNT
      , CASE WHEN E.SALARY =
        ( SELECT MAX ( SALARY )
          FROM EMP MS ) THEN 'MAX SALARY'
                        ELSE 'REGULAR PERSON' END AS MAX_INDICATOR
      FROM EMP E
      WHERE SALARY BETWEEN
        ( SELECT AVG ( SALARY )
          FROM EMP ) AND
        ( SELECT MAX ( SALARY )
          FROM EMP EP
          WHERE EP.WORKDEPT = E.WORKDEPT )
```

3.7.3 Common Table Expressions

Common table expressions can be merged with the outer statement that references them, but can also be materialized. If a common table expression is referenced more than once it is materialized.

3.7.4 UNION in View and Table Expression Distribution

Placing a UNION ALL in a nested table expression or view can be a potent construct that can enable significantly powerfully complex processing within a single SQL statement. Some of this can include:

- Multi-table search
- Temporal table access
  - Both homegrown and Db2 provided
- UNION in a view
  - Flexible table design
  - Ultra-large table support

While this construct can be powerful it can also become expensive. A thorough knowledge combined with some testing can create an understanding of the potential costs and benefits. One of the important aspects to understand is that any predicates and joins coded against the UNION in the table expression can be distributed across each block of the UNION if the table expression is merged and not materialized. The following query exhibits a very powerful search in which information about employees that are useful (working on or responsible for projects) is returned.

```
SELECT DISTINCT E.EMPNO
      , E.LASTNAME
  FROM  EMP E
  INNER
  JOIN  ( SELECT EMPNO FROM EMPPROJACT UNION ALL SELECT RESPEMP FROM
        PROJ ) AS WORK ( EMPNO )
    ON  WORK.EMPNO = E.EMPNO
  WHERE E.WORKDEPT = 'C01'
```

The advantage is the power of the query, but the potential performance disadvantage is that there may be redundant table access. A user may examine this query and say that three tables are being accessed: EMP, EMPPROJACT, and PROJ. However, the fact of the matter is that the join is distributed across the UNION ALL, so there are really four tables being accessed because the join to EMP is repeated for each block of the UNION. Since there is no memory between the query blocks, the EMP table is read twice. This can be especially expensive when joining UNION ALL table expressions to other UNION ALL table expressions. Such is the case of system-period temporal tables when a period-specification is utilized in the FROM clauses. Imagine if the EMP and DEPT tables were system period temporal tables then the following query, which appears to join two tables, would actually join (2^n)×n times where n is the number of tables in the coded join. In this case, 8 tables are joined; EMP to DEPT, EMP history to DEPT, EMP to DEPT history, and EMP history to DEPT history.

```
SELECT * FROM EMP FOR SYSTEM_TIME AS OF CURRENT TIMESTAMP E
INNER JOIN DEPT FOR SYSTEM_TIME AS OF CURRENT TIMESTAMP D
ON E.WORKDEPT = D.DEPTNO WHERE E.EMPNO = '000010';
```

When joining to UNIONs and join distributions becomes significant, consider programmatic joins rather than SQL joins. Another option is a correlated reference. The following example is a modification of the query to report on useful employees. In this example, correlation is used to avoid multiple accesses to the EMP table. Use caution with these types of queries and test to determine if they will really be of benefit to the situation.

```
SELECT DISTINCT E.EMPNO
      , E.LASTNAME
  FROM  EMP E
  INNER
  JOIN  TABLE ( SELECT EMPNO FROM EMPPROJACT EPA
  WHERE EPA.EMPNO
      = E.EMPNO
  UNION ALL
SELECT  RESPEMP
  FROM  PROJ P
  WHERE P.RESPEMP
      = E.EMPNO ) AS WORK ( EMPNO ) ON WORK.EMPNO = E.EMPNO
  WHERE E.WORKDEPT = 'C01'
```

Using UNION ALL in a view can be a powerful construct that can serve many purposes:

- Rotate individual tables in and out of a view
- Make tables that are larger than the largest possible tables
- Separate a very large table design into smaller tables
  - May be easier to manage
- Operate a temporal design
  - Base table
  - History table
  - Retrieve data from both as one

One common design is to create a history table for each year for a certain number of years. A view is created with a UNION ALL to concatenate several tables together and make them appear as one:

```
CREATE VIEW ACCT_HIST ( ACCT_ID , ACCT_YEAR , ACCT_ACT_TSP , ACCT_BAL
  , ACTIVE_FLG , TRAN_CDE ) AS (
SELECT  ACCT_ID
      , ACCT_YEAR
      , ACCT_ACT_TSP
      , ACCT_BAL
      , ACTIVE_FLG
      , TRAN_CDE
  FROM  ACCT_HIST_2011
  WHERE ACCT_YEAR = '2011'
  UNION ALL
SELECT  ACCT_ID
      , ACCT_YEAR
      , ACCT_ACT_TSP
      , ACCT_BAL
      , ACTIVE_FLG
      , TRAN_CDE
  FROM  ACCT_HIST_2012
  WHERE ACCT_YEAR = '2012' )
```

In this way, a query can be made against the ACCT_HIST view as it appears to contain the data for multiple years in a single table. Predicates coded against this view are distributed across all blocks of the UNION ALL. There may already be predicates coded within the view that seem unnecessary. However, when a query is coded against the view any predicates are distributed across all the query blocks and any impossible predicates cause an entire query block to be pruned. For example, the following query against the view results in only the first block of the UNION ALL to be executed since the predicate ACCT_YEAR = '2011' is distributed resulting in a compound predicate of WHERE ACCT_YEAR = '2011' AND ACCT_YEAR = '2011' for the first query block and WHERE ACCT_YEAR = '2011' AND ACCT_YEAR = '2012' for the second query block.

```
SELECT *
FROM ACCT_HIST
WHERE ACCT_YEAR = '2011'
```

Observe that predicate distribution can occur for a variety of queries against UNION in a view. However, query block pruning, as demonstrated above, is only possible for predicates containing literal values and host variables and not joined columns. For query block pruning based upon joined columns, the performance choice is a programmatic join so that the literal value or host variable can be provided in the predicate versus the join column.

3.7.5 Impact of UNION on System-Period Temporal Time Travel Queries

System-period temporal tables are a powerful feature introduced with Db2 10 for z/OS. Db2 automation replacing significant quantities of application programming proved a huge advantage with regards to simplifying the application development process and reducing time to delivery for a solution. Customers began implementing system-period temporal base tables and history tables, and coding time travel queries against these tables.

An element that became evident quite quickly, however, was that always using a time travel query to retrieve data could become a challenge from a performance perspective. This was because a system-period time travel query is always transformed into a UNION ALL between the base table and the history table (see the section above on UNION distribution of joins for additional detail). Therefore, even if *as of now* data is desired, both the base and history table are accessed. This performance impact is even more significant with table joins, as joins must be distributed across base and history table. So, what appears to be a two table join between two system-period temporal tables with period-specifications is actually a join of two tables four times for a total access of eight tables. Given that current data represented the majority of typical access, a performance hit was taken 100% of the time. Application developers had to code separate queries to retrieve current data versus historical data to maintain an acceptable level of performance.

Imagine a system-period temporal table called T_EMP. In the following query, a period-specification is used to access the table:

```
SELECT LASTNAME
FROM T_EMP FOR SYSTEM_TIME AS OF CURRENT TIMESTAMP
WHERE EMPNO = '000010'
```

The query transformation component of Db2 transforms the above query to the following:

```
(SELECT LASTNAME
    FROM T_EMP WHERE (
       T_EMP.EMPNO = '000010'
    AND T_EMP.START_TS <= CURRENT TIMESTAMP
    AND T_EMP.END_TS > CURRENT TIMESTAMP)
UNION ALL
SELECT LASTNAME
FROM T_EMP_HIST WHERE (
       T_EMP_HIST.EMPNO = '000010'
    AND T_EMP_HIST.START_TS <= CURRENT TIMESTAMP
    AND T_EMP_HIST.END_TS > CURRENT TIMESTAMP)
)
```

If the application only wants current data, it can access the T_EMP table directly without a period-specification. That is the only way to avoid the UNION ALL in Db2 10 for z/OS.

With the introduction of the CURRENT TEMPORAL SYSTEM_TIME special register in Db2 11 for z/OS, this potential performance issue is addressed. During statement compile time (prepare for dynamic or bind for static) an extended section is added to the statement access path. Db2 builds two sections for the table access for queries that do not specify a period-specification; one without the UNION ALL and temporal predicates and a second with the UNION ALL and temporal predicates. Db2 does this only if the package bind parameter SYSTIMESENSITIVE is set to YES, which is the default. The creation of the alternate access paths for dynamic statements is also dependent upon the package bind parameter for the dynamic package the application is using. The choice of access path at execution time is then dependent upon the setting of the CURRENT TEMPORAL SYSTEM_TIME special register. If the value is set to the null value, then the original section is executed and no UNION ALL or time travel predicates apply. If the value of the special register is set to something other than the null value, the extended section is used, including the UNION ALL and time travel predicates. Since the null value is the default for this special register, an existing table can be converted to a system-period temporal table without application impact at all. A small application change to include the setting (or not setting) of the special register can then dictate whether or not the query is a base query or time travel query, again without changes to the original statement. For example, the following statement against a system-period temporal table actually has two separate access paths if SYSTIMESENSITIVE is YES:

```
SELECT LASTNAME
FROM T_EMP
WHERE EMPNO = '000010'
```

The first access path represents the statement as coded, and the second represents the time travel query:

```
(SELECT LASTNAME
    FROM T_EMP WHERE (
       T_EMP.EMPNO = '000010'
    AND T_EMP.START_TS <= CURRENT TEMPORAL SYSTEM_TIME
    AND T_EMP.END_TS > CURRENT TEMPORAL SYSTEM_TIME)
UNION ALL
SELECT LASTNAME
FROM T_EMP_HIST WHERE (
       T_EMP_HIST.EMPNO = '000010'
    AND T_EMP_HIST.START_TS <= CURRENT TEMPORAL SYSTEM_TIME
    AND T_EMP_HIST.END_TS > CURRENT TEMPORAL SYSTEM_TIME)
)
```

The value of the CURRENT TEMPORAL SYSTEM_TIME special register controls which access path is used, original or extended, and any query that requests *as of now* data using a CURRENT TEMPORAL SYSTEM_TIME set to the null value does not incur the overhead of the UNION ALL. This same performance feature is also available for the new archive enabled tables.

3.8 Query Parallelism

Query parallelism can be a significant performance enhancer from an elapsed time perspective, but does not result in less CPU consumed. Parallelism is controlled across a subsystem via several installation parameters (CDSSRDEF, PARAMDEG, PARAMDEG_DPSI, and PARA_EFF) and via the CURRENT DEGREE special register or DEGREE bind parameter. Query parallelism allows for Db2 to receive a query for processing, break that query into multiple pieces to execute in parallel, and then merge the individual result sets together for a final return to the process executing the query. There are two settings for parallelism at the application level: ANY or 1. These settings control whether or not parallelism is considered for queries issued by an application. When in use, the parallelism is limited only by available resources and the subsystem defined limits PARAMDEG (maximum degree of parallelism) and PARAMDEG_DPSI (maximum degree of parallelism when a DPSI is used to drive the parallelism). It is quite possible to achieve absolutely astounding query response time for large queries when parallelism is utilized and adequate system resources are available.

Query parallelism is ideal for data warehouses and report queries, but not recommended for transactions. Parallelism can be enabled by default (subsystem parameters) or at the application level, and if the application is an OLTP then parallelism may be a performance detriment. This negative is due to the fact that the extra overhead involved in establishing and coordinating the parallel tasks almost always exceeds what would have been the expected or normal response time for a query that processes little. In addition, that coordination increases CPU consumption for transactions.

Therefore, in general, using parallelism for transactions is not recommended from a performance perspective. However, it could possibly be ideal from a cost perspective since CPU for parallel tasks can be offloaded to cheaper zIIP processors.

Parallel tasks spawned within a query can be offloaded to zIIP engines if zIIPs are available. Again, this is optimal for large report type queries, but still may not be the ideal for transactions. The z/OS parameter IIPHONORPRIORITY setting can also significantly affect the execution of parallel tasks. Refer to *Db2 Query CPU Parallelism and &IIPHONORPRIORITY* by Jeff Lane of J. Lane Consulting, on the IDUG Content Committee blog at IDUG.org. The

general recommendation is to utilize parallelism for large queries at times when the machine resources are available, and to not use parallelism for transactions. Reference Chapter 7 and Chapter 8 for database and subsystem configurations to improve parallelism. In addition, the Db2 Installation Guide and the Db2 for z/OS Managing Performance Guide both contain information on parallelism and tuning for parallelism.

3.9 Sequential Detection and Index Lookaside

The significance of these two performance enhancers cannot be overstated. Sequential detection is Db2's ability to detect a sequential access pattern, at a thread level and across one or multiple units of work, for table spaces and indexes. When a sequential access pattern is detected, Db2 launches one or more sequential prefetch engines that are independent of the thread requesting the data in an effort to stage the data in advance of the thread request. This can result in amazingly efficient read I/O response times or zero read I/O response times in some situations. Db2 continues to monitor the access to confirm whether or not pages of data are being requested in a sequentially available fashion and can engage or disengage the sequential prefetch on the fly. Index lookaside is a method in which Db2 keeps track of the index value ranges and checks whether or not a requested index entry is on the same leaf page as the previous request. If Db2 determines that the key being requested is indeed on the same leaf page as the previous request, then the entry can be returned without a traverse of the index b-tree or even a getpage request for the leaf page. This can result in a tremendous amount of CPU saved for index intensive operations.

Note that the mechanisms for sequential detection and index lookaside are stored in the thread storage of the thread making the SQL requests. Each thread thus has its own storage for these mechanisms independent of other threads, and whether or not this storage is maintained across the boundaries of a unit of work is dictated by the RELEASE setting of the package the thread is using for the process. If the setting is RELEASE(COMMIT) then it is telling Db2 that *when I commit, I am not coming back*. So, the storage is released on every commit and the potential for index lookaside and sequential detection is reduced. If the setting is RELEASE(DEALLOCATE) then the memory for these mechanisms is retained across a unit of work, and the potential for sequential detection and index lookaside greatly increases. For this reason, the setting of RELEASE(DEALLOCATE) is highly recommended for batch processing, as well as for high-speed transaction processing. For transaction processing under CICS, use protected threads as well as RELEASE(DEALLOCATE), and for remote threads, employ high-performance DBATs (described in Chapter 4). RELEASE(DEALLOCATE) is further described in the BIND options section of Chapter 4.

Effective use of these performance enhancers depends greatly upon the design of the database and application processes. A common cluster amongst joined tables, or even tables accessed individually in a repeating pattern, can affect sequential detection and index lookaside. In addition, for large batch processes the input to the process can be sorted to match the clustering sequence of the search to take advantage of these features. Even with a massive skip sequential process, a benefit to sequential detection is observed (index lookaside is unlikely for a skip sequential process); whereas, even with a terrible buffer hit ratio of –241%, sequential prefetch is still a better performer than random access. With an input to the process organized in the same sequence as the data stored in the indexes and tables, RELEASE(DEALLOCATE), protected threads, and high performance DBATs, extreme transaction rates can be achieved by taking advantage of these performance enhancers.

Chapter 4: Coding SQL for Performance

SQL is far more than a data access language. It is a fully functional programming language with significant flexibility. It is also fairly easy to learn, which could be a good or bad thing. Usually, programmers are taught just enough SQL to access the information required from the database, and not any more. This results in many simple SQL statements that pull the minimally required information for solving a given access requirement. In other situations, the developer may be using a tool to access the database and not in complete control of the SQL being generated and executed. IBM is doing a great job of making SQL processing more efficient with every new release of the software. This offsets some of the performance implications of SQL that are generated by tools and created by developers with the minimum level of experience. If good performance is desired then Db2 is a strong choice.

If high performance and cost savings are desired then SQL must be coded with performance in mind. This does not mean that every statement must be coded with performance in mind. It means that for critical processing where performance is of primary concern each SQL statement must take performance into consideration. This represents a trade-off on the time spent coding and testing versus the performance of the SQL statement at execution time. Good architects and developers must understand when speed and flexibility of development are important and when SQL statement performance is important and strike a balance between the two. Examine the application design and predicted or current transaction rates to quickly identify the area of logic that requires the most attention. Is there a transaction that is executed 1000 times per day? It may be wasteful to spend time designing this transaction with performance as the primary concern. What about the transaction that is executed 200 million times per day? Obviously any performance considerations made to the design of the SQL in this transaction will have a significant impact on performance and operational costs. *Detector* collects SQL query details and allows quick identification of the most expensive statements.

Focus time reasonably and choose battles accordingly. Speed and flexibility of application development is paramount. It is impossible to inject SQL performance concepts into every piece of application logic written. In the majority of cases, the most difference is made by focusing on the performance of a few critical processes.

4.1 Efficient SQL Statements

There is a saying that the most efficient SQL statement is the one that is never executed. Calling the database can be expensive, especially when it is called across a network. Observe the following three rules for efficient SQL coding:

- Only call the database when it is absolutely necessary.
- If the database must be called, do the work in the fewest number of calls.
- When the database is called, code the statement in a format that the database can use for performance.

NOTE: *Plan Analyzer* comes with a set of predefined SQL rules that can help automatically validate SQL statements efficiency against well-known recommendation.

4.1.1 First Rule: Call the Database Only When Necessary

This statement cannot be overemphasized. The single largest impact to application performance today is the frequency of SQL execution. Many generic application designs lead to the over-execution of simple SQL statements. The only way to achieve a higher level of performance in these situations is to change application code. There are no database or SQL solutions. Therefore, it is vital to consider the frequency of access for certain portions of the application and to code database access efficiently in these situations. Do you already have an object in memory? Is it really important to re-access the database objects again? Here are some suggestions for avoiding frequent SQL executions:

- Cache common objects in memory. This is especially important for objects such as code tables. Place access counters, update detection, or time limits against objects that are placed in cache and then refresh them at appropriate times. Examples of such objects include arrays in batch programs, CICS transient data queues, and Java Caching System.

- Utilize an optimistic locking strategy. Db2 supplied mechanisms, discussed in this section as well as in Chapter 7, can be used to help applications avoid unnecessary calls to the database to retrieve data prior to changing that data.
- Combine multiple SQL statements into one statement. More details on this below.
- Do not use Db2 for transient data storage. In many situations DBAs create tables to persist data across disparate processes. They are familiar with Db2, so this is a simple thing to do. If performance is a concern, then there is nothing good about this. This data belongs in shared memory, flat files, or message queues, and not in Db2. Forcing transient data to be stored in Db2 is the worst choice from a performance perspective.
- Let Db2 automation do some of the work. Features such as triggers and database enforced constraints allow for database automation to replace multitudes of SQL statements. See sections in this chapter and Chapter 7 about utilizing database automation for performance.

This first rule is easily the most important. Data-intensive work should be in the database engine. If it is not, then the result is a proliferation of SQL calls that each, on their own, do very little work. If the work is in the database, then it can be exposed via EXPLAIN and can be tuned by a DBA. If the work is done in the application, there is nothing that can be done on the database side of things.

4.1.2 Second Rule: Do the Most Work in the Fewest Calls

One way to reduce the quantity of SQL issued in an application is to combine multiple SQL calls into a single SQL call. There are many ways to do this, and in fact, the vast majority of the content of this guide is focused on advanced SQL calls and processing that are designed to reduce the number of times the database is actually called. The basic question to ask is: When accessing table A, will table B also be accessed? If the answer is yes, then from a performance perspective code access to both tables in a single statement.

- Code joins versus single table access. This is as simple as it gets. Is data needed from two tables that are related? Code a two-table join versus a programmatic join via separate SQL statements. The advantage to a join versus individual SQL statements is twofold: first, it avoids excessive SQL calls, and second, Db2 chooses the most efficient access path versus the application developer coding the statements. That second point is extremely important to understand. When coding a join in a program, the table access sequence is forced, which is an extremely critical factor in database performance. When coding a SQL join, the database optimizer makes a decision as to which table to access first. The database decision is based upon statistics and changes due to changes in tables, indexes, and table contents. The multi-table access path coded in an application program does not take any of this into account and will not change unless the developer modifies the code. In simple tests, a two-table join outperforms an equivalent programmatic join by 30%.
- Use database-enforced referential integrity. Database-enforced RI is discussed in detail in Chapter 7, but the bottom line is that if there are relationships to check and deletes to restrict or cascade then have the database do the work rather than the application. This seriously reduces the calls to the database. From a performance perspective, one of the worst decisions a DBA can make is to not implement a cascading delete in the database and insist the application cascade the deletes itself.
- Use triggers for multi-table changes. If there is a need to modify the contents of one table when the contents of another table change, then this can be accomplished within the database engine via database triggers. Triggers are discussed in detail in Chapter 7, but essentially they eliminate multiple database calls.
- Use some database automation. Sequence objects, identity columns, and temporal and archive tables all allow for multiple database calls to be replaced by single calls that result in multiple actions. Read about these features in Chapter 7 for additional information.
- Read from result tables. The table-reference in the FROM clause of a subselect includes something called a data-change-table-reference, which allows for read access to a result set of an INSERT, UPDATE, DELETE, or MERGE statement. This includes the ability to generate additional data for processing within the context of the entire statement. Further information about this can be found in the nested table expression section of this chapter.

Using SQL coding techniques to consolidate database calls is extremely critical to application performance. The key to this is knowledge. Explore the database features and test them to see if they work in the environment. Then make common guidelines for coding these in the environment. The result can lead to significant improvements in application performance without much pain for the designers and developers.

4.1.3 Third Rule: Code Performance Effective SQL Statements

In observing the first two rules of coding SQL for performance you are well over 80% to achieving high performance. Coding more complex SQL statements in an effort to reduce the calls to the database places more responsibility for the performance of those statements from the application developer to the database engine. This is optimal for the developer, and in the vast majority of circumstances, it is optimal for overall application and database performance. The Db2 engine has evolved over the years, and the SQL optimization in the product is substantially improved with each release of the product. SQL performance is statistics-based and query performance adapts as databases change over time. In over 90% of given opportunities, Db2 chooses an access path that is the best performance choice.

If the ultimate in application performance is desired, there is still some responsibility in the hands of the developer and DBA to understand how query optimization works and how some SQL coding techniques can be utilized to give the Db2 engine better optimization choices. Remember, the basic underlying premise of great SQL performance is to filter as much as possible as early as possible.

Advancing to this level of SQL performance requires an understanding of how Db2 works. The majority of this section, as well as Chapter 4, Chapter 5, and Chapter 6 are dedicated to understanding SQL optimization and improving the performance of individual SQL statements.

An understanding of the relativity of SQL performance is important. What is the better performing SQL statement: the statement that does a table space scan or the one with matching index access? There is no correct answer except that it depends upon how much data is expected to be returned to the application. If the application requires all of the data from a table then a table space scan is a very appropriate and efficient access path. If zero or one row is expected then the matching index access is very likely the best performing access path. What about when the expected result set quantity is somewhere between zero and infinity? That is where the challenge lies, and an understanding of the engine is important to guarantee the best performance.

4.2 The Basics of Coding SQL Statements for Performance

There are some very simple and basic rules of coding an individual SQL statement for performance. For the most part, these recommendations do not generally result in significant performance improvements, but are good general techniques. If they are implemented as part of standard guidelines for SQL program across an enterprise, they can make a significant impact. There is certainly no reason to go back and change existing SQL statements to conform to these guidelines.

4.2.1 Retrieve Only the Rows Required

Chapter 3 discussed the types of predicates and how they are processed by Db2, including Stage 1 and Stage 2 predicates. There is also the fictitious Stage 3 predicate where rows are retrieved into an application and then discarded. There is absolutely nothing efficient about Stage 3 predicates. Any filtering should be in a WHERE clause predicate in a SQL statement. In some situations, developers have coded Stage 3 predicates as a means of avoiding DBAs rejecting the SQL upon a performance review because the SQL contains Stage 2 predicates. The fact is that a Stage 2 predicate is always better than a Stage 3 predicate. In addition, there are constant performance enhancements to the Db2 engine and many predicates that used to be Stage 2 predicates are no longer Stage 2 predicates, or the processing of Stage 2 predicates has become more efficient. The conclusion is to filter the data in the WHERE clause predicate of a SQL statement.

4.2.2 Retrieve Only the Columns Required

This is challenging due to the fact that adjusting the number of columns returned from a table based upon the needs of a particular transaction or process means coding either more SQL statements or using dynamic SQL with constantly changing SELECT lists. The performance ramifications of lengthy columns lists can be significant depending upon the frequency of execution and number of columns retrieved. Performance tests have been conducted where the only difference between statements executed were the number of columns retrieved and a significant CPU reduction has

been observed for the reduced column list. So, while coding multiple statements may be a bad idea from a development perspective it is smart from a performance perspective. This is a situation where it is definitely a benefit to identify the most often executed statements and transactions, and to consider the column requirements for those specific processes. If there is something to gain from a shorter column list in those situations it may be a benefit to code a special SQL statement. Always run some benchmark tests, as described in Chapter 10, and document the potential CPU savings for these transactions. That should make it easier to decide whether or not special code is needed for those transactions. In situations with extremely high transaction rates, retrieving only the columns required can have a huge impact on CPU consumption and ultimately the operational cost of the application. There is a balance between the cost of additional program logic and CPU savings that is worthy of exploration.

4.2.3 Code the Most Selective Predicates First

Db2 processes predicates in a WHERE clause in a specific sequence that is well documented in the Db2 for z/OS Managing Performance Guide. Basically, predicates are processed, and thus rows filtered, in a given sequence by stage and then in a specific order within that stage. Predicate stages are documented in Chapter 3. In general the sequence of predicate execution is:

1. Index matching predicates in matching column sequence
2. Index screening predicates
3. Page range screening predicates
4. Other Stage 1 predicates
5. Stage 2 predicates

Within each of the steps listed above and after the index predicates, the predicates are applied in the following order:

1. Equality predicates
2. Range predicates
3. Other predicates

Within each of these subgroupings, predicates are evaluated in the order coded in the SQL statement. In conclusion, code the predicates in the WHERE clause in the sequence of what is believed to be the most to least restrictive.

4.2.4 Code Efficient Predicates

Assure that predicates are being coded efficiently and that these efficiencies are part of the SQL programming guidelines. Chapter 3 documents the different Db2 predicate types. Use Stage 1 index matching predicates whenever possible, trying to include all leading columns of the potential matching index. Avoid coding functions or expressions against columns of a table in a predicate as it is likely a Stage 2 predicate, and thus non-indexable. Use equalities whenever possible to ensure the finest level of filtering and greatest potential for index matching. There are many exceptions to this rule, and Db2 can convert what is potentially a Stage 2 predicate into a Stage 1 index matching predicate in some situations. Observe the fact that a Stage 2 predicate that is connected to a Stage 1 predicate with an OR in a compound predicate makes the entire compound predicate Stage 2.

4.2.5 Use Explicit Join Syntax

The use of explicit join syntax is encouraged versus implicit join syntax. For example, the join between the EMP and DEPT Db2 sample tables can be coded one of two ways:

Implicit join syntax:

```
SELECT A.LASTNAME, B.DEPTNAME
FROM EMP A, DEPT B
WHERE A.WORKDEPT = B.WORKDEPT
AND B.DEPTNO = 'C01'
```

Explicit join syntax:

```
SELECT A.LASTNAME, B.DEPTNAME
FROM EMP A
JOIN DEPT B
ON A.WORKDEPT = B.WORKDEPT
WHERE B.DEPTNO = 'C01'
```

While this is not particularly a direct performance recommendation, it can be extremely helpful when diagnosing SQL problems and also when tuning SQL statements. There are several reasons to favor explicit join syntax:

- It is easier to read and understand than implicit join syntax, since the join predicates are in the ON clause and the filtering predicates are in the WHERE clause.
- It is harder to miss coding a join predicate. The explicit join syntax requires a join predicate be coded in an ON clause. Using implicit join syntax mashes together join predicates with filtering predicate, which can lead to confusion and poor performing SQL.
- It is easy to change an inner join to an outer join if when coding explicit join syntax. In the example that uses explicit join syntax above, simply replace the word JOIN with LEFT JOIN to change the query from an inner to a left outer join. If implicit join syntax is used for inner joins then the query must be rewritten. Convert inner joins to left joins when attempting to influence table selection sequences (see Chapter 6 for additional details).

4.2.6 Code Efficient Host Variables

Even though the Db2 engine is extremely tolerant of data type mismatches, it is good practice to code and bind host variables that match the data type of the corresponding columns to the SQL statements. Using host variables or parameter markers in queries is extremely important from a performance perspective, and it is encouraged to code using host variables and parameter markers versus using literal values, especially for dynamic SQL. Observe, however, that using a host variable or parameter marker generally hides a value from the optimizer and puts Db2 in a position where it must use default filter factor calculations to determine the potential filtering for a predicate. This is not necessarily a bad thing as static, embedded SQL and dynamic statements coded with parameter markers can reuse already built access paths and avoid incremental binds or long prepares. However, observe that the access path may not be optimal in situations where there may be data skew. In these situations, there are many options for improving the access paths of these statements. These options are described in Chapter 6 and include:

- Access path reoptimization
- Selectivity overrides
- Statement and package level hints

If literal values are coded into dynamic SQL statements and heavily skewed data is not being accessed, then a potential performance option may be literal concentration (described in Chapter 6).

4.3 Subqueries and Joins

When coding multi-table access in a SQL statement there are several choices with regard to performance. With every release of Db2 these decisions become less relevant due to the improved power of query transformation, also known as query rewrite (discussed in detail in Chapter 3). Nonetheless, code multi-table access queries multiple ways, explain each option, and benchmark each option as well. There are three ways to code multi-table access queries.

- Non-correlated subquery
- Correlated subquery
- Join

Below are some guidelines for choosing the right query for the application. For reference, here are three queries that each return the same result set coded in each of the three ways:

Non-correlated subquery:

```
SELECT WORKDEPT, EMPNO, LASTNAME
FROM EMP EMP2
WHERE WORKDEPT IN
(SELECT DEPTNO
FROM DEPT DEPT
WHERE DEPTNAME LIKE '%SYSTEMS%')
```

Correlated subquery:

```
SELECT WORKDEPT, EMPNO, LASTNAME
FROM EMP EMP2
WHERE EXISTS
(SELECT 1
FROM DEPT DEPT
WHERE DEPT.DEPTNO = EMP2.WORKDEPT
AND DEPT.DEPTNAME LIKE '%SYSTEMS%')
```

Join:

```
SELECT EMP2.WORKDEPT, EMP2.EMPNO, EMP2.LASTNAME
FROM EMP EMP2 INNER JOIN
DEPT DEPT
ON DEPT.DEPTNO = EMP2.WORKDEPT
WHERE DEPT.DEPTNAME LIKE '%SYSTEMS%'
```

Observe that the query transformation component and/or the access path selection components of the Db2 engine (discussed in detail in Chapter 3) can change non-correlated subqueries into correlated subqueries or joins, and correlated subqueries into non-correlated subqueries or joins. This section discusses the performance of these queries as if they were not transformed by Db2.

4.3.1 Non-Correlated Subquery

Non-correlated subqueries that are not transformed into a correlated subquery or join are processed in a bottom up fashion. The subquery is executed first, and the result of the subquery is sorted and placed into a workfile, and is then used as a Stage 1 indexable predicate (described in Chapter 3) in the outer portion of the query. An index can be used for matching index access in the outer query. If an index is not used, then the predicate is processed as either Stage 1 or Stage 2. Db2 can build a sparse index on the fly in support of faster access to the table of values generated by the subquery.

Non-correlated subqueries are useful when multi-table access is required, but data is only required from one of the tables, and they are especially useful when the data from the inner table must be aggregated or modified in some way. One way to utilize non-correlated subqueries is in support of generic search screens that utilize a variety of range values as input. For example, suppose there is a generic search screen for employees in the Db2 sample database. The screen supports full-range searches on the employee's education level, hire date, and bonus. If the query was coded as a simple generic query that contains the three range predicates, it can at best get single-column matching index access.

```
SELECT *
FROM EMP A
WHERE BONUS BETWEEN ? AND ?
AND HIREDATE BETWEEN ? AND ?
AND EDLEVEL BETWEEN ? AND ?
```

Given that the domains of the education level and hire dates are limited, code tables can be built that contain the entire domain of values for these columns. Then non-correlated subqueries can be used to generate the qualifying values based upon filters against these limited domains for three-column matching index access against the employee table (given the appropriate supporting index).

```
SELECT *
FROM EMP A
    WHERE BONUS BETWEEN ? AND ?
    AND HIREDATE IN (
        SELECT VALID_DATE
        FROM VALID_DATES
        WHERE VALID_DATE BETWEEN ? AND ?)
    AND EDLEVEL IN (
        SELECT VALID_ED_LEVEL
        FROM VALID_ED_LEVELS
        WHERE VALID_ED_LEVEL BETWEEN ? AND ?
```

Queries such as this have been used to enable generic searches against very large tables to utilize matching index access for dramatic query performance improvements.

Below are general guidelines for coding a non-correlated subquery versus a correlated subquery or join.

- When the expected result of the subquery is small compared to outer query
- When the subquery result is not large
- When the outer query can utilize a matching index on the subquery results
- When there is no available index on the matching columns of the subquery

Observe that Db2 can transform a non-correlated subquery into a correlated subquery or a join. Nonetheless, follow these guidelines. As always, an EXPLAIN and a benchmark test indicate which type of query performs the best.

4.3.2 Correlated Subquery

Correlated subqueries that are not transformed into a non-correlated subquery or join are processed in a top-bottom, top-bottom, top-bottom, and so on fashion. The outer query is executed first, and for each qualifying row of the outer query the correlated subquery is executed. The correlated subquery is considered a Stage 2 predicate for the outer query as the correlated subquery cannot be executed until the data from the outer query is available to resolve the correlated reference. The predicate that contains the correlated reference in the subquery can be an indexable Stage 1 predicate.

Correlated subqueries are useful instances when the result of a query is dependent upon an existence check, such as the following query.

```
SELECT EMPNO, LASTNAME
FROM EMP E
WHERE EXISTS
(SELECT 1
FROM PROJ P
WHERE P.RESPEMP = E.EMPNO)
```

Below are general guidelines for coding a correlated subquery versus a non-correlated subquery or join.

- When the subquery result is potentially larger than the outer query
- When the outer query has no supporting index on the matching columns
- When there is good index matching potential for the subquery

Observe that Db2 can transform a correlated subquery into a non-correlated subquery or a join. Nonetheless, follow these guidelines. As always, an EXPLAIN and a benchmark test indicates which type of query performs the best.

4.3.3 Join

Joins are an important performance choice because Db2 can choose the table access sequence based upon available indexes and statistics (observe that subqueries can be transformed). Of course, if data is required from both of the tables involved then a join is a more obvious choice over a subquery. When coding a join versus a subquery, be aware of the fact that a join may introduce duplicate rows in some situations, and a DISTINCT clause may need to be added in the SELECT to eliminate those duplicate rows in the result set.

Below are general guidelines for coding a join versus a correlated or non-correlated subquery.

- There's good matching index potential for outer query and subquery
- The subquery converted to a join does not introduce duplicate rows in the result

When thinking about join performance, Db2 should first access the table that qualifies the fewest number of rows. Db2 has a variety of join methods to choose from based upon the catalog statistics.

4.3.4 Anti-Join

An anti-join is a fabulous alternative to NOT IN and NOT EXISTS subqueries, and can represent a significant performance boost to these types of queries when data volumes are extremely large and/or workfile resources are constrained. An anti-join utilizes an after join predicate in an outer join to filter data based upon the fact that the relationship between the two tables does not exist. When an outer join is executed, Db2 supplies null values for the null-supplying table when the relationship between the two tables in the query does not exist. For example, in a left outer join the table on the right side of the join operation is the null-supplying table. When Db2 does not find rows in this right side table based upon the join predicate, nulls are returned for those left table rows. Therefore, if a predicate looking for those null values is coded, then rows of the left table are returned that are not found in the right table. This is the same as a NOT IN or NOT EXISTS. The following three queries all return the same results, but their execution is extremely different. Use the rules for coding subqueries versus joins above to help determine which type of query to code. Always remember that EXPLAIN and benchmark tests help make the ultimate decision.

Non-correlated subquery:

```
SELECT WORKDEPT, EMPNO, LASTNAME
FROM EMP EMP2
WHERE WORKDEPT NOT IN
(SELECT DEPTNO
FROM DEPT DEPT
WHERE DEPTNAME LIKE '%SYSTEMS%')
```

Correlated subquery:

```
SELECT WORKDEPT, EMPNO, LASTNAME
FROM EMP EMP2
WHERE NOT EXISTS
(SELECT 1
FROM DEPT DEPT
WHERE DEPT.DEPTNO = EMP2.WORKDEPT
AND DEPT.DEPTNAME LIKE '%SYSTEMS%')
```

Anti-join:

```
SELECT EMP2.WORKDEPT, EMP2.EMPNO, EMP2.LASTNAME
FROM EMP EMP2
LEFT JOIN
DEPT DEPT
ON DEPT.DEPTNO = EMP2.WORKDEPT
AND DEPT.DEPTNAME LIKE '%SYSTEMS%'
WHERE DEPT.DEPTNAME IS NULL
```

4.4 Table Expressions

Nested table expressions (hereafter often referenced as NTE) allow the power of SQL to be harnessed. They allow for the creation and manipulation of intermediate SQL results for further processing in an outer portion of a statement. Not only can nested table expressions be utilized to solve complex problems, but they can be coded to have an important performance impact.

Table expressions can be a performance advantage or disadvantage and require a significant amount of practice to determine exactly how they perform in an environment. From a logical perspective, a nested table expression produces an intermediate result table that can be further processed, but from a physical perspective, the table expression is subject to the concept of merge versus materialization that is described in Chapter 3.

Table expressions include the following constructs:

- Nested table expressions
- Views
- Common table expressions
- SQL table functions
- Scalar fullselects in SELECT and WHERE clauses
- There are many ways you can utilize table expressions for performance.
- Combining line item and aggregate information together in the same query for reports or transactions
- Searches using relational division
- Making decisions based upon aggregated or modified results
- Building queries piece by piece
- Pushing down during join predicates in outer queries
- Forcing materialization
- Forcing table access sequence

The top performance advantage in using nested table expressions is the fact that they can replace significant quantities of application code and seriously reduce multiple calls to the database to solve a complex business problem. Application processes that ran for days have been transformed into single SQL statements that ran for minutes by utilizing table expressions. This is especially true when an application is issuing many SQL statements to process data in pieces, and those statements are combined into one statement. A classic example of using the power of nested table expressions is in exploiting relational division. Relational division is a way of saying join, but it enables the ability to search for things inside other things. That is, a small quantity of data can be joined into a large quantity of data to find a relationship between the two. Analysis can be applied to the result using table expressions. Relation division is an extremely powerful tool in OLTP, decision support, and especially warehouse situations. In the following example, one of the employees in the sample database, Christine Haas, has decided to leave the company. Before she leaves it is important to make sure that someone else has worked on her projects. Relational division provides a solution by joining the result of a query that returns Christine’s projects into others’ projects.

```
SELECT DISTINCT E.EMPNO
    FROM EMPPROJACT E
    INNER JOIN (SELECT EPA.EMPNO, EPA.PROJNO
       FROM EMPPROJACT EPA
       WHERE EPA.EMPNO = '000010') AS F(EMPNO,PROJNO)
    ON E.PROJNO = F.PROJNO
    AND E.EMPNO <> F.EMPNO
    ORDER BY E.EMPNO
```

Taking things a step further, it is realized that Christine is leaving due to the fact that she believes she works harder than the other employees and logs more time on projects than others that have worked on the same projects. Relational division can prove her right or wrong.

```
SELECT E.EMPNO, E.PROJNO, C_TIME, SUM(E.EMPTIME) AS O_TIME
FROM EMPPROJACT E
INNER JOIN (
    SELECT EPA.EMPNO, EPA.PROJNO, SUM(EPA.EMPTIME)
    FROM EMPPROJACT EPA
    WHERE EPA.EMPNO = '000010'
    GROUP BY EPA.EMPNO, EPA.PROJNO) AS F(EMPNO,PROJNO,C_TIME)
ON E.PROJNO = F.PROJNO
AND E.EMPNO <> F.EMPNO
GROUP BY E.EMPNO, E.PROJNO, F.C_TIME
HAVING SUM(E.EMPTIME) > (
    SELECT SUM(G.EMPTIME)
    FROM EMPPROJACT G
    WHERE G.EMPNO = '000010'
       AND G.PROJNO = E.PROJNO)
```

Relational division and common table expressions have also been utilized as another way to increase matching index access for search queries. The query below solves the same search request as the previous non-correlated subquery example earlier in this section using relational division and achieving three-column matching index access (given the appropriate supporting index). Notice the use of the RAND() function in the common table expression to force materialization and encourage Db2 to access the result of the common table expression first in the access plan.

```
WITH SEARCH(HIREDATE, EDLEVEL, N) AS (
    SELECT VALID_DATE, VALID_EDLEVEL, RAND()
    FROM VALID_DATES, VALID_EDLEVELS
    WHERE VALID_DATE BETWEEN ? AND ?
       AND VALID_EDLEVEL BETWEEN ? AND ?)
SELECT EMP.*
FROM EMP EMP
INNER JOIN SEARCH SRCH
    ON EMP.HIREDATE = SRCH.HIREDATE
AND EMP.EDLEVEL = SRCH.EDLEVEL
WHERE EMP.BONUS BETWEEN ? AND ?
```

4.4.1 Correlated vs. Non-Correlated Nested Table Expression

As with subqueries, nested table expressions can be correlated or non-correlated. Likewise, the way that Db2 processes non-correlated and correlated nested table expressions is extremely similar to the way it processes non-correlated and correlated subqueries that are not transformed. Thus, the same bottom-top and top-bottom, top-bottom situation exists. Below are two queries that are logically equivalent, but perform completely differently.

Non-correlated nested table expression:

```
SELECT EMPNO, SALARY, DEPTSAL.AVGSAL
FROM EMP EMP
LEFT JOIN
(SELECT WORKDEPT, AVG(SALARY)
FROM EMP
GROUP BY WORKDEPT) DEPTSAL(WORKDEPT, AVGSAL)
ON EMP.WORKDEPT = DEPTSAL.WORKDEPT
```

Correlated nested table expression:

```
SELECT E.EMPNO, E.SALARY, DEPTSAL.AVGSAL
FROM EMP E
LEFT JOIN
TABLE (SELECT F.WORKDEPT, AVG(F.SALARY)
FROM EMP F
WHERE F.WORKDEPT = E.WORKDEPT
GROUP BY WORKDEPT) DEPTSAL(WORKDEPT, AVGSAL)
ON E.WORKDEPT = DEPTSAL.WORKDEPT
```

The non-correlated table expression is great for larger volumes of data, especially when most or all of the data in the table expression will be used by the outer portion of the query. The correlated table expression is better for transactions where very little data inside the correlated table expression qualifies. In the example above, the non-correlated version is better since all of the data is processed from both table references. If the predicate WHERE E.EMPNO = '000010' is added to each of the queries, then there is a very good chance that the correlated version performs better since only a portion of data from each of the table references is accessed. In contrast, the non-correlated version still processes the entire table expression before filtering. Since the results of the non-correlated subquery can be materialized into a workfile, workfile resource limitations may occur. This could make the correlated table expression a better choice in those situations in regards to getting the statement to run, but the CPU usage could be higher. Observe that, due to the top-bottom-top-bottom processing of the correlated nested table expression, the cost of such a statement can be extremely high for large volumes of data qualifying for the outer query. In these cases, the non-correlated version is definitely the better choice.

When coding scalar fullselects in a SELECT clause observe the fact that, regardless of whether or not it is correlated or non-correlated, it is executed once for every row processed by that SELECT clause (see Chapter 3 for details).

Below are general guidelines for coding nested table expressions:

- Use non-correlated if the NTE processes all of the data from the tables in the NTE
- Use correlated if the NTE processes only a fraction of the data from the tables in the NTE
- An available index on the correlated NTE query column(s) in the correlated predicate is critical

Stay aware of the concept of merge versus materialization discussed in the table expression section of Chapter 3 and also the options available for improved performance of nested table expressions.

4.5 SQL Features and Performance

There is a very robust set of database features available on Db2 for z/OS. There are many good reasons to utilize these features, and many of those reasons have to do with performance. If there are processes that are data intensive, those processes should be executing close to the data. Most of the features discussed here can be utilized to save processing time and CPU cost. As always, testing a solution is the ultimate answer as to whether or not it will perform. Use *SYSVIEW for Db2* and *Detector* to collect and compare the performance results of testing these features.

4.5.1 Stored Procedures

There are several reasons to use stored procedures, but the top reason is to improve performance of transactions that issue multiple SQL statements over a network. From a performance perspective, the main objective when implementing a stored procedure is to replace remote SQL calls with a single call to a stored procedure. The stored procedure contains the multiple SQL statements and some business logic, and returns a result back to the caller. When writing single statement stored procedures, performance is hurt more than helped due to the increased code path required to execute the statement.

There are three types of stored procedures:

- External
- External SQL
- Native SQL

External stored procedures are written in one of several programming languages including COBOL, Assembler, and Java, and execute in a workload managed application environment (WLM) stored procedure address space (SPAS). This SPAS is external to the Db2 address spaces. Therefore, any calls to these external stored procedures are cross-memory calls. IBM has optimized calls to these external routines, but the overhead of calling them has not been completely eliminated. This makes native SQL procedures a more attractive choice, since they execute inside the Db2 engine. However, external stored procedures do serve a strong purpose in that legacy programs can easily be converted into stored procedures and thus make these programs available to remote SQL calls. Also, if a stored procedure is required that includes intensive non-database related processing it may be more efficient to write this stored procedure in a high-performance language such as COBOL or Assembler as opposed to a native SQL procedure. Also, there are certain things, such as calling external services and directly accessing mainframe resources, that can only be accomplished in an external procedure. While the flexibility and portability of Java as a stored procedure programming language is extremely important and powerful, the expected CPU cost of running these procedures on Db2 for z/OS is about twice that of COBOL. External stored procedures that execute in a WLM managed application environment are not zIIP eligible, even if they are called remotely.

SQL procedures can be either native or external. If they are created as an external SQL procedure, they are converted into C programs, compiled, and installed as if they were a normal external stored procedure. From a performance perspective, they are probably going to have a level of performance slightly less than the equivalent COBOL or Assembler programs. So, the advantage is in the flexibility and the portability of the SQL procedure, as well as the ability to draw on a comparatively more available talent pool of technicians. SQL external procedures exist primarily for compatibility with older releases of Db2 where there were no native SQL procedures. From a performance perspective, native SQL procedures are the better choice. Native SQL procedures execute internal to the Db2 engine, and can utilize zIIP engines for remote requests. While a native stored procedure may not outperform an external procedure that is non-SQL process intensive, the elimination of any cross memory call offsets some of that cost. For procedures that are primarily SQL statements, the native SQL procedure is the best performance choice.

4.5.2 Triggers

Triggers are SQL-based processes that are attached to tables and activated in response to DML statements. Triggers exist as a means of controlling and guaranteeing certain processing happens in a centralized fashion when DML is issued against a table. This includes such functionality as:

- Data validation
- Data replication and summarization
- Automated population of column values
- Stored procedure and UDF invocation
- Messaging
- Advanced referential integrity enforcement

Triggers can be abused, but they are generally a good thing from a performance perspective. Compare what is being done in the body of a trigger to the equivalent work performed by an application program to see how multiple SQL statements can be replaced by a single SQL statement and a trigger. The only example of triggers being a performance detriment is if they were used to perform simple data validation that could be performed locally within an application, such as code validation or existence checking (for cached items). In that situation, there could be multiple messages going back and forth between the application and the database as successive validations failed. Otherwise, triggers are generally recommended from a performance perspective.

4.5.3 Db2 Built-In Functions and Expressions

Db2 comes bundled with a variety of built-in scalar functions. This allows for incredible flexibility of SQL as a programming language and allows for developers to transform simple data elements into virtually anything ready for display or further implementation. Some items that have generated using the built-in scalar function:

- Page 1 for customer invoices
- Web pages
- Complete XML documents
- Assembler DSECTs

The conclusion on scalar functions in a SELECT from a performance perspective is that they cost more relative to the equivalent application logic. So, if scalar functions are used simply for data manipulation then expect them to always be more expensive than equivalent application code. These types of things should be coded into statements for portability and flexibility, and not performance. The same is also true for various expressions, such as CAST and CASE expressions, when used purely for data manipulation.

If the use of functions and expressions in a SQL statement results in further filtering of data, then the use of those functions or expressions can be a performance benefit as compared to sending all of the data back to an application program and doing the filtering there. When coding CASE expressions that contain multiple search conditions, code the search conditions in a sequence such that the conditions that should test positive most often are coded earlier in the expression as CASE takes an early out. Aggregate functions can be a performance advantage when compared to sending all of the data back to an application program for aggregation. The Db2 for z/OS Managing Performance Guide contains recommendations regarding how to code for aggregate function performance.

4.5.4 User-Defined Functions

UDFs allow a user to extend the capabilities of the Db2 engine beyond what is available and built into the product. As an example is an application that had its own customized soundex function. This function was written in IBM Assembler language in the 1970's and the developers had lost the source code. As a solution, a COBOL wrapper was written to call the Assembler program and install it all as a Db2 UDF. Suddenly the legacy soundex function was available to execute within the context of a normal SQL statement and to access remotely from the web. This represented a huge advantage for the enterprise by solving a very serious programming issue. The downside was that it was relatively expensive to execute the function in this manner. Remember that a UDF is executed for each reference in a SELECT list for every row processed. UDFs exist primarily for functionality and not performance. If performance is the primary concern and UDFs are only going to be used for data manipulation and not data filtering or aggregation, then they should be avoided in favor of the equivalent application code.

There are several types of UDFs:

- Inline SQL scalar functions
- Non-line SQL scalar functions (discussed in the next section)
- External scalar functions
- External table functions

Inline scalar UDFs enable DBAs and developers to place commonly executed SQL expressions into a function stored in the Db2 system catalog. These functions are then available to use enterprise-wide. This enables a higher level of accuracy in function execution and a centralized control such that if the function changes it only needs to change in one place. The downside is decreased performance in that parameters passed to the function are cast to the data types of the variables used in the function regardless of whether or not the data type needs to be cast. This can result in up to 10% overhead for the invocation of an inline SQL function as compared to the same expression coded directly in a statement.

External scalar and table functions behave in a similar manner to external stored procedures from a performance perspective. They are written in a host language and are executed in a WLM managed application environment SPAS. As such, there is a similar amount of cross memory overhead as with an external stored procedure. However, given the nature of scalar UDFs executed in a SELECT clause and table UDFs executed for blocks of rows returned, there can be hundreds, thousands, or millions of external function calls per execution of the SQL statement that invokes them. So again, these functions are important for flexibility and reusability of new and existing program logic and are not necessarily a performance feature.

4.5.5 Non-Inline SQL Scalar Functions and SQL Table Functions

Non-inline SQL scalar functions allow for common SQL and business logic functionality to be incorporated into a scalar UDF. They can contain SQL procedure language (SQLPL) control statements similar to a native SQL procedure. These functions have a lot of the same performance advantages as native SQL stored procedures. However, just as with every UDF they could be executed many times in a SQL statement even if the results are redundant. Therefore, their use should be carefully considered with the understanding that better performance is probably possible by using a native SQL procedure. The big advantage with these UDFs is in functionality, flexibility, and control, and not so much performance.

SQL table functions allow for a table expression to be embedded in a function that returns a table to the caller. They do have some promise as a performance feature, but come with some challenges. The execution of these functions is very similar to how correlated nested table expressions are executed. In fact, compare the execution of views and SQL table functions to that of nested table expressions and correlated nested table expressions, and equate views to nested table expressions and SQL table functions to correlated nested table expressions. SQL table functions can be thought of as parameterized views, as parameters can be passed into the table function and used within the context of the statement embedded in the function. Parameters passed to SQL table functions and used in predicates within the function may be Stage 1 or Stage 2 predicates. It is recommended to create the function, write a SQL statement against the function, and EXPLAIN it. Refer to APARs PM82908 and PM95541 for details. Below is an example of a SQL table function that can be used as a parameterized view:

```
CREATE FUNCTION DANL.EMP1 (INDEPT CHAR(3))
RETURNS TABLE (WORKDEPT CHAR(3), AVGSAL DEC(9,2))
RETURN
SELECT F.WORKDEPT, AVG(F.SALARY)
FROM DANL.EMP F
WHERE F.WORKDEPT = INDEPT
GROUP BY WORKDEPT;
```

4.5.6 Multi-Row Statements

Multi-row FETCH, INSERT, DELETE, and MERGE exist for one reason: performance. The purpose of multi-row operations is to reduce the number of SQL calls to complete a batch operation. Remote SQL calls that take advantage of block fetching using non-ambiguous, read-only cursors automatically get multi-row FETCH between the Db2 distributed address space and the Db2 database manager address space. Unfortunately, multi-row operations beyond the automatic FETCH for remote applications are only available to locally executing applications written in COBOL, Assembler, or C programming languages. Multi-row statements are not available to Java programs.

COBOL programs have been benchmarked that use multi-row FETCH and have discovered up to 60% reduction in CPU when comparing single-row FETCH to multi-row FETCH for a sequential batch cursor that retrieved 50 rows per FETCH, and a 25% reduction in CPU for an online cursor that averaged 20 rows per FETCH.

4.5.7 Select From a Table Expression

As mentioned earlier in this section, table expressions are a powerful construct that the replacement of multiple SQL statements with a single multi-function statement. The concept is that the result of a SQL statement is a table, and if the result is a table, then that table can be input to another statement. Tables in and tables out. This concept is true for data change statements as well, including INSERT, UPDATE, DELETE, and MERGE. The result table from a data change statement is called a data-change-table-reference and this table can be referenced in the FROM clause of a fullselect. The keywords FINAL TABLE and OLD TABLE are used to indicate whether the view of the data affected by the data change statement is before or after the change has been applied. Being able to return data from a data change statement means multiple SQL calls can be combined for significant CPU and elapsed time savings. The following example selects data that has been added to a table via an INSERT:

```
SELECT EMPNO, FIRSTNME, LASTNAME
FROM FINAL TABLE (
INSERT INTO EMP2 (FIRSTNME, LASTNAME)
SELECT FIRSTNME, LASTNAME
FROM EMP
WHERE WORKDEPT = 'C01')
```

So, in a single statement a table is read, filtered, and inserted into a second table. The results of that insert, including the system-generated column EMPNO and identity column, are returned in the final SELECT. With three operations in one SQL statement the potential cost savings is quite obvious.

The power and potential cost savings can be taken even further through the use of INCLUDE columns within the data change table. These INCLUDE columns allow the generation of new data within the context of the data change statement that can then be referenced in the outer SELECT. These constructs allow for an even greater potential to replace several SQL statements and program logic with a single SQL statement. The following gives employees in department C01 a raise and reports on that raise in a single SQL statement, including a generated, old salary value.

```
SELECT EMPNO, OLD_SALARY, SALARY
FROM FINAL TABLE (
    UPDATE EMP
    INCLUDE (OLD_SALARY DEC(9,2))
    SET SALARY = SALARY * 1.05,
    OLD_SALARY = SALARY
WHERE WORKDEPT = 'C01')
```

From multiple tests and implementations, there are no downsides to these types of statements, and only a benefit from a reduction in SQL calls within a transaction.

4.5.8 Common Table Expressions

Common table expressions are temporary tables that exist within the execution of a single SQL statement. There is a maximum of 225 tables that can be referenced in one statement. Theoretically there can be 224 common table expressions in a statement. This allows a multi-step, multi-statement process to be condensed into one SQL statement execution. This is an obvious performance enhancement when multiple SQL calls can be combined into a single statement. Performance will vary, and it is a good idea to test these statements. The following example shows how multiple common table expressions can be specified in a single statement to process and reprocess data in a single complex operation.

```
WITH DEPTSAL (DEPTNO, AVGSAL) AS (
    SELECT EMP.WORKDEPT,AVG(EMP.SALARY)
       FROM EMP EMP
       GROUP BY EMP.WORKDEPT),
    HIGHLOWSAL (HIGHAVG, LOWAVG) AS (
       SELECT MAX(AVGSAL), MIN(AVGSAL)
       FROM DEPTSAL)
SELECT DEPTNO, AVGSAL
FROM DEPTSAL
WHERE AVGSAL = (SELECT HIGHAVG FROM HIGHLOWSAL)
ORDER BY DEPTNO
```

The section joins in this chapter contain an example of a common table expression used in relational division, and Chapter 7 contains an example of a common table expression used in benchmark testing.

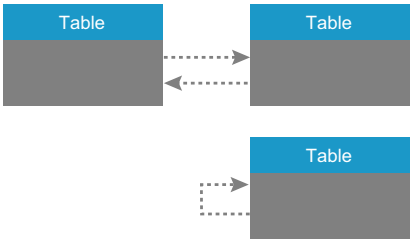
A common table expression can be merged with the subselect that references it, as is described in Chapter 3, but if a common table expression is referenced more than once it is materialized. Common table expressions are key to constructing recursive SQL, which can prove to be a performance improvement in certain situations and are discussed in the next section of this chapter.

In addition to being useful in eliminating multiple database calls, common table expressions can prove to be a potential performance improvement for complex statements where the same complicated table expression may need to be referenced multiple times in the same statement. By taking that one complicated table expression, placing it in a common table expression, and then referencing the common table expression in place of the multiple complex table expression, the common table expression is materialized and the subsequent table scans may prove to be more efficient than running the complex table expression multiple times.

4.5.9 Recursive SQL

When the FROM clause of a common table expression references itself, it is known as a recursive common table expression, or recursive SQL. A recursive SQL statement can be a tremendous performance advantage when it is used to replace multiple SQL statements and application logic with a single SQL call. This saving is most significant when the tables accessed are in a circular relationship, where two tables reference each other or a single table references itself as in Figure 2.

Figure 2: Tables with a Circular Reference Relationship



Recursive SQL is perfect for traversing these circular references in a single statement, as opposed to doing the same thing within a program loop. This is perfect for traversing hierarchies and networks in such things as bill of material application, scheduling, banking, and web applications. In the following example, a website menu is stored within a hierarchy in a single table. The web site menu is a hierarchy.

A PRODUCTS menu item may have the following sub-items:

- MEN'S CLOTHING
  - SHIRTS
  - SUITS
  - PANTS
- WOMEN'S CLOTHING
  - DRESSES
  - BLOUSES
  - SHOES
- CHILDREN'S CLOTHING
  - BOYS
  - GIRLS

The single table that contains the web menu content contains a NODE column that uniquely identifies a position in the menu, and a PARENT_NODE column that identifies the parent node of a particular node. So, the SHIRTS menu item would have a parent node of the MEN'S CLOTHING menu item. Assuming that the main node, PRODUCTS is node zero, a recursive SQL statement can traverse this hierarchy and produce the web menu in a single statement, replacing what would otherwise be a loop in an application program with multiple SQL statements. This could result in a significant performance advantage (and did in an actual implementation).

```
WITH GEN_MENU(NODE, PARENT_NODE, NODE_NAME, NODE_DESC, N) AS (
    SELECT NODE, PARENT_NODE, NODE_NAME, NODE_DESC, 1
        FROM MENU_ITEM
        WHERE NODE = 0
            AND ACTIVE_FLG = 'Y'
UNION ALL
SELECT B.NODE, B.PARENT_NODE, B.NODE_NAME, B.NODE_DESC, N+1
    FROM MENU_ITEM B , GEN_MENU A
    WHERE B.PARENT_NODE = A.NODE
        AND N < 20
        AND ACTIVE_FLG = 'Y'
)
SELECT NODE, PARENT_NODE, NODE_NAME, NODE_DESC, N
FROM GEN_MENU
```

Recursive SQL is also useful in generating data and statements to be used in testing and benchmarking statements and table designs. See Chapter 10 for details. This ability to generate data is also useful in production implementations, as in the following example where a recursive SQL statement is used to generate 100 sequence values in a batch application and avoid 100 separate statements.

```
WITH GEN_KEYS(N) AS
(SELECT 1 FROM SYSIBM.SYSDUMMY1
UNION ALL
SELECT N+1 FROM GEN_KEYS
WHERE N < 100)
SELECT NEXT VALUE FOR SEQ1
FROM GEN_KEYS
```

Recursive SQL can potentially introduce an infinite loop, so it is very important to code a stop predicate in the recursive portion of the statement. This is typically done by introducing a counter and testing for a maximum value of the counter as in each of the previous examples.

4.5.10 BIND Options and Performance

Certain BIND options promote a higher level of performance.

- RELEASE(DEALLOCATE). Setting RELEASE to COMMIT tells Db2 that when a thread issues a COMMIT statement the thread goes away and does not come back. This is good for concurrency in that various locks are released and open cursors closed. It is bad for performance if the application continues to issue SQL statements. That is because all resources that were released have to be reacquired. During execution certain resources are obtained and held including: xPROCS (fast code paths for common statements), sequential detection, index lookaside, and object locks. If RELEASE(DEALLOCATE) is used, these performance enhancers are retained across a COMMIT and significant CPU savings are realized. RELEASE(DEALLOCATE) limits the concurrency of high-performance applications with Db2 commands and certain utilities. Therefore, an appropriate available plan should be in place when using RELEASE(DEALLOCATE) and appropriate maintenance windows established. Db2 11 for z/OS now allows for commands and utilities to break into threads to force a maintenance process. Also, high-performance DBATs that enable RELEASE(DEALLOCATE) for dynamic remote transactions can be turned on and off.
- CACHESIZE. Setting the CACHESIZE such that all authorization IDs that use a package can be held in memory avoids catalog lookups for incoming authorization IDs.
- CURRENTDATA. The default is NO, and allows Db2 to use lock avoidance. This default is appropriate and should be used to avoid the overhead of taking read locks instead of latches as well as to enable block fetching for remote cursors.
- DEFER(PREPARE). This setting allows for dynamic SQL programs to combine PREPAREs of statements with the invocation of the statement and therefore reduce the number of messages issued by remote applications.
- DEGREE. This setting controls the degree of parallelism. Set this to 1, the default, for transactions that process little or no data per statement. Parallelism is an important feature for query elapsed time performance of large queries, but can be a performance detriment for transaction processing systems.
- IMMEDIATEWRITE. The default is NO and should stay no, except for extreme situations. Setting this to YES forces all writes to DASD immediately upon COMMIT. This could be important in some data sharing environments where readers are reading with UR, but in most cases setting this to YES simply slows the application down and increase CPU consumption.
- KEEPDYNAMIC. Setting this to YES caches prepared dynamic statements in thread storage and keep those statements across a commit. It requires coordination with application development to enable this to work properly. The existence of the global dynamic statement cache and high performance DBATs reduce the need for KEEPDYNAMIC.
- REOPT. This option can be used to invoke various forms of statement reoptimization at execution time based upon host variable values. Setting any runtime reoptimization may improve access paths for situations where host variables or parameter markers are in use and data values in the accessed tables are skewed, but statements incur overhead due to incremental binds that happen at run time. Success has only been achieved with runtime reoptimization when isolating single statements in their own package.

- VALIDATE. This option controls when authorization to objects is checked. Setting this to BIND uses the package owner's authid for object access authorization and avoid a look up at run time. This is the performance choice.
- CONCURRENTACCESSRESOLUTION. This may be an interesting choice for performance. By setting this option to USECURRENTLYCOMMITTED an application that attempts to read data that is locked by an insert or a delete operation does not wait for the lock to be released, but instead accesses the currently committed row, if one exists, and continues the operation. This can really change the access paradigm for an application and can be considered a significant performance feature, especially when coupled with an optimistic locking strategy. However, it only works for rows impacted by insert and delete operations, and does not work for updates. This makes its use limited unless you implement updateless operations for select applications, which means doing deletes and inserts instead of updates.

See Chapter 6 for additional information on BIND options used to control SQL access paths. *Plan Analyzer* can help with viewing and changing Db2 package BIND options.

4.6 Dynamic SQL and Performance

The standard for programming against a Db2 for z/OS database has been steadily making the move from traditional programming languages, such as COBOL issuing static embedded SQL locally, to remote web-based applications coded in Java and issuing dynamic SQL statements. Dynamic SQL in remote applications can achieve a level of performance that is almost as good as static embedded SQL in local applications if a few performance guidelines are followed. *SYSVIEW for Db2* provides multiple reports aimed to help tuning Db2 subsystem for the best dynamic SQL performance. For analysis and tuning the dynamic SQL statements, *Detector* can be used as it captures the text and their execution statistics.

4.6.1 Block Fetching

For SELECT statements that are read-only in nature, specify FOR FETCH ONLY or FOR READ ONLY at the end of the statement. This encourages Db2 to utilize block fetching for these remote cursors. Block fetching returns multiple rows to the remote application in a single DRDA message, as well as enable multi-row fetch between the Db2 distributed address space and the Db2 database manager address space. If there are SELECT statements that are expected to return no more than one row, then specify OPTIMIZE FOR 1 ROW FETCH 1 ROW ONLY at the end of the statement to disable any block fetching. Refer to the Db2 for z/OS Managing Performance Guide for additional details on ensuring block fetch.

4.6.2 Utilizing Dynamic Statement Cache

Dynamic SQL statements can be cached either globally in the global statement cache or locally in thread storage via the KEEPDYNAMIC bind option. Doing so will have a profound impact on performance as statement prepares will not have to go through a complete compilation process if an equivalent compiled statement is already located in cache. The global dynamic statement cache is enabled via EDMSTMTC subsystem parameter, which indicates the size of the cache. Increasing the cache size can improve the statement hit rate in the global cache and improve query performance by replacing long prepares (full statement compile) with short prepares (reusing an already compiled statement). A local statement cache can be enabled via the KEEPDYNAMIC bind option for the package used by the dynamic SQL in the application. The MAXKEEPD subsystem parameter controls how many statements are retained in the local statement cache.

4.6.3 Parameter Markers vs. Embedded Literals

For transaction processing applications where data skew is not an issue, use parameter markers in the predicate in the SQL statements as opposed to literal values. This allows Db2 to take advantage of the dynamic statement cache and reuse already prepared statements. To reuse statements in the global dynamic statement cache, Db2 attempts to match the incoming statement text byte-for-byte with previous statements issued by the same authorization ID. As a rule, using constantly changing literal values leads to very low match rates for inbound statements higher statement prepare costs.

If the data is highly skewed, try embedding literal values in the SQL statements to potentially get better access paths. However, this should be done in conjunction with the gathering of distribution statistics or histogram statistics as described in Chapter 3.

4.6.4 Enabling Literal Concentration

For applications that have already existing SQL statements using embedded literal values in predicates, or for packaged applications that only issue SQL using embedded literals, Db2 provides a potential performance improvement by means of literal concentration. This feature is enabled via the CONCENTRATE STATEMENTS WITH LITERALS attribute of the PREPARE statement, or via the statementConcentrator connection property in a JDBC application. When literal concentration is enabled, Db2 replaces literal values in the SQL statements with parameter markers, thus enabling a higher level of dynamic statement cache reuse and a much lower PREPARE cost. Db2 only concentrates literal values for statements that use 100% literal values. Statements that have a mixture of literal values and parameter markers are not eligible for literal concentration.

4.6.5 Utilization of High-Performance DBATs

One of the challenges of remote application performance is in balancing high performance with thread reuse and availability. DBAs must balance performance and availability requirements with memory consumption.

Remote threads have traditionally been pooled in the Db2 distributed address space. That is, many threads are connected to the Db2 distributed address space, but a fewer number of threads that are actually active are connected from the Db2 distributed address space to the Db2 database manager address space. These connections to the database manager address space are call Database Access Threads or DBATs. Once a thread issues a commit it is considered inactive and releases its associated DBAT. In that way, a pool of DBATs can be used by many connections. The number of connections, as well as the number of DBATs, is controlled by subsystem parameters MAXDBAT and CONDBAT that are described in the Db2 Installation Guide and in Chapter 8. Since DBATs are released and shared across multiple connections, thread reuse and certain Db2 performance enhancers are not available for remote connections. This also means that such things as sequential detection and index lookaside are not available for remote connections.

High-performance DBATs were introduced in Db2 10 for z/OS and allow for remote DRDA connections to behave in a similar fashion to CICS protected threads, as they take advantage of thread reuse and the various performance enhancers. These performance enhancers include dynamic prefetch, index lookaside, and xPROCS (fast path code paths for repeated statements). These performance enhancers are traditionally enabled via the RELEASE(DEALLOCATE) bind parameter, but prior to Db2 10 this bind parameter was ignored for packages accessed via remote threads. Db2 10 introduced the command MODIFY DDF PKGREL(BNDOPT) which now causes Db2 to respect the RELEASE(DEALLOCATE) parameter for remote packages and enables all the performance enhancers available for reused threads. When implemented, high-performance DBATs can have a profound impact on remote application performance and a significant reduction in CPU consumed by remote applications.

Enabling RELEASE(DEALLOCATE) reduces the concurrency of the applications with certain Db2 utilities and commands, much in the same way as CICS protected threads. This is why Db2 terminates high-performance DBATs after 200 executions. Also, by issuing the MODIFY DDF PKGREL(COMMIT) command, the high-performance DBATs are returned to normal DBATs, which allows for utilities and commands to run without conflict.

Chapter 5: Utilizing Db2 EXPLAIN

The Db2 EXPLAIN facility is a means for estimating SQL execution cost and for externalizing the transformed (rewritten) query and selected access path. It is one of two key techniques, with the other being benchmark tests, for predicting the performance of production queries and applications. EXPLAIN should be a part of every SQL development and testing process and can externalize the following information:

- Access path
- Transformed query text
- Filter factors
- Predicted cardinalities
- Missing or conflicting statistics
- Statement cost information

5.1 EXPLAIN Processing

There are three different ways to invoke an EXPLAIN of a SQL statement or group of SQL statements:

- EXPLAIN statement
- EXPLAIN attribute of a PREPARE statement
- EXPLAIN BIND parameter

The result of an EXPLAIN is the population of a set of explain tables that must pre-exist before EXPLAIN can be processed for a given userid. This userid is the authorization ID of the process performing the EXPLAIN, or the owner of a package that is bound with EXPLAIN(YES) or EXPLAIN(ONLY). The set of explain tables must exist with a creator of the userid. As of Db2 11 for z/OS there are 20 EXPLAIN tables that are used to interpret the predicted query performance or to control the access path selected by the optimizer.

5.2 Interpreting EXPLAIN Results

Given that there are 20 different EXPLAIN tables and most of the information contained in the tables is difficult to interpret, it is advised to utilize a tool to interpret the data. *Plan Analyzer* offers robust access path analysis, comparison of old and new versions of SQL, SQL costs, and EXPLAIN data highlighting changes that may affect performance. There are other tools that can be used to interpret EXPLAIN table data, and one of those tools, the IBM Data Studio, is available free. This tool, however, is PC-based and requires a remote connection to the Db2 data server to interpret the EXPLAIN table data.

5.3 The PLAN_TABLE

The main EXPLAIN table is the PLAN_TABLE. This table contains the basic access path information for a given query and can be used quite effectively on its own to interpret an access path. Query the PLAN_TABLE directly to interpret access path information for a given query or set of queries. The PLAN_TABLE contains information about whether or not an index is used to access a table, the number of matching columns, the join method, and whether or not sorts and workfiles are utilized (as described in Chapter 3). A description of the columns of the PLAN_TABLE, along with all of the other EXPLAIN tables, is located in the Db2 Performance Guide. The output for a particular statement access path recorded in the PLAN_TABLE can be identified by the columns COLLID, PROGNAME, QUERYNO, and EXPLAIN_TIME. If the results are ordered by QBLOCKNO and PLANNO, this yields access path information for a particular query within a collection and package, for the time of the EXPLAIN, and ordered in the query block and plan step within each query block.

The following example is a single statement EXPLAINed from within SPUFI.

```
EXPLAIN PLAN SET QUERYNO=999 FOR
    SELECT * FROM DANL.EMP
    WHERE WORKDEPT IN (
       SELECT WORKDEPT
       FROM DANL.EMP
       GROUP BY WORKDEPT);
COMMIT;
SELECT * FROM PLAN_TABLE
    WHERE COLLID = 'DSNESPCS'
       AND PROGNAME = 'DSNESM68'
       AND QUERYNO = 999
ORDER BY QBLOCKNO, PLANNO;
```

The following is an example of executing an EXPLAIN statement dynamically for a single query and then using a query to read the PLAN_TABLE data for the explained statement. Some formatting is also applied that focuses on some of the most important aspects of the access path. It is common to run multiple EXPLAINs for a given query with variations to indexes or the query text to determine variations in the access path.

```
EXPLAIN PLAN SET QUERYNO=999 FOR
SELECT * FROM DANL.EMP
    WHERE WORKDEPT IN (
       SELECT WORKDEPT
       FROM DANL.EMP
       GROUP BY WORKDEPT);
COMMIT;
SELECT SUBSTR(P.PROGNAME, 1, 8) AS PROGNAME,
    SUBSTR(DIGITS(P.QUERYNO), 6)
       CONCAT '-'
       CONCAT SUBSTR(DIGITS(P.QBLOCKNO), 4)
       CONCAT '-'
       CONCAT SUBSTR(DIGITS(P.PLANNO), 4) AS QQP,
    SUBSTR(CHAR(P.METHOD), 1, 3) AS MTH,
    SUBSTR(CHAR(P.MERGE_JOIN_COLS), 1, 3) AS MJC,
    SUBSTR(P.CREATOR, 1, 8) AS TBCREATOR,
    SUBSTR(P.TNAME, 1, 18) AS TBNAME,
    SUBSTR(P.CORRELATION_NAME, 1, 8) AS CORR_NM,
    P.ACCESSTYPE AS ATYP,
    SUBSTR(P.ACCESSNAME, 1, 15) AS A_NM,
    P.INDEXONLY AS IXO,
    CHAR(P.MIXOPSEQ) AS MIX,
    CHAR(P.MATCHCOLS) MCOL,
    P.SORTN_JOIN CONCAT P.SORTC_UNIQ
       CONCAT P.SORTC_JOIN
       CONCAT P.SORTC_ORDERBY
       CONCAT P.SORTC_GROUPBY AS NJ_CUJOG,
    P.PREFETCH AS PF,
    P.COLUMN_FN_EVAL AS CFE,
    P.PAGE_RANGE AS PGRNG,
    P.JOIN_TYPE AS JT,
    P.QBLOCK_TYPE AS QB_TYP,
    P.PARENT_QBLOCKNO AS P_QB,
    P.TABLE_TYPE AS TB_TYP,
    P. EXPLAIN_TIME AS B_TM
FROM PLAN_TABLE P
WHERE P.QUERYNO = 999
ORDER BY PROGNAME, B_TM, QQP, MIX;
```

5.3.1 Advanced EXPLAIN Analysis

If access to an EXPLAIN tool cannot be obtained, advanced EXPLAIN information can still be found from some of the EXPLAIN tables beyond the PLAN_TABLE alone. While each EXPLAIN table can be read independently for analysis of a particular query, it is advised to ignore many of them due to complexity and/or proprietary information contained in the tables. However, some of the tables do contain some information that is not too difficult to interpret, and can be queried individually for a specific query and EXPLAIN_TIME.

- DSN_FILTER_TABLE: This table contains information about how predicates are used in a query. This includes the predicate number, the order number of the predicate that reflects the order of predicate processing, the stage the predicate was processed (MATCHING, SCREENING, STAGE1, STAGE2), and the PUSHDOWN column that reflects whether or not a Stage 2 predicate was actually processed from Stage 1 index or data processing. Use the information from this table together with the DSN_PREDICATE_TABLE to identify the predicate text along with the information in this table by matching the PROGNAME, QUERYNO, QBLOCKNO, PREDNO, and EXPLAIN_TIME columns of this table to the DSN_PREDICAT_ TABLE.
- DSN_PREDICAT_TABLE: This table contains information about all the predicates in a query. This includes the predicate number, whether or not it is a Boolean term, whether or not the predicate was added to the query during query transformation, the filter factor for the predicate, and the predicate text itself. This is useful for seeing information about predicates generated via predicate transitive closure or for temporal or archival time travel access. Use this information together with the DSN_FILTER_ TABLE by matching the PROGNAME, QUERYNO, QBLOCKNO, PREDNO, and EXPLAIN_TIME columns of this table to the DSN_FILTER_TABLE.
- DSN_QUERY_TABLE: This table contains the formatted original and transformed queries. Read the query text from the table to determine the level to which the query was rewritten by the query transformation component before being sent to access path select. While querying this table is as simple as selecting the NODE_DATA column to get the query text for a TYPE of either BEFORE or AFTER, the result is a bit difficult to read due to the fact that the result is in XML and meant to be interpreted by a tool. Nonetheless, it can be useful when a tool is not available to obtain some information about the transformed query.
- DSN_DETCOST_TABLE: There is a great deal of valuable cost information in this table and it is important for understanding the intricacies of the cost calculations at all levels of an access path. However, without guidance from IBM or a very careful process of trial and error EXPLAINs to understand the subtleties of the data contained in this table, leave it alone. Do pay attention to the ONECOMPROWS column as that contains the number of rows expected to qualify for a table after all local predicates are applied. This can be an important tool in understanding why Db2 picked a certain table access sequence for a multi-table query. There can be multiple rows for a given query block (QBLOCKNO) and plan step (PLANNO) so ensure the lowest ONECOMPROWS is returned for a given PROGNAME, QUERYNO, QBLOCKNO, PLANNO, and EXPLAIN_TIME.

The following is a recommended advanced EXPLAIN query that returns the valuable PLAN_TABLE access path information along with filter factor, predicate stage, Boolean term, and predicate text information from DSN_FILTER_TABLE and DSN_PREDICAT_TABLE, and the number of rows expected after local filters for a plan step from the DSN_DETCOST_TABLE.

```
EXPLAIN PLAN SET QUERYNO=1 FOR
    SELECT * FROM DANL.EMP
       WHERE WORKDEPT IN (
          SELECT WORKDEPT
          FROM DANL.EMP
          GROUP BY WORKDEPT
);
WITH MAXTIME (COLLID, PROGNAME, QUERYNO, EXPLAIN_TIME) AS (
    SELECT COLLID, PROGNAME, QUERYNO, MAX(EXPLAIN_TIME)
    FROM PLAN_TABLE
    WHERE COLLID = 'DSNESPCS'
       AND PROGNAME = 'DSNESM68'
       AND QUERYNO = 1
    GROUP BY COLLID, PROGNAME, QUERYNO)
SELECT SUBSTR(P.PROGNAME, 1, 8) AS PROGNAME,
    SUBSTR(DIGITS(P.QUERYNO), 6)
       CONCAT '-'
       CONCAT SUBSTR(DIGITS(P.QBLOCKNO), 4)
       CONCAT '-'
```

```
            CONCAT SUBSTR(DIGITS(P.PLANNO), 4) AS QQP,
         SUBSTR(CHAR(P.METHOD), 1, 3) AS MTH,
         SUBSTR(CHAR(F.PREDNO), 1, 3) AS P_NO,
         SUBSTR(CHAR(P.MERGE_JOIN_COLS), 1, 3) AS MJC,
         SUBSTR(P.CREATOR, 1, 8) AS TBCREATOR,
         SUBSTR(P.TNAME, 1, 18) AS TBNAME,
         SUBSTR(P.CORRELATION_NAME, 1, 8) AS CORR_NM,
         DEC(D.ONECOMPROWS, 10, 1) AS ROWS_POST_FILTER,
         P.ACCESSTYPE AS ATYP,
         SUBSTR(P.ACCESSNAME, 1, 15) AS A_NM,
         P.INDEXONLY AS IXO,
         CHAR(P.MIXOPSEQ) AS MIX,
         CHAR(P.MATCHCOLS) MCOL,
         F.STAGE AS STAGE,
         DEC(E.FILTER_FACTOR, 11, 10) AS FF,
         E.BOOLEAN_TERM AS BT,
         SUBSTR(E.TEXT, 1, 30) AS PRED_TEXT30,
         P.SORTN_JOIN
            CONCAT P.SORTC_UNIQ
            CONCAT P.SORTC_JOIN
            CONCAT P.SORTC_ORDERBY
            CONCAT P.SORTC_GROUPBY AS NJ_CUJOG,
         P.PREFETCH AS PF,
         P.COLUMN_FN_EVAL AS CFE,
         P.PAGE_RANGE AS PGRNG,
         P.JOIN_TYPE AS JT,
         P.QBLOCK_TYPE AS QB_TYP,
         P.PARENT_QBLOCKNO AS P_QB,
         P.TABLE_TYPE AS TB_TYP,
         P.EXPLAIN_TIME AS B_TM
      FROM PLAN_TABLE P
      INNER JOIN MAXTIME M
         ON M.COLLID = P.COLLID
         AND M.PROGNAME = P.PROGNAME
         AND M.QUERYNO = P.QUERYNO
         AND M. EXPLAIN_TIME = P. EXPLAIN_TIME
      LEFT JOIN DSN_FILTER_TABLE F
         ON M.COLLID = F.COLLID
         AND M.PROGNAME = F.PROGNAME
         AND M.QUERYNO = F.QUERYNO
         AND P.QBLOCKNO = F.QBLOCKNO
         AND P.PLANNO = F.PLANNO
         AND M. EXPLAIN_TIME = F.EXPLAIN_TIME
         AND P.ACCESSTYPE Not IN ('MX', 'MI', 'MU')
      LEFT JOIN DSN_PREDICAT_TABLE E
         ON F.PROGNAME = E.PROGNAME
         AND F.QUERYNO = E.QUERYNO
         AND F.QBLOCKNO = E.QBLOCKNO
         AND F.PREDNO = E.PREDNO
         AND M. EXPLAIN_TIME = E.EXPLAIN_TIME
      LEFT JOIN TABLE (
      SELECT MIN(X.ONECOMPROWS) AS ONECOMPROWS
      FROM DSN_DETCOST_TABLE X
      WHERE M.PROGNAME = X.PROGNAME
         AND M.QUERYNO = X.QUERYNO
         AND P.QBLOCKNO = X.QBLOCKNO
         AND P.PLANNO = X.PLANNO
         AND M. EXPLAIN_TIME = X.EXPLAIN_TIME) AS D
      ON 1=1v
   ORDER BY PROGNAME, B_TM, QQP, MIX, F.PREDNO;
```

5.3.2 DSN_STATEMNT_TABLE

This table contains information about the estimated cost of a SQL statement. It has long been used by many DBAs to compare the cost of one query versus another when query tuning is performed. Some people even have shop standards that require a minimum query cost proven via an EXPLAIN before a query can be migrated to a production environment. Some DBAs analyze this table to look for queries that exceed a predetermined cost value. While these techniques may be effective in determining relative query costs in many situations, it can be perilous since the cost figures are an estimate of query cost based upon optimizer calculations. Do not rely on the cost figures in this table alone as proof of the cost of one query versus another. If the values are used in this table, it is done in conjunction with the access path information provided by the PLAN_TABLE and other EXPLAIN tables. Even so, rely more on performance benchmarks than query cost estimates to determine the predicted query cost once a query is promoted to production. See Chapter 10 for information on how to perform these benchmarks.

5.4 Externalizing the Dynamic Statement Cache via EXPLAIN

With an ever-increasing workload utilizing dynamic SQL, it has become harder for DBAs and application developers to collect and report on SQL statements since statement text is no longer stored in the Db2 system catalog as it is instead with static embedded SQL programs. Use *SYSVIEW for Db2* or the basic Db2 EXPLAIN facility to collect the text and performance metrics of dynamic SQL statements stored in the SQL statement cache. In addition, SYSVIEW performs this activity on a schedule, identifying and capturing the most resource-intensive dynamic and static SQL statements from the statement cache and EDM pool.

The EXPLAIN STMTCACHE ALL SQL statement externalizes the dynamic SQL statements in a Db2 subsystem to a table called DSN_STATEMENT_CACHE_TABLE for the authorization ID of the process executing the EXPLAIN STMTCACHE ALL. If the authorization ID of the process has SYSADM or SQLADM authority, then all of the statements in the cache are exposed; otherwise only the statements for the authorization ID are exposed. Once the EXPLAIN STMTCACHE ALL statement is executed, the DSN_STATEMENT_CACHE_TABLE table for the authorization ID can then be queried to retrieve the statement ID, statement token, and statement text. If actual EXPLAIN output is desired, an EXPLAIN STMTCACHE STMTID or EXPLAIN STMTCACHE STMTTOKEN can be issued and results in the population of all of the EXPLAIN information for the identified statement in the same way as for a normal EXPLAIN execution. Observe that EXPLAIN STMTCACHE ALL only collects statement text and optional statement metrics and populates the DSN_STATEMENT_CACHE_TABLE table.

If IFCIDs 316 and 318 are active[4], the DSN_STATEMENT_CACHE_TABLE is populated with a significant quantity of extremely valuable performance metrics for individual dynamic SQL statements executing in a subsystem. These metrics include such things as:

- Number of executions
- Getpages
- Rows processed
- Rows read
- Table space scans
- Sorts
- Elapsed time
- CPU time
- Locks
- The statement text, and many more

4. *SYSVIEW for Db2* automatically enables corresponding IFCIDs to collect dynamic SQL statement cache details.

Db2 Performance Guide Appendix B contains descriptions for all of the columns. One of the most valuable things to get from the DSN_STATEMENT_CACHE table is the total CPU consumed by a SQL statement since it was cached and the performance metrics collected by the IFCIDs. The reason this is so valuable is because it shows the total CPU, which can be a factor of individual statement cost and/or frequency of execution, and is thus an extremely important tool in determining which statement or process to tune first. It also makes explaining the statement cache an important benchmarking tool. What follows is a recommended and simple query for determining which statements require additional metrics for possible analysis and tuning:

```
SELECT CACHED_TS,
       STAT_EXEC,
       DEC(STAT_ELAP,12,2) AS STAT_ELAP,
       DEC(STAT_CPU,12,2) AS STAT_CPU,
       SUBSTR(STMT_TEXT,1,50)
FROM ESPNLCP.DSN_STATEMENT_CACHE_TABLE
WHERE PRIMAUTH = '<authid>'
  AND EXPLAIN_TS > '<timestamp>'
ORDER BY STAT_CPU DESC
```

See Chapter 9 for additional information on turning on IFCID 316 and 318.

Chapter 6: Controlling SQL Access Paths

With every new version of Db2, the query processing becomes more complex and access path issues become rarer and rarer. However, with every new version of Db2 it becomes more difficult for a user to manipulate the statement and database in a manner that influences Db2 to a more favorable access path when the chosen path is not desirable. The good news is that there are now many choices for using built-in features to control the access path of certain statements. The bad news is that the choices are confusing, overlapping, and in some cases complicated. *Plan Analyzer* offers multiple capabilities to simplify access path management.

Controlling access paths should, in the vast majority of cases, be a non-issue. As long as the catalog statistics accurately represent the data, the data is well organized, and developers and DBAs have paid a modest amount of attention to input values, the percentage of SQL statements that require special attention should be few and far between. With that being said, stability, which is completely different from tuning, is a major concern and should be controlled. Db2 provides many methods of ensuring and preserving SQL access paths that can be utilized to promote stability. These options are the major focus of this chapter.

6.1 Parallelism

Parallelism is great for large report or warehouse queries, and not good at all for transactions that process little or no data. There are several subsystem parameters that control parallelism (see Chapter 8) as well as a BIND parameter and special register (see Chapter 3).

6.2 Maintaining Access Paths

Db2 provides for, and is almost guaranteeing that, at least for static embedded SQL an access path will not change when rebinding a package. As of Db2 11 for z/OS, this is true even when moving from one release of Db2 to the next. So, there is a choice as to whether or not an access path is retained at migration time, and that is certainly a conservative thing to do. However, it is recommended to allow Db2 to potentially find a new access path that takes advantage of new Db2 features. In addition, it is typical that certain performance features are disabled during the execution of packages bound in a prior release of Db2; therefore, rebinding packages on migration is always recommended whether or not you elect to retain access paths.

Access paths for static embedded SQL can be managed via a feature generally referred to as access plan stability or plan management. This feature[5] is enabled via several BIND options. A combination of these BIND options pretty much gives full control over access path changes, or access path stability, across REBINDS. Observe that the different options operate independent of each other, with the exception of APRETAINDUP which works together with PLANMGMT. Also observe that the PLANMGMT and APRETAINDUP options are only REBIND options while the other options pertaining to access path comparison and retention can work with BIND or REBIND. Many of the options can be combined, allowing for a customization of access path management for static embedded SQL. Take time to understand the options, run tests, and develop a strategy of using all or some of these options in your environment.

6.2.1 PLANMGMT, SWITCH, and APRETAINDUP

This option allows for the retention of access path information for previous binds of a package. There are three settings for this option that allow for no retention or the retention of up to two previous binds for the package. This is a rebind-only option that permits access paths to be saved. In many enterprises, DBAs have established a regular policy of the three Rs (REORG, RUNSTATS, and REBIND). This is not recommended as a generic strategy since an access path may go bad at any time and put a dent in production performance (see Chapter 3 for commentary on RUNSTATS). If a strategy is deployed that includes regular, unregulated rebinds, this option enables the ability to back out on all of the

5. *Plan Analyzer* supports access path compare of before and after rebind.

access paths that result from a REBIND of a package by using the SWITCH REBIND option. This way, if an access path goes bad it can be backed out. The APRETAINDUP option is used together with PLANMGMT on a REBIND to tell Db2 what to do if REBIND is used and there are no access path changes. This allows for a REBIND to not overlay a previous access path if there were no differences.

PLANMGMT is the recommended way to preserve access paths across Db2 migrations.

6.2.2 APCOMPARE

This option can be used on a BIND or REBIND and is used to control the result of the command if access paths are different from a previous BIND or REBIND. Observe that this option is independent from the other plan management and access path stability options. The way Db2 searches for previous access paths is not simple and a review of this process as described in the Db2 Performance Guide is advised. The option allows for no action to be taken, a warning to be issued, or the rebind process to be terminated if access paths are different from a previous bind or rebind of a statement in the package.

6.2.3 APPLCOMPAT

This option is new as of Db2 11 for z/OS and allows for the guarantee of access path stability across the migration of Db2 from Db2 10 to Db2 11 (and presumably going forward as well). One major hesitation in regards to version migration is the fear of access path regression. This option eliminates this fear for static embedded SQL, and applies to both BIND and REBIND. Observe that this option is independent from the other plan management and access path stability options. The way Db2 searches for previous access paths is not simple and a review of this process as described in the Db2 Performance Guide is advised.

6.2.4 APREUSE

This is a powerful BIND and REBIND option that tells Db2 to reuse existing access paths for recognized statements when possible, and then specifies what action to take if an access path from a previously existing statement cannot be reused. The choices are to simply perform the bind, fail to bind if paths cannot be reused, or bind all the statements and reuse paths when possible also issuing a warning message for the paths not reused (new for Db2 11 for z/OS). Note that prior to Db2 11 APREUSE(ERROR) applied to the entire package. If any single statement failed then the entire package would fail. With Db2 11 APREUSE(WARN) is at the statement level. So only the statements that fail are reverted back to original access path.

6.3 Optimization Hints

Db2 allows for the creation and use of optimization hints at the statement level and user level[6]. The use of optimization hints is available for static and dynamic statements and is available for a given user or globally. Using optimization hints is documented in the Db2 Performance Guide and Db2 Command Reference. They involve the use of user EXPLAIN tables and system catalog tables. Reference the Db2 documentation for instructions on how to use hints. Options are as follows:

- Statement-level optimization parameter hints: Specify certain optimization parameters that are to be considered, independent of system or application level defaults, based upon a particular statement text.
- Statement-level access path hints: Specify access paths for particular statements and the scope of the application is variable. The hints can be controlled globally or at a package and/or authorization ID level.
- Statement-level selectivity overrides: Predicate-level filter factor hints for individual statements. This is new for Db2 11 for z/OS and presents an opportunity to do predicate-level influencing. This should eliminate the need for the various desperation tricks mentioned in this section.
- PLAN_TABLE hints: More traditional hints that allow the specification of an access path for a particular package and authorization ID.

6. *Plan Analyzer* manages the creation of statement-level hints.

Hints rely on EXPLAIN tables that exist for a particular authorization ID, or are globally based upon a set of Db2 system catalog EXPLAIN tables. Hints are activated via a BIND PACKAGE or BIND QUERY command, depending upon whether or not the hint is plan table level or global. There also exists an entire infrastructure for managing, testing, and moving hints to and from the Db2 system catalog tables.

6.4 Influencing the Optimizer

This section is going to talk specifically about manipulation in an effort to influence the optimizer, and should be used in context with everything discussed in this section as well as in Chapter 3, Chapter 4, Chapter 5, and Chapter 7. It is advised to influence the optimizer using conventional techniques rather than trying to trick it. The following is a list of conventional techniques in order of preference.

- Proper RUNSTATS (Chapter 3)
- Coding SQL for proper performance (Chapter 3 and Chapter 4)
- Plan management (Chapter 7)
- Access plan stability (Chapter 7)
- Literal Concentration for dynamic SQL (Chapter 4)
- Runtime reoptimization (Chapter 4)
- Optimization hints (Chapter 7)

There are several less conventional techniques that DBAs have used, some of which are documented in the Db2 Performance Guide. However, as Db2 SQL optimization evolves more and more some of these unconventional techniques become obsolete or even impair proper SQL optimization. For this reason, expect to see the techniques that are documented in the Db2 Performance Guide removed from that documentation in the future. Try to employ the practice of properly coding SQL for performance as is documented in Chapter 3 and Chapter 4. This involves not just coding the SQL properly, but also understanding which coding techniques offer the best level of performance for certain situations. From a simplistic point of view, consider whether or not the SQL is going to process very little data or a lot of data and make the coding decisions based upon that simple information. Always use EXPLAIN and always benchmark every written statement. What follows is a list of techniques used to influence the optimizer. Most of these are useful primarily for multi-table queries or for trying to convince Db2 to use one index versus another index. Most of these are acts of desperation, unless otherwise specified in the description.

- **OPTIMIZE FOR.** Plan the OPTIMIZE FOR clause at the end of a SQL statement to communicate to the optimizer exactly how many rows to process from the SQL statement. This is NOT the number of rows the optimizer is expected to process, but instead the number of rows intended to process. The clause was created in response to the fact that some pagination queries may qualify a serious number of rows, but only display a page's worth on a screen before exiting a FETCH loop. When using OPTIMIZE FOR the general guideline is to specify the number of rows intended to process for the query. When processing the entire result set do not specify the clause at all. Also be aware that specifying OPTIMIZE FOR may inaccurately influence the query cost estimate in an EXPLAIN, making it unusable for statement cost comparison (it is an easy way to get a query to pass a cost analysis comparison based upon an inaccurate EXPLAIN only to have it cripple production with bad performance). This option also influences the block size used for block fetching for remote applications. So, abusing OPTIMIZE FOR can hurt performance as much or more than it can help performance. A common tuning choice for transactions that has been used quite extensively is OPTIMIZE FOR 1 ROW. This choice discourages Db2 from considering sorts, sequential prefetch, and list prefetch for some SQL statements. The behavior of OPTIMIZE FOR 1 ROW changed in Db2 10 for z/OS. The change is described in APAR PM56845 and gives a choice of modifying the behavior of OPTIMIZE FOR 1 ROW and/or introducing OPTIMIZE FOR 2 ROWS into the tuning arsenal.
- **VOLATILE table option.** This option, as described in Chapter 7, encourages Db2 to choose an access path that favors an index. This option is recommended for tables that are indeed volatile. Use it to influence access paths as well for other tables. Use caution, however, as it is an act of desperation and could hurt more than help.

- **Predicate enablers.** This type of technique is generally used to influence Db2 to pick an index over a table space scan, or to pick one index versus another index. This technique can be used to modify indexes such that index-only access is possible or to increase the matching number of columns based upon existing predicates in a query. This technique can also be used to attempt to add predicates to a query, including redundant predicates. This is especially helpful if the predicates use host variables or parameter markers rather than literal values. Add a predicate that provides no actual real filtering for a query, but increases the filter factor calculated for a table or the filter factor calculated for index access on a table. The filter factor may then influence the choice of one table versus another in a multi-table statement or the choice of one index versus another if it is perceived to increase filtering or matching. For example, if an index contains COL1, COL2, COL3, and COL4 and the query has a compound predicate WHERE COL1 = ? AND COL4 = ?, add another predicate such as AND COL2 BETWEEN ? AND ? to increase match columns and influence the access path if it is of potential benefit. The values provided for the parameter markers represent the minimum and maximum column values.
- **Predicate disablers.** This technique is used to discourage Db2 from choosing a particular index or to modify the table access sequence in a multi-table query. It is based upon the concept that a Stage 2 predicate connected to a Stage 1 predicate with an OR makes the entire compound predicate Stage 2. For example, COL1 = ? is Stage 1 indexable, whereas (COL1 = ? OR 0=1) is Stage 2 and non-indexable, even though the right side of the OR is meaningless. This is a quite common technique.
- **Using ORDER BY.** Db2 considers an index if it can be used to avoid a sort. By coding an ORDER BY, specifying the leading columns of an index that is desired, it is possible to influence Db2 to use that index over other indexes or a table space scan, which is not so much an act of desperation.
- **Influence table access sequence.** Lots of time can be spent tuning multi-table statements and attempting to encourage Db2 to pick the tables in a sequence that may be more efficient only after the statement appeared as a potential performance problem. Many of the choices here are not acts of desperation, except for the use of predicate enablers and disablers.

  The issues here are many due to the fact that Db2 does a strong job of determining which table is accessed first based upon catalog statistics and the simple concept that the table that returns the fewest rows should be accessed first in a multi-table operation. One of the problems can be called *one is the lowest number*. To be specific, when estimating the rows to be returned from a table, any number lower than one is rounded up to one. So, even though all the tables in a multi-table statement (think join) that are predicted to return one row are thrown to the beginning of the join operation, relative to each other they are considered the same in that they return one row. What if the operation includes inner joins that could result in rows being eliminated by a table that will more often return zero rows than one row? That table should be accessed before the tables that actually return one row. In general, using these techniques attempt to encourage Db2 to first pick the tables that return fewer rows even though Db2 does not know. This could involve the one row concept, some data skew without distribution statistics, parameter markers and host variables, or the input to the query and Db2 (again, parameter markers and host variables).
  - **Toggle between joins, correlated, and non-correlated subqueries when possible.** Examine the columns being returned. Are they coming from all the tables? If not, options exist for coding the statement as either of the three, including anti-joins. See Chapter 4 for details.
  - **Increase indexability of the table to be accessed first.** This could be one or more of a combination of elements including adding columns to the index of the table to be accessed first, or the use of predicate enables or disablers.
  - **Use predicate enablers or disablers.** The same technique to encourage the use of one index over another can also influence table access sequence.
  - **Code an ORDER BY on the columns from the table to be accessed first.** Db2 may consider the index to avoid a sort, and Db2 can use an index to avoid a sort in a join when all of the columns of the sort come from only one table and that table is accessed first in the join sequence.
  - **Use a correlated nested table expression.** This is done often, even though with each version of Db2 it does become slightly less effective. Db2 has limited access paths to choose from if correlation is used and almost always uses nested loop join. To create this effect, take a table in a join that you do not want accessed first, put it in a table expression and create a correlated reference to the table to be accessed first. Db2 generally cannot access the table in the table expression until the data is available from the table in the correlated reference. This can be an effective method and is good for transactions, but a bad idea for larger queries. See Chapter 4 for details.

- **Force materialization of the table to be accessed first.** Put a table to be accessed first into a nested table expression and force materialization (see Chapter 3 on merge versus materialization). Use DISTINCT, GROUP BY, or ORDER BY in the table expression to force a sort. This can be useful in situations where joined tables are not in an optimal clustering sequence and Db2 has chosen nested loop join. It may also be an alternative to hybrid join or nested loop join with intermediate sorts (or hash join) but it is recommended to benchmark these attempts to determine effectiveness.
- **Code non-transitive closure predicates.** Depending upon the version of Db2, LIKE and subqueries are not available for transitive closure (see Chapter 3 on query transformation). Db2 uses transitive closure to generate local predicates against more tables in a join. In that way, more access path choices and indexes are available for consideration. To discourage this behavior and disable transitive closure for a given predicate, consider using a subquery. To use a subquery, change the following ON A.COL1 = B.COL1 WHERE A.COL1 = ?, to ON A.COL1 = B.COL1 WHERE A.COL1 = (SELECT ? FROM SYSIBM. SYSDUMMY1).

Any effort to influence SQL optimization with a trick should only occur after other options have failed.

Chapter 7: Table and Index Design for High Performance

Logical database design is the responsibility of the DBA. Physical database design is the responsibility of the DBA and is to be performed in cooperation with the application development team. The database design decisions should be based on facts. Deliberating over how something may perform is a waste of time, and most often results in an over-designed database and/or process that performs horribly. The basic guideline is to build the database that the logical modelers developed, as long as it is in third normal form, and use database automation when possible to improve performance and reduce application development time. This saves significant time in developing a physical model and leaves the performance concerns to be addressed in two tasks: fix it when it is broken, and let the database inform on how to design the database.

If the development life cycle does not contain allotted time for performance analysis and tuning, then management is not concerned with performance and emphasis should not be placed on performance because there will be little support for recommendations. Of course, management is concerned about performance and so there must be a tuning phase of development. When subscribing to the fix it when it is broken philosophy of performance tuning, this phase of development is the time for EXPLAIN, benchmarking, and monitoring of the application and database in action. Changes can be implemented at that time to improve the performance of the application as prescribed by a service level agreement (SLA). If extreme performance challenges are expected then a performance-based design is a good move; but what choices should be made? This is the point at which meetings help determine the possible design choices for high performance, and then establish a means to test and prove them.

A strong philosophy for coming up with a high-performance design is to let the database determine how to design the database. If the performance features of the database (many of which are covered in this guide) are understood, then there is already a starting point. Now, which performance features are advantages for the particular database and application and which hurt the performance of the database or application? The answer is in performance testing, but with potentially no database, data, or application code available to test, what can be done? The answer is to simulate the entire design, or portions of it in a proof of concept (POC). Since, in the vast majority of database applications, most of the business logic is contained in the application layer, simulate the database layer quite easily with dumbed down SQL access and table designs that reflect the ultimate design. Using SQL to generate SQL and data, SPUFI, and REXX for the application layer, build test cases in as little as a few hours or days. Then, using the testing techniques described in Chapter 10, make variations to the database and application design and measure the effects. In this manner, the ultimate database design is one based upon the performance measurements taken during the POC, and not based upon guessing about performance in a meeting room. It is this very technique that has led to some of the most extreme database applications reaching astounding transaction rates and data volumes from day 1 and with little to no post-implementation tuning.

7.1 Selecting a Table Space Type and Features

The types of available table spaces include segmented, classic partitioned, universal range-partitioned, and universal partition-by-growth. Given the growing number of database features that are dependent upon universal table spaces, choose either range-partitioned or partition-by-growth universal table spaces. Do not choose segmented unless there are many small code tables that must share a table space, and do not choose classic partitioned unless pre-Db2 10 and the MEMBER CLUSTER feature are in use.

7.1.1 Partitioning

Table spaces can be partitioned either as universal partition-by-growth or range-partitioned. These are the modern ways to partition data within a Db2 data server and should be the choices made going forward. Also available is table and index controlled classic partitioning. However, there are no advantages moving forward to selecting these options. Since partitioning is a table feature, see Section 7.2.1, Range-Partitioning to understand the performance advantages to range-partitioning.

An additional advantage to partitioning is that certain table space settings are possible at the table space partition level. This allows for certain performance adjustments to be made via ALTER statements as certain partitions become more or less active, including free space, TRACKMOD, compression, and group buffer pool caching.

7.1.2 Group Caching

When operating in a data sharing environment, specify which level of caching is desired for the group buffer pools in Db2. The choices are ALL, CHANGED, and NONE. Generally, the default option CHANGED is adequate to balance between group buffer pool performance and concurrency when updates are allowed across all data sharing members. There are some delicate choices here, however, between the distribution of processes, updates across members, range-partitioning configuration, and performance. In many situations, the majority of high-performance updates to a table come in the form of large-scale batch operations. This is where something called application-controlled parallelism comes into play and where group caching can play a major role in the performance of these large-scale operations. In these situations, partitions match processes, group caching is set to NONE, locking is at the partition level, readers that read across partitions are doing so as uncommitted readers using WITH UR (if possible), and system affinities are applied. All of this is detailed in Section 7.2.1, Range-Partitioning. Setting the group caching to NONE is only useful for this situation where all large scale update processes are directed to individual members and executed during online quiet times.

For any large-scale batch operation, remove group buffer pool dependency for all of the objects that the batch operation touches. This is accomplished via the following Db2 command:

```
-ACCESS DB(<database name>) SP(<space name>) PART(n) MODE(NGBPDEP)
```

The general guideline is to issue this command on the data sharing member where the large-scale batch process runs. However, the best success has been found by avoiding the overhead of group caching for group buffer pool-dependent objects by running the command on each and every data sharing member.

7.1.3 Lock Size

Setting the lock size is a practice in the balance between performance and concurrency. The lock size of a table space must be balanced with the expectations of the application, how the application is coded, the concurrency control setting for the application, and the isolation level that is set by the application. Often, DBAs overlook this balance and attempt to resolve perceived concurrency or performance problems by setting the lock size to row. What is not realized is that by setting the lock size to row, the number of locks held by an application and managed by Db2 can be dramatically increased. This increased number of locks can consume significant memory and CPU resources as well as dramatically increase the number of messages sent between data sharing members and the coupling facility. Row-level locking should only be used in extreme concurrency situations on tables that have a small quantity of rows shared by a high number of concurrent threads. Do not use a lock size of row in high volume, high transaction rate situations as tests conducted demonstrate significant CPU and elapsed time resource consumption over other lock sizes. In almost all implementations, use a lock size of PAGE or ANY, but mostly PAGE, so as to avoid lock escalations.

If possible in the environment, use the application-controlled parallelism configuration, which is described in Section 7.2.1, Range-Partitioning. In these situations, any transactions that update objects or any high-volume batch update operations are split by a logical value that matches the range-partitioning and are applied to specific partitions. The lock size is set at the partition level to minimize locking overhead. All readers use WITH UR to read uncommitted, and in some cases the update transactions employ an optimistic locking strategy. See the rest of this section for more details on these options.

Another option to adjusting the lock size that is worth investigating is currency control or concurrent access resolution. This is a feature that allows readers to see only data that is currently committed or to wait for an outcome. By setting the readers to read only currently committed data, they do wait for any locks, but instead return only the data that has already been committed by other applications. This is a great feature, but is limited in its implementation on Db2 for z/OS in that the currently committed reader avoids uncommitted inserts and deletes, but not updates. Therefore, to implement this strategy all updates are required to be executed as deletes and inserts.

Review all options, including uncommitted read, optimistic locking, concurrency control, and other isolation level options prior to, or in conjunction with, selecting a lock size.

7.1.4 MEMBER CLUSTER

This feature is specifically designed for high performance and availability table spaces that are subject to very high insert activity. Setting MEMBER CLUSTER together with PCTFREE 0 and FREEPAGE 0 for a table space does two things: It establishes an alternate insert algorithm by placing the majority of inserts to the end of the table space or target table space partition; and it also sets one space map page for every 99 data pages and reserves the space map pages exclusively for every data sharing member acting against the table space or table space partition. The space map feature can significantly improve the performance and concurrency of high insert applications that are distributed across data sharing members because the unshared space map pages are not a source of contention in the coupling facility. Setting MEMBER CLUSTER, like APPEND ON at the table level, ignores clustering and place inserts at the end. However, unlike APPEND ON, it is more aggressive in searching for available free space before extending a table space.

7.1.5 Page Size

Select a page size that is meaningful for the table, and not necessarily for a belief that a large page size results in cheaper I/O and getpage costs. In most performance tests that compare one page size over another (for example, 4K versus 8K), there is never a performance gain realized for sequential or random access. There are always exceptions, however, so do not hesitate to run some tests of alternate page sizes.

A larger page size becomes more of a performance concern with situations in which space is wasted, thus impacting I/O and memory performance, due to hitting the 255 rows per page limit before filling a page. Also observe that compression also plays a role in the number of rows that can fit on a page. Larger page sizes are more critical when it comes to LOB storage. Observe that a LOB table space has a limit of one LOB per page. When storing mostly smaller LOBs, a smaller page size may save space and improve performance.

7.1.6 Compression

It is recommended to apply compression more often than not to a table space. Compression not only saves on mass storage space, but improves memory utilization in the buffer pools and improves the performance of many types of processes. In the vast majority of cases, the cost of compression is more than offset by the improved I/O and memory efficiencies, and a compression rate of 45% or higher is generally accepted. The only time to avoid compression is for tables that store primarily numeric values or tables with a compression rate of less than 45%.

7.2 Table Design Features and Performance

7.2.1 Range-Partitioning

There are several reasons for choosing range-partitioning:

- Rotating and aging data
- Separating old and new data
- Separating data logically for region or business segment based availability
- Spreading data out to distribute access
- Logically organizing data to match processes for high concurrency

One of the performance advantages to range-partitioning is in distributing the data to spread out overall access to the table space. What this means is that index b-tree levels can potentially be reduced due to reduced entry count per partition and that can reduce I/Os and getpages to indexes. In addition, free space searches could be more efficient in a partitioned situation since the data is broken up and the searches are on a partition-by-partition basis. The same is true for any partitioned indexes defined against the table space.

From a performance perspective, range-partitioning is useful to enable a high degree of parallelism for queries and utilities. In addition, queries coded against range-partitioned tables can take advantage of partition elimination, also sometimes called page range screening, when predicates are coded against partitioning columns. These predicates can contain host variable or parameter markers, literal values, and, beginning with Db2 11 for z/OS, joined columns.

For the highest level of partitioned table access possible, a design technique called application controlled parallelism is recommended. This technique is useful when there exists high-volume batch processes acting against very large OLTP data stores. In these situations, it is a careful balance between partitioning, clustering (or intentionally not clustering), and distribution of transactions in a meaningful way across multiple application processes. What is meant by a meaningful way is that the distribution of inbound transactions must match the partitioning and/or clustering of the data in the table space partitions accessed during the processing. In this way, each independent (or sometimes dependent) process operates against its own set of partitions. This eliminates locking contention and possibly allows for a lock size of partition and use of MEMBER CLUSTER to further improve performance of ultra-high insert tables.

When the input is clustered in the same sequence as the data is stored, or when using MEMBER CLUSTER or APPEND ON to place data at the end of a table space partition, Db2 can take advantage of sequential detection to further improve the performance of these types of processing. In these situations, transaction rates as high as 10,000 per second, single-table insert rates as high as 13,000 per second, and application-wide insert rates as high as 17,000 per second have been achieved. These are not test cases but real-world results.

As a final note on the distribution of transactions across partitions, a meaningful distribution of data across partitions and an application process pattern to match are highly recommended. There are many implementations where data and transactions are randomized to distribute access randomly and eliminate hot spots. This approach typically results in a random access nightmare and potentially extreme locking conflicts. Db2 handles hot spots just fine. Between the power of index lookaside, sequential detection, good buffer pool configuration, and advanced DASD subsystem, there are no true physical hot spots with Db2.

7.2.2 Materialized Query Tables

A Materialized Query Table (MQT) is a table that is designed to help the performance of complex queries that are coded against one or more very large tables. The idea is that a single table can be used to present a summary of data that is normally produced by a complex query and then have Db2 intercept the complex query when it is executed and direct the request to the MQT instead of the original large tables. In this way, MQTs are most effective for report queries that aggregate data, especially in situations where there are many similar report queries that can share the same MQT and thus avoid many redundant accesses to the original tables that the MQT replaced. What follows is a simple example of the definition of an MQT (untested, just an example for discussion purposes).

```
CREATE TABLE EMPINFO (EMPNO, SALARY, AVGSAL) AS (
    SELECT EMPNO, SALARY, DEPTSAL.AVGSAL
    FROM EMP EMP
    LEFT JOIN (
        SELECT WORKDEPT, AVG(SALARY)
        FROM EMP
        GROUP BY WORKDEPT) AS DEPTSAL(WORKDEPT, AVGSAL)
    ON EMP.WORKDEPT = DEPTSAL.WORKDEPT )
DATA INITIALLY DEFERRED
REFRESH DEFERRED
MAINTAINED BY SYSTEM
ENABLE QUERY OPTIMIZATION;
```

If it is assumed that the EMP table is extremely large, then the aggregation of values in the table expression can become quite expensive. The ENABLE QUERY OPTIMIZATION setting gives Db2 the ability to analyze queries that are similar to the one coded in the MQT definition and elect to use the MQT to retrieve the data rather than the original query. Observe that the data in the MQT may not be completely in sync with the data generated by the original query, and the ability of Db2 to select the alternate access is dependent upon the CURRENT MAINTAINED TABLE TYPES and CURRENT AGE special registers, as well as the SPRMMQT subsystem parameter. Review the Db2 Administration

Guide and SQL Reference for additional information on the optimization of queries eligible to use MQTs. To properly take advantage of an MQT, code a query directly against the MQT, which both guarantees the performance advantage as well as the query results since the data in the MQT is actually a snapshot in time. That snapshot may be important and relative for report queries that are issued repeatedly and expect the same results within a given period of time.

DBAs often confuse MQTs as a performance choice for transaction processing systems. Observe that this feature is designed in support of report queries and data warehouses, not transactions. The query transformation feature is only available for dynamic SQL and the MQT is not guaranteed to be a current representation of the data in the original tables that the MQT is based upon. The confusion begins when it is believed that the MAINTAINED BY SYSTEM setting means that Db2 is going to update the MQT every time a change is made to one of the original tables. This is not the case at all. The only way to refresh an MQT is via an unload and a LOAD, use of a REFRESH TABLE statement, or by creating a set of triggers that can maintain the MQT in sync with the source tables.

7.2.3 Storing Large Strings and Large Objects

There are multiple choices for the storage of large strings which include the use of VARCHAR and CLOB data types. A single VARCHAR column can be defined up to 32,704 bytes for a table stored in a table space with a page size of 32K. If the long character strings are going under that length, a VARCHAR is the preferred method of storage since all of the data can be contained in the base table and can be compressed. Consider using multiple rows of VARCHAR fields for long string storage as this could possibly outperform CLOBs, but of course, additional programming is required to assemble and disassemble the strings.

CLOBs can be up to almost 2 GB in length and so a CLOB data type is a good choice for very large strings when a more simplified approach to data access is required. Observe, however, that there are trade-offs with CLOB performance and management. Large objects are stored in separate table spaces from the base table data, and access to these auxiliary LOB table spaces is completely random. In addition, all LOBs generally require special attention when running LOADs, unloads, REORGs, and other Db2 utilities. LOB table spaces cannot be compressed and a maximum of only one LOB can be stored per page of a LOB table space. So, it is completely senseless and a large performance detriment to define small LOBs or to define large LOB columns only to put small LOBs into them.

Store all or a portion of a LOB in the base table via the INLINE option of a LOB column definition. This allows for a LOB definition with all the advantages of storing one or more 2 GB objects in a table, while still taking advantage of potential sequential access and compression that is available for the base table. Using the INLINE LOB feature is only a performance improvement if all or most of the LOBs stored in the table fit into the base table portion without overflowing into the LOB table space. If even a modest percentage (perhaps 10% of LOBs) end up overflowing, then in-lining the LOB data can actually result in a performance detriment due to the extra access to the LOB table space and potential extreme waste of space in the LOB table space.

7.2.4 XML Storage

Is the utilization of an XML column a performance feature? It can depend. From a pure performance perspective, the following questions must be answered:

- Is the database going to be used simply to deposit and retrieve XML?

  If this is true, then an XML data type is not the performance choice. Store the XML as a large string and avoid the overhead that would be incurred with an underutilized XML column.
- Do applications need to share the data in both XML and relational format?

  In this case, store the data in relational tables. Db2 provides all of the functionality to both shred and build XML documents, as well as do direct translation from relational to XML and back. This may give the highest level of flexibility, and may avoid the unnecessary and costly duplication of data. Be sure to test the overhead of the execution of the many functions required to do the back-and-forth conversion.
- Is direct access and validation of the XML documents required?

  The performance choice here just may be to utilize an XML column. This gives direct access to all or a portion of an XML document, enables searching and indexing of portions of a document, allows the translation to and from relational, enables updates of only a portion of a document, and enables document validation.

From a development perspective, consider the use of an XML data type to be a performance advantage. Below are some of the built-in XML features of Db2:

- XML schema storage and validation
- XQuery and XPATH expression processing
  - Variable value processing
  - Looping
  - Data manipulation
- Conversion to and from relational data
- Partial document update
- XML indexing

Taking advantage of these features can be a performance boost from a development perspective in that processes that may take months to code in Java or another language may take days or even minutes to code using the Db2 built-in XML functionality. In addition, if analysis of all or a portion of an XML document can occur before all of it is returned to an application, then this can represent a significant performance improvement over simply passing the entire document to and from an application, especially when that passing of data is across a network.

7.2.5 Optimistic Locking Support

A properly implemented optimistic locking strategy can represent a significant performance and concurrency improvement to an application that updates data. Below is an overview of optimistic locking:

1. All tables contain a timestamp column that represents the time of last update or insert.

   The timestamp column in the table is the key to optimistic locking and enables concurrent processes to share data without initial concern for locking. As an application carries the data along, it holds the responsibility for maintaining the update timestamp in memory and checking it against the table in the database for a given primary key. The update timestamp itself is not a part of the primary key, but is used for change detection for the row represented by the primary key. What follows is a very simple example of such a table definition.

   ```
   CREATE TABLE BOB1
   (PRI_KEY BIGINT NOT NULL
   ,DATA_COL CHAR(50) NOT NULL WITH DEFAULT
   ,UPDATE_TS TIMESTAMP NOT NULL);
   ALTER TABLE BOB1 ADD CONSTRAINT PK_BOB
   PRIMARY KEY (PRI_KEY);
   ```

2. All tables are read with isolation level uncommitted read.

Using an isolation level of UR means potentially reading dirty uncommitted data, however the application does not wait for any lock that is held on a piece of data that has been updated by a concurrent in-flight transaction. The read of the data absolutely has to include, at the very least, the primary key value and the update timestamp. This update timestamp must be retained for use in testing the validity of the data held in memory by the process. What follows is an example of such a read.

```
SELECT PRI_KEY, DATA_COL, UPDATE_TS
FROM BOB1
WHERE PRI_KEY = ?
WITH UR
```

3. The timestamp column is tested and updated with every update.

   When a process moves to update data it has previously retrieved, it must do two things. First, it must test the update timestamp to determine if the state of the data in the table is the same as when it was initially retrieved, and second, it must update the update timestamp to reflect the change in the state of the data as a result of its processing. What follows is an example of such an update. In the example, the update timestamp is tested for the value that was retrieved when the row was originally read and updated to the timestamp of the update.

```
UPDATE BOB1
SET DATA_COL = ?
, UPDATE_TS = ?
WHERE PRI_KEY = ?
AND UPDATE_TS = ?
```

This technique does a great job of improving the performance and concurrency of an application. It does, however, relieve the database engine of some of the concurrency control by using uncommitted read and puts a tremendous responsibility on the application to properly maintain the update timestamps and, thus, the data integrity.

Db2 provides support for optimistic locking which removes some of the application responsibility in the control of optimistic locking. This support comes in the form of an automated generated column called a row change timestamp column. This column can be generated by default or always by Db2, but for optimistic locking situations it is strongly advised to force it as generated always. The advantage of this generated column is that it moves the responsibility of updating the timestamp column out of the hands of the application and into the hands of Db2, thus guaranteeing the accuracy of the timestamp value enterprise-wide. This is quite obvious if we compare the fully application-controlled, optimistic locking strategy laid out above with the same strategy that uses the built-in Db2 functionality.

- All tables contain a timestamp column that represents the time of last update or insert as maintained by Db2.

```
CREATE TABLE BOB1
(PRI_KEY BIGINT NOT NULL
,DATA_COL CHAR(50) NOT NULL WITH DEFAUL
,UPDATE_TS TIMESTAMP NOT NULL GENERATED ALWAYS FOR EACH ROW
ON UPDATE AS ROW CHANGE TIMESTAMP );
ALTER TABLE BOB1 ADD CONSTRAINT PK_BOB
PRIMARY KEY (PRI_KEY);
```

- All tables are read with isolation level uncommitted read.

  The difference here is in how the update timestamp is retrieved. The row change timestamp column is not named in the SELECT but instead specified. Select the column by name, if desired.

```
SELECT PRI_KEY, DATA_COL, ROW CHANGE TIMESTAMP FOR BOB2
FROM BOB1
WHERE PRI_KEY = ?
WITH UR
```

- The timestamp column is tested and updated with every update.

  While the testing of the timestamp must be performed by the application, the updating of the timestamp happens automatically by Db2. This ensures a higher level of data integrity for optimistic locking.

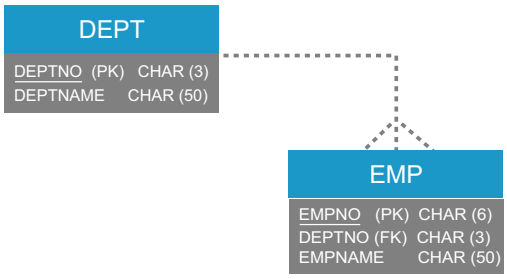
```
UPDATE BOB1
SET DATA_COL = ?
WHERE PRI_KEY = ?
AND ROW CHANGE TIMESTAMP FOR BOB1 = ?
```

7.2.6 Database-Enforced Referential Integrity

There frequent debate within the Db2 community with regards to the cost, benefits, and manageability of database-enforced referential integrity (RI). From a performance perspective, database-enforced RI is recommended. Although, everything is relative, the less controlled the data is the more the database enforced RI is going to cost. Considering the fact that the most expensive thing possible is making a call to the database engine, the database-enforced RI is going to eliminate many calls to the database. Enforcing RI is a data-intensive process, and any data intensive process should be handled as close to the data as possible. For example, utilizing cascading deletes may be viewed as too resource-intensive, especially for multiple levels of cascading. However, what is the alternative? The answer is many calls to the database to perform the cascading of the deletes at the application level, which ultimately results in a longer overall code path and greater quantity of CPU consumed. Also, while one may contend that an application can check a parent key once prior to the insertion of many child rows of data, Db2 has the ability to cache repeated calls for parent key lookups and so the impact of such operations on performance is minimized.

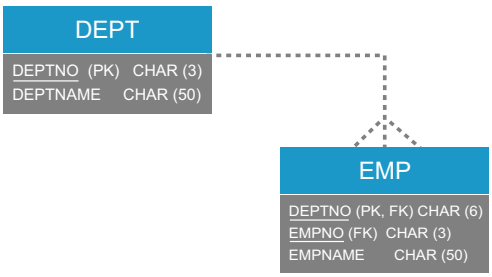
An identifying relationship is one in which an instance of the child entity is identified through its association with a parent entity; and the primary key attributes of the parent entity become primary key attributes of the child. Examine the Db2 sample database and observe that the primary key of the employee table is completely independent of the department table, but there is a foreign key to the department table. This is considered a non-identifying relationship. The following simplified example shows the original relationship.

Figure 3: Non-identifying Relationship Between Tables



If the relationship between the employee and the department was identifying, then the employee table would contain the department number primary key of the department table as part of the primary key of the employee table, as in the following simplified example.

Figure 4: Identifying Relationship Between Tables



Actually, not only is the department number part of the primary key of the employee table, but it is the leading column. From a pure performance perspective, there are two advantages to establishing these types of relationships in the physical model and DDL: reduction in the number of indexes required to support the relationships, and the ability to use the primary key indexes as clustering indexes. These two elements are extremely important for performance- or database-enforced, or even application-enforced, RI as it minimizes the number of indexes in the database, reduces the frequency of random I/Os to navigate relationships in the database, and promotes common clustering of related tables.

In the example with the non-identifying relationship, there is one supporting index for the primary key on the department table, one supporting index for the primary key on the employee table, and one supporting index for the foreign key on the employee table. Clustering is via primary key indexes. In the example that utilizes the identifying relationship, there is one supporting index for the primary key on the department table and one supporting index for the primary key and foreign key on the employee table. Clustering is again via primary key indexes. Not only does one index serve two purposes for the employee table, but the common clustering results in fewer I/Os, less random I/O, and promote Db2's ability to utilize the dynamic prefetch and index lookaside performance enhancements described in Chapter 3.

It is possible to achieve a common cluster with the design that utilizes a non-identifying relationship by establishing cluster based upon the foreign key index of the department number on the employee table. However, full clustering may be desired in situations where employees are processed in sequence, and that may require the creation of a third index on the employee table using the department number and employee number. This is all obviously relative to the design and the processes that act on the tables. Nonetheless, from a performance perspective, the identifying relationships utilizing the parent primary keys as leading columns is the proper choice.

The pros and cons of utilizing identifying relationships must be carefully considered during the development of the database such that performance can be balanced with functionality and flexibility of the design. There is a tremendous pushback from developers and data administrators against DBAs who want to construct these types of identifying relationships, especially for object-relational designs. In many cases, the original design is accepted that utilizes system-generated keys and non-identifying relationships for most objects in the database, but then utilizes the identifying relationship design (with leading column parent keys) for objects that have high performance considerations. The only way to convince modelers and developers is to establish benchmark tests in a proof-of-concept (POC) and demonstrate the performance advantage and disadvantage of each design, all while making sure that management understands the operational costs of each design. Hopefully, a balance can be struck. This is the daily struggle played in high-performance design. See Chapter 10 for details on establishing performance benchmarks and POCs. It is recommended to always support foreign keys with the proper backing indexes.

7.2.7 Check Constraints

Table check constraints allow us to add automated validation of column values to the definition of tables in our databases. For example, if there is a one-character column in the employee table called SEX that represents the gender of the employee represented by the row in the table, then a check constraint can be established on that column to force the value to either M or F. Then, when a row is inserted or modified the input code is verified against the check constraint. If the constraint is violated, the statement fails.

While table check constraints can be a valuable tool in controlling and centralizing the control of column values, they are not at all to be considered a performance feature. This is especially true for simple code value validations. Once a check constraint is violated, control is returned back to the application. If there are multiple constraints against the table then there can possibly be multiple messages back and forth between the data server and application just to get a single row into the database. In addition, column validation is using data server CPU resources, which could be more expensive than application server CPU resources. Placing column validation in the application layer significantly reduces the number of calls to the data server and save CPU. It is highly recommended to perform a cache refresh on the application server at a frequency that can ensure a relatively high level of accuracy of the valid values.

7.2.8 Triggers

Triggers are a form of routines that are activated when a data change statement is initiated against a table with a trigger defined on it. Triggers are useful for many reasons:

- Setting advanced default values for columns
- Data validation
- Replication of data from one table to another
- Sending messages to other applications
- Invoking stored procedures when a data value changes
- Performing external operations when a table is modified

Triggers are recommended, both from a functionality perspective and a database performance perspective. From a functionality perspective, triggers save development time because complex data validation and complex table changes can be performed within the context of a trigger; and in general, it is easier and faster to develop and validate the logic in a trigger than it is in the equivalent application logic. From a performance perspective, the operations performed by triggers generally tend to be data intensive. For example, if the data in TABLE A is changed then this value in TABLE B also changes. If the value in the second table always changes when the value in the first table changes then why call the data server twice to make the overall change? Instead, if the value in the second table can be changed within the action of changing the first table, then by all means define a trigger to perform that action. This reduces the number of calls to the data server, as well as potentially decreases the duration of the unit of work required to make the change. The result is an improvement in database performance and concurrency. For example, if there is an update to a detail table and the update requires an update to a corresponding summary table, then a trigger could very well be the performance choice for making that associated update.

Triggers are often used for data-intensive multi-table operations with great success in many situations and the use of triggers is encouraged for these types of operations. In addition, triggers have also been used in support of database-enforced RI that goes beyond the built-in capabilities of Db2 with great success. Although performance may vary, there are few situations in which triggers are a performance detriment when compared with the equivalent application logic that makes multiple calls to the data server.

7.2.9 Views

Views are a very complex subject from a performance perspective, and an entirely separate guide could be written on the effects of views on performance. In an effort to keep things simple, avoid defining views in high-performance designs. To be more specific, simple views against single tables that contain either all of the columns or a subset of the columns for security purposes are just fine.

Even single-table views with predicates can be useful in a high-performance design. It is recommended to avoid more complex views that contain multiple table references, aggregation, or DISTINCT. The purpose being to keep greater control of the SQL coded at the application level. In addition, Db2 has some issues with the ability to push predicates coded against views into the view definitions themselves. This is especially true in the case when view references in a SQL statement result in materialization, or when there are joins to views where predicate transitive closure can be applied to joined columns. With each new version of Db2 there are improvements to the ability to push predicates into views, but full control is still recommended. The issue of predicate pushdown is extremely difficult to understand, and thus one reason to avoid views in high-performance designs. It is always best to conduct thorough tests when using more complex views to ensure all filtering is getting pushed as close to the data as possible. It is especially important to be observant of, and carefully test, predicate pushdown when using outer joins. Additional important considerations must be made when using UNION in a view. See nested table expressions in Chapter 3, as well as the temporal table section of this chapter, for additional details.

When views are used and Db2 fails to adequately push predicates into a view, use either correlated nested table expressions or SQL table functions to achieve the desired pushdown. For example, consider the following view and query. The local predicate is not pushed into the view even though the average salary information is needed for only one department.

```
CREATE VIEW DANL.V_AVGSAL (WORKDEPT, AVGSAL) AS
SELECT WORKDEPT, AVG(SALARY)
FROM DANL.EMP
GROUP BY WORKDEPT;
SELECT E.EMPNO, E.SALARY, DEPTSAL.AVGSAL
FROM DANL.EMP E
LEFT JOIN
DANL.V_AVGSAL DEPTSAL
ON DEPTSAL.WORKDEPT = E.WORKDEPT
AND E.WORKDEPT = 'C01';
```

The performance choice is to avoid the view and utilize either a correlated nested table expression or a SQL table function (with appropriate fixes applied).

```
SELECT E.EMPNO, E.SALARY, DEPTSAL.AVGSAL
FROM DANL.EMP E
LEFT JOIN TABLE (
    SELECT WORKDEPT, AVG(SALARY)
    FROM DANL.EMP E2
    WHERE E2.WORKDEPT = E.WORKDEPT
    GROUP BY WORKDEPT) AS DEPTSAL(WORKDEPT, AVGSAL)
 ON DEPTSAL.WORKDEPT = E.WORKDEPT
AND E.WORKDEPT = 'C01';

CREATE FUNCTION DANL.EMP1 (INDEPT CHAR(3))
RETURNS TABLE (WORKDEPT CHAR(3), AVGSAL DEC(9,2))
RETURN
    SELECT F.WORKDEPT, AVG(F.SALARY)
    FROM DANL.EMP F
    WHERE F.WORKDEPT = INDEPT
    GROUP BY WORKDEPT;

SELECT E.EMPNO, E.SALARY, DEPTSAL.AVGSAL
FROM DANL.EMP E
LEFT JOIN TABLE (
    DANL.EMP1(E.WORKDEPT) AS DEPTSAL(WORKDEPT,AVGSAL)
 ON DEPTSAL.WORKDEPT = E.WORKDEPT
AND E.WORKDEPT = 'C01';
```

7.2.10 Views and Instead Of Triggers

There is an advantage to using views in conjunction with *instead of* triggers in certain object-relational designs. This all revolves around the concept that the developer is going to want to map single tables to single objects in the data access layer of the application. This type of design results in a proliferation of SQL calls to retrieve-related objects in support of a transaction. Assume, using the Db2 sample database, that an application always collects information about departments and employees at the same time. If an object is mapped to the department table and another object mapped to the employee table, then each invocation of a transaction to get the data results in two calls to the data server. If a view is created that joins the department and employee tables together, the data access layer of the application can map only one object to the view, which it treats as a table. Any requests to populate the object result in only one call to the data server versus two. Updates to the object are not possible in this situation, however, unless *instead of* triggers are employed. In addition, the underlying join of the two tables may represent a denormalization to the application, which may or may not be acceptable.

An *instead of* trigger is a type of database trigger that is defined against a view and causes an action to be fired whenever there is a data change statement executed against the view. This potentially allows for updates, inserts, and deletes against a multi-table view. From an application perspective a change is being made to a table, but in reality the trigger intercepts the change and the logic within the trigger can take an alternate action, such as properly updating the underlying base tables.

This technique is not usually deployed, so thoroughly test this as a potential option to denormalization in these types of situations.

7.2.11 Temporal and Archive Tables

Db2 temporal tables are an outstanding database automation feature that can replace significant amounts of application programming. An application-period temporal table is a table that has been defined with the appropriate time columns along with the specification of a business period. They are useful for managing data active during a certain time, and for allowing data to be staged (active in the future), current, and historical. An application-period temporal table can be useful for such things as reference tables and code tables where descriptions change over time, or for more involved applications such as the active period of a specific insurance policy. The application-period is created by including a PERIOD BUSINESS_TIME clause that identifies the start and end time columns. These columns can be DATE or TIMESTAMP data types. A system-period temporal table is a table that has been defined with the appropriate timestamp columns along with the specification of a system-period; it can be useful when all changes to a table must be tracked with a retained history to fulfill auditing or compliance requirements. The system-period is created by including a PERIOD SYSTEM_ TIME clause that identifies the start and end timestamp columns. When defining a system-period for a table, Db2 is in control of the start and end timestamps; the timestamps reflect the state of the data for the time specified. Data that is currently effective is represented. Optionally, define a history table and associate it to the base table. Any changes to data then results in before images of the changed data being automatically replicated to the history table, with appropriate updates to the timestamps in both the base and history tables.

The main incentive for using Db2 automated temporal tables is indeed the automation. Db2 can automate the updating and control of temporal data, which can result in a dramatic reduction in application development time for these sorts of implementations. Db2 also automates the movement of data from base to history tables for system-period temporal tables. Time travel queries can be managed by either the application or Db2, with the Db2 option being the obvious choice for reduction in application development time.

From a performance perspective, be aware of the following situations when implementing temporal tables:

- Time travel queries introduce range predicates into what may seem to be simple primary key queries against application-period temporal tables. In addition, time travel queries against system-period temporal tables introduce a UNION ALL between the base and history table. See the information on UNION ALL and nested table expressions in Chapter 3 for details.
- When implementing a design that incorporates application-period temporal tables, observe that database-enforced RI is not directly possible for these tables. Db2 does not currently support time-based referential integrity. it is possible to define a primary key on an application-period temporal table, but not establish relationships with other tables. Since the whole point of application-period temporal tables is to add a time component to what was otherwise a primary key, this adds some complexity to a database design that uses application-period temporal tables. One solution is to establish separate key tables that support the database-enforced referential integrity, while their application-period temporal children support storage of the detailed elements.
- System-period temporal history tables should be implemented as high-performance insert-only tables. See the section on these types of tables in this chapter.

For more details and examples about time travel and temporal tables, refer to *How to Leverage Db2's Automated Time Travel Queries and Temporal Tables* in the June/July 2012 issue of Enterprise Tech Journal.[7]

Archive tables share some similarities to system-period temporal tables, especially in the area where Db2 can automatically move data from a base table to a history/archive table. Archival tables are designed with a base table, also called the archive-enabled table, and an archive table. When archiving is activated, any rows deleted from the archive-enabled base table are then inserted into the archive table. Archival activation can be controlled via two built-in global variables. Therefore, it is quite easy to control whether or not deleted rows are automatically moved to the archive table, and also whether or not a SELECT from the archive-enabled table considers data from both the base and archive table. When the reading of archived data is activated, the underlying table access is via a generated UNION ALL between the

7. *How to Leverage Db2's Automated Time Travel Queries and Temporal Tables*, Enterprise Systems Media. http://enterprisesystemsmedia.com/article/how-to-leverage-db2s-automated-time-travel-queries-and-temporal-tables

base and archive table. This UNION ALL access is very similar to the access generated for system-period temporal tables, so reference that information in this section, as well as the information on UNION ALL and nested table expressions in Chapter 3 for details. Just as with system-period temporal history tables, it is possible to design the archive table as a high-performance insert table.

7.2.12 CCSID

Consider the CCSID of the character data in use as a potential performance advantage or disadvantage. It is quite easy to contemplate the performance advantage of EBCDIC with a code page of 037 when data is stored and accessed by locally run COBOL programs also using a code page of 037. This is how applications were run in the days of local access by batch jobs run on the mainframe. That world no longer exists, and yet in the vast majority of situations, tables are defined on Db2 for z/OS as CCSID EBCDIC. By not considering CCSID when creating tables, there is a risk of increased CPU consumption and elapsed time spent performing code page conversion for all character columns. If the primary access is via local programs written in traditional programming languages, then by all means use EDCDIC. However, if the majority of access is via Java then consider UNICODE to avoid code page conversion. If the vast majority of the access is performed locally (local connection only) using a type 2 driver then the character strings should be stored as UTF-16. If the majority of access is performed remotely (even via local hipersocket connection) then the character strings should be stored as UTF-8.

Test this thoroughly to see if it is really going to be a benefit to the situation. Also, while advances in tooling on the mainframe have made the code set of the data stored irrelevant as far as viewing goes, it is still important to be sure all tooling on the mainframe can deal with data stored in Unicode.

NOTE: It should be noted that for SELECTs, Db2 sends whatever the CCSID of the table is back to the application, and the conversion happens in the driver. Also, in the latest version of the Java driver, data conversion can happen within the driver before it sends data to the server if a describe has been done on the table in advance. Finally, it is possible to direct the type 2 driver to talk UTF-8 to the data server by setting the db2.jcc.sendCharInputsUTF8 property to a value of 1.

7.2.13 Sequence Objects and Identity Columns

Sequence objects and identity columns are both system-generated, numeric values that are most often used to generate next key values. They are a direct replacement, from a performance perspective, to the outdated technique of utilizing next key tables to generate ascending numeric keys. Identity columns and sequence objects are very similar in their behavior and settings, with the primary difference being that an identity column is part of a table definition and directly controls a column value, and a sequence object is its own independent object, completely separate from a table definition. While the use of system-generated keys as part of a high performance design is generally discouraged, these generated values are recommended when the design either requires system-generated key values, or the design can tolerate the performance degradation that can be associated with system-generated values and the resulting random database access. In short, maintain a common clustering between tables that can be accessed together in a transaction, and if using sequence objects and identity columns for generated key values, ensure those keys are inherited as identifying (part of the child table's primary key value) and are common clustering maintained. As far as identity versus sequence object, the sequence object is preferred such that the actual sequence is independent of the table. Only in situations in which the assignment of system-generated values is dependent upon a LOAD process would the use of identity columns be considered.

One of the great advantages of sequence objects and identity columns is the automatic assignment of values and retrieval of those values from a data-change-table-reference in an INSERT within a SELECT. This can replace multiple SQL statements with a single statement and dramatically improve the performance of an application. An example of this type of statement can be found in Chapter 4.

There are two settings that can greatly affect the performance of the assignment of values for sequence objects and identity columns: CACHE and ORDER. The impact of these settings can be quite dramatic in a data sharing environment.

- CACHE: This setting affects the rate at which a sequence object or identity column's value is generated from the Db2 system catalog and held in memory. The settings are either NO CACHE or CACHE n, where n is a number greater than or equal to two and represents the upper range of values that can be held in memory at any given time. The default is CACHE 20, which means that 20 values are generated and cached if the cache is empty and a value is requested. Each time the cache is refreshed results in a synchronous I/O to the Db2 system catalog. Setting NO CACHE means that every request results in a synchronous I/O, and thus is the antithesis of the proper performance setting. NO CACHE is only a choice if a continuous sequence of values assigned is needed, but again this is not the performance choice. The downside of the caching of values means that values that have been cached but not committed to an application are lost upon the shutdown of a subsystem. In a data sharing environment, using CACHE n and NO ORDER is the high-performance choice. Also, in a data sharing environment each member of the group gets its own cache. As far as the number of values to cache, the default of 20 works quite well until the requests for values gets into the thousands per second, dependent of course on available system resources (CPU, memory, DASD, and so on). However, if the application is requesting sequence values in excess of 1,000 per second, it is strongly recommend to increase the cache value via an ALTER until any noticeable stress is relieved. This stress is indicated in an accounting report for an application by excessive system catalog I/O activity and lock contention (if there is a high level of concurrency). The locking contention can be greatly exaggerated in a data sharing environment.
- ORDER: This setting specifies whether or not values are generated in the order of the request. The default setting is NO ORDER and this is the performance setting. Setting ORDER makes no sense from a performance perspective, and from an application perspective, the ordering of values is only guaranteed within a single application process and also requires the setting of NO CACHE to guarantee the order. So, while it may make sense to specify ORDER for specific test cases in a controlled testing environment where performance is of no concern, there really is no need to set ORDER on in a production environment. The obvious performance choice is CACHE n and NO ORDER.

7.2.14 Volatile Tables

The VOLATILE table setting tells Db2 how to base its access to the table. Set VOLATILE tells Db2 to use an index for access whenever possible; basically telling it to ignore the catalog statistics for the table. This is an especially useful setting in situations in which a table may be used to hold transient data, such as a transaction input staging table. These tables may fluctuate dramatically in size and the statistics may not accurately reflect the quantity of data in the table at any given time. VOLATILE helps guarantee the stability of the table access in these situations, especially for an application that uses dynamic SQL, since statement prepares may happen, often making the access path less predictable. The VOLATILE setting has been used quite successfully for tables that can dramatically vary in size from process to process, and this setting is recommended for these types of tables. However, observe that for transaction input staging tables, if the entire table is being read all the time, the order of the data is irrelevant, and there is no concurrency between processes, then it is recommended to neither specify VOLATILE nor an index on the table so that a table space scan is guaranteed. Otherwise, VOLATILE is recommended.

7.2.15 Append

The APPEND table setting affects the behavior of inserts against a particular table. By default, the setting is APPEND NO, and any rows inserted into the table are based upon the clustering index (except if MEMBER CLUSTER is set for the table space). Setting APPEND YES tells Db2 that any inserts into the table ignore clustering and free space completely and place the new data at the end of the table. This is definitely a setting to consider for a high-performance insert configuration, and can be an option to set alone or use in conjunction with the MEMBER CLUSTER table space setting. Observe that by setting APPEND YES, Db2 is being told to only put inserted rows at the end of the table and ignore any space that may have been acquired by deletes. Therefore, the table space may need frequent REORGs if clustering is important for efficient query processing against the table. This also works a bit different than MEMBER CLUSTER. See the details about MEMBER CLUSTER in this section as well as the section on design recommendations for high-performance insert in this section for additional information about fast insert processing.

7.3 Index Choices

A good database design requires indexes[8]. These indexes are created to satisfy specific requirements:

- Primary key support
- Foreign key support
- Unique rule enforcement
- Clustering
- Performance
- Partitioning support (but no longer required for partitioning)

Indexes are obviously important for good database performance. However, it is important to deploy them wisely and conservatively. Many times the ready solution to a poor database design or any poorly performing query is to make a supporting index. DBAs do not often consider the negative performance implications of creating a new index. Basically, for every new non-clustering index created another random reader is introduced for every insert and delete operation, as well as for any update operation that changes key values. Once an index is added, it is difficult to confidently remove it. In many situations in which indexes have been recklessly added to a database, the most expensive SQL statements can be seen, from a CPU resource perspective, being inserts and deletes, and typically the only way to tune these statements is to remove indexes.

It is for these very reasons that every new database design should begin with a simple philosophy; one index and one index only per table. The objective is that this index satisfies all of the requirements identified at the beginning of this section. Designing for only one index per table greatly contributes to the ultimate in high-performance database design. Carefully follow the guidelines in this section for partitioning, clustering, include columns, referential integrity, and key inheritance to develop a design that minimizes the number of indexes created. Also, observe that this is the recommended design guideline for performance, and there may be trade-offs in flexibility.

7.3.1 Partitioned and Data Partitioned Secondary

There can be a benefit to index partitions in that the dataset supporting them is smaller and easier to manage, and the b-tree structure can possibly have fewer levels. Partitioned indexes can only be created against range-partitioned tables. Non-partitioned indexes can also be specified.

There are two types of partitioned indexes: partitioned, and data portioned secondary. When the leading columns of the index key match the leading columns of the portioning key then the index is considered partitioned. When the leading columns do not match, the index is considered data partitioned secondary. Both partitioned and data partitioned secondary indexes can be used for clustering, which allow for some strong opportunities for doing a form of multi-dimensional clustering where one set of values is used to partition and a separate set of values is used to cluster within those partitions.

The primary benefit for performance is that queries can take advantage of the partitioning key columns to eliminate partitions during query processing. For a query to utilize partition elimination, it must have predicates coded against the columns of the partitioning key. These columns can be parameter markers and host variables. Beginning with Db2 11 for z/OS partition elimination can be done on joined columns as well. Observe that matching on the leading columns of a partitioned or non-partitioned index gets index matching access and not partition elimination. For data partitioned secondary indexes, partition elimination can be achieved if the index leading columns and include predicates are matched against partitioning key columns.

8. *Fast Index® for Db2 for z/OS* (Fast Index) can help conserve system resources by deleting indexes that are no longer needed.

7.3.2 Include Columns

Index include columns are a recommended way to get index-only access when required against a given table without the overhead of creating an additional index. Since include columns can only be added to unique indexes, the major advantage is to add them to existing unique indexes to achieve index-only access. Observe that adding additional columns to the index does increase the index size and possibly increases the number of index levels. In addition, adding columns to the index could increase index activity if those columns are modified via updates.

It may be beneficial to perform an index consolidation by eliminating indexes that contain the same leading columns but have a column set that is a super set of an already existing unique index. Assuming that the extra index was originally created for performance and for certain queries to achieve index only access, the additional columns can be included in other existing unique indexes and then the extra index eliminated. The following query is recommended for identifying potential redundant indexes. This query looks at indexes within a schema (creator) to determine if there are any potentially redundant indexes. The term redundant index means an index that has the same leading column as other indexes. Once this query identifies potential redundancies then it is up to the DBA to determine whether or not an index can be eliminated. The query works by first finding indexes with different names that contain the same leading columns. It then takes the result of that comparison to produce a report that aligns the indexes, showing the full key of each index, and highlighting where the columns match up.

```
WITH IXMATCH(CREATOR, NAME, ICREATOR,
             INAME1, ICOLCOUNT1, IUNIQUE1,
             INAME2, ICOLCOUNT2, IUNIQUE2)
AS (
  SELECT I.TBCREATOR, I.TBNAME, I.CREATOR,
         I.NAME, I.COLCOUNT, I.UNIQUERULE,
         I2.NAME, I2.COLCOUNT, I2.UNIQUERULE
  FROM SYSIBM.SYSKEYS AS K
  INNER JOIN SYSIBM.SYSINDEXES AS I
     ON K.IXNAME = I.NAME
    AND K.IXCREATOR = I.CREATOR
  INNER JOIN SYSIBM.SYSINDEXES I2
     ON I.TBNAME = I2.TBNAME
    AND I.CREATOR = I2.CREATOR
    AND I.NAME < I2.NAME
  INNER JOIN SYSIBM.SYSKEYS K2
     ON K2.IXNAME = I2.NAME
    AND K2.IXCREATOR = I2.CREATOR
    AND K.COLNAME = K2.COLNAME
    AND K.COLSEQ = K2.COLSEQ
  WHERE K.IXCREATOR='<schema name here>'
   AND (K.ORDERING <> ' ' AND K2.ORDERING <> ' ')
    AND K.COLSEQ = 1 )
SELECT COALESCE(I1.TABLE_NAME,I2.TABLE_NAME) AS TABLE_NAME,
       COALESCE(I1.INDEX_NAME1, I2.INDEX_NAME1) AS INDEX_
       NAME1,
       I1.COLNAME,
       COALESCE(I1.COLSEQ,I2.COLSEQ) AS COLSEQ,
       I2.COLNAME,
       COALESCE(I1.INDEX_NAME2, I2.INDEX_NAME2) AS INDEX_NAME2
FROM (
  SELECT IM.NAME,
         IM.INAME1 CONCAT '(' CONCAT IUNIQUE1 CONCAT ')',
         IM.ICOLCOUNT1,
         IM.IUNIQUE1,
         K.COLNAME CONCAT '(' CONCAT ORDERING CONCAT ')',
         K.COLSEQ,
         IM.INAME2 CONCAT '(' CONCAT IUNIQUE2 CONCAT ')'
  FROM IXMATCH IM
  INNER JOIN SYSIBM.SYSKEYS K
     ON IM.ICREATOR = K.IXCREATOR
    AND IM.INAME1 = K.IXNAME)
```

```
AS I1(TABLE_NAME, INDEX_NAME1, COL_CNT,
      UNIQUE, COLNAME, COLSEQ, INDEX_NAME2)
FULL OUTER JOIN (
  SELECT IM.NAME,
         IM.INAME2 CONCAT '(' CONCAT IUNIQUE2 CONCAT ')',
         IM.ICOLCOUNT2, IM.IUNIQUE2,
         K.COLNAME CONCAT '(' CONCAT ORDERING CONCAT ')',
         K.COLSEQ,
         IM.INAME1 CONCAT '(' CONCAT IUNIQUE1 CONCAT ')'
  FROM IXMATCH IM
  INNER JOIN SYSIBM.SYSKEYS K
     ON IM.ICREATOR = K.IXCREATOR
    AND IM.INAME2 = K.IXNAME)
    AS I2(TABLE_NAME, INDEX_NAME2, COL_CNT,
          UNIQUE, COLNAME, COLSEQ, INDEX_NAME1)
    ON I1.TABLE_NAME = I2.TABLE_NAME
   AND I1.INDEX_NAME1 = I2.INDEX_NAME1
   AND I1.INDEX_NAME2 = I2.INDEX_NAME2
   AND I1.COLSEQ = I2.COLSEQ
ORDER BY TABLE_NAME, INDEX_NAME1, INDEX_NAME2, COLSEQ
WITH UR
```

7.3.3 Extended Indexes

It is possible to create extended indexes, which include indexes on expressions as well as indexes on XPATH expressions. These types of indexes can be extremely useful for improving the performance against portions of XML documents and for various search queries. For example, in the following situation a query searches on the last name of an employee in the sample database. However, if the name can contain both uppercase and lowercase characters, the search may have to incorporate a Stage 2 predicate.

```
SELECT EMPNO
FROM EMP
WHERE UPPER(LASTNAME) = UPPER(?)
```

This Stage 2 predicate is not indexable. However, an extended index can be created on the result of the expression and then Stage 1 index matching access is possible.

```
CREATE INDEX DANL.XEMP_LN
ON DANL.EMP
(UPPER(LASTNAME,'EN_US') ASC);
```

7.4 Keys and Clustering

As mentioned throughout this section and other chapters of this guide, clustering is important for two major reasons: sequential processing of large batches of input and efficient access of tables in multi-table statements. When determining proper clustering of tables, consider the major processes that are hitting the data, and then cluster based upon the ordering of the input for the most significant process. It may be required to choose more than one major clustering sequence for the tables in the database based upon whatever major inputs are predicted and the table accessed during those processes. This goes along with the concepts of partitioning for application-controlled parallelism, using identifying relationships for primary/foreign keys, minimizing the number of indexes, and sorting input to major processes by the clustering keys of the tables that are processed. Careful testing of predicted access patterns informs on how to cluster. Remember to let the database indicate how to design the database. See Chapter 10 for details on testing.

7.5 Design Recommendations for High-Performance Insert

Many of the techniques described in this guide can be combined in the design of tables that can process an extremely high insert rate. Using these techniques has resulted in real-life insert rates as high as 13,000 per second, and application-wide insert rates as high as 17,000 per second. Use the following combination of design ideas presented in this guide to achieve ultra-high insert rates.

- Use range-partitioning to separate the table into partitions using a separation that can also be applied to the data that is input to the high-volume application process. The data is then fanned out and input to multiple parallel application processes that each act upon their own partition.
- Cluster the table to be inserted into by the clustering key of the data that is input to the process performing the inserts. If clustering is to be used, a proper quantity of free space and free pages should be maintained to preserve that clustering as data is added. Monitor the insert activity via the real-time statistics tables to determine the frequency of REORGs.
- As an alternative to clustering for the inserts, instead cluster for data retrieval and then utilize APPEND YES and/or MEMBER CLUSTER.
  - APPEND YES for pure insert only strategies.
  - MEMBER CLUSTER in a data sharing environment and for an insert algorithm that will slightly more aggressively look for free space versus APPEND YES.
  - Use both settings for high-volume insert in a data sharing environment for a process that does not need to search for free space.
- Set PCTFREE and FREEPAGE to 0 if MEMBER CLUSTER and/or APPEND YES are being used.
- Set TRACKMOD NO if incremental image copies are not desired.
- Create only one index on the table.
- Use a larger index page size. 8K is recommended. If an ascending key is not being used, set up PCTFREE in the index such that there is never a page split between REORGs. Do not use FREEPAGE for the index in this situation.
- Be sure to use pre-formatting for the table space, especially if MEMBER CLUSTER and APPEND YES are being used.

In addition to these settings, set up a REORG strategy that can accommodate the readers of this data. If clustering is being done by something other than an ever-ascending key, then REORG the table space to keep the data organized for efficient read access. Also, if an APPEND strategy is not used for table space (MEMBER CLUSTER or APPEND), frequent table space REORGs are required to avoid excessive free space search during the insert processing. Develop an index REORG strategy such that REORGs are performed on the index at regular intervals. For indexes that do not have an ever-ascending key, REORG often enough so that there is never an index page split during the high-volume insert processing.

7.6 Minimizing Change

Another technique for achieving a high level of performance from a physical design is to enact a policy of minimizing the amount of change that happens within the physical database. There are two industry-wide trends that lend themselves to a proliferation of change in Db2 tables. The first is that there is a significant quantity of migration from legacy systems (flat files, VSAM, IMS, and so on) into the more modern relational database structure and Db2. The second is the use of a service-oriented architecture to manage large data stores in an enterprise environment.

7.6.1 Minimizing Change to Tables

In a legacy migration situation, records from files are often simply converted to rows in tables. In addition, legacy enterprise applications may be retained, or worse yet, layered upon to avoid a lengthy application rewrite. While this strategy of minimal application impact saves time, in a legacy migration scenario it can severely impact operation costs. In other words, porting flat files to a relational database gets a modern access method and backup/recovery support, but costs a significant increase in CPU consumption unless programming changes are made. In many cases management is looking for minimal operational cost along with minimal development cost. In these situations, a relatively easy thing to do is to attempt to minimize changes to the tables involved. If the application performs a full record

replacement strategy for applying changes, then it may be beneficial to identify exactly what changes most often in the affected tables and then separate that data into its own separate table. Careful analysis typically shows that most data in these sorts of processes does not change. This separation of data can save a lot of resources if a change detection process is also employed (see the next section for details).

Encoding schemas can be utilized to detect and avoid the application of non-changes to data. This typically involves identifying the data that does not typically change, separating the data that changes from the data that does not change, and then hashing the data values of the data that does not change into a value that can be used for change detection. This hash value is stored along with the key value of the data that does frequently change. Now changes to the more stable data can be avoided by comparing the hash value of the incoming change with the hash value stored.

Figure 5: Original Set of Tables Where All Data Changes at All Times

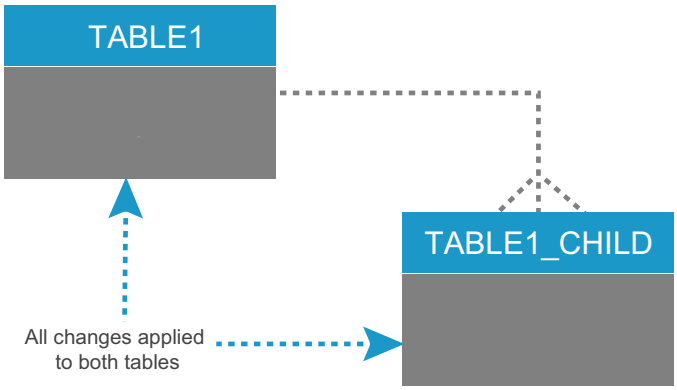
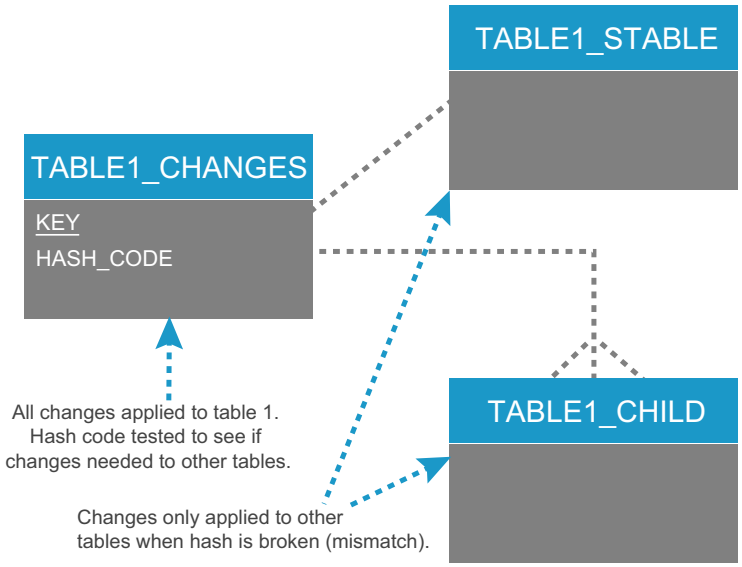


Figure 6: Table Design with Hash Code to Avoid Changes to More Stable Data



7.6.2 Reducing the Impact of Unknown Change

Service-oriented systems can be thought of as large-scale message processing systems. A request comes into a service to retrieve some data for a specific set of data. That data is retrieved in full whether or not all or a portion of the data is needed. Eventually the data may or may not come back in another request to change the data. Of course, there is no identification as to what data is needed and what data has changed. Typically in these types of implementations there is a vast quantity of SQL being issued as well as many unnecessary updates to the database. A combination of a change detection process along with some reduction in data access goes a long way in reducing the quantity of SQL issued. It is also recommended to occasionally employ a method of caching commonly accessed, as well as recently accessed, data in an effort to avoid rereading of data. When incoming data is returned to a service for update, a

comparison may be possible with cached values, or a change detection process (discussed above) using either hash codes or a direct comparison (especially when using a cache) can be employed to avoid rereading of data and unnecessary application of changes. This can also be combined with some denormalization light, as is discussed in the next section below.

7.7 Denormalization

In the relational world, denormalization equals havoc. A proper relational design can be a performance advantage in that it can be used to avoid update anomalies, reduce redundancy of data storage, minimize the impact of data change, and reduce the quantity of physical data access required for a process. Use the relational design unless it is proven to introduce performance problems via a proof of concept test (Chapter 10).

Denormalization can be used occasionally, but only when all other attempts at managing performance have failed. The types of denormalization recommended, however, do not align with the normal concepts.

7.7.1 Denormalization Light

This technique has been useful in large scale environments when there is a single parent table (a primary entity) surrounded by one or more level of child tables that contain optional data. In situations where a process most often requests all data for a given primary key, there may be many unnecessary table accesses to child tables that contain no data for the key presented. In a situation where the pattern of requests is truly random, there can be excessive random requests to many tables that most often return no data. If a test proves that this type of access does meet a given service level agreement, a technique may be employed that utilizes indicator columns in the primary entity that can be used to avoid access to child tables that contain no data. The downside is that any update process must maintain the indicator columns. The good news is that access to child tables with no data for a key can be avoided. The great news is that full denormalization can be avoided.

Figure 7: Original Table Design

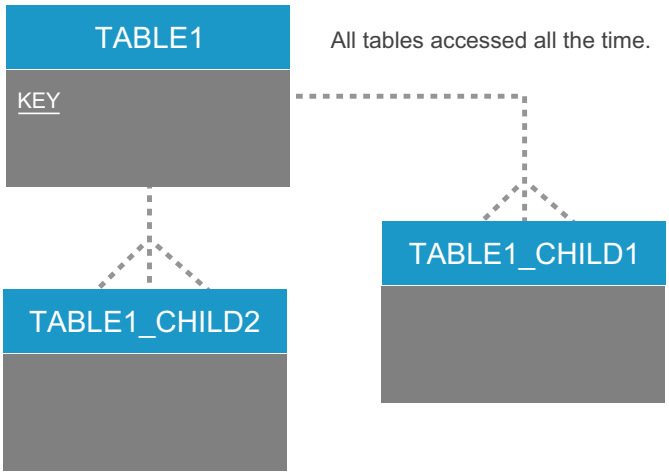
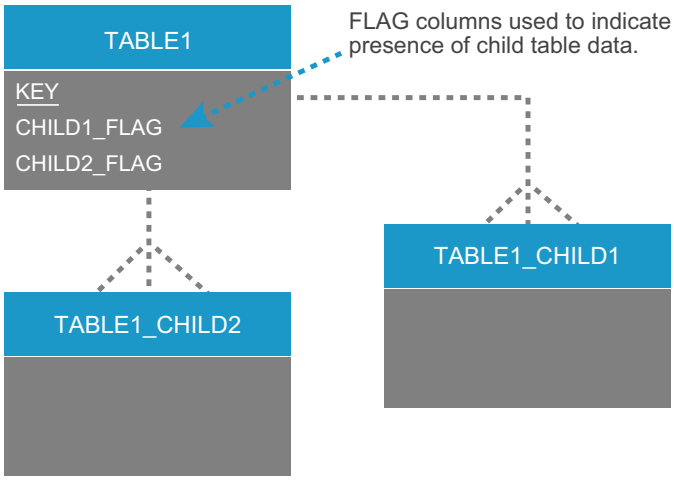


Figure 8: Table Design with Indicator Columns



In many cases, code for table access avoidance by utilizing Db2 during join predicates. In this case, Db2 does not join to the child tables unless the indicator column has a value that indicates the child data is present.

Original query that accesses all tables:

```
SELECT *
FROM TABLE1 P
LEFT OUTER JOIN
       TABLE1_CHILD1 TC1
ON P.KEY = TC1.KEY
LEFT OUTER JOIN
       TABLE1_CHILD2 TC2
ON P.KEY = TC2.KEY
WHERE P.KEY = ?
```

Query that uses the indicator columns to avoid access to child tables with no data for the key:

```
SELECT *
FROM TABLE1 P
LEFT OUTER JOIN
       TABLE1_CHILD1 TC1
ON P.KEY = TC1.KEY
AND P.CHILD1_FLAG = 'Y'
LEFT OUTER JOIN
       TABLE1_CHILD2 TC2
ON P.KEY = TC2.KEY
AND P.CHILD2_FLAG = 'Y'
WHERE P.KEY = ?
```

7.7.2 Full Partial Denormalization

One of the biggest challenges in complex environments is the performance of search queries. This guide contains many recommendations that can be applied to improve the performance of search queries. However, sometimes the cost of a complex search that involves access to several tables can be too expensive to meet an SLA. While denormalization is a possible solution, it can present many challenges and can actually increase costs rather than reduce them. In tight situations, there is a technique called full partial denormalization. This technique has several components:

1. An analysis of the data hopefully shows the source of the performance challenge. This is typically in the form of more common data values. These more common data values may actually only represent a portion of the full volume of data. For example, the name Smith versus the name Luksetich. In this example, it is likely that there are more of the first than the latter when searching on name. This common set of data can be combined into a set of common search key values that may or may not be spread across different tables. This set of keys are then identified and placed into a special common key only table.
2. The common key only table is used to pull all of the related search data from all the other tables and is denormalized into a special early out search table. Remember that for this to be effective it must represent only a subset of the entire quantity of data being searched. In an example implementation, there were 600,000 keys in the common key only table and 30,000,000 rows in the denormalized search table. The full quantity of search data represented about 1.1 billion rows. This is a very good ratio.
3. Establish a set of triggers to maintain the early out search table values. The triggers use the common key only table in a WHEN condition and then perform the denormalization on the fly as the underlying data changes.
4. Modify the search process to use an early out strategy. The input arguments are used to match against the common key only table. If there is a match then the denormalized table is searched. If there is no match then the normal search query is executed.

Always test design ideas to determine if they perform in the specific situation. More simplified early out techniques have been successfully implemented for searches where one query was used to satisfy the requests using the most common input arguments, and a second more versatile query was executed for all other requests.

Chapter 8: Memory, Subsystem Parameters, and Performance

80% of the performance to be gained is at the application and database level. However, a minimally decent subsystem configuration is required, so this section addresses some of the big button subsystem settings. As with any database configuration, available memory is a big issue and its proper configuration and use is a key factor to overall system health. There is a substantial amount of system performance tuning information available in the Db2 Administration Guide, the Db2 Installation Guide, and the Db2 Performance Guide, as well as in various articles, blogs, and presentations found in the Internet. *SYSVIEW for Db2* and *Subsystem Analyzer* provide a robust set of capabilities for ongoing and exceptional Db2 monitoring and tuning.

8.1 Buffers

Db2 buffer pools may be the single biggest subsystem level performance tuning option available. When in doubt and if you have the memory but not the time to spare, bigger is better. Use *Subsystem Analyzer* to examine current buffer pool use and physical I/O activity and understand how efficiently the system is performing.

If you have the time to spare, then an intelligent buffer configuration is an option that will benefit both application and subsystem health. Below are some buffer recommendations:

- Db2 system catalog and directory. If these are not in their own buffer pool sized such that most or all of it is memory resident, then make it so. Do not mix anything with the catalog and directory.
- Workfile database. Put the workfile database in its own buffer pool. In addition, separate the workfiles from the temporary table storage and place them each in their own buffer pool. The sequential percentage should remain at 80% due to the fact that there will be some random access to workfiles via sparse indexes and when there are indexes defined on the temporary tables. Deferred write thresholds should be set high to keep as much of the workfiles and temporary tables in memory as possible. This pool should be relatively large, but you may want to monitor just how much you are writing to DASD and balance the memory consumption here with support for the occasional large sort.
- Indexes and tables. Always separate indexes from tables in buffer pools since the access patterns are different.
- Random and sequential. Objects that are accessed primarily sequentially should be in their own buffer pools since one large sequential read could wipe out a lot of cached objects. In addition, a very frequently accessed table or index that has an extremely random access pattern should be separated from other objects that have a high level of re-referenced pages. Use the DISPLAY BUFFERPOOL command to watch these access patterns and perform the proper separation.
- Code tables. These should be in their own buffer pool with enough memory allocated as to avoid any I/O. Monitor the access to this pool carefully to see if there is any opportunity for applications to cache code values locally if it appears they are going to these tables way too often. Monitoring this pool closely helps to identify tables that really should not be in this pool (sequential access or frequent updates) as they can seriously impact the efficiency of this special cache.
- High-volume update objects. These objects must be in their own buffer pool. The vertical deferred write threshold should be set to 0,40 to trickle the writes to DASD. Do not allow writes to be triggered on system checkpoints for these objects.

Page fixing is highly recommended and should be used whenever possible. If the Db2 subsystem is the primary subsystem on an LPAR, then the memory it uses should not be shared with anything else. Therefore page fixing should be a non-issue as it will save significant CPU resources used to manage the I/O for database objects.

Although monitoring the buffer hit ratio can be a productive way of tuning the buffer pools, monitor the number of I/Os per second on a pool-by-pool basis. The goal of buffer tuning is to reduce the I/O activity. Monitoring the I/O rate is the true way to measure success or failure of buffer pool tuning. High-performance DASD can a friend and an enemy when it comes to buffer pool tuning. Throwing tons of memory at the Db2 buffers is great, but only if it is going to make a difference. If the memory can be used elsewhere, it should be. Therefore, monitor the I/O rate when tuning the buffers

but also monitor the random and sequential response wait time per I/O. Reduce the I/Os, but if the response time per I/O increases while the I/O rate decreases, then a balance has likely been reached between the Db2 buffer caching and the DASD cache. At that point it may be time to use the memory for other buffer pools or for other Db2 (other subsystems on the LPAR) resources.

8.2 Logging

The Db2 logs are a central resource and are critical for performance. The active logs should be sized large enough to map to the available logical DASD devices (2 GB active log size is preferred but not a rule) and the logs should be split (using dual logging, of course) onto separate DASD subsystems. Rarely are there benefits from striping the logs so do not consider it. The default log buffer size is too small so be sure to increase it. There should be enough active logs such that rollbacks (and replication tools) never have to go to an archive log. Put a policy in place such that archive logs initially go to DASD and move to tape once everything, especially the system catalog and directory, have been image copied. Use *SYSVIEW for Db2* to monitor and report on Db2 logging activity.

8.3 DASD and I/O

High-performance DASD subsystems are making DBAs look like geniuses. If your enterprise is serious about performance, then you have invested in large scale, high-performance DASD subsystems with the largest amount of cache available and parallel access volumes enabled. If this is the case in your environment, then spend a minimal amount of time worrying about physical storage. While separating Db2 logs, bootstrap database, and system catalog and directory from the other database objects is important, there is little concern in separating indexes from table spaces and high-performance objects from low-performance objects except for extreme cases. The logical devices can be made large and should be extended addressability enabled. Typically, set PRIQTY and SECQTY to -1 except for very high-performance objects and do not worry about extents unless the number gets very large (see the RTS queries in Chapter 3 for an example).

8.4 Big Impact Subsystem Parameters

The following is a list of subsystem parameters that must be considered in a high-performance environment. Use *SYSVIEW for Db2* or the Thread Termination/Dynamic DSNZPARM Value Pack option to monitor Db2 subsystem parameters. In addition, the Thread Termination/Dynamic DSNZPARM Value Pack option allows altering most Db2 parameters and attributes online or on a scheduled cadence.

Name	ACCUMACC
Description	Db2 accounting records are rolled up per user for DDF and RRSAF threads. Possible Values: No, 2–65535.
Default Value	10
Performance Implications	Since a Db2 accounting record is produced whenever a DDF thread goes inactive (or with sign-on for RRSAF threads), less overhead is incurred if this option is used. Using the default of 10 rolls up every 10 accounting records into 1 SMF 101 record. This can be helpful in reducing the number of Db2 accounting records (SMF 101). A typical production environment may set ACCUMACC to 10, or 100, or higher to reduce the number of accounting records produced. Non-prod environments may set ACCUMACC to 100 or higher since detail accounting records are not regularly reviewed in these environments. There is a trade-off here between the quantity of SMF records produced and the ability to produce a thread-by-thread accounting trace report. Use 1,000 as a production environment value for high-volume environments. However, in a data sharing environment set one member to 1 to have the ability to get a detailed trace report if desired.

Name	AUTHCACH
Description	Default authorization cache size per plan if CACHESIZE is not specified on the BIND PLAN command.
Possible Values	0–4096
Default Value	3072

Performance Implications	If 0 is specified, or a number too small to contain all the authorization IDs that can concurrently execute the PLAN, a security check (or read) to the Db2 catalog (SYSPLANAUTH) is required for each plan execution per user. The default size should be sufficient, but to determine the required storage, use this formula: 8 bytes × the number of concurrent users (userids) + 32 bytes of overhead.

Name	CACHEDYN
Description	Whether prepared dynamic SQL statements are to be cached for future use Possible Values: YES, NO.
Default Value	YES
Performance Implications	If a dynamic SQL statement is already (prepared) in the statement cache, a prepare is not performed on the statement, improving performance. Also, the SQL statements must use parameter markers instead of host variables to be eligible for cache statement reuse.

Name	CACHEDYN_FREELOCAL
Description	Allows Db2 to free cached dynamic statements if DBM1 is using too much below-the-bar storage.
Possible Values	0,1
Default Value	1
Performance Implications	Use the default in case DBM1 uses too much storage below the bar for cached dynamic SQL statements. Db2 will free some cached dynamic SQL statements.

Name	CACHEPAC
Description	Storage needed in DBM1 for caching package authorizations. Possible Values: 0–10M.
Default Value	5M
Performance Implications	Caching authorization IDs, which are authorized to execute a package, improves performance by eliminating reads to the Db2 catalog (SYSPACKAUTH).

Name	CACHERAC
Description	Storage needed in DBM1 for caching routine (Stored Procedures, User-defined functions) authorizations.
Possible Values	0–10M
Default Value	5M
Performance Implications	Caching authids, which are authorized to execute routines (Stored Procedures or User-defined Function), improves performance by eliminating reads to the Db2 catalog (SYSROUTINEAUTH).

Name	CDSSRDEF
Description	This is the default value for the CURRENT DEGREE special register for dynamically prepared SQL statements when SET CURRENT DEGREE is not specified.
Possible Values	1, ANY
Default Value	1
Performance Implications	In almost all cases, the default of 1 should be used to disable Db2 query parallelism for dynamic SQL statements. Use query parallelism only in cases where parallelism will help. For example, with long running, CPU-intensive, data warehouse type queries. This value can be overridden with SET CURRENT DEGREE statement.

Name	INDEX_IO_PARALLELISM
Description	For tables with multiple indexes, allow insert processing on multiple indexes in parallel. Possible Values: YES, NO
Default Value	YES

Performance Implications	Can reduce in-Db2 elapsed time for insert operations on tables with multiple indexes. The insert processing is performed concurrently on the indexes.

Name	CHKTYPE, CHKFREQ, CHKLOGR, CHKMINS
Description	These subsystem parameters are used to control the frequency of system checkpoints. Possible Values: LOGRECS, MINUTES, BOTH, or SINGLE.
Default Value	MINUTES
Performance Implications	For subsystem efficiency, log checkpoints should not be too frequent or too far apart. If a log checkpoint is too frequent, Db2 can consume unnecessary resources. If log checkpoints are too far apart, Db2 recovery can be elongated. Checkpointing every 5 to 15 minutes is recommended. Remember that there is quite a bit of activity that is triggered upon a checkpoint so lean towards the 15 minutes and adjust the vertical deferred write threshold in the buffer pools to trickle writes for high-volume update objects.

Name	CMTSTAT
Description	Allows DBATs to be marked INACTIVE after commit (or rollback) if they hold no cursors, or temp tables.
Possible Values	ACTIVE, INACTIVE
Default Value	INACTIVE
Performance Implications	CMTSTAT enables INACTIVE DBATs to be returned to the pool for reuse and disconnects them from the active connection. This allows the best use of DBATs and remote connections to support large numbers of distributed connections. The default should be used in 99% of situations. The only reason to set it to ACTIVE would be in super high volume, remote batch environments and only if high-performance DBATs are not possible.

Name	COMPACT
Description	Compresses data written to archive logs on tape. Possible Values: NO, YES.
Default Value	NO
Performance Implications	Compressing archive log data on tape reduces tape usage, but tape devices must support IDRC (improved data recording capability). In a high-performance environment it is typical to archive to DASD and then eventually move the logs to a tape or virtual tape device.

Name	CONDBAT
Description	Maximum number of concurrent DDF connections Possible Values: 0–150000.
Default Value	10000
Performance Implications	CONDBAT must be greater than or equal to MAXDBATs. If CONDBAT is reached, connection requests will be rejected, subsequently impacting distributed applications.

Name	CONTSTOR
Description	Contract thread storage after commit instead of at thread deallocation. Possible Values: YES, NO.
Default Value	NO
Performance Implications	If the DBM1 address space is under virtual storage constraints, set CONTSTOR to YES to free up unused thread storage. If DBM1 is not storage constrained, the default (NO) is recommended. Setting this value to YES consumes more CPU, so it should be set to NO unless a real memory problem exists. In addition, in Db2 10 for z/OS almost all thread storage is above the 2G bar making this parameter even less necessary.

Name	CTHREAD
Description	Total number of concurrent allied threads to a Db2 subsystem. Possible Values: 1–20000.
Default Value	200
Performance Implications	If CTHREAD is exceeded, all new thread requests are queued, causing applications to wait. CTHREAD is the total of all concurrent TSO users, batch jobs, CICS and IMS threads, utilities, and DDF connections. Observe that utilities can create multiple threads due to parallel tasks which count toward total CTHREADs. Also, query parallelism creates parallel tasks for queries which are counted toward CTHREAD totals. Use caution, as this parameter must be balanced with available resources.

Name	EDM_SKELETON_POOL
Description	Minimum storage required in the EDM pool at Db2 start up to hold skeleton package tables.
Possible Values	5120–2097152 KB
Default Value	10240
Performance Implications	Since the EDM Skeleton pool is storage above the 2G bar, the setting can be liberal. However, if the Db2 subsystem uses all the EDM_SKELETON_POOL storage, package allocations will fail with a –904 resource unavailable.

Name	EDMDBDC
Description	Minimum storage required in the EDM pool at Db2 start up to hold DBDs (Database Descriptors).
Possible Values	5000–2097152 KB
Default Value	23400
Performance Implications	The DBD cache in the EDM pool is storage above the 2G bar which allows you to be generous with the size. If the Db2 runs out of EDM pool DBD cache (EDMDBDC), DBDs do load into memory resulting in –904 resource unavailable errors. In Db2 Data Sharing, EDMDBDC should be increased on each member due to Db2 storing duplicate copies of DBDs in each member. A member can have multiple copies of a DBD loaded in its EDMDBDC until all threads using that DBD are deallocated.

Name	EDMPOOL
Description	Maximum storage required for the EDM pool below the 2G bar. Possible Values: 0–2097152 KB.
Default Value	0
Performance Implications	EDM pool storage is critical for the operation and performance of a Db2 subsystem. In Db2 10 for z/OS, the EDM subpools (DBD, Skeleton, and Statement Cache storage pools) are above the 2G bar. However, EDM pool storage below the 2G bar is needed for plan and package allocations that were bound in a prior release until all plans and packages are rebound under Db2 10 for z/OS. The recommendation is to use the same EDM pool size defined for the Db2 9 for z/OS subsystem. Once rebound under Db2 10 for z/OS, plans and packages are loaded above the 2G bar upon allocation. Also, after all plans and packages have been rebound under Db2 10 for z/OS, the EDMPOOL size can be reduced. Moving these structures about the bar frees up thread storage below the bar in DBM1 allowing for larger numbers of concurrent threads. If any of the EMD pools become full, page stealing of unused pages from any of the pools begins to satisfy new requests. Sizing these pools correctly allows Db2 to be more efficient and reduces application elapsed time. Whichever structures cannot be found in these pools forces reads (I/Os) to the Db2 catalog and directory in order to load them. In addition, costly and time consuming prepares of dynamic SQL statements can result if the EDM Statement Cache is too small.

Name	EDMSTMTC
Description	Minimum storage required in the EDM pool at Db2 start up for (dynamic) prepared SQL statements.
Possible Values	5000–1048576 KB
Default Value	113386
Performance Implications	The EDM Statement Cache (also called Dynamic Statement Cache, DSC) is above the 2G bar allowing for generous allocation sizes. The best practice is to make the EDM Statement Cache large enough to hold most of the frequently executed dynamic SQL statements. If the dynamic SQL statement is found in the cache, Db2 can avoid costly and time consuming SQL statement prepares. Be aware that if this pool is set extremely large, it can increase the cost of searching for a statement, which will impact the performance over all dynamic statements, so there must be a balance between the hit rate and overall performance. Make changes slowly.

Name	IDBACK and IDFORE
Description	Number of concurrent foreground (or TSO) and background (or batch) allied threads connected to a Db2.
Possible Values	1–20000
Default Value	50
Performance Implications	If this number is exceeded, the thread allocation request is rejected. This is something to balance between the other parameters that control the number of threads and probably only an issue in high-volume environments.

Name	IDTHTOIN
Description	Idle thread timeout value for distributed access threads (DBATs). Possible Values: 0–9999.
Default Value	120
Performance Implications	This value determines how long Db2 (server) waits for a client response after sending a result before it cancels the clients DBAT (thread). In most cases, Db2 is waiting for a request from the client for Db2 to send more results (rows) or Db2 is waiting for the client to signal it is ready to commit. But if the client is not responding, a DBAT is being held and can be holding locks on Db2 resources. This reduces concurrency and limits the number of DBATs available to other clients. Once the Idle Thread Timeout value is reached, the client's thread is canceled.

Name	MAXDBAT
Description	Maximum number of distributed access threads connected to a Db2. Possible Values: 0–19999.
Default Value	200
Performance Implications	If MAXDBATs is reached, the next DBAT request is queued and waits for an available DBAT. It is a good practice for distributed applications to connect to the database (data source), perform its work, issue a commit (do not rely on Autocommit), and disconnect from the database. When the application issues the disconnect, the DBAT becomes an Inactive DBAT (provided CMTSTAT=INACTIVE) and releases all Db2 resources. In addition, the DBAT becomes disconnected from the connection and the DBAT is returned to the pool for reuse. The DBAT stays inactive in the pool for the time specified on the POOLINAC subsystem parameter, or until reuse. Some distributed applications may require a constant (distributed) connection which reduces the number of DBATs available for reuse. Many organizations classify their DDF workload in WLM Service Classes which have service periods. A DDF Service Class with service periods means that after a DBAT uses x number of z/OS Service Units, the priority of the work through that DBAT (and Service Class) is reduced. The result is that the workload running through that DBAT runs slower in Db2, holding locks longer and reducing concurrency. Be careful with DBAT reuse in this manner since the WLM classification does not get reset until the DBAT is marked Inactive (at disconnect time). Db2 10 for z/OS introduced high-performance DBATs which is the equivalent of DBAT using RELEASE(DEALLOCATE). High-performance DBATs have the same characteristics as CICS or Batch plans bound with RELEASE(DEALLOCATE), which means concurrent DDL changes, binds, and utilities could encounter locking contention. See Chapter 4 for additional information on high-performance DBATs.

Name	MAXKEEPD
Description	Number of prepared dynamic SQL statements kept past a commit in the dynamic statement cache for Plans and Packages bound with KEEPDYNAMIC(YES).
Possible Values	0–65535
Default Value	5000
Performance Implications	Keeping prepared dynamic SQL statements in cache past commits helps keep prepare time and costs down for local (static packaged with dynamic SQL) and distributed applications. Distributed applications using CURSOR WITH HOLD benefit from this option since their prepared SQL statement is in cache after the commit.

Name	MAXRBLK
Description	The amount of storage required for RID processing. Possible Values: 9, 128–10000000 KB.
Default Value	400000
Performance Implications	Access paths that require RID processing use this storage area. Since this storage is above the 2G bar, allocations can be generous. If too many RIDs qualify for RID processing, or too much of the RID pool is required for RID processing of an access path, Db2 may change the access path to a table space scan at run time or overflow the RID list to a workfile. Specify that Db2 uses workfiles to continue RID list processing when the RID pool is not large enough by specifying a MAXTEMPS_RID value.

Name	MAXTEMPS_RID
Description	The maximum amount of temporary storage in the workfile database that a single RID list can use at a time. Possible Values: NONE, NOLIMIT, or 1 to 329166.
Default Value	NOLIMIT
Performance Implications	The default is recommended, but adjust down if there is an extreme amount of large RID list processing.

Name	MAXRTU
Description	Maximum number of tape units Db2 can use to read archive log tapes. Possible Values: 1–99.
Default Value	2
Performance Implications	Choosing the proper setting for this parameter can be an involved process. If you are in Data Sharing, other members cannot use the tape drives allocated to another member until the DEALLCT is reached. It may be beneficial to submit all recovery jobs from the same member. Try to set the number as high as possible, leaving a few tape drives available for other work. For example, if there are 10 tape drives available to Db2, set this parameter to 6 or 8. Do not impact archive log processing if all the drives are taken by recovery processes reading archive logs. Also, if the installation has Change Data Capture or other replication products that can read Db2 archive logs if it falls behind, a higher number may be necessary for MAXRTU.

Name	MAXTEMPS
Description	Maximum amount of temporary storage in the workfile database any one user (thread) can use.
Possible Values	0–2147483647 MB
Default Value	0
Performance Implications	MAXTEMPS limits the impact when just a few users consume a large amount of the temp workfiles for large sorts, temp tables, or scrollable cursors. By limiting how much workfile storage a user can use, normal transaction workloads are less likely to encounter contention for workfiles.

Name	WFDBSEP
Description	Specifies whether Db2 should provide an unconditional separation of table spaces in the workfile database based on the allocation attributes of the table spaces.
Possible Values	YES, NO
Default Value	NO
Performance Implications	Separate the workfile utilization for sorts from temporary table usage. If YES is specified, Db2 separates the use of the workfile table spaces depending upon whether or not SECQTY is specified in the table space allocation. This enables the usage to be split, allocating different sizes and buffer pools for temp table usage versus pure workfile usage which is a definite advantage for a high-volume environment.

Name	WFSTGUSE_AGENT_THRESHOLDP
Description	This parameter determines the percentage of available space in the workfile database on a Db2 subsystem or data sharing member that can be consumed by a single agent before a warning message is issued.
Possible Values	0 to 100
Default Value	0
Performance Implications	Set this to a value other than the default to help point out the processes that are over-utilizing the workfile database.

Name	WFSTGUSE_SYSTEM_THRESHOLD
Description	This parameter determines the percentage of available space in the workfile database on a Db2 subsystem or data sharing member that can be consumed by all agents before a warning message is issued.
Possible Values	0 to 100
Default Value	90
Performance Implications	90 may be too small. Set this lower if there are many out-of-control sorts to obtain information on when they are running and when the workfile database is under stress.

Name	MINSTOR
Description	Have Db2 invoke storage management techniques to reduce a thread's storage. Possible Values: YES, NO.
Default Value	NO
Performance Implications	Turning this on is only recommended if DBM1 is under storage constraints, or if IBM recommends it. Otherwise, DBM1 can consume more CPU trying to manage/reduce thread storage.

Name	NUMLKTS
Description	Total number of locks a user can have on one table space before lock escalation occurs. Possible Values: 0–104857600.
Default Value	2000
Performance Implications	Applications want to avoid hitting this threshold. When lock escalation occurs on an object, concurrency goes down and timeouts and/or deadlocks can occur. If an application hits this threshold consistently, it could be that the application is not committing frequently enough, the wrong isolation level is being used, or lock size (page or row). In addition, the storage usage increases (540 bytes per lock) due to all the locks being held. Some (CRM) applications may require a higher number because there are many tables in one table space, or because they have very large units of work. Increasing the NUMLKTS may require increasing IRLM region size.

Name	NUMLKUS
Description	Total number of locks a user can hold across all table spaces concurrently. Possible Values: 0–104857600.
Default Value	10000
Performance Implications	Some applications may acquire more than 10,000 locks in a unit of work. Therefore, it may be necessary to raise the NUMLKUS value. However, increasing this number has risks. Additional storage is required as more locks are obtained. More locking could reduce concurrency and increase timeouts and/or deadlocks. In Data Sharing, more locks mean more lock propagation to the CF, which increases overhead and path length.

Name	OPTHINTS
Description	Enables the use of optimization hints during the bind process to influence access path select for static and dynamic SQL statements.
Possible Values	YES, NO
Default Value	NO
Performance Implications	Sometimes it is necessary to help the Db2 engine choose a more desirable access path. These situations should be less and less frequent due to improvements in Db2, but are certainly required occasionally. The recommendation is to use OPTHINTS only in special situations and not as a standard. OPTHINTS is best used when the DBA knows exactly which access path is best and how to specify the proper hints to get the Optimizer to generate that access path. It is the DBA's responsibility to manage the optimization hints once they are used.

Name	OUTBUFF
Description	Size of the log output buffers. Possible Values: 400–400000 KB.
Default Value	4000
Performance Implications	Db2 page fixes the log output buffers in real memory. The larger the log output buffer, the greater the likelihood a log record remains in memory, which can reduce physical log reads. Db2 statistics trace records can show how many times a log write had to wait due to a full log buffer. Too many waits due to log buffer full conditions would be an indication the log buffer is too small. Set this value larger as this is a critical shared resource.

Name	PARA_EFF
Description	Set the parallelism efficiency Db2 assumes when determining parallelism access paths. Possible Values: 0–100.
Default Value	50
Performance Implications	Since most installations are not set for achieving optimally balanced parallel tasks, the default setting is recommended. Many variables come into play when Db2 is determining parallelism access paths, and unless you have a very controlled environment, changing this setting may or may not provide the results you want.

Name	PARAMDEG
Description	Maximum number of parallel tasks (degree) Db2 allows at run time. Possible Values: 0–254.
Default Value	0
Performance Implications	Because this sets the limit of parallel tasks in a parallel group, it overrides the degree parameter specified at bind time. This can be helpful for controlling the number of parallel tasks in a query instead of allowing Db2 to determine the number of tasks. The number of available general processors (GPs) and available zIIPs (Specialty Engines - SEs) must be considered when setting this number. A good rule of thumb is 2 times the number of engines (GPs + SEs). Notice that the default is zero. To take advantage of parallelism, set this parameter first.

Name	POOLINAC
Description	Time inactive DBATs stay in the pool before being destroyed. Possible Values: 0–9999 seconds.
Default Value	120
Performance Implications	It is important for distributed applications to disconnect from the database (data source) after committing so the DBAT becomes inactive and is returned to the pool for reuse.

Name	PTASKROL
Description	Roll up parallel task accounting data into the parent task accounting record. Possible Values: YES, NO.
Default Value	YES
Performance Implications	This reduces the number of SMF 101 accounting records produced when using parallelism. All of the parallel task information is rolled up into the parent task accounting record.

Name	SMFCOMP
Description	Tells Db2 to compress trace records (SMF100, SMF101, and SMF102) written to SMF. Possible Values: OFF, ON.
Default Value	OFF
Performance Implications	This reduces the size of Db2 SMF records and saves SMF record processing time. Turn this on in a high-performance environment.

Name	SRTPOOL
Description	This is the size of the Sort Pool storage. Possible Values: 240–128000 KB.
Default Value	10000
Performance Implications	The larger this pool is, the more efficient sort processing will be, and more concurrent sorts can be supported. When an order by or distinct is needed in a query, sorting the data in memory (or the Sort Pool) is much faster than if workfiles must be used. If there is memory to spare, increasing this value is recommended as it can have a serious impact on moderately sized sorts.

Name	STORTIME
Description	Time to wait for a Stored Procedure or UDF to start. Possible Values: NOLIMIT, 5–1800.
Default Value	180
Performance Implications	The recommendation is to not use NOLIMIT because the application could wait indefinitely if the SP address space is down. There may be a variety of reasons causing the application to wait and the longer the wait time the more likely there are other timeouts and/or deadlocks within Db2.

Name	TCPKPALV
Description	Overrides the TCP/IP value for keeping a TCP/IP session alive. Possible Values: DISABLE, ENABLE, or 1–65534.
Default Value	120
Performance Implications	Do not let TCP/IP cancel communication sessions between clients and Db2. This value should be close to, or a little higher than, the Idle Thread Timeout (IDTHTOIN) value. Too small a value causes excessive network traffic as TCP/IP probes more often to check if the connections are still alive.

Name	UTSORTAL
Description	Should the Db2 utilities dynamically allocate the sort work datasets. Possible Values: YES, NO.
Default Value	YES
Performance Implications	Allowing the Db2 utilities to allocate the sort work dataset increases the chances of parallelism in the utilities (CHECK, LOAD, REBUILD, REORG, and RUNSTATS). UTSORTAL can be set to YES if IGNSORTN is set to YES. Different combinations of UTSORTAL and IGSORTN subsystem parameters, along with the SORTNUM utility control card determine if the Sort utility or the Db2 utility allocates the sort workfiles.

Name	IGNSORTN
Description	Should the Db2 utilities ignore the SORTNUM control card. Possible Values: YES, NO.
Default Value	NO
Performance Implications	UTSORTAL can be set to YES if IGNSORTN is set to YES. Different combinations of UTSORTAL and IGSORTN subsystem parameters, along with the SORTNUM utility control card determine if the Sort utility or the Db2 utility allocates the sort workfiles.

8.5 zIIP Engines

In brief, observe that the zIIP secondary engines are a capacity and licensing issue, not a performance feature. It is recommended to tune the queries to reduce CPU time. When monitoring, add the secondary engine CPU time from the accounting reports to the CPU time as they are accounted separately and the proportion of time spent on each type of processor varies from execution to execution. Both *SYSVIEW for Db2* and *Detector* provide detailed information about CPU usage and report aggregated CPU and separate CP and zIIP times.

Chapter 9: Monitoring Subsystem and Application Performance

Monitoring is the key to designing, understanding, and maintaining a high-performance implementation in Db2 for z/OS. Without monitoring there is nothing. There must be proof of the cost of an application, and there must be a way to compare the before and after impact of making a change in an effort to improve performance. While EXPLAIN enables a way to predict access patterns and cost, it should never be the *be all end all* for performance analysis. Monitoring is the only definitive proof of performance.

Use the *SYSVIEW for Db2* for monitoring. It collects Db2 performance traces, has online and batch interfaces and reports real-time and history performance information. The cost of running the recommended statistics and accounting traces is quite low and the tools pay for themselves many times over in the savings realized by interrogating the output. Of course, if policy does not exist for reviewing trace output then do not collect it.

9.1 Db2 Traces

Without Db2 traces, there is a limited ability to collect valuable performance information unless very specialized tools are employed. Db2 traces can monitor all sorts of activities within a subsystem depending on the types of traces and levels of traces set. The basic component of a trace is something called an instrumentation facility component identifier (IFCID). IFCIDs are grouped into classes and classes can be grouped into trace types. There are several types of traces, but this section only covers statistics, accounting, and performance traces.[9]

Traces can be started by default via subsystem parameters, but they can also be turned on and off as well as adjusted via Db2 commands. With *SYSVIEW for Db2*, the traces are started and stopped automatically as needed.

9.1.1 Statistics Trace

A statistics trace collects performance metrics at a subsystem level. The trace records produced are typically directed towards system management facility (SMF) datasets and hopefully the system programmer is externalizing these SMF records for Db2 subsystems into separate datasets for analysis. Statistics traces are relatively very low cost and the data is typically externalized every 1 to 10 minutes. By default, Db2 starts statistics trace classes 1, 3, 4, 5, and 6. The information collected is subsystem-wide and contains the following information:

- Class 1 = Db2 basic statistics
- Class 3 = Exceptions like deadlock, timeout, datasets extents
- Class 4 = Distributed activity
- Class 5 = Data sharing related statistics
- Class 6 = Storage usage statistics

9.1.2 Accounting Trace

The accounting trace collects thread-level performance metrics and is an essential key to understanding and improving application performance. Like the statistics trace records, the accounting trace records produced are typically directed towards system management facility (SMF) datasets and hopefully the system programmer is externalizing these SMF records for Db2 subsystems into separate datasets for analysis. Accounting traces are very low cost traces which may add up to 15% overall CPU overhead to a subsystem (however results can vary dramatically). The accounting trace data these days is typically externalized upon the termination of each individual thread. So, there is one record per thread. This means that for large-scale batch jobs, CICS transactions that use protected threads, distributed threads with

9. *SYSVIEW for Db2* supports all Db2 IFCIDs and provides additional custom records

ACCUMAC subsystem parameter set, or high-performance DBATs, there are multiple transactions bundled together into the same accounting trace record. By default, Db2 only starts accounting trace class 1, which is not enough to accurately diagnose and track the performance of applications. The recommended accounting trace classes to set are 1, 2, 3, 7, and 8.

- Class 1 = Total elapsed time and CPU used by a thread while connected to Db2 at the plan level.
- Class 2 = Total elapsed time and CPU used by a thread within Db2 at the plan level. This is a subset of class 1. The elapsed time is broken into suspension time and CPU time.
- Class 3 = Total time waiting for resources in Db2 at the plan level. This is a subset of the class 2 time and is equal to the class 2 suspension time.
- Class 7 and 8 = These are, respectively, the class 2 and 3 times divided between packages utilized during thread execution.

9.1.3 Performance Trace

Performance traces are not set by default and can be used to track specific threads or sets of threads at an extremely detailed level. Typically, it is recommended to start performance traces at a very specific level using a Db2 command to collect information for a problem application for which other methods of diagnosis and tuning has fallen short. Run a performance trace in situations in which specific events need to be identified within the execution of an application. Performance traces are typically used to get detailed performance metrics for individual SQL statements in static embedded applications, buffer access patterns, excessive index access, and other very detailed metrics. Performance traces are also used in conjunction with a performance monitor tool. Given the advances in buffer pool monitoring, advanced tooling, and the capabilities to externalize the dynamic statement cache, there is less reliance on performance traces.

Running a performance trace is a very expensive proposition and should only be done in a controlled and/or understood situation. Limit the trace as much as possible to the thread of interest.

9.1.4 IFCID 316 and 318

These are the IFCIDs that must be set to collect performance metrics within the global dynamic statement cache. Given the proliferation of dynamic SQL these days, it is quite critical to collect this data routinely, not as an exception. These traces are not turned on by default but can be turned on via the following command.

```
-START TRACE(ACCTG) IFCID(316,318)
```

There has been some debate over the overhead of running this trace. A number of years ago, a redbook was published that stated a value like 4% CPU overhead subsystem wide. This number has been greatly exaggerated. In every tested customer site, as well as every DBA interviewed, there has been no discernible increase in CPU consumption as a result of turning on this trace. Besides, the benefits of the trace far outweigh any potential impact, if an impact can be detected. Further discussion can be found on the following podcast recorded with two famous IBM Db2 professionals: https://www.db2expert.com/index.php?page=podcasts#S1P6

Once this trace is activated, use the techniques described in Chapter 5 to externalize the information generated.

9.2 Understanding and Reporting Trace Output

Interpreting trace output requires either a strong background in programming or a good tool. Clever programmers can find the macros that lay out the Db2 SMF record formats in the SDSNMACS Db2 library in members DSNDQWST for statistics trace records type 100, and members starting with DSNDQW for accounting trace records. If there is no tool available for reading and formatting Db2 accounting and statistic trace records, try an option called DSN1SMFP. Information can be found at http://www-01.ibm.com/support/docview.wss?uid=swg1PM94545.

With *SYSVIEW for Db2*, various reports can be produced and analyzed to determine whether or not there are resource constraints or bottlenecks at the subsystem, data sharing group, or application level.

In a statistics report, generally start with a one-day summary and watch for daily usage, as well as accumulating the summaries to look for trends in certain metrics. When viewing an accounting report, get a statistics report for the same time period that the thread of interest was executing. This way, some of the accounting metrics can be correlated with the statistics metrics.

Some statistics to monitor:

- Threads, commits, sign-ons. SQL frequency statistics. These are solid numbers to collect and monitor over time because they are a good way to gauge relative subsystem activity. That is, if management indicates that CPU consumption is way up and capacity planning is identifying Db2 as a potential reason, review resource consumption and use these numbers to determine whether or not overall activity is up corresponding to the increase, or if not, then maybe some rogue processes have been introduced that may require tuning.
- Checkpoints taken. It is possible to set the system checkpoint frequency by time or the number of checkpoints written. Do not checkpoint once per day, and especially not every 5 seconds. Remember, checkpoints are used for crash recovery as well as normal subsystem restart. However, they also trigger system events including the launching of asynchronous buffer write requests. Checkpoint in the area of once every 5 to 10 minutes depending upon overall system activity.
- Reads from archived logs. If there are processes failing and rolling back, and those processes end up reading log records from archived logs, then it is quite likely there is a problem that needs to be corrected. There are either unstable processes with excessively long units of work, or the active logs are too small to accommodate the normal amount of overall logging that contains a typical unit of work.
- Log writes suspended. Log records are written to an output buffer. Suspended log writes may indicate a log I/O bottleneck. If this number appears high relative to log records written, then consider increasing the size of the log output buffer. Be generous—the log is a central point of contention.
- DRDA requests. This is an indication of remote request activity, and it is recommended to monitor this as a way of determining whether or not there are enough DBATs to accommodate the inbound requests.
- Deadlocks and timeouts. Deadlocks and timeouts are discouraged, although they may not be entirely avoidable in normal applications. Routinely monitor and track these statistics for trends. Any increase should require investigation into which applications are responsible. Examining the console log for the subsystem in which the deadlocks occur over the time period represented by the statistics report should show messages that identify the applications involved in locking conflicts.
- Lock escalations. These are not typically desired and are an indication that one or more applications are acquiring more locks than allowed and causing larger locks to be taken. Examining the console log for the subsystem in which the escalations occur over the time period represented by the statistics report should show a message for the application that experienced the escalation.
- RID list and list prefetch. These are numbers that reflect the quality of processing in support of SQL operations that utilize RID processing and the memory reserved for this processing including list prefetch, multi-index access, hybrid join, and other access paths. These numbers indicate whether or not RID processing overflowed into workfiles or failed. A response to any overflows or failures should require first an investigation into which applications were involved (accounting reports) and a potential adjustment to the SQL or database objects involved (index changes, clustering changes, better matching predicates). Also consider increasing the size of RID storage if the applications are considered well-behaved.
- Parallelism. These values indicate how much parallelism was active on behalf of SQL running with parallelism, as well as how effective the parallelism was. If there are serious reductions in parallelism, or failure to get parallelism at all, consider increasing buffer resources or scheduling the queries to run at times when more CPU is available. If parallelism is evident when it is not expected, determine if packages are being bound with parallelism that really should not be.
- Global locks false contention. A large number of false contentions may indicate a need to increase the memory and/or resources available to the coupling facility.
- Dynamic prepare statements found in cache. If a lot of dynamic SQL is being processed, then a high percentage of statements found in-cache should be seen versus the total number of dynamic statements. If the number is low, consider increasing the size of the statement cache or look into the types of SQL being issued. If the SQL is constructed with embedded literal values, consider changes to the SQL or the use of literal concentration.
- Buffer pool statistics. This is one of the most valuable measurements presented in a statistics report. Watch for extremely busy buffer pools, as well as pools that have high proportions of sequential versus random activity. The subsystem-level buffer information should be used together with the detailed information provided by accounting

traces and by using the DISPLAY BUFFERPOOL command. Remember that the ultimate goal of buffer tuning is to reduce the number of I/Os executed. Use the information here to monitor buffer hit ratios, but more importantly to monitor overall activity and especially I/O activity.

The vast majority of performance analysis time is spent looking at Db2 accounting reports. These reports are the key to understanding application performance and are not only extremely useful for monitoring production performance, but are also important in evaluating proposed performance changes tested via benchmark tests or POCs. It is also recommended to accumulate accounting information over time to look for trends in application performance for specific critical applications. In this way, patterns can be detected that may indicate the need to perform REORGs, collect RUNSTATS, or examine potential application changes that may have introduced bad access paths or changes to transaction input patterns.

Some accounting fields to monitor.

- Elapsed time and CPU time: If a call comes in that says an application is not responding, obtain an accounting report. First examine the class 1 and class 2 elapsed and CPU times. Is there a constraint? Is the application spending the majority of class 1 time doing class 2 things? If yes, it is a Db2 issue and if no, then it is not a Db2 issue. What portion of the class 2 time is elapsed time versus CPU time? If class 2 CPU is a minor portion of the elapsed time, then there are class 3 suspensions that must be investigated. If the majority is CPU time, then examine the quantity of SQL issued and perhaps even divide the number of statements into the CPU time to get an average. If the average is relatively high, tune some statements, but if the CPU time per statement is very low, there may be a quantity of SQL issue.
- Secondary engine CPU time: If zIIP processors are used, determine how much an application is using them. Remember zIIPs are not a performance feature but a cost feature.
- Time spent in routines: If the application is utilizing stored procedures, user-defined functions, and triggers, then the time spent in these routines is broken out from the remaining Db2 and application time. This is important if these routines are used for extraneous processing such that a cost can be attached to that processing. Also, if one or more routines are having a performance issue, these numbers can indicate as much and attention can be directed to the package level information if it exists for the routines (always for triggers and stored procedures).
- Lock and latch suspension time: This indicates the number of locking and latching events that incurred a suspension, as well as the time spent in suspension. A little bit of time spent here is quite normal, but if locking represents a majority of the elapsed time then there may be a concurrency issue that must be addressed. Look for additional information such as deadlocks and timeouts, and check the console log for messages related to logging conflicts. Sometimes excessive latch time can be an indication of limited CPU resources, so do not be fooled by this. Double check against unaccounted for time (class 2 time elapsed time, class 2 CPU time, class 2 suspension time) and if there is significant unaccounted for time associated with excessive latch wait time then there is likely a CPU shortage during the thread execution.
- Global lock and latch suspension time: Any significant values here indicate a concurrency problem with a resource across members of a data sharing group. Look for things such as identity columns and sequence objects (increasing cache helps) or frequently updated tables shared across applications (system affinities or alternate locking sizes or strategies may be required). Large values here could also indicate undersized coupling facility resources.
- Synchronous I/O suspension time: Death by random I/O. If time spent here is excessive, examine the clustering of the data in tables and the input to transactions. Buffer tuning can help, as well as additional indexes. There are many opportunities here for SQL and database tuning. The first thing to do is identify the objects and SQL statements involved.
- Other I/O wait time: While asynchronous I/Os are more expensive than synchronous I/Os, applications typically do not wait due to the fact that the asynchronous I/Os are independent of the application process. If there is excessive time spent here, there may be a DASD performance issue or some buffer pool separation (separating sequentially accessed objects from pools that contain sequentially accessed objects), and size increases may be required.
- Log writes: Logging should not be a bottleneck until extremely high rates of change are achieved in the database. However, add up the amount of data logged and determine how well it matches the amount of data processed by the transactions. It may be an indication of excessively modifying data.
- SQL activity and commits: These are good counts to gauge how much work an application is doing and how that work changes over time. Divide elapsed and CPU time by SQL and commits to get a per-unit measurement that can be used to identify specific tuning of statements, REORG opportunities, or adjustments to the size of the units of work. CPU trending over time up for a relative stable number of statements and commits is a good indication that a REORG is required somewhere.

- Deadlocks and timeouts: These counters should be zero, but if they are not go to the console log for the period of time the thread was active to look for messages that detail the conflicts.
- Parallelism: If parallelism is expected for one or more queries in the application the only way to really know is here.
- Buffer pool statistics: The buffers are one of the most important resources in a Db2 subsystem, and buffer pool usage statistics are delivered in an accounting trace at the thread level. It is also possible to gather these statistics at the package level if the appropriate trace class and IFCIDs are set (although there may be a higher trace cost). The information presented here is extremely valuable to see how an individual application is using (and impacting) the buffers. These statistics can be used together with the statistics trace buffer information and the information derived from using a DISPLAY BUFFERPOOL command to get a really concise picture of the buffer activity.
- Package level statistics: When accounting trace classes 7 and 8 are active various elapsed, CPU, SQL, and suspension time is gathered at the package level. This is extremely valuable information for static embedded applications in that you can identify which programs should get the most tuning attention (the programs that use the most resources). These package level statistics also report on triggers, stored procedures, and some UDFs used by the application.

9.3 Db2 Performance Database

Detector supports offloading its performance historical data into a Db2 database. Similarly *SYSVIEW for Db2* includes a performance Db2 database that is loaded with Db2 accounting and statistics trace record data. There is value in loading the data into a Db2 table and writing a series of queries to analyze it. These databases can be extraordinarily useful for reporting trends on subsystem and application levels. A performance database can become very large very quickly. Aggregations and regular purging of obsolete data can help. Moving data off the mainframe can be beneficial as well.

Explore the performance database, compile trending using SQL, and then display the query results with various charts. This can contribute to the launch of tuning projects and result in significant savings. Do not underestimate the power of trending and figures to make a point.

9.4 Displaying Buffer Statistics

The DISPLAY BUFFERPOOL command can also be used as a very powerful reporting tool. This is a recommended DISPLAY BUFFERPOOL command:

```
-DIS BUFFERPOOL(ACTIVE) DETAIL(INTERVAL) LSTATS(*)
```

This command displays the accumulated buffer pool statistics since the last time it was issued or since the subsystem was started if no previous command was issued. In addition, it produces a report for every open dataset assigned to the pool that includes statistics since the last time the command was issued, or since the subsystem was started if no previous command was issued.

The total buffer pool statistics can be monitored and compared to previous reports to see how recent activity has impacted the pool. In addition the dataset list, which is listed by table space or index space name, gives detailed access information for each of the objects in the pool. In this way, objects that are dominating the pool can be seen as well as both synchronous and asynchronous I/O delays for each object. Alternatively, use *Subsystem Analyzer* as it also provides these statistics along with more detailed real-time and historical buffer pool, object, and I/O activity information.

Chapter 10: Testing Performance Designs and Decisions

Rather than sitting in a meeting room trying to figure out a physical database design, spend time letting the database indicate how to create the database. Use the ideas presented in this guide and test them in the specific situation. Are you tuning? Did you run an EXPLAIN before and after a change and the EXPLAIN shows an obvious improvement based upon the change to the statement or database? It does not mean much unless a proof of concept (POC) or at least a before-and-after performance test is performed.

If there is not a database or application to test with, it does not matter. Make each in a matter of minutes. The primary tools for testing:

- Recursive SQL to generate data.
- SQL to generate additional data.
- Recursive SQL to generate statements.
- SQL to generate additional statements.
- Interactive SQL facility or SPUF for statement and data generation, as well as for running some test scenarios.
- Batch Processor for Db2 for z/OS, DSNTEP2 or DSNTIAUL for running test scenarios.
- REXX for performance benchmarks and test application simulation.
- SQLPL stored procedures for performance benchmarks and test application simulation.
- Shell scripts and db2batch for remote access simulation.

10.1 Establishing a Test Database

In a situation in which modifications or enhancements are being made to existing databases and applications it can be assumed that there is a test environment. However, what if there is a brand new design? Go ahead and create a simple test database. The key tables, primary keys, and at least one data column are all that is needed. Of course it depends on the strategies to be tested, whether it be partitioning or clustering or various alternate table designs. Go ahead and make all of the table variations so that the same sets of data can be loaded into the tables and test scenarios are easy to choose and execute. Representative catalog statistics do present somewhat of a challenge, but an appropriate amount of test data can be generated, which is a key factor, then a normal RUNSTATS execution may be enough to get representative statistics.

10.2 Generating Data and Statements

When in a situation where there is a new database being proposed, and some POCs are required, but no existing application or data exists, then custom data and statements must be generated. Another option is to use SQL to generate key values that can be placed into a file and used as input to a test process. The primary tool for this generation is SQL. The primary statement to start with is the most simple of recursive SQL statements, which is a statement that generates a result set from nothing.

```
WITH GEN_ROWS(N) AS
(SELECT 1 FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT N+1 FROM GEN_ROWS
    WHERE N < 100)
SELECT N
FROM GEN_KEYS
ORDER BY N
```

10.2.1 Generating Data

In the following scenario, a test is required against a proposed employee table. This proposal is for a new application and database, so no current tables or data exists. Once the various design options to test are decided, a table, data, and statements must be created. As long as the table definition contains the appropriate structure for the test, a primary key, any potential additional indexes, and some non-indexed columns, it is good enough to test against.

```
CREATE TABLE DANL.EMPT
(EMPNO        BIGINT NOT NULL
,WORKDEPT     CHAR(3) NOT NULL
,LASTNAME     CHAR(50)
,PRIMARY KEY (EMPNO)
)
IN DANLDB.DANEMPT
CCSID EBCDIC;
CREATE UNIQUE INDEX DANL.XEMP2T
       ON DANL.EMPT
       (EMPNO ASC)
       USING STOGROUP DANLSG
       CLUSTER
       BUFFERPOOL BP8
       CLOSE NO;
```

In this example, primary key values, presumed foreign key values, and some data must be generated. Use a common table expression to make the foreign key values, an increasing value to create the primary key values, and just a simple string to make the data. The following statement generates 100 rows of data.

```
INSERT INTO DANL.EMPT
WITH GEN_ROWS(N) AS
(SELECT 1 FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT N+1 FROM GEN_ROWS
    WHERE N < 100)
    ,GENDEPT (WORKDEPT) AS
    (SELECT 'D01' FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT 'E01' FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT 'E02' FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT 'F01' FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT 'G04' FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT 'X01' FROM SYSIBM.SYSDUMMY1
)
       SELECT A.N
       ,X.WORKDEPT
       ,'BOBRADY'
       FROM GEN_ROWS A
       INNER JOIN TABLE
           (SELECT WORKDEPT, RAND() AS RANDOM_VALUE
           FROM GENDEPT
           WHERE A.N > 0
           ORDER BY RANDOM_VALUE
           FETCH FIRST 1 ROW ONLY) AS X(WORKDEPT, RV)
       ON 1=1
;
```

The first recursive common table expression generates 100 rows and also supplies the primary key. The second common table expression presents six different possible values for the WORKDEPT column. The final SELECT statement retrieves the primary key and non-indexed data from the generation table, and then it joins that to a nested table expression that contains a nonsense correlated reference to force materialization and a RAND function with an ORDER BY and FETCH FIRST in an effort to randomly supply a WORKDEPT value to each generated row. Now there are 100 rows in the test EMPT table with generated primary key values and randomly selected foreign key values.

Data can also be generated from data. This allows for the generation of more variations in values that are more difficult to generate randomly or by using a sequence value. In the following example we use the 100 rows just generated from nothing to generate 100 more rows using the same WORKDEPT values, but introducing a new data column value.

```
INSERT INTO DANL.EMPT
SELECT EMPNO + 100, WORKDEPT, 'LUKSETICH'
FROM   DANL.EMPT;
```

This type of generation can be repeated over and over with ever increasing quantities of data to fully populate a test table in a manner that is suitable for the test at hand. Clustering can be changed and REORG executed and then the clustering changed back in an effort to test organized and disorganized data scenarios. Any variation in table design can be made and the original generated data can be used to populate the various table variations.

10.2.2 Generating Statements

Just as with generating data it is possible to generate statements in the same manner. Generate statements from nothing using recursive SQL, or use the data in the table to generate statements that act against the table. In the following example, the data in the test table is used to generate random SELECT statements that will test random primary key index access with table access.

```
SELECT STMT
FROM (
SELECT 'SELECT LASTNAME FROM DANL.EMPT WHERE EMPNO = ' ||
       STRIP(CHAR(EMPNO)) ||
       ';'
       ,RAND() AS BOB
FROM   DANL.EMPT) AS T(STMT, BOB)
ORDER  BY BOB
```

The generated statements can then be used as input to Interactive SQL facility, SPUFI, Batch Processor for Db2 for z/OS, DSNTEP2, or DSNTIAUL to run a performance test. One of the drawbacks of the above statement is that, while it tests random access to the test table, every statement finds data. To test misses as well as hits, randomly delete data once the statements are generated. Another option is to generate the statements independent of the data in the table. Once again, recursive SQL is used to generate something from nothing.

```
WITH GEN_ROWS(N) AS
(SELECT 1 FROM SYSIBM.SYSDUMMY1
    UNION ALL
    SELECT N+1 FROM GEN_ROWS
    WHERE N < 100)
SELECT 'SELECT LASTNAME FROM DANL.EMPT WHERE EMPNO = ' ||
       CHAR(INT(RAND()*POWER(10,INT(RAND()*6)))) ||
       ';'
FROM   GEN_ROWS
```

Often, a simple REXX program can test a SQL statement in a loop. One version of a REXX test is used to test access to a table or tables based upon a set of input keys read from a file. Use statements similar to the ones above to generate the key values. So, instead of generating statements they simply generate keys that are then placed in a file.

```
SELECT STRIP(CHAR(EMPNO))
,RAND() AS BOB
FROM DANL.EMPT
ORDER BY BOB;
```

10.3 Simple Performance Benchmarks

There are several different tools used to perform performance benchmarks. A primary tool of choice is REXX. REXX is an extremely powerful and easy-to-learn scripting language that allows for the extremely fast development of simple applications that can include embedded dynamic SQL statements. The vast majority of tests are performed using two simple REXX routines. One tests the same statement with the same values over and over, and is used to test for CPU consumption. The other uses an input file to supply key values, either sequential or random, in an effort to test a query for response time. ISQL and SPUFI are used to test queries that process large values of data, as well as large numbers of SQL statements. Batch Processor for Db2 for z/OS, DSNTEP2, and DSNTIAUL are also both effective benchmarking tools when using a SQL script containing large single statements or large volumes of individual SQL statements.

If a remote connection is possible from a PC or UNIX-based system then it is possible to also use shell scripts, windows batch files, and the db2batch system command if at least a Db2 client is installed on the PC or other system. Db2 Express-C should be installed on a local PC which includes mainframe connectivity or IBM Data Studio. Both of these software products are free downloads from IBM. With a PC, use Cygwin to simulate a UNIX environment and then use shell scripting. Db2batch use works great for running benchmarks against a Db2 for LUW database, but is somewhat limited when running against a Db2 for z/OS subsystem. It is, however, worth a try.

10.3.1 REXX Routine Examples

The following REXX routine example is used to test for CPU usage. It runs the same statement repeatedly dependent upon the set loop limit.

```
/*REXX*/
CALL INITIALIZE
/* SET A VARIABLE EQUAL TO THE DESIRED SQL STATMENT.
*/
/*
*/
SQLSTMT=”SELECT A.LASTNAME, A.WORKDEPT
“,
“ FROM DANL.EMP A
“,
“ WHERE A.EMPNO = '000010'
“
/* PREPARE THE STATEMENT FOR EXECUTION BY DECLARING THE
CURSOR, */
/* DOING A PREPARE OF THE STATEMENT, AND OPENING THE CURSOR.
*/
/*
*/
ADDRESS DSNREXX
“EXECSQL DECLARE C1 CURSOR FOR S1”
IF SQLCODE \= “0” THEN
DO
SAY “DECLARE CURSOR FAILED WITH SQLCODE = “ SQLCODE
EXIT 8
END
“EXECSQL PREPARE S1 FROM :SQLSTMT”
```

```
IF SQLCODE < "0" THEN
DO
SAY "PREPARE FAILED WITH SQLCODE = " SQLCODE
EXIT 8
END
/* OPEN/FETCH/CLOSE 50 TIMES
*/
DO 50
"EXECSQL OPEN C1 "
IF SQLCODE \= "0" THEN
DO
SAY "OPEN FAILED WITH SQLCODE = " SQLCODE
EXIT 8
END
DO UNTIL SQLCODE \= "0"
"EXECSQL FETCH C1 INTO :TESTMSG, :t2 "
IF SQLCODE = "0" THEN
DO
/* SAY TESTMSG */
END
END
/* HERE THE FETCH LOOP HAS ENDED (SQLCODE <> 0), AND WE CHECK
WHY.*/
SELECT
WHEN SQLCODE = 0 THEN DO
END
WHEN SQLCODE = 100 THEN DO
END
OTHERWISE
SAY "FETCH FAILED WITH SQLCODE = " SQLCODE
SAY SQLERRMC
END
/* ALL IS WELL, SO THE CURSOR IS CLOSED.
*/
"EXECSQL CLOSE C1"
IF SQLCODE \= "0" THEN
DO
SAY "CLOSE FAILED WITH SQLCODE = " SQLCODE
END
/* END THE DO LOOP HERE */
END
/* TRACE ADDED TO CAPTURE INFO IN ONLINE MONITOR
*/
trace ?I
/* CLEANUP.
*/
ADDRESS MVS "DELSTACK"
ADDRESS DSNREXX "DISCONNECT"
S_RC = RXSUBCOM('ADD','DSNREXX','DSNREXX')
EXIT 0
INITIALIZE:
/* CHECK TO SEE IF THE REXX/Db2 COMMAND ENVIRONMENT IS
AVAILABLE */
/* IF IT IS NOT, THEN ESTABLISH IT.
*/
/* THEN CONNECT TO THE APPROPRIATE DATABASE (SUBSYSTEM)
*/
'SUBCOM DSNREXX'
IF RC THEN
S_RC = RXSUBCOM('ADD','DSNREXX','DSNREXX')
/* CHANGE 'DSN1' IN THE LINE BELOW TO YOUR TARGET SUBSYSTEM
*/
ADDRESS DSNREXX "CONNECT" "DSN1"
IF SQLCODE \= "0" THEN
```

```
DO
SAY "FAILURE TO CONNECT TO DATABASE"
EXIT 8
END
/* INITIALIZE STACK AND FREE ANY */
ADDRESS MVS "DELSTACK"
ADDRESS MVS "NEWSTACK"
RETURN;
```

The following REXX routine example is used to test for I/O dependent upon the sequence of values in the associated input file.

```
/*REXX*/
CALL INITIALIZE
/* SET A VARIABLE EQUAL TO THE DESIRED SQL STATMENT.
*/
" FROM DANL.EMP A
",
" WHERE A.EMPNO = ?
"
/* PREPARE THE STATEMENT FOR EXECUTION BY DECLARING THE
CURSOR, */
/* DOING A PREPARE OF THE STATEMENT, AND OPENING THE CURSOR.
*/
ADDRESS DSNREXX
"EXECSQL DECLARE C1 CURSOR FOR S1"
IF SQLCODE \= "0" THEN
DO
SAY "DECLARE CURSOR FAILED WITH SQLCODE = " SQLCODE
EXIT 8
END
"EXECSQL PREPARE S1 FROM :SQLSTMT"
IF SQLCODE < "0" THEN
DO
SAY "PREPARE FAILED WITH SQLCODE = " SQLCODE
EXIT 8
END
/* */
DO 50
PARSE PULL empcusr.
"EXECSQL OPEN C1 USING :empcusr "
IF SQLCODE \= "0" THEN
DO
SAY "OPEN FAILED WITH SQLCODE = " SQLCODE
EXIT 8
END
/* FETCH LOOP.
*/
DO UNTIL SQLCODE \= "0"
"EXECSQL FETCH C1 INTO :TESTMSG, :t2 "
IF SQLCODE = "0" THEN
DO
END
END
/* HERE THE FETCH LOOP HAS ENDED (SQLCODE <> 0), AND WE CHECK
WHY.*/
SELECT
WHEN SQLCODE = 0 THEN DO
END
WHEN SQLCODE = 100 THEN DO
END
OTHERWISE
SAY "FETCH FAILED WITH SQLCODE = " SQLCODE
```

```
SAY SQLERRMC
END
/* ALL IS WELL, SO THE CURSOR IS CLOSED.
*/
"EXECSQL CLOSE C1"
IF SQLCODE \= "0" THEN
DO
SAY "CLOSE FAILED WITH SQLCODE = " SQLCODE
END
/* END THE DO LOOP HERE */
END
/* TRACE PLACED AT END TO CATCH DATA IN ONLIN MONITOR */
trace ?I
/* CLEANUP.
*/
/* DISCONNECT FROM THE DATABASE, AND RELEASE ALLOCATIONS.
*/
ADDRESS MVS "DELSTACK"
ADDRESS DSNREXX "DISCONNECT"
S_RC = RXSUBCOM('ADD','DSNREXX','DSNREXX')
EXIT 0
INITIALIZE:
/* CHECK TO SEE IF THE REXX/Db2 COMMAND ENVIRONMENT IS
AVAILABLE */
/* IF IT IS NOT, THEN ESTABLISH IT.
*/
/* THEN CONNECT TO THE APPROPRIATE DATABASE (SUBSYSTEM)
*/
'SUBCOM DSNREXX'
IF RC THEN
S_RC = RXSUBCOM('ADD','DSNREXX','DSNREXX')
/*
*/
/* CHANGE 'DSN1' IN THE LINE BELOW TO YOUR TARGET SUBSYSTEM
*/
/*
*/
ADDRESS DSNREXX "CONNECT" "DSN1"
IF SQLCODE \= "0" THEN
DO
SAY "FAILURE TO CONNECT TO DATABASE"
EXIT 8
END
/* INITIALIZE STACK AND FREE ANY */
/* LEFT OVER ALLOCATED FILES */
ADDRESS MVS "DELSTACK"
ADDRESS MVS "NEWSTACK"
X = OUTTRAP(TRASH.) /* SUPPRESS MESSAGES */
ADDRESS TSO "FREE F(SYSUT1,SYSUT2)"
X = OUTTRAP(OFF) /* SUPPRESS MESSAGES */
/* ALLOCATE THE INPUT FILE */
/* */
ADDRESS TSO "ALLOC F(SYSUT1) DA(idinpt.text) SHR "
IF RC /=0 THEN DO
SAY "FAILURE TO ALLOCATE INPUT DATASET"
EXIT 8
END
/* READ THE INPUT FILE INTO THE STACK */
ADDRESS TSO "EXECIO * DISKR SYSUT1 (FINIS"
IF RC /=0 THEN DO
SAY "FAILURE TO READ INPUT DATASET"
EXIT 8
END
ADDRESS TSO "FREE F(SYSUT1)"
```

```
RETURN;
```

10.3.2 Running a Benchmark

There must be a certain level of control and coordination when running one of these benchmark tests. Regardless of the tool used to execute the test, there must also be a certain level of preparation to guarantee repeatability, as well as control after the test to collect the performance measurements. A performance monitoring tool such as *Detector* or *SYSVIEW for Db2* is required. At the very least, a Db2 accounting trace must be set with the appropriate classes, and there must be a means of reporting from the trace records generated. It is also possible to use the dynamic statement cache and EXPLAIN STMTCACHE ALL to collect performance metrics for the tested statements. Use an authorization ID that is unique to the testing and document the exact start and end time of each test so that the report generated from whatever tool is being used can be associated to a particular test.

1. Prepare the data for the test. This involves ensuring that the test tables have the correct data in them, are backed up if the test modifies data, and are either organized or disorganized based upon the test.
2. Prepare any input files for the test. This may involve generating the input files and/or sorting the file to simulate a particular input pattern. Make sure that there is a base copy on the input data that can be used to recreate the input if modifications are made and must eventually go back to the original.
3. Make sure the appropriate traces are set and any monitoring tools are active.
4. Flush the dynamic statement cache if the metrics stored there are to be used as test results. To flush the statement cache, run a RUNSTATS UPDATE NONE REPORT NO against each of the database objects involved in the test.
5. Make sure the machine is not currently overloaded. A busy LPAR is going to heavily impact test results. Make sure tests are run when there is some headroom so machine stress is not a significant variable. Always pay attention to in-Db2 times only when reviewing test results, but make sure to check for *not accounted for* time in the results to make sure machine stress is no a factor.
6. Flush the Db2 buffers. Especially when testing for I/O, flush the buffers before running a test. Also, make sure that objects and buffers are sized in such a way that reality is somewhat reflected when running the tests. To flush the buffers, stop and start all of the database objects involved in the test prior to executing the test.
7. Execute the benchmark test. Be sure to mark the exact start and stop time of the test so that the results can correlate with the test. Set up a Microsoft Excel document to document the tests along with the key metrics.
8. Collect the results. Put the results in a spreadsheet with full description and metrics. Include a paragraph that explains the reason for the test.

When interpreting benchmark results, make sure to examine the class 2 and class 3 measurements. There can be great variations in REXX performance, as well as any batch or online testing performed due to the workload manager settings for the test jobs or TSO address space. Repeat an identical test several times to make sure that a test that should result in consistent performance metrics actually achieves those consistent performance metrics. Make sure to keep very detailed and careful documentation, including any bar charts or graphs, so that the final results and purpose are understood.

Appendix A: Recommended Tuning Tips

Below is a collection of tips commonly brought up when discussing Db2 performance monitoring and tuning.

A.1 Start with the Given Design

It is senseless to debate how to design a database for performance. The DBAs doing a logical model have done so for a specific purpose. So there are two choices: The first is to completely abandon what has already been done and begin testing new designs based upon various hypotheses. The second is to implement the vision that has been presented and immediately begin a POC to prove where it may or may not be performance challenged. Time must be reserved in the project plan for the performance testing and any adjustments that may have to be made, but testing in a POC can happen while the application is being developed. If there is no time reserved for proving performance, then just implement the logical model and fix problems when they happen in production.

A.2 Deploy Indexes Slowly

It is easy to deploy an index as a potential solution to a performance problem. Did it really solve the problem? What is the cost of inserts and deletes to the index? Hopefully thorough performance tests are performed prior to deploying the index in production. Once indexes are deployed it is not so easy to get rid of them, especially if they are primarily accessed by dynamic SQL. The real-time statistics table SYSIBM.SYSINDEXSPACESTATS does contain a LAST_USED column which is somewhat helpful, but not perfect, as there may be a subtle enough difference to pick one index over another when the benefit is next to nothing.

A.3 Develop a Table Access Sequence

When developing an application, establish a prescribed sequence of table access for transactions that access multiple tables. If every transaction accesses tables in the same sequence, then the worst that ever happens is a transaction waits for a lock, but never deadlocks.

A.4 Update at the End

Retain all changes to tables in a transaction until the end of the transaction and then apply all of the changes at once before issuing a commit. This way, locks are held for the least amount of time possible.

A.5 Always Test Performance Changes

Every database or SQL change in the name of performance should be proven by doing both an EXPLAIN and by conducting a representative performance test. Do not rely on just the cost comparison of two EXPLAINs. A benchmark test tells the truth, and can also be used to predict actual cost savings in production.

A.6 Add Data to the Table

Are there specialized tables that are used to control the flow of an application? These may be exception tables or tables that indicate one-time processing or implement bypass processing for a given key value. If these tables are empty most of the time, but accessed quite frequently, then consider putting some dummy data in the table. This is only important if there is an index on the table that is used for access (make the table VOLATILE). Index lookaside appears to be dependent upon checking key values in a leaf page. If there is no data in the index, there are no upper bound keys to

test and so for some reason index lookaside is not activated. Therefore, the application can incur millions of getpages for an index that contains no keys. So, put some phony data in the table that is never retrieved in a query and make sure the key values are higher than anything that is requested. Then index lookaside can be used. For high volume transactions the savings can actually be quite large.

A.7 Obtain a Sponsor

Application developers do not change code in support of performance unless management backs it up. Make sure to collect performance metrics and make charts based upon performance benchmarks to demonstrate the potential savings. If the formula for converting CPU times to dollars can be obtained from the capacity planner, add it to the chart. This may inspire some sponsorship and be able to pressure development into making changes to support better performance.

A.8 Take Advantage of SQL Features

There are many SQL features that are designed specifically to reduce the number of calls to the data server. Multi-row operations, select from table expression, nested table expressions, common table expressions, triggers, stored procedures, and many more. Follow the directions in this guide to learn how to use them to reduce the number of calls being made. This is the most important directive for performance.

A.9 Use One Authid per Application

An easy way to separate Db2 accounting records by application is to assign one unique authorization ID per application. This way, summary reports can easily be created by application, regardless of whether it is static or dynamic SQL, or from a variety of sources. It also makes it much easier to identify which statements in the dynamic statement cache are from a particular application.

A.10 Add a Comment to the Statement

Place a comment in a dynamic SQL statement that contains the name of the method or program that contains the statement, to make it much easier to communicate to a developer which statement and which method it came from when you retrieve the statement text from the dynamic statement cache.

A.11 Use Query Numbers

Similar to sticking a comment in a statement, add custom query numbers to statements. This is especially good for dynamic statements, but is generally good for all statements. It makes it easier to identify statements, but also easier to employ statement level hints if needed.

A.12 Take Advantage of Cache

Cache stuff locally in the application. Cache common code values. How often do they change?

It is also recommended to cache some more commonly used reference data that changes much less frequently. Place counters in the cache that cause it to break and refresh at regular intervals. For example, if there are four warehouses in the shipping chain why query the warehouse information table for every order?

A.13 Grab Those Resources

Machines are meant to be utilized and idle time is a good time to conduct experiments or run some great report queries that utilize parallelism. Buffers need memory. Inquire about available resources with the system programmer.

A.14 Understand the Trade-Offs

Establish realistic SLAs. Make sure it is understood that flexibility and performance are at odds, and often availability is as well. Perform POCs with various configurations that favor one design option versus another and document the performance trade-offs. It is surprising how wrong conjectures can be when it comes to guessing performance.

A.15 Ensure There Is Enough zIIP Capacity

Not enough zIIP processors leads to performance degradation. No zIIP at all may be better.

A.16 Consider Acquiring a Db2 Analytics Accelerator

Combining IBM Db2 for z/OS and IBM Db2 Analytics Accelerator (IDAA) is a great and economically feasible solution when processing a large number of SQL statements for business analytics. Although not covered in detail in this guide, *Database Management for Db2 for z/OS* (Database Management) supports IBM Db2 Analytics Accelerator.

Appendix B: Database Management Solutions for Db2 for z/OS

Database Management from Broadcom provides a powerful and flexible set of tools that are designed to ensure optimal database and SQL performance, efficient administration, and reliable backup and recovery of Db2 databases, systems, and applications. With these interoperable solution suites, an enterprise can also improve service levels, data availability, and application responsiveness—helping to reduce costs.

Database Management is flexible and provides choice without giving up control. Utilize full automation where appropriate, powerful manual control is desired or use expert software-guided assistance. Reduce the cost and risk associated with Db2 version upgrades and streamline workflows, use available skill sets, make more precise updates, and improve responsiveness across complex database and application environments.

This section provides additional details about the complete set of *Database Management* from Broadcom.

B.1 Database Administration Suite

Database Administration Suite for Db2 for z/OS (Database Administration Suite) automates routine administrative tasks while keeping complete control of the database environment in the DBA's hands. It helps reduce costs, simplifies Db2 object schema and data management, and helps provide for the integrity of the Db2 environment. This solution increases database availability through automation and helps easily perform complex database administration tasks. The Database Administration Suite includes:

- ***RC/Query® for Db2 for z/OS*:** Provides catalog management capabilities and alleviates the time-consuming task of manually developing and testing specialized queries. RC/Query enables you to take immediate action-whether that means executing a command, invoking a utility or moving to another product from the *Database Management Solutions for Db2 for z/OS* product suite.
- ***RC/Update™ for Db2 for z/OS*:** Automates labor-intensive tasks related to changing Db2 objects and data. It provides a development environment for the application developer, an editor and data copy feature for the end user, and sophisticated object management facilities for the DBA. These features result in simplified database administration tasks, reduced database downtime, and increased DBA productivity.
- ***RC/Migrator™ for Db2 for z/OS*:** Provides automation that increases database availability and helps reduce the time and risk of human error involved with complex database administration tasks.
- ***RC/Compare™ for Db2 for z/OS*:** Helps compare and synchronize Db2 structures that reside on different subsystems.
- ***Fast Unload® for Db2 for z/OS*:** Helps reduce the time required to unload Db2 data, thus improving the availability of corporate data.
- ***Fast Load™ for Db2 for z/OS*:** A high-speed utility that helps load large amounts of data into Db2 tables.
- ***RC/Secure™ for Db2 for z/OS*:** A comprehensive online security administration tool for Db2 for z/OS that helps streamline and automate the tasks of Db2 security administration.
- ***Quick Copy for Db2 for z/OS*:** Provides backups of Db2 data by making single or multiple image copies at high speed.
- ***Fast Recover™ for Db2 for z/OS* (Fast Recover):** Provides the ability to quickly recover Db2 data (tablespaces and indexes) after a disaster or system failure while minimizing CPU cycles, service units, and EXCPs. Fast Recover offers significant performance advantages over other utilities, incorporating multiple advanced features that differentiate it from competing products.

B.2 Database Backup and Recovery Suite

Database Backup and Recovery Suite for Db2 for z/OS (Database Backup and Recovery Suite) enables organizations to back out a single update, support auditing of data changes, and replicate data changes to remote subsystems. Additionally, it is possible to quickly backup the data and consolidate incremental backups or accumulate log changes to produce a new backup to streamline the processing and improve the overall efficiency of the recovery jobs. These backup and recovery solutions also help to reduce the risk of a prolonged outage due to manual creation of recover jobs. *Database Backup and Recovery Suite* includes:

- ***Log Analyzer™ for Db2 for z/OS*:** A powerful product that analyzes Db2 log and SMF records to aid in auditing data changes.
- ***Recovery Analyzer™ for Db2 for z/OS*:** Simplifies complex Db2 recovery situations by automating the generation of efficient recovery jobs.
- ***Fast Recover*:** Provides the ability to quickly recover Db2 data (tablespaces and indexes) after a disaster or system failure, while minimizing CPU cycles, service units and EXCPs.
- ***Merge/Modify™ for Db2 for z/OS*:** Accelerates image copy and recovery processes to help reduce the drain on valuable CPU resources and streamline backup and recovery procedures.
- ***Quick Copy for Db2 for z/OS*:** Provides backups of Db2 data by making single or multiple image copies at high speed.

B.3 Database Performance Suite

Database Performance Suite for Db2 for z/OS (Database Performance Suite) helps increase database administrator (DBA) productivity by leveraging existing Db2 Real-Time Statistics (RTS), collecting new statistics on Db2 objects, and using them to automate Db2 housekeeping, automate utility scheduling and execution, and perform space management following user-defined thresholds. The included high-speed reorganization utility is designed to increase data availability and performance and save resources. *Database Performance Suite* includes:

- ***Database Analyzer*:** A sophisticated analysis engine that uses real-time statistics to provide graphs, trending, and forecasting information as well as a flexible scripting language to proactively take corrective actions.
- ***Rapid Reorg® for Db2 for z/OS*:** Performs quick and effective Db2 data reorganizations to help increase data availability and performance and save resources.

B.4 SQL Performance Suite

SQL Performance Suite for Db2 for z/OS (SQL Performance Suite) helps quickly identify poorly running SQL statements and recommends changes to these statements based on expert rules. The access path, SQL performance, and Db2 object usage history can be stored for future trending and analysis. Application change control procedures can automatically detect and stop an inefficient SQL statement from moving into production, saving the company money due to high CPU usage and improving customer experience by reducing the risk of slow performing applications. *SQL Performance Suite* includes:

- ***Detector*:** Provides in-depth analysis capabilities that enables the identification of programs and SQL statements that most significantly affect Db2 system performance.
- ***Subsystem Analyzer*:** Designed to save database administrators (DBAs) time by consolidating information into a clear, concise view.
- ***Plan Analyzer*:** Designed to improve Db2 performance by efficiently analyzing SQL and utilizing expert rules to offer SQL performance improvement recommendations.

B.5 SYSVIEW for Db2

SYSVIEW for Db2 is a real-time monitor that provides database administrators (DBAs) with the tools required to maximize the Db2 system and application performance. With its extensive Insight Query Language (IQL), this product can be tailored and extended to perform customized monitoring functions.

In addition, the *YSVIEW for Db2* processor detects subsystem resource utilization that has exceeded a user-defined limit and notifies DBAs about exceptions as they occur—helping DBAs take immediate corrective action, or examine a log of recent exceptions to detect trends.

SYSVIEW for Db2 uses subsystem statistics and thread accounting data to analyze the performance of new or modified applications during stress testing, before they are migrated to a production environment. In addition, this solution helps DBAs determine the cause of Db2 application performance problems and provides the information needed to tune an application.

B.6 Report Facility

Report Facility is a full-function Db2 for z/OS reporting environment that provides users with easy access to business information. The product offers a robust yet easy-to-use reporting environment that combines an SQL creation system with multiple diverse and flexible report formatting styles. It provides users with intuitive access to business data, builds the queries designed to obtain that data, and formats the data into business information documents designed to meet operational and management requirements without forfeiting any measure of control.

Appendix C: Acronyms and Abbreviations

The table below lists the acronyms and abbreviations used in this document.

Table 1: Acronyms and Abbreviations

Term	Definition
BPAM	Basic partitioned access method
BSAM	Basic sequential access method
BSDS	Bootstrap data set
DASD	Direct access storage device
DBA	Database administrator
Db2	IBM Db2 for z/OS
DML	Data manipulation language
FIC	Full image copy
IIR	Incremental image copy
JCL	Job control language
LOB	Large object
LRSN	Log record sequence number
PIT	Point-in-time
RO	Read-only
RTS	Real time statistics
RTO	Recovery time objective
RBA	Relative byte address
QSAM	Queued sequential access method
STCK	Store clock
SLA	Service level agreement
VSAM	Virtual storage access method

Revision History

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