SYBASE®

Performance and Tuning Series:
Query Processing and Abstract Plans

Adaptive Server® Enterprise

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Contents

About This Book

Audience

This book is for System and Database Administrators.

How to use this book

This book describes the query processor in Adaptive Server® Enterprise and how it is used to optimize query processing in Adaptive Server. It also describes how to create and use abstract query plans.

- Chapter 1, "Understanding Query Processing," provides an overview of the query processor in Adaptive Server Enterprise.
- Chapter 2, "Using showplan," describes the messages printed by the showplan utility.
- Chapter 3, "Displaying Query Optimization Strategies and Estimates," describes the messages printed by the set commands designed for query optimization.
- Chapter 4, "Parallel Query Processing," describes how Adaptive Server supports horizontal and vertical parallelism for query execution.
- Chapter 5, "Controlling Optimization," describes query processing options that affect the query processor's choice of join order, index, I/O size, and cache strategy
- Chapter 6, "Using Statistics to Improve Performance," explains how and when to use the commands that manage statistics.
- Chapter 7, "Introduction to Abstract Plans," reviews the basic concepts of abstract plans.
- Chapter 8, "Creating and Using Abstract Plans," provides an overview of the commands used to capture abstract plans and to associate incoming SQL queries with saved plans.
- Chapter 9, "Abstract Query Plan Guide," provides guidelines for your use in writing abstract plans.
- Chapter 10, "Managing Abstract Plans with System Procedures," provides an introduction to the basic functionality and use of system procedures for working with abstract plans.

- Chapter 11, "Query Processing Metrics,"explains what query processing metrics are, what they do, and how you can use them.

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Conventions

This section describes the conventions used in this manual.

SQL is a free-form language. There are no rules about the number of words you can put on a line or where you must break a line. However, for readability, all examples and most syntax statements in this manual are formatted so that each clause of a statement begins on a new line. Clauses that have more than one part extend to additional lines, which are indented. Complex commands are formatted using modified Backus Naur Form (BNF) notation.

Table 1 shows the conventions for syntax statements that appear in this manual:

Table 1: Font and syntax conventions for this manual

Element	Example
Command names, procedure names, utility names, and other keywords display in sans serif font.	select sp_configure
Database names and datatypes display in sans serif font.	master database
File names, variables, and path names display in italics.	*sql.ini* file *column_name* *$SYBASE/ASE* directory

Variables—or words that stand for values that you fill in—when they are part of a query or statement, display in italics in Courier font.	`select` *`column_name`*
	    `from` *`table_name`*
	    `where` *`search_conditions`*

Type parentheses as part of the command.	compute *row_aggregate* (*column_name*)
Double colon, equals sign indicates that the syntax is written in BNF notation. Do not type this symbol. Indicates “is defined as”.	`::=`
Curly braces mean that you must choose at least one of the enclosed options. Do not type the braces.	`{cash, check, credit}`
Brackets mean that you have the option to choose one or more of the enclosed choices. Do not type the brackets.	`[cash | check | credit]`
The comma means that you may choose as many of the options shown as you want. Separate your choices with commas as part of the command.	`cash, check, credit`
The pipe or vertical bar (|) means that you may select only one of the options shown.	`cash | check | credit`

An ellipsis (...) means that you can *repeat* the last unit as many times as you like.	`buy thing = price [cash | check | credit]`
	`[, thing = price [cash | check | credit]]...`
	You must buy at least one thing and give its price. You may choose a method of payment: one of the items enclosed in square brackets. You may also choose to buy additional things: as many of them as you like. For each thing you buy, give its name, its price, and (optionally) a method of payment.

- Syntax statements (displaying the syntax and all options for a command) appear as follows:

  sp_dropdevice [*device_name*]

  For a command with more options:

  select *column_name*
     from *table_name*
     where *search_conditions*

  In syntax statements, keywords (commands) are in normal font and identifiers are in lowercase. Italics show user-supplied words.

- Examples showing the use of Transact-SQL™ commands are printed like this:

```
select * from publishers
```

- Examples of output from the computer appear as follows:

```
pub_id    pub_name                  city          state
-------   ---------------------     -----------   -----
0736      New Age Books             Boston        MA
0877      Binnet & Hardley          Washington    DC
1389      Algodata Infosystems      Berkeley      CA

(3 rows affected)
```

In this manual, most of the examples are in lowercase. However, you can disregard case when typing Transact-SQL keywords. For example, SELECT, Select, and select are the same.

Adaptive Server sensitivity to the case of database objects, such as table names, depends on the sort order installed on Adaptive Server. You can change case sensitivity for single-byte character sets by reconfiguring the Adaptive Server sort order. For more information, see the *System Administration Guide*.

Accessibility features

This document is available in an HTML version that is specialized for accessibility. You can navigate the HTML with an adaptive technology such as a screen reader, or view it with a screen enlarger.

Adaptive Server 15.0 and the HTML documentation have been tested for compliance with U.S. government Section 508 Accessibility requirements. Documents that comply with Section 508 generally also meet nonU.S. accessibility guidelines, such as the World Wide Web Consortium (W3C) guidelines for Web sites.

The online help for this product is also provided in HTML, which you can navigate using a screen reader.

Note You might need to configure your accessibility tool for optimal use. Some screen readers pronounce text based on its case; for example, they pronounce ALL UPPERCASE TEXT as initials, and MixedCase Text as words. You might find it helpful to configure your tool to announce syntax conventions. Consult the documentation for your tool.

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CHAPTER 1 Understanding Query Processing

This chapter provides an overview of the query processor in Adaptive Server Enterprise.

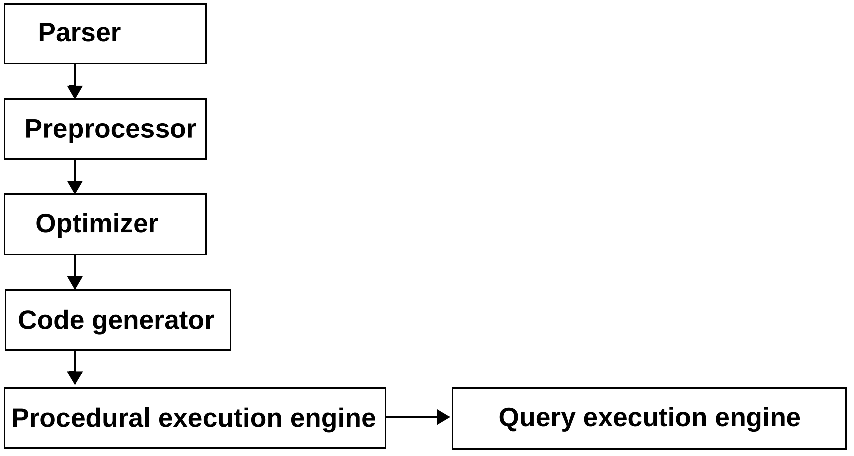
The query processor processes queries that you specify. The processor yields highly efficient query plans that execute using minimal resources and ensure that results are consistent and correct.

To process a query efficiently, the query processor uses:

- The specified query
- Statistics about the tables, indexes, and columns named in the query
- Configurable variables

To successfully process a query, the query processor must execute several steps across several modules, which are shown in Figure 1-1:

Figure 1-1: Query processor modules



- The parser converts the text of the SQL statement to an internal representation called a query tree.
- The preprocessor transforms the query tree for some types of SQL statements, such as SQL statements with subqueries and views, to a more efficient query tree.
- The optimizer analyzes the possible combinations of operations (join ordering, access and join methods, parallelism) to execute the SQL statement, and selects an efficient one based on the cost estimates of the alternatives.
- The code generator converts the query plan generated by the optimizer into a format more suitable for the query execution engine.
- The procedural engine executes command statements such as create table, execute procedure, and declare cursor directly. For data manipulation language (DML) statements, such as select, insert, delete, and update, the engine sets up the execution environment for all query plans and calls the query execution engine.
- The query execution engine executes the ordered steps specified in the query plan provided by the code generator.

Query optimizer

The query optimizer provides speed and efficiency for online transaction processing (OLTP) and operational decision-support systems (DSS). You can choose an optimization strategy that best suits your query environment.

The query optimizer is self-tuning, and requires fewer interventions than earlier versions of Adaptive Server Enterprise. It relies infrequently on worktables for materialization between steps of operations; however, more worktables may be used if the optimizer determines that hash and merge operations are more effective.

Some of the key features in the query optimizer include support for:

- New optimization techniques and query execution operator supports that enhance query performance, such as:
  - On-the-fly grouping and ordering operator support using in-memory sorting and hashing for queries with group by and order by clauses
  - hash and MergeJoin operator support for efficient join operations
  - index union and index intersection strategies for queries with predicates on different indexes

  The complete list of optimization techniques and operator support in Adaptive Server is listed in Table 1-1. Many of these techniques map directly to the operators supported in the query execution. See "Query execution engine" on page 22.
- Improved index selection, especially for joins with or clauses, and joins with and search arguments (SARGs) with mismatched but compatible datatypes.
- Improved costing that employs join histograms to prevent inaccuracies that might otherwise arise due to data skews in joining columns.
- New cost-based pruning and timeout mechanisms in join ordering and plan strategies for large, multi-way joins, and for star and snowflake schema joins.
- New optimization techniques to support data and index partitioning (building blocks for parallelism) that are especially beneficial for very large data sets.
- Improved query optimization techniques for vertical and horizontal parallelism. See Chapter 4, "Parallel Query Processing," for more details.
- Improved problem diagnosis and resolution through:

- Searchable XML format trace outputs
- Detailed diagnostic output from new set commands. See Chapter 11, “Query Processing Metrics,” for more details.

Table 1-1: Optimization techniques and operator support

Operator	Description
hash join	This physical operator supports the hash join algorithm. hash join may consume more runtime resources, but is valuable when the joining columns do not have useful indexes or when a relatively large number of rows satisfy the join condition, compared to the product of the number of rows in the joined tables.
hash union distinct	This physical operator supports the hash union distinct algorithm, which is used to remove duplicates from multiple data sources. It is used for the SQL UNION operator, as well as when removing duplicate RIDs from multiple index scans in an OR optimization. This operator is most effective when few distinct values exist, compared to the number of rows.
merge join	This physical operator supports the merge join algorithm, which relies on ordered input. merge join is most valuable when input is ordered on the merge key, for example, from an index scan. merge join is less valuable if sort operators are required to order input.
merge union all	This physical operator supports the merge algorithm for union all. merge union all maintains the ordering of the result rows from the union input. merge union all is particularly valuable if the input is ordered and a parent operator (such as merge join) benefits from that ordering. Otherwise, merge union all may require sort operators that reduce efficiency.
merge union distinct	This physical operator supports the merge algorithm for union. merge union distinct is similar to merge union all, except that duplicate rows are not retained. merge union distinct requires ordered input and provides ordered output.
nested-loop-join	This physical operator supports the nested-loop-join algorithm. It is the most common type of join method and is most useful in simple OLTP queries that do not require ordering.
append union all	This physical operator supports the append algorithm for union all, which is cheaper than the merge union all operator, since no ordering is required for inputs and, as a result, is used when no output ordering is required.
distinct hashing	This physical operator supports a hashing algorithm to eliminate duplicates, which is very efficient when there are few distinct values compared to the number of rows.
distinct sorted	This physical operator supports a single-pass algorithm to eliminate duplicates. distinct sorted relies on an ordered input stream, and may increase the number of sort operators if its input is not ordered.

Operator	Description
group sorted	This physical operator supports an on-the-fly grouping algorithm. group sorted relies on an input stream sorted on the grouping columns, and it preserves this ordering in its output.
distinct sorting	This physical operator supports the sorting algorithm to eliminate duplicates. distinct sorting is useful when the input is not ordered (for example, if there is no index) and the output ordering generated by the sorting algorithm could benefit; for example, in a merge join.
group hashing	This physical operator supports a group hashing algorithm to process aggregates.

Technique	Description
multi table store ind	Determines whether the query optimizer may use store index operator on the result of a multiple table join. Using multi table store ind may increase the use of worktables.
opportunistic distinct view	This physical operator supports a more flexible algorithm when enforcing distinctness. The operator could be used with flattened EXISTS subqueries as well as DISTINCT views or SELECT DISTINCT queries.
index intersection	This physical operator supports the intersection of multiple index scans as part of the query plan in the search space.
store index	This physical operator supports the store index algorithm (sometimes known as reformatting), which dynamically creates an index on the project restrict of a scan so that a more efficient nested loop index scan operation can be used when no useful index exists.
group inserting	This physical operator supports the group by aggregation algorithm that creates a clustered index work table on the grouping columns and evaluates the aggregate by inserting rows into the work table.
advanced aggregation	This technique attempts to reduce the number of tuples processed by joins by partially evaluating aggregates prior to joins. Also, this technique evaluates partial aggregates on each side of a union, rather than processing all the rows of a union prior to aggregating.
bushy space search	This technique increases the search space to look at more plans that could possibly improve performance. This may increase compilation time.
replicated partitioning	This technique applies only to parallel plans in which the performance of parallel nested loop joins could be helped by multiple scans of the same table in different threads.

Factors analyzed in optimizing queries

Query plans consist of retrieval tactics and an ordered set of execution steps, which retrieve the data needed by the query. In developing query plans, the query optimizer examines:

- The size of each table in the query, both in rows and data pages, and the number of OAM and allocation pages to be read.
- The indexes that exist on the tables and columns used in the query, the type of index, and the height, number of leaf pages, and cluster ratios for each index.
- The index coverage of the query; that is, whether the query can be satisfied by retrieving data from the index leaf pages without accessing the data pages. Adaptive Server can use indexes that cover queries, even if no where clauses are included in the query.
- The density and distribution of keys in the indexes.
- The size of the available data cache or caches, the size of I/O supported by the caches, and the cache strategy to be used.
- The cost of physical and logical reads; that is, reads of physical I/O pages from the disk, and of logical I/O reads from main memory.
- join clauses, with the best join order and join type, considering the costs and number of scans required for each join and the usefulness of indexes in limiting the I/O.
- Whether building a worktable (an internal, temporary table) with an index on the join columns is faster than repeated table scans if there are no useful indexes for the inner table in a join.
- Whether the query contains a max or min aggregate that can use an index to find the value without scanning the table.
- Whether data or index pages must be used repeatedly, to satisfy a query such as a join, or whether a fetch-and-discard strategy should be employed to avoid flushing of the buffer cache of useful pages of other tables, since the pages of this table need to be scanned only once.

For each plan, the query optimizer determines the total cost by computing the costs of logical and physical I/Os, and CPU processing. If there are proxy tables, additional network related costs are evaluated as well. The query optimizer then selects the cheapest plan.

Statements in a stored procedure or trigger are optimized when the respective statements are first executed, and the query plan is stored in the procedure cache. If a respective statement is not executed, then it will not be optimized until a later execution of the stored procedure in which the statement is executed. If other users execute the same procedure while an unused instance of a stored procedure resides in the cache, then that instance is used, and previous executed statements in that stored procedure are not recompiled.

Transformations for query optimization

After a query is parsed and preprocessed, but before the query optimizer begins its plan analysis, the query is transformed to increase the number of clauses that can be optimized. The transformation changes made by the optimizer are transparent unless the output of such query tuning tools as showplan, dbcc(200), statistics io, or the set commands is examined. If you run queries that benefit from the addition of optimized search arguments, the added clauses are visible. In showplan output, these clauses appear as "Keys are" messages for tables for which you specify no search argument or join.

Search arguments converted to equivalent arguments

The optimizer looks for query clauses to convert to the form used for search arguments. These are listed in Table 1-2.

Table 1-2: Search argument equivalents

Clause	Conversion
between	Converted to >= and <= clauses. For example, between 10 and 20 is converted to >= 10 and <= 20.
like	If the first character in the pattern is a constant, like clauses can be converted to greater than or less than queries. For example, like "sm%" becomes >= "sm" and < "sn". If the first character is a wildcard, a clause such as like "%x" cannot use an index for access, but histogram values can be used to estimate the number of matching rows.
in(values_list)	Converted to a list of OR queries, that is, int_col in (1, 2, 3) becomes int_col = 1 or int_col = 2 or int_col = 3. If the number of IN list elements is less than 40 then the optimizer uses OR optimization. If the number of elements is greater than 40, then the optimizer models this as a work table of values which is joined to the column associated with the IN list. There is no limit on the number of members in the IN list.

Search argument transitive closure applied where applicable

The optimizer applies transitive closure to search arguments. For example, the following query joins titles and titleauthor on title_id and includes a search argument on titles.title_id:

```
select au_lname, title
from titles t, titleauthor ta, authors a
where t.title_id = ta.title_id
        and a.au_id = ta.au_id
        and t.title_id = "T81002"
```

This query is optimized as if it also included the search argument on titleauthor.title_id:

```
select au_lname, title
from titles t, titleauthor ta, authors a
where t.title_id = ta.title_id
        and a.au_id = ta.au_id
        and t.title_id = "T81002"
        and ta.title_id = "T81002"
```

With this additional clause, the query optimizer can use index statistics on titles.title_id to estimate the number of matching rows in the titleauthor table. The more accurate cost estimates improve index and join order selection.

equijoin predicate transitive closure applied where applicable

The optimizer applies transitive closure to join columns for a normal equijoin. The following query specifies the equijoin of t1.c11 and t2.c21, and the equijoin of t2.c21 and t3.c31:

```
select *
from t1, t2, t3
where t1.c11 = t2.c21
      and t2.c21 = t3.c31
      and t3.c31 = 1
```

Without join transitive closure, the only join orders considered are (t1, t2, t3), (t2, t1, t3), (t2, t3, t1),and (t3, t2, t1). By adding the join on t1.c11 = t3.c31, the query processor expands the list of join orders with these possibilities: (t1, t3, t2) and (t3, t1, t2). Search argument transitive closure applies the condition specified by t3.c31 = 1 to the join columns of t1 and t2.

Similarly, equijoin transitive closure is also applied to equijoins with or predicates as follows:

```
select *
from R,S
where R.a = S.a
and (R.a = 5 OR S.b = 6)
```

The query optimizer infers that the following query would be equivalent to:

```
select *
from R,S
where R.a = S.a
and (S.a = 5 or S.b = 6)
```

The or predicate could be evaluated on the scan of S and possibly be used for an or optimization, thereby using the indexes of S very effectively.

Another example of join transitive closure is its application to nonsimple SARGs, so that a query such as:

```
select *
from R,S
where R.a = S.a and (R.a + S.b = 6)
```

is transformed and inferred as:

```
select *
from R,S
where R.a = S.a
and (S.a + S.b = 6)
```

The complex predicate could be evaluated on the scan of S, resulting in significant performance improvements due to early result-set filtering.

Transitive closure is used only for normal equijoins, as shown. join transitive closure is not performed for:

- Nonequijoins; for example, t1.c1 > t2.c2
- Outer joins; for example t1.c11 *= t2.c2, or left join or right join
- joins across subquery boundaries
- joins used to check referential integrity or the with check option on views

---

Note As of Adaptive Server Enterprise 15.0, the sp_configure option to turn on or off join transitive closure and sort merge join has been discontinued. Whenever applicable, join transitive closure is always applied in Adaptive Server Enterprise 15.0 and later.

Predicate transformation and factoring to provide additional optimization paths

Predicate transformation and factoring increases the number of choices available to the query processor by adding clauses that can be optimized to a query by extracting clauses from blocks of predicates linked with or into clauses linked by and. The additional optimized clauses mean that there are more access paths available for query execution. Whenever possible, the original OR predicate is modified to reduce the redundant filtering, which also reduces the CPU consumption.

All of the clauses optimized in this sample query are enclosed in the or clauses:

```
select p.pub_id, price
from publishers p, titles t
```

```
where (
     t.pub_id = p.pub_id
     and type = "travel"
     and price between 15 and 30
     and p.pub_id in ("P220", "P583", "P780")
     )
or  (
     t.pub_id = p.pub_id
     and type = "business"
     and price between 15 and 50
     and p.pub_id in ("P651", "P066", "P629")
     )
```

During predicate transformation:

1 Simple predicates (joins, search arguments, and in lists) that are an exact match in each or clause are extracted. In the sample query, this clause matches exactly in each block, so it is extracted:

   ```
   t.pub_id = p.pub_id
   ```

   between clauses are converted to greater-than-or-equal and less-than-or-equal clauses before predicate transformation. The sample query uses between 15 in both query blocks (though the end ranges are different). The equivalent clause is extracted by step 1:

   ```
   price >=15
   ```

2 Search arguments on the same table are extracted; all terms that reference the same table are treated as a single predicate during expansion. Both type and price are columns in the titles table, so the extracted clauses are:

   ```
   (type = "travel" and price >=15 and price <= 30)
   or
   (type = "business" and price >= 15 and price <= 50)
   ```

3 in lists and or clauses are extracted. If there are multiple in lists for a table within a block, only the first is extracted. The extracted lists for the sample query are:

   ```
   p.pub_id in ("P220", "P583", "P780")
   or
   p.pub_id in ("P651", "P066", "P629")
   ```

   Since these steps can overlap and extract the same clause, duplicates are eliminated.

   Each generated term is examined to determine whether it can be used as an optimized search argument or a join clause. Only those terms that are useful in query optimization are retained.

The additional clauses are added to the query clauses specified by the user.

Predicate transformation pulls clauses linked with AND from blocks of clauses linked with OR, such as those shown above. It extracts only clauses that occur in all parenthesized blocks. If the example above had a clause in one of the blocks linked with OR that did not appear in the other clause, that clause would not be extracted.

Handling search arguments and useful indexes

It is important to distinguish between where and having clause predicates that can be used to optimize the query, and those that are used later during query processing to filter the returned rows.

You can use search arguments to determine the access path to the data rows when a column in the where clause matches an index key. The index can be used to locate and retrieve the matching data rows. Once the row has been located in the data cache or has been read into the data cache from disk, any remaining clauses are applied.

For example, if the authors table has an index on au_lname and another on city, either index can be used to locate the matching rows for this query:

```
select au_lname, city, state
from authors
where city = “Washington”
and au_lname = “Catmull”
```

The query optimizer uses statistics (including histograms), the number of rows in the table, the index heights, and the cluster ratios for the index and data pages to determine which index provides the cheapest access. The index that provides the cheapest access to the data pages is chosen and used to execute the query, and the other clause is applied to the data rows once they have been accessed.

Nonequality operators

The query optimizer checks whether the index contains all columns necessary to satisfy the query without accessing the data row, and uses a covered index scan if this is the case. However, if the index does not cover the query, the table is accessed through a row ID lookup of the data pages during the index scan.

Examples of search argument optimization

Shown below are examples of clauses that can be fully optimized. If there are statistics on these columns, they can be used to help estimate the number of rows the query will return. If there are indexes on the columns, the indexes can be used to access the data.

```
au_lname = “Bennett”
price >= $12.00
advance > $10000 and advance < $20000
au_lname like "Ben%" and price > $12.00
```

A row filtering estimate on the following single attribute predicates is made if the histogram is available on the respective attributes advance and au_lname. However, these predicates are not optimized as limiting SARGs unless a function index is built on them, since SARGs cannot have operations involving the column name.

```
advance * 2 = 5000  /*expression on column side
                      not permitted */
substring(au_lname,1,3) = "Ben" /* function on
                      column name */
```

However, the two clauses above can be optimized as SARGs if they are rewritten in this form:

```
advance = 5000/2
au_lname like "Ben%”
```

Consider this query, with the only index on au_lname:

```
select au_lname, au_fname, phone
from authors
where au_lname = “Gerland”
and city = “San Francisco”
```

SARGs provide a performance advantage since they can be evaluated deep in the data manager directly on the data or index page, whereas other, more complex, expression predicates need extra processing for their evaluation. A limiting SARG reduces the number of rows scanned on an index; a filtering SARG does not reduce the number of rows scanned, but instead reduces the number of rows selected during the scan.

The clause on au_lname qualifies as a limiting SARG, since an index exists on this column, which can use this predicate for positioning to limit the index rows scanned.

```
au_lname = “Gerland”
```

- There is an index on au_lname.

- There are no functions or other operations on the column name.
- The operator is a valid SARG operator.

The clause city = "San Francisco" matches all the criteria above except the first; there is no index on the city column, so this clause is considered to be a filtering SARG. In this case, the index on au_lname is used for the query. All data pages with a matching last name are brought into cache, and each matching row is examined to see if the city matches the search criteria.

Handling *joins*

The query optimizer deals with join predicates the same way it deals with search arguments, in that it uses statistics, number of rows in the table, index heights, and the cluster ratios for the index and data pages to determine which index and join method provides the cheapest access. In addition, the query optimizer also uses join density estimates derived from join histograms that give accurate estimates of qualifying joining rows and the rows to be scanned in the outer and inner tables. The query optimizer also must decide on the optimal join ordering that will yield the most efficient query plan. The next sections describe the key techniques used in processing joins.

join density and *join* histograms

The query optimizer uses a cost model for joins that use table-normalized histograms of the joining attributes. This technique gives an exact value for the skewed values (that is, frequency count) and uses the range cell densities from each histogram to estimate the cell counts of corresponding range cells.

The join density is dynamically computed from the "join histogram," which considers the joining of histograms from both sides of the join operator. The first histogram join occurs typically between two base tables when both attributes have histograms. Every histogram join creates a new histogram on the corresponding attribute of the parent join's projection.

The outcome of the join histogram technique is accurate join selectivity estimates, even if data distributions of the joining columns are skewed, resulting in superior join orders and performance.

joins with mixed datatypes

A basic requirement is the ability to build keys for index lookups whenever possible, without regard to mixed datatypes of any of the join predicates versus the index key. Consider the following query:

```
create table T1 (c1 int, c2 int)
create table T2 (c1 int, c2 float)
create index i1 on T1(c2)
create index i1 on T2(c2)

select * from T1, T2 where T1.c2=T2.c2
```

Assume that T1.c2 is of type int and has an index on it, and that T2.c2 is of type float with an index.

As long as datatypes are implicitly convertible, index scans can be gainfully used to process the join. In other words, the query optimizer will use the column value from the outer table to position the index scan on the inner table, even when the lookup value from the outer table has a different datatype than the respective index attribute of the inner table.

joins with expressions and *or* predicates

See "Predicate transformation and factoring to provide additional optimization paths" on page 9 for description of how the query optimizer handles joins with expressions and or predicates

join ordering

One of the key tasks of the query optimizer is to generate a query plan for join queries so that the order of the relations in the joins processed during query execution is optimal. This involves elaborate plan search strategies that can consume significant time and memory. The query optimizer uses several effective techniques to obtain the optimal join ordering. The key techniques are:

- Use of a "greedy strategy" to obtain an initial good ordering that can be used as an upper boundary to prune out other, subsequent join orderings. The greedy strategy employs join row estimates and the nested-loop-join method to arrive at the initial ordering.
- An exhaustive ordering strategy follows the greedy strategy. A potentially better join ordering replaces the join ordering obtained in the greedy strategy. This ordering may employ any join method associated with the current active optimization goal.

- Use of extensive cost-based and rule-based pruning techniques eliminates undesirable join orders from consideration. The key aspect of the pruning technique is that it always compares partial join orders (the prefix of a potential join ordering) against the best complete join ordering to decide whether to proceed with the given prefix. This significantly improves the time required determine an optimal join order.
- The query optimizer can recognize and process star or snowflake schema joins and process their join ordering in the most efficient way. A typical star schema join involves a large fact table that has equijoin predicates that join it with several dimension tables. The dimension tables have no join predicates connecting each other; that is, there are no joins between the dimension tables themselves, but there are join predicates between the dimension tables and the fact table. The query optimizer employs special join ordering techniques during which the large fact table is pushed to the end of the join order and the dimension tables are pulled up front, yielding highly efficient query plans. The query optimizer will not, however, use this technique if the star schema joins contain subqueries, outer joins or or predicates.

Optimization goals

Optimization goals are a convenient way to match query demands with the best optimization techniques, thus ensuring optimal use of the optimizer's time and resources. The query optimizer allows you to configure two types of optimization goals, which you can specify at three levels: server, session, and query.

Set the optimization goal at the desired level. The server-level optimization goal is overridden at the session level, which is overridden at the query level.

These optimization goals allow you to choose an optimization strategy that best fits your query environment:

- allrows_oltp – this goal attempts to reduce any query processing behavior changes when upgrading from pre-15.0 releases.
- allrows_mix – the default goal, and the most useful goal in a mixed-query environment. This goal balances the needs of OLTP and DSS query environments.
- allrows_dss – the most useful goal for operational DSS queries of medium-to-high complexity.

At the server level, use sp_configure. For example:

```
sp_configure optimization goal", 0, "allrows_mix"
```

At the session level, use set plan optgoal. For example:

```
set plan optgoal allrows_dss
```

At the query level, use the select or other DML command. For example:

```
select * from A order by A.a plan
   "(use optgoal allrows_dss)"
```

Exceptions

In general, you can set query-level optimization goals using select, update, and delete statements. However, you cannot set query-level optimization goals in pure insert statements, although you can set optimization goals in insert…select statements.

Limiting the time spent optimizing a query

Long-running and complex queries can be time-consuming and costly to optimize. The timeout mechanism helps to limit that time while supplying a satisfactory query plan. The query optimizer provides a mechanism by which the optimizer can limit the time taken by long-running and complex queries; timing out allows the query processor to stop optimizing when it is reasonable to do so.

However, changing timeout values should be a last resort, as there are usually better alternatives to try. For example, make sure statistics exist (by using the show_missing_stats set command) and are up to date, since poor or missing statistics can result is overestimating costs which could result in excessive optimization time as the optimizer tries to find a better plan, even though the current best plan may actually execute quickly. Another solution for reducing compilation time, rather than reducing the timeout, is to turn on the statement cache so that queries that are re-executed frequently are only optimized once and cached. Another solution for complex queries could be to use allrows_oltp, which reduces the options considered during optimization. Yet another solution for reducing compilation time rather than reducing timeout is to use abstract plans. This effectively skips the optimizer and can be used if current performance is acceptable and it is anticipated that the data distribution changes are minimal or will not affect the query plans.

The optimizer triggers timeout during optimization when both these circumstances are met:

- At least one complete plan has been retained as the best plan.
- The user-configured timeout percentage limit has been exceeded.

You can limit the amount of time Adaptive Server spends optimizing a query at every level, setting the optimization timeout limit parameter to a value between 0 and 1000. The optimization timeout limit parameter represents the percentage of estimated query execution time that Adaptive Server must spend to optimize the query. For example, specifying a value of 10 tells Adaptive Server to spend 10% of the estimated query execution time in optimizing the query. Similarly, a value of 1000 tells Adaptive Server to spend 1000% of the estimated query execution time, or 10 times the estimated query execution time, in optimizing the query.

A separate configuration parameter, sproc optimize timeout limit, is used for stored procedures. It has a default value of 40 and a maximum value of 4000. Since a stored procedure is usually cached, it is worthwhile to spend more time looking for better plans for complex queries, since a procedure is optimized once and then cached for reuse.

A large timeout value may be useful for optimization of stored procedures with complex queries. It is expected that the longer optimization time of the stored procedures will yield better plans; the longer optimization time can be amortized over several executions of the stored procedure.

A small timeout value may be used when a faster compilation time is wanted from complex ad-hoc queries that normally take a long time to compile. However, for most queries, the default timeout value of 10 should suffice.

Use sp_configure to set the optimization timeout limit configuration parameter at the server level. For example, to limit optimization time to 10% of total query processing time, enter:

```
sp_configure "optimization timeout limit", 10
```

Use set to set optimization time at the session level:

```
set plan opttimeoutlimit <n>
```

Where *n* is any integer between 0 and 1000.

Use select to limit optimization time at the query level:

```
select * from <table> plan "(use opttimeoutlimit <n>)"
```

Where *n* is any integer between 0 and 1000. 0 is used to indicate that no timeout should be used, which could take hours to optimize queries with 20 or more tables if no low cost plan is found.

Table 1-3: Optimization timeout limit

Summary information	
Default value	10
Range of values	0 – 1000
Status	Dynamic
Display level	Comprehensive
Required role	System Administrator

Parallelism

Adaptive Server supports horizontal and vertical parallelism for query execution. Vertical parallelism is the ability to run multiple operators at the same time by employing different system resources such as CPUs, disks, and so on. Horizontal parallelism is the ability to run multiple instances of an operator on the specified portion of the data.

See Chapter 4, "Parallel Query Processing," for a more detailed discussion of parallel query optimization in Adaptive Server.

Optimization issues

Although the query optimizer can optimize most queries efficiently, there are some optimization issues:

- If statistics have not been updated recently, the actual data distribution may not match the values used to optimize queries.
- The rows referenced by a specified transaction may not fit the pattern reflected by the index statistics.
- An index may access a large portion of the table.
- where clauses (SARGS) may be written in a form that cannot be optimized.

- No appropriate index exists for a critical query.
- A stored procedure was compiled before significant changes to the underlying tables were performed.
- No statistics exists for the SARG or joining columns.

Use the set option show_missing_stats on command before you execute a problem query to determine if there are any statistics that the optimizer could have used that were not available. Use update statistics, if possible, to eliminate the missing statistics warnings.

These situations highlight the need to follow some best practices that will allow the query optimizer to perform at its full potential. Some of the practices that you may choose to employ are discussed below.

Create search arguments

When you write search arguments for your queries:

- Avoid functions, arithmetic operations, and other expressions on the column side of search clauses. When possible, move functions and other operations to the expression side of the clause.
- Use all the search arguments you can to give the query processor as much as possible to work with.
- If a query has more than 400 predicates for a table, place the most potentially useful clauses near the beginning of the query. (All of the search conditions are used to qualify the rows.)
- Queries using > (greater than) may perform better if you can rewrite them to use >= (greater than or equal to). For example, this query, with an index on int_col, uses the index to find the first value where int_col equals 3, and then scans forward to find the first value that is greater than 3. If there are many rows where int_col equals 3, the server must scan many pages to find the first row where int_col is greater than 3:

  ```
  select * from table1 where int_col > 3
  ```

  It is more efficient to write the query this way:

  ```
  select * from table1 where int_col >= 4
  ```

  However, this optimization is more difficult with character strings and floating-point data.
- Check the showplan output to see which keys and indexes are used.

- If an index is not being used when you expect it to be, use output from the set commands in Table 1-4 and Table 1-6 to see whether the query processor is considering the index.The set commands and options shown in these tables save diagnostic information to a file.

Table 1-4: set commands

set command	Arguments
set show_sqltext	on | off
set showplan	on | off
set statistics io	on | off
set statistics time	on | off
set statistics plancost	on | off

Table 1-5: set options

set option	Arguments
set option show	normal | brief | long | on | off
set option show_lop	normal | brief | long | on | off
set option show_parallel	normal | brief | long | on | off
set option show_search_engine	normal | brief | long | on | off
set option show_counters	normal | brief | long | on | off
set option show_managers	normal | brief | long | on | off
set option show_histograms	normal | brief | long | on | off
set option show_abstract_plan	normal | brief | long | on | off
set option show_best_plan	normal | brief | long | on | off
set option show_code_gen	normal | brief | long | on | off
set option show_pio_costing	normal | brief | long | on | off
set option show_lio_costing	normal | brief | long | on | off
set option show_log_props	normal | brief | long | on | off
set option show_elimination	normal | brief | long | on | off

Use SQL-derived tables

Queries expressed as a single SQL statement make better use of the query processor than queries expressed in two or more SQL statements. SQL-derived tables enable you to express, in a single step, what might otherwise require several SQL statements and temporary tables, especially where intermediate aggregate results must be stored. For example:

```
select dt_1.* from
    (select sum(total_sales)
          from titles_west group by total_sales)
                 dt_1(sales_sum),
    (select sum(total_sales)
```

```
            from titles_east group by total_sales)
                  dt_2(sales_sum)
where dt_1.sales_sum = dt_2.sales_sum
```

Here, aggregate results are obtained from the SQL-derived tables dt_1 and dt_2, and a join is computed between the two SQL-derived tables. Everything is accomplished in a single SQL statement.

For more information on SQL-derived tables, see the *Transact-SQL User's Guide*.

Tune according to object sizes

To understand query and system behavior, know the sizes of your tables and indexes. At several stages of tuning work, you need size data to:

- Understand statistics i/o reports for a specific query plan.
- Understand the query processor's choice of query plan. The Adaptive Server cost-based query processor estimates the physical and logical I/O required for each possible access method and selects the cheapest method.
- Determine object placement, based on the sizes of database objects and on the expected I/O patterns on the objects.

  To improve performance, distribute database objects across physical devices, so that reads and writes to disk are evenly distributed.

  Object placement is described in Chapter 5, “Controlling Physical Data Placement,” in *Performance and Tuning: Basics*.
- Understand changes in performance. If objects grow, their performance characteristics can change. For example, consider a table that is heavily used and is usually 100% cached. If the table grows too large for its cache, queries that access the table can suffer poor performance. This is particularly true of joins that require multiple scans.
- Do capacity planning. Whether you are designing a new system or planning for the growth of an existing system, you must know the space requirements to plan for physical disks and memory needs.
- Understand output from Adaptive Server Monitor Server and from sp_sysmon reports on physical I/O.

See the *System Administration Guide* for more information on sizing.

Query execution engine

In Adaptive Server, all query plans are submitted to the procedural execution engine. The procedural execution engine drives execution of the query plan by:

- Directly executing simple SQL statements such as set, while, and goto.
- Calling out to the utility modules to execute create table, create index, and other utility commands.
- Setting up the context for and driving the execution of stored procedures and triggers.
- Setting up the execution context and calling the query execution engine to execute query plans for select, insert, delete, and update statements.
- Setting up the cursor execution context for cursor open, fetch and close statements and calling the query execution engine to execute these statements.
- Doing transaction processing and post execution cleanup.

To support the demands of today's applications, a new generation of query execution techniques is required. To meet that demand, the query execution engine has been completely rewritten. With a new query execution engine and query optimizer in place, the procedural execution engine in Adaptive Server 15.0 passes all query plans generated by the new query optimizer to the query execution engine.

The query execution engine executes query plans. All query plans chosen by the optimizer are compiled into query plans. However, SQL statements that are not optimized, such as set or create, are compiled into query plans like those in versions of Adaptive Server earlier than 15.0, and are not executed by the query execution engine. Earlier query plans are either executed by the procedural execution engine or by utility modules called by the procedural engine. Adaptive Server version 15.0 has two distinct kinds of query plans and this is clearly seen in the showplan output (see Chapter 2, "Using showplan.")

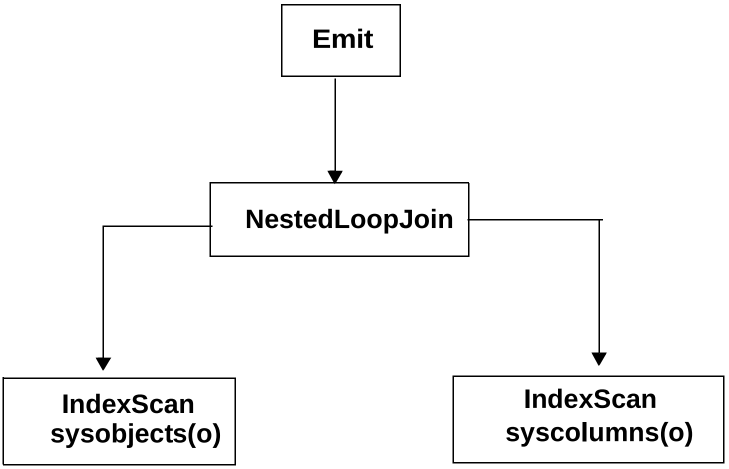
Query plans

A query plan is built as an upside down tree of operators: The top operator can have one or more child operators, which in turn can have one or more child operators, and so on, thus building a bottom-up tree of operators. The exact shape of the tree and the operators in it are chosen by the optimizer.

An example of a query plan for the following query is shown in Figure 1-2 below:

```
select o.id from sysobjects o, syscolumns c
where o.id = c.id and o.id < 2
```

Figure 1-2: Query plan



The query plan for this query consists of four operators. The top operator is an Emit (also called Root) operator that dispatches the results of query execution either by sending the rows to the client or by assigning values to local variables.

The only child operator of the Emit is a NestedLoopJoin (NLJoin) that uses the nested-loop-join algorithm to join the rows coming from its two child operators, (1) the scan of sysobjects and (2) the scan of syscolumns.

Since the optimizer optimizes all select, insert, delete, and update statements, these are always compiled into query plans and executed by the query engine.

Some SQL statements are compiled into hybrid query plans. Such plans have multiple steps, some of which are executed by the utility modules and a final step that is a query plan. An example is the select into statement; select into is compiled into a two-step query plan. The first step is a create table step to create the target table of the statement. The second step is a query plan to insert the rows into the target table. To execute this query plan, the procedural execution engine calls the create table utility to execute the first step to create the table. Then the procedural engine calls the query execution engine to execute the query plan to select and insert the rows into the target table. The two other SQL statements that generate hybrid query plans are alter table (but only when data copying is required) and reorg rebuild.

A query plan is also generated and executed to support bcp. The support for bcp in Adaptive Server has always been in the bcp utility. In version 15.0 and later, the bcp utility generates a query plan and calls the query execution engine to execute the plan.

More examples of query plans can be found in Chapter 2, "Using showplan."

Query plan operators

The query plans are built of operators. Each operator is a self-contained software object that implements one of the basic physical operations that the optimizer uses to build query plans. Each operator has five methods that can be called by its parent operator. These five methods correspond to the five phases of query execution and are called Acquire, Open, Next, Close, and Release. Because the query plan operators all provide the same methods (that is, the same APIs), they can be interchanged like building blocks in a query plan. The NLJoin operator in Figure 1-1 on page 2 can be replaced by a MergeJoin operator or a HashJoin operator without impacting any of the other three operators in the query plan.

The query plan operators that can be chosen by the optimizer to build query plans are listed in Table 1-6:

Table 1-6: Query plan operators

Operator	Description
BulkOp	Executes the part of bcp processing that is done in the query engine. Only found in query plans that are created by the bcp utility, not those created by the optimizer.
CacheScanOp	Reads rows from an in-memory table.
DelTextOp	Deletes text page chains as part of the alter table drop column processing.
DeleteOp	Deletes rows from a local table. Deletes rows from a proxy table when the entire SQL statement cannot be shipped to the remote server. See also RemoteScanOp.
EmitOp (RootOp)	Routes query execution result rows. Can send results to the client or assign result values to local variables or fetch into variables. An EmitOp is always the top operator in a query plan.
EmitExchangeOp	Routes result rows from a subplan that is executed in parallel to the ExchangeOp in the parent plan fragment. EmitExchangeOp always appears directly under an ExchangeOp. See Chapter 4, "Parallel Query Processing."
GroupSortedOp (Aggregation)	Performs vector aggregation (group by) when the input rows are already sorted on the group-by columns. See also HashVectorAggOp.
GroupSorted (Distinct)	Eliminates duplicate rows. Requires the input rows to be sorted on all columns. See also HashDistinctOp and SortOp (Distinct).

Operator	Description
HashVectorAggOp	Performs vector aggregation (group by). Uses a Hash algorithm to group the input rows, so no requirements on ordering of the input rows. See also GroupSortedOp (Aggregation).
HashDistinctOp	Eliminates duplicate rows using a hashing algorithm to find duplicate rows. See also GroupSortedOp (Distinct) and SortOp (Distinct).
HashJoinOp	Performs a join of two input row streams using the HashJoin algorithm.
HashUnionOp	Performs a union operation of two or more input row streams using a hashing algorithm to find and eliminate duplicate rows. See also MergeUnionOp and UnionAllOp.
InsScrollOp	Implements extra processing needed to support insensitive scrollable cursors. See also SemiInsScrollOp.
InsertOp	Inserts rows to a local table. Inserts rows to a proxy table when the entire SQL statement cannot be shipped to the remote server. See also RemoteScanOp.
MergeJoinOp	Performs a join of two streams of rows that are sorted on the joining columns using the merge join algorithm.
MergeUnionOp	Performs a union or union all operation on two or more sorted input streams. Guarantees that the output stream retains the ordering of the input streams. See also HashUnionOp and UnionAllOp.
NestedLoopJoinOp	Performs a join of two input streams using the NestedLoopJoin algorithm.
NaryNestedLoopJoinOp	Performs a join of three or more input streams using an enhanced NestedLoopJoin algorithm. This operator replaces a left-deep tree of NestedLoopJoin operators and can lead to significant performance improvements when rows of some of the input streams can be skipped.
OrScanOp	Inserts the in or or values into an in-memory table, sorts the values, and removes the duplicates.Then returns the values, one at a time. Used only for SQL statements with in clauses or multiple or clauses on the same column.
PtnScanOp	Reads rows from a local table (partitioned or not) using either a table scan or an index scan to access the rows.
RIDJoinOp	Receives one or more row identifiers (RIDs) from its left child operator and calls on its right child operator (PtnScanOp) to find the corresponding rows. Used only on SQL statements with or clauses on different columns of the same table.
RIFilterOp (Direct)	Drives the execution of a subplan to enforce referential integrity constraints that can be checked on a row-by-row basis. Appears only in insert, delete, or update queries on tables with referential integrity constraints.
RIFilterOp (Deferred)	Drives the execution of a subplan to enforce referential integrity constraints that can be checked only after all rows that will be affected by the query have been processed.

Operator	Description
RemoteScanOp	Accesses proxy tables. The RemoteScanOp can: • Reads rows from a single proxy table for further processing in a query plan on the local host. • Passes complete SQL statements to a remote host for execution: insert, delete, update, and select statements. In this case, the query plan will consist of an EmitOp with a RemoteScanOp as its only child operator. • Passes an arbitrarily complex query plan fragment to a remote host for execution and read in the result rows (function shipping).
RestrictOp	Evaluates expressions.
SQFilterOp	Drives the execution of a subplan to execute one or more subqueries.
ScalarAggOp	Performs scalar aggregation, such as aggregates without group by.
SemiInsScrollOp	Performs extra processing to support semiinsensitive scrollable cursors. See also InsScrollOp.
SequencerOp	Enforces sequential execution of different subplans in the query plan.
SortOp	Sorts its input rows based upon specified keys.
SortOp (Distinct)	Sorts its input and removes duplicate rows. See also HashDisitnctOp and GroupSortedOp (Distinct).
StoreOp	Creates and coordinates the filling of a worktable, and creates a clustered index on the worktable if required. StoreOp can have only InsertOp as a child; InsertOp populates the worktable.
UnionAllOp	Performs a union all operation on two or more input streams. See also HashUnionOp and MergeUnionOp.
UpdateOp	Changes the value of columns in rows of a local table or of a proxy table when the entire update statement cannot be sent to the remote server. See also RemoteScanOp.
ExchangeOp	Enables and coordinates parallel execution of query plans. The ExchangeOp can be inserted between almost any two query plan operators in a query plan to divide the plan into subplans that can be executed in parallel. See Chapter 4, “Parallel Query Processing.”

Query plan execution

Execution of a query plan involves five phases:

1. Acquire – acquires resources needed for execution, such as memory buffers and worktables.
2. Open – prepares to return result rows.
3. Next – generates the next result row.
4. Close – cleans up; for example, notifies the access layer that scanning is complete, or truncate worktables.

5 Release – releases resources obtained during the acquire phase, such as memory buffers and worktables.

Each operator has a method with the same name as the phase, which is invoked for each of these phases.

The query plan in Figure 1-2 on page 23 demonstrates query plan execution:

- Acquire phase

  The Acquire method of the Emit operator is invoked. The Emit operator calls Acquire on its child, the NLJoin operator, which in turn calls Acquire on its left child operator (the index scan of *sysobjects*) and then on its right child operator (the index scan of *syscolumns*).

- Open phase

  The Open method of the Emit operator is invoked. The Emit operator calls Open on the NLJoin operator, which calls Open only on its left child operator.

- Next phase

  The Next method of the Emit operator is invoked. Emit calls Next on the NLJoin operator, which calls Next on its left child, the index scan of *sysobjects*. The index scan operator reads the first row from *sysobjects* and returns it to the NLJoin operator. The NLJoin operator then calls the Open method of its right child operator, the index scan of *syscolumns*. Then the NLJoin operator calls the Next method of the index scan of *syscolumns* to get a row that matches the joining key of the row from *sysobjects*. When a matching row has been found, it is returned to the Emit operator, which sends it back to the client. Repeated invocations of the Next method of the Emit operator generate more result rows.

- Close phase

  After all rows have been returned, the Close method of the Emit operator is invoked, which in turn calls Close of the NLJoin operator, which in turn calls Close on both of its child operators.

- Release phase

  The Release method of the Emit operator is invoked and the calls to the Release method of the other operators is propagated down the query plan.

After successfully completing the Release phase of execution, the query engine returns control to the procedural execution engine for final statement processing.

CHAPTER 2 # Using *showplan*

This chapter describes the messages printed by the showplan utility, which displays the query plan in a text-based format for each SQL statement in a batch or stored procedure.

Displaying a query plan

To see query plans, use:

```
set showplan on
```

To stop displaying query plans, use:

```
set showplan off
```

You can use showplan in conjunction with other set commands.

To display query plans for a stored procedure, but not execute them, use the set fmtonly command.

See Chapter 4, "Query Tuning Tools" in the *Performance and Tuning: Optimizer and Abstract Plans* for information on how options interact.

Note Do not use set noexec with stored procedures—compilation and execution does not occur and you do not receive the necessary output.

Query plans in Adaptive Server Enterprise 15.0

In Adaptive Server, there are two kinds of query plans:

- Legacy query plans from versions earlier than 15.0 are still used for SQL statements that are not executed by the query engine, such as set or create table, and so on.
- In version 15.0 and later, the query plans chosen by the optimizer are executed by the query execution engine.

The legacy query plans are unchanged in Adaptive Server 15.0, and their showplan output is also unchanged.

The query plans that are executed by the query engine are different from those executed by the query engine in versions of Adaptive Server earlier than 15.0. The corresponding showplan output has changed significantly as well. Some of the new features of the query plans that showplan must display include:

- Plan elements – query plans can be composed from over thirty different operators.
- Plan shape – query plans are upside down trees of operators. In general, more operators in a query plan results in more combinations of possible tree shapes.15.0 query plans can be more complex than those found in earlier Adaptive Server Enterprise versions. Nested indentation is provided to assist in visualizing the tree shape of these query plans.
- Subplans that are executed in parallel.

The rest of this chapter describes the showplan output for query plans.

Statement-level output

The first section of showplan output for each query plan presents some statement-level information. There is always a message giving the statement and line number in the batch or stored procedure of the query for which the query plan was generated:

```
QUERY PLAN FOR STATEMENT N (at line N).
```

This message may be followed by a series of messages that apply to the statement's query plan as a whole. A message about abstract plan usage appears next if the query plan was generated using an abstract plan. The message indicates how the abstract plan was forced.

- If an explicit abstract plan was given by a plan clause in the SQL statement, the message is:

```
Optimized using the Abstract Plan in the PLAN clause.
```

- If an abstract plan has been internally generated (that is, for alter table and reorg commands that are executed in parallel) the message is:

```
Optimized using the forced options (internally
generated Abstract Plan).
```

- If an abstract plan has been retrieved from *sysqueryplans* because automatic abstract plan usage is enabled, the message is:

```
Optimized using an Abstract Plan (ID : N).
```

- If the query plan is a parallel query plan, the following message shows the number of processes (coordinator plus worker) that are required to execute the query plan.

```
Executed in parallel by coordinating process and N
worker processes.
```

- If the query plan was optimized using simulated statistics, this message appears next:

```
Optimized using simulated statistics.
```

- Adaptive Server uses a scan descriptor for each database object that is accessed during query execution. Each connection (or each worker process for parallel query plans) has 28 scan descriptors by default. If the query plan requires access to more than 28 database objects, auxiliary scan descriptors are allocated from a global pool. If the query plan uses auxiliary scan descriptors, this message is printed, showing the total number required:

```
Auxiliary scan descriptors required: N
```

- This message shows the total number of operators appearing in the query plan:

```
N operator(s) under root
```

- The next message shows the type of query for the query plan. For query plans, the query type is select, insert, delete, or update:

```
The type of query is SELECT.
```

- A final statement-level message is printed at the end of showplan output if Adaptive Server has been configured to enable resource limits. The message displays the optimizer's total estimated cost of logical and physical I/O:

  ```
  Total estimated I/O cost for statement N (at line M):
  X.
  ```

The following query, with showplan output, shows some of these messages:

```
1> use pubs2

1> set showplan on

1> select stores.stor_name, sales.ord_num
2> from stores, sales, salesdetail
3> where salesdetail.stor_id = sales.stor_id
4> and stores.stor_id = sales.stor_id
5> plan " ( m_join ( i_scan salesdetailind salesdetail)
6> ( m_join ( i_scan salesind sales ) ( sort ( t_scan stores ) ) ) )"


QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using the Abstract Plan in the PLAN clause.

6 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |MERGE JOIN Operator (Join Type: Inner Join)
    | Using Worktable3 for internal storage.
    |  Key Count: 1
    |  Key Ordering: ASC
    |
    |   |SCAN Operator
    |   |  FROM TABLE
    |   |  salesdetail
    |   |  Index : salesdetailind
    |   |  Forward Scan.
    |   |  Positioning at index start.
    |   |  Index contains all needed columns. Base table will not be read.
    |   |  Using I/O Size 2 Kbytes for index leaf pages.
    |   |  With LRU Buffer Replacement Strategy for index leaf pages.
    |
    |   |MERGE JOIN Operator (Join Type: Inner Join)
```

```
|     | Using Worktable2 for internal storage.
|     |  Key Count: 1
|     |  Key Ordering: ASC
|     |
|     |    |SCAN Operator
|     |    |  FROM TABLE
|     |    |  sales
|     |    |  Table Scan.
|     |    |  Forward Scan.
|     |    |  Positioning at start of table.
|     |    |  Using I/O Size 2 Kbytes for data pages.
|     |    |  With LRU Buffer Replacement Strategy for data pages.
|     |
|     |    |SORT Operator
|     |    | Using Worktable1 for internal storage.
|     |    |
|     |    |    |SCAN Operator
|     |    |    |  FROM TABLE
|     |    |    |  stores
|     |    |    |  Table Scan.
|     |    |    |  Forward Scan.
|     |    |    |  Positioning at start of table.
|     |    |    |  Using I/O Size 2 Kbytes for data pages.
|     |    |    |  With LRU Buffer Replacement Strategy for data pages.
```

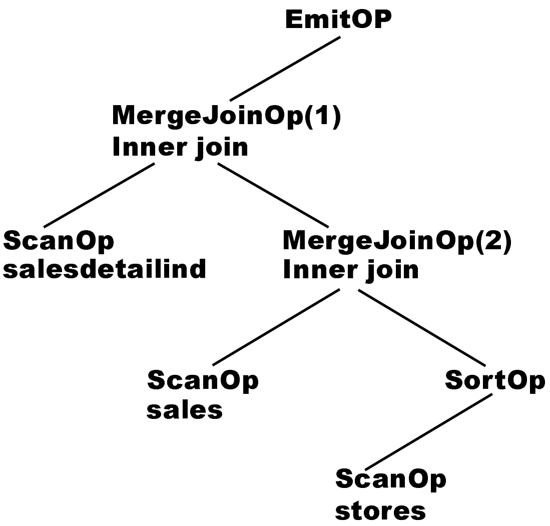
After the statement level output, the query plan is displayed. The showplan output of the query plan consists of two components:

- The names of the operators (some provide additional information) to show which operations are being executed in the query plan.
- Vertical bars (the "|" symbol) with indentation to show the shape of the query plan operator tree.

Query plan shape

A query plan is an upside down tree of operators. The position of each operator in the tree determines its order of execution. Execution starts down the left-most branch of the tree and proceeds to the right. To illustrate execution, this section steps through the execution of the query plan for the example, above. Figure 2-1 shows a graphical representation of the query plan.

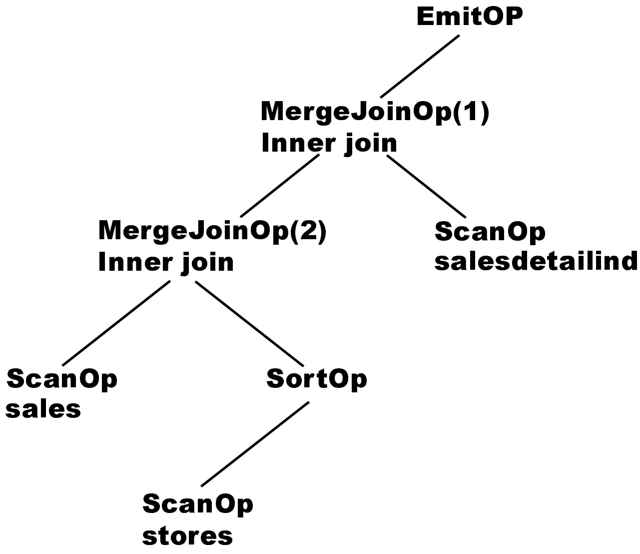
Figure 2-1: Query plan



To generate a result row, the EmitOp calls for a row from its child, the MergeJoinOp(1). MergeJoinOp(1) calls for a row from its left child, the ScanOp for salesdetailind. When it receives a row from its left child, MergeJoinOp(1) calls for a row from its right child, MergeJoinOp(2). MergeJoinOp(2) calls for a row from its left child, the ScanOp for sales. When it receives a row from its left child, MergeJoinOp(2) calls for a row from its right child, the SortOp. The SortOp is a data blocking operator. That is, it needs all of its input rows before it can sort them, so the SortOp keeps calling for rows from its child, the ScanOp for stores, until all rows have been returned. Then the SortOp sorts the rows and passes the first one up to the MergeJoinOp(2). The MergeJoinOp(2) keeps calling for rows from either the left or right child operators until it gets two rows that match on the joining keys. The matching row is then passed up to MergeJoinOp(1). MergeJoinOp(1) also calls for rows from its child operators until a match is found, which is then passed up to the EmitOp to be returned to the client. In effect, the operators are processed using a left-deep postfix recursive strategy.

Figure 2-2 shows a graphical representation of an alternate query plan for the same example query. This query plan contains all of the same operators, but the shape of the tree is different.

Figure 2-2: Alternate query plan



The showplan output corresponding to the query plan in Figure 2-2 is:

```
QUERY PLAN FOR STATEMENT 1 (at line 1).

6 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |MERGE JOIN Operator (Join Type: Inner Join)
    | Using Worktable3 for internal storage.
    |  Key Count: 1
    |  Key Ordering: ASC
    |
    |   |MERGE JOIN Operator (Join Type: Inner Join)
    |   | Using Worktable2 for internal storage.
    |   |  Key Count: 1
    |   |  Key Ordering: ASC
    |   |
    |   |   |SCAN Operator
    |   |   |  FROM TABLE
```

```
|     |     |   sales
|     |     |   Table Scan.
|     |     |   Forward Scan.
|     |     |   Positioning at start of table.
|     |     |   Using I/O Size 2 Kbytes for data pages.
|     |     |   With LRU Buffer Replacement Strategy for data pages.
|     |
|     |     |SORT Operator
|     |     | Using Worktable1 for internal storage.
|     |     |
|     |     |     |SCAN Operator
|     |     |     |   FROM TABLE
|     |     |     |   stores
|     |     |     |   Table Scan.
|     |     |     |   Forward Scan.
|     |     |     |   Positioning at start of table.
|     |     |     |   Using I/O Size 2 Kbytes for data pages.
|     |     |     |   With LRU Buffer Replacement Strategy for data pages.
|
|     |SCAN Operator
|     |   FROM TABLE
|     |   salesdetail
|     |   Index : salesdetailind
|     |   Forward Scan.
|     |   Positioning at index start.
|     |   Index contains all needed columns. Base table will not be read.
|     |   Using I/O Size 2 Kbytes for index leaf pages.
|     |   With LRU Buffer Replacement Strategy for index leaf pages.
```

The showplan output conveys the shape of the query plan by using indentation and the "|" symbol to indicate which operators are under which and which ones are on the same or different branches of the tree. There are two rules to interpreting the tree shape:

- The pipe "|" symbols form a vertical line that starts at the operator's name and continue down past all of the operators that are under it on the same branch.
- Child operators are indented to the left for each level of nesting.

Using these rules, the shape of the query plan in Figure 2-2 can be derived from the previous showplan output with the following steps:

1. The root or emit operator is at the top of the query plan tree.

2 The merge join operator (MergeJoinOp(1)) is the left child of the root. The vertical line that starts at MergeJoinOp(1) travels down the length of the entire output, so all of the other operators are below MergeJoinOp(1) and on the same branch.

3 The left child operator of the MergeJoinOp(1) is another merge join operator, (MergeJoinOp(2)).

4 The vertical line that starts at MergeJoinOp(2) travels down past a scan, a sort, and another scan operator before it ends. These operators are all nested as a sub-branch under MergeJoinOp(2).

5 The first scan under MergeJoinOp(2) is its left child, the scan of the sales table.

6 The sort operator is the right child of MergeJoinOp(2) and the scan of the stores table is the only child of the sort.

7 Below the output for the scan of the stores table, several vertical lines end. This indicates that a branch of the tree has ended.

8 The next output is for the scan of the salesdetail table. It has the same indentation as MergeJoinOp(2), indicating that it is on the same level. In fact, this scan is the right child of MergeJoinOp(1).

Note Most operators are either unary or binary. That is, they have either a single child operator or two child operators directly beneath. Operators that have more than two child operators are called "nary". Operators that have no children are leaf operators in the tree and are termed "nullary."

Another way to get a graphical representation of the query plan is to use the command set statistics plancost on. See *Adaptive Server Reference Manual: Commands* for more information. This command is used to compare the estimated and actual costs in a query plan. It prints its output as a semigraphical tree representing the query plan tree. It is a very useful tool for diagnosing query performance problems.

Query plan operators

The query plan operators, and a description of each, are listed in Table 1-6 on page 24. This section contains additional messages that give more detailed information about each operator.

emit operator

The emit operator appears at the top of every query plan. emit is the root of the query plan tree and always has exactly one child operator. The emit operator routes the result rows of the query by sending them to the client (an application or another Adaptive Server instance) or by assigning values from the result row to local variables or to fetch into variables.

scan operator

The scan operator reads rows into the query plan and makes them available for further processing by the other operators in the query plan. The scan operator is a leaf operator; that is, it never has any child operators. The scan operator can read rows from multiple sources, so the showplan message identifying it is always followed by a from message to identify what kind of scan is being performed. The three from messages are: from cache, from or list, and from table.

from cache message

This message shows that a CacheScanOp is reading a single-row in-memory table.

from or *list*

An or list has as many as *N* rows of or/in values.

The first message shows that an OrScanOp is reading rows from an in-memory table that contain values from an in list or multiple or clauses on the same column. The OrScanOp appears only in query plans that use the special or strategy for in lists. The second message shows the maximum number of rows (*N*) that the in-memory table can have. Since OrScanOp eliminates duplicate values when filling the in-memory table, *N* may be less than the number of values appearing in the SQL statement. As an example, the following query generates a query plan with the special or strategy and an OrScanOp:

```
1> select s.id from sysobjects s where s.id in (1, 0, 1, 2, 3)
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).
```

```
4 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |NESTED LOOP JOIN Operator (Join Type: Inner Join)
    |
    |    |SCAN Operator
    |    |  FROM OR List
    |    |  OR List has up to 5 rows of OR/IN values.
    |
    |    |SCAN Operator
    |    |  FROM TABLE
    |    |  sysobjects
    |    |  s
    |    |  Using Clustered Index.
    |    |  Index : csysobjects
    |    |  Forward Scan.
    |    |  Positioning by key.
    |    |  Index contains all needed columns. Base
            table will not be read.
    |    |  Keys are:
    |    |    id ASC
    |    |  Using I/O Size 2 Kbytes for index leaf pages.
    |    |  With LRU Buffer Replacement Strategy for index leaf pages.
```

This example has five values in the in list, but only four are distinct, so the OrScanOp puts only the four distinct values in its in-memory table. In the example query plan, the OrScanOp is the left child operator of the NLJoinOp and a ScanOp is the right child of the NLJoinOp. When this plan executes, the NLJoinOp calls the OrScanOp to return a row from its in-memory table, then the NLJoinOp calls on the ScanOp to find all matching rows (one at a time), using the clustered index for lookup. This example query plan is much more efficient than reading all of the rows of sysobjects and comparing the value of sysobjects.id in each row to the five values in the in list.

from table

from table shows that a PtnScanOp is reading a database table. A second message gives the table name, and, if there is a correlation name, that is printed on the next line. Under the from table message in the previous example output, `sysobjects` is the table name and `s` is the correlation name. The previous example also shows additional messages under the from table message. These messages give more information about how the PtnScanOp is directing the access layer of Adaptive Server to get the rows from the table being scanned.

The messages below indicate whether the scan is a table scan or an index scan:

- table scan – the rows are fetched by reading the pages of the table.
- using clustered index – a clustered index is used to fetch the rows of the table.
- Index : *indexname* – an index is used to fetch the table rows. If this message is not preceded by the "using clustered index" message, a nonclustered index is used. *indexname* is the name of the index that will be used.

These messages indicates the direction of a table or index scan. The scan direction depends on the ordering specified when the indexes were created and the order specified for columns in the order by clause or other useful orderings that could be exploited by operators further up in the query plan (for example, a sorted ordering for a merge-join strategy).

Backward scans can be used when the order by clause contains the ascending or descending qualifiers on index keys, in the exact opposite of those in the create index clause.

```
Forward scan
```

```
Backward scan
```

The scan-direction messages are followed by positioning messages, which describe how access to a table or to the leaf level of an index takes place:

- `Positioning at start of table` – a table scan that starts at the first row of the table and goes forward.
- `Positioning at end of table` – a table scan that starts at the last row of the table and goes backward.
- `Positioning by key` – the index is used to position the scan at the first qualifying row.
- `Positioning at index start/positioning at index end` – these messages are similar to the corresponding messages for table scans, except that an index is being scanned instead of a table.

If the scan can be limited due to the nature of the query, the following messages describe how:

- `Scanning only the last page of the table` – appears when the scan uses an index and is searching for the maximum value for scalar aggregation. If the index is on the column whose maximum is sought, and the index values are in ascending order, the maximum value will be on the last page.
- `Scanning only up to the first qualifying row` – appears when the scan uses an index and is searching for the minimum value for scalar aggregation.

Note If the index key is sorted in descending order, the above messages for minimum and maximum aggregates are reversed.

In some cases, the index being scanned contains all of the columns of the table that are needed in the query. In such a case, this message is printed:

```
Index contains all needed columns. Base table will
not be read.
```

The optimizer may choose an index scan over a table scan even though there are no useful keys on the index columns, if the index contains all of the columns needed in the query. The amount of I/O required to read the index can be significantly less than that required to read the base table. Index scans that do not require base table pages to be read are call *covered index scans*.

If an index scan is using keys to position the scan, the following message is printed:

```
Keys are:
     Key <ASD/DESC>
```

This message shows the names of the columns used as keys (each key on its own output line) and shows the index ordering on that key: ASC for ascending and DESC for descending.

After the messages that describe the type of access being used by the scan operator, messages about the I/O sizes and buffer cache strategy are printed.

I/O size messages

The I/O messages are:

```
Using I/O size N Kbtyes for data pages.
```

```
Using I/O size N Kbtyes for index leaf pages.
```

These messages report the I/O sizes used in the query. The possible sizes are 2K, 4K, 8K, and 16K.

If the table, index, or database used in the query uses a data cache with large I/O pools, the optimizer can choose large I/O. It can choose to use one I/O size for reading index leaf pages, and a different size for data pages. The choice depends on the pool size available in the cache, the number of pages to be read, the cache bindings for the objects, and the cluster ratio for the table or index pages.

Either or both of these messages can appear in the showplan output for a scan operator. For a table scan, only the first message is printed; for a covered index scan, only the second message is printed. For an index scan that requires base table access, both messages are printed.

After each I/O size message, a cache strategy message is printed:

```
With <LRU/MRU> Buffer Replacement Strategy for data
pages.

With <LRU/MRU> Buffer Replacement Strategy for index
leaf pages.
```

In an LRU Replacement Strategy, the most recently accessed pages are positioned in the cache to be retained as long as possible. In an MRU Replacement Strategy, the most recently accessed pages are positioned in the cache for qquick replacement.

Sample I/O and cache messages are shown in the following query:

```
1> use pubs2
1> set showplan on
1> select au_fname, au_lname, au_id from authors
2> where au_lname = "Williams"

QUERY PLAN FOR STATEMENT 1 (at line 1).

1 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

    |SCAN Operator
    |  FROM TABLE
    |  authors
```

```
|   Index : aunmind
|   Forward Scan.
|   Positioning by key.
|   Keys are:
|     au_lname ASC
|   Using I/O Size 2 Kbytes for index leaf pages.
|   With LRU Buffer Replacement Strategy for index leaf pages.
|   Using I/O Size 2 Kbytes for data pages.
|   With LRU Buffer Replacement Strategy for data pages.
```

The scan of the *authors* table uses the index aunmind, but must also read the base table pages to get all of the required columns from *authors*. In this example, there are two I/O size messages, each followed by the corresponding buffer replacement message.

There are two special kinds of table scan operators that have their own special messages—the rid scan and the log scan.

rid scan

The rid scan is found only in query plans that use the second or strategy that the optimizer can choose, the general or strategy. The general or strategy may be used when multiple or clauses are present on different columns. An example of a query for which the optimizer can choose a general or strategy and its showplan output is:

```
1> use pubs2
1> set showplan on
1> select id from sysobjects where id = 4 or name = 'foo'

QUERY PLAN FOR STATEMENT 1 (at line 1).

6 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |RID JOIN Operator
    | Using Worktable2 for internal storage.
    |
    |   |HASH UNION Operator has 2 children.
    |   | Using Worktable1 for internal storage.
    |   |
    |   |   |SCAN Operator
    |   |   |  FROM TABLE
```

```
|    |    |  sysobjects
|    |    |  Using Clustered Index.
|    |    |  Index : csysobjects
|    |    |  Forward Scan.
|    |    |  Positioning by key.
|    |    |  Index contains all needed columns. Base table will not be read.
|    |    |  Keys are:
|    |    |    id ASC
|    |    |  Using I/O Size 2 Kbytes for index leaf pages.
|    |    |  With LRU Buffer Replacement Strategy for index leaf pages.
|    |
|    |    |SCAN Operator
|    |    |  FROM TABLE
|    |    |  sysobjects
|    |    |  Index : ncsysobjects
|    |    |  Forward Scan.
|    |    |  Positioning by key.
|    |    |  Index contains all needed columns. Base table will not be read.
|    |    |  Keys are:
|    |    |    name ASC
|    |    |  Using I/O Size 2 Kbytes for index leaf pages.
|    |    |  With LRU Buffer Replacement Strategy for index leaf pages.
|
|    |RESTRICT Operator
|    |
|    |    |SCAN Operator
|    |    |  FROM TABLE
|    |    |  sysobjects
|    |    |  Using Dynamic Index.
|    |    |  Forward Scan.
|    |    |  Positioning by Row IDentifier (RID).
|    |    |  Using I/O Size 2 Kbytes for data pages.
|    |    |  With LRU Buffer Replacement Strategy for data pages.
```

In this example, the where clause contains two disjunctions, each on a different column (id and name). There are indexes on each of these columns (csysobjects and ncsysobjects), so the optimizer chose a query plan that uses an index scan to find all rows whose id column is 4 and another index scan to find all rows whose name is “foo.” Since it is possible that a single row has both an ID of 4 and a name of “foo,” that row would appear twice in the result set. To eliminate these duplicate rows, the index scans return only the row identifiers (RIDs) of the qualifying rows. The two streams of RIDs are concatenated by the hash union operator, which also removes any duplicate RIDs. The stream of unique RIDs is passed to the rid join operator. The rid join operator creates a worktable and fills it with a single-column row with each RID. The rid join operator then passes its worktable of RIDs to the rid scan operator. The rid scan operator passes the worktable to the access layer, where it is treated as a keyless nonclustered index and the rows corresponding to the RIDs are fetched and returned. The last scan in the showplan output is the rid scan. As can be seen from the example output, the rid scan output contains many of the messages already discussed above, but it also contains two messages that are printed only for the rid scan:

- `Using Dynamic Index` – indicates the scan is using the worktable with RIDs that was built during execution by the rid join operator as an index to locate the matching rows.
- `Positioning by Row Identifier (RID)` – indicates the rows are being located directly by the RID.

log scan

log scan appears only in triggers that access inserted or deleted tables. These tables are dynamically built by scanning the transaction log when the trigger is executed. Triggers are executed only after insert, delete, or update queries modify a table with a trigger defined on it for the specific query type. The following example is a delete query on the titles table, which has a delete trigger called deltitle defined on it:

```
1> use pubs2
1> set showplan on
1> delete from titles where title_id = 'xxxx'

QUERY PLAN FOR STATEMENT 1 (at line 1).

2 operator(s) under root

The type of query is DELETE.
```

```
ROOT:EMIT Operator

    |DELETE Operator
    |  The update mode is direct.
    |
    |   |SCAN Operator
    |   |  FROM TABLE
    |   |  titles
    |   |  Using Clustered Index.
    |   |  Index : titleidind
    |   |  Forward Scan.
    |   |  Positioning by key.
    |   |  Keys are:
    |   |    title_id ASC
    |   |  Using I/O Size 2 Kbytes for data pages.
    |   |  With LRU Buffer Replacement Strategy for data pages.
    |
    |  TO TABLE
    |  titles
    |  Using I/O Size 2 Kbytes for data pages.
```

The showplan output up to this point is for the actual delete query. The output below is for the trigger, deltitle.

```
QUERY PLAN FOR STATEMENT 1 (at line 5).

6 operator(s) under root

The type of query is COND.

ROOT:EMIT Operator

    |RESTRICT Operator
    |
    |   |SCALAR AGGREGATE Operator
    |   |  Evaluate Ungrouped COUNT AGGREGATE.
    |   |
    |   |   |MERGE JOIN Operator (Join Type: Inner Join)
    |   |   | Using Worktable2 for internal storage.
    |   |   |  Key Count: 1
    |   |   |  Key Ordering: ASC
    |   |   |
    |   |   |   |SORT Operator
    |   |   |   | Using Worktable1 for internal storage.
    |   |   |   |
    |   |   |   |   |SCAN Operator
    |   |   |   |   |  FROM TABLE
```

```
    |   |   |   |   |  titles
    |   |   |   |   |  Log Scan.
    |   |   |   |   |  Forward Scan.
    |   |   |   |   |  Positioning at start of table.
    |   |   |   |   |  Using I/O Size 2 Kbytes for data pages.
    |   |   |   |   |  With MRU Buffer Replacement Strategy for data pages.
    |   |   |
    |   |   |   |SCAN Operator
    |   |   |   |  FROM TABLE
    |   |   |   |  salesdetail
    |   |   |   |  Index : titleidind
    |   |   |   |  Forward Scan.
    |   |   |   |  Positioning at index start.
    |   |   |   |  Index contains all needed columns. Base table will not be
                   read.
    |   |   |   |  Using I/O Size 2 Kbytes for index leaf pages.
    |   |   |   |  With LRU Buffer Replacement Strategy for index leaf pages.

QUERY PLAN FOR STATEMENT 2 (at line 8).

     STEP 1
          The type of query is ROLLBACK TRANSACTION.

QUERY PLAN FOR STATEMENT 3 (at line 9).

     STEP 1
          The type of query is PRINT.

QUERY PLAN FOR STATEMENT 4 (at line 0).

    STEP 1
         The type of query is GOTO.
```

The procedure that defines the deltitle trigger consists of four SQL statements. Use sp_helptext deltitle to display the text of deltitle. The first statement in deltitle has been compiled into a query plan, the other three statements are compiled into legacy query plans and are executed by the procedural execution engine, not the query execution engine.

The showplan output for the scan operator for the titles table indicates that it is doing a scan of the log by printing `Log Scan`.

***delete*, *insert*, and *update* operators**

The DML operators usually have only one child operator. However, they can have as many as two additional child operators to enforce referential integrity constraints and to deallocate text data in the case of alter table drop of a text column.

The DML operators modify data by inserting, deleting, or updating rows belonging to a target table.

Child operators of DML operators can be scan operators, join operators, or any data streaming operator.

The data modification can be done using different update modes, as specified by this message:

```
The Update Mode is <Update Mode>.
```

The table update mode may be direct, deferred, deferred for an index, or deferred for a variable column. The update mode for a worktable is always direct. See the *Performance and Tuning: Monitoring and Analyzing*, Chapter 5, “Using set showplan,” for more information.

The target table for the data modification is displayed in this message:

```
TO TABLE
<Table Name>
```

Also displayed is the I/O size used for the data modification:

```
Using I/O Size <N> Kbytes for data pages.
```

The next example uses the delete DML operator:

```
1> use pubs2
2> go
1> set showplan on
2> go
1> delete from authors where postalcode = '90210'
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).

2 operator(s) under root

The type of query is DELETE.

ROOT:EMIT Operator

       |DELETE Operator
```

```
        |  The update mode is direct.
        |
        |    |SCAN Operator
        |    |  FROM TABLE
        |    |  authors
        |    |  Table Scan.
        |    |  Forward Scan.
        |    |  Positioning at start of table.
        |    |  Using I/O Size 4 Kbytes for data pages.
        |    |  With LRU Buffer Replacement Strategy for data pages.
        |
        |  TO TABLE
        |  authors
        |  Using I/O Size 4 Kbytes for data pages.
```

text delete **operator**

Another type of query plan where a DML operator can have more than one child operator is the alter table drop textcol command, where textcol is the name of a column whose datatype is text, image, or unitext. The following queries and query plan are an example of the use of the text delete operator:

```
1> use tempdb
1> create table t1 (c1 int, c2 text, c3 text)
1> set showplan on
1> alter table t1 drop c2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using the Abstract Plan in the PLAN clause.

5 operator(s) under root

The type of query is ALTER TABLE.

ROOT:EMIT Operator

        |INSERT Operator
        |  The update mode is direct.
        |
        |    |RESTRICT Operator
        |    |
        |    |    |SCAN Operator
        |    |    |  FROM TABLE
        |    |    |  t1
        |    |    |  Table Scan.
        |    |    |  Forward Scan.
```

```
|    |    |  Positioning at start of table.
|    |    |  Using I/O Size 2 Kbytes for data pages.
|    |    |  With LRU Buffer Replacement Strategy for data pages.
|
|    |TEXT DELETE Operator
|    |  The update mode is direct.
|    |
|    |    |SCAN Operator
|    |    |  FROM TABLE
|    |    |  t1
|    |    |  Table Scan.
|    |    |  Forward Scan.
|    |    |  Positioning at start of table.
|    |    |  Using I/O Size 2 Kbytes for data pages.
|    |    |  With LRU Buffer Replacement Strategy for data pages.
|
|  TO TABLE
|  #syb__altab
|  Using I/O Size 2 Kbytes for data pages.
```

One of the two text columns in t1 is dropped, using the alter table command. The showplan output looks like a select into query plan because alter table internally generated a select into query plan. The insert operator calls on its left child operator, the scan of t1, to read the rows of t1, and builds new rows with only the c1 and c3 columns inserted into #syb_altab. When all the new rows have been inserted into #syb_altab, the insert operator calls on its right child, the text delete operator, to delete the text page chains for the c2 columns that have been dropped from t1. Post-processing replaces the original pages of t1 with those of #syb_altab to complete the alter table command.

- The text delete operator appears only in alter table commands that drop some, but not all text columns of a table, and it always appears as the right child of an insert operator.
- The deltext operator displays the update mode message, exactly like the update, delete, and insert operators.

Query plans for referential integrity enforcement

When insert, delete, or update operators are used on a table that has one or more referential integrity constraints, the showplan output shows one or two additional child operators of the DML operator. The two additional operators are the direct ri filter operator and the deferred ri filter operator. The kind of referential integrity constraint determines whether one or both of these operators are present.

The following example is for an insert into the titles table of the pubs3 database. This table has a column called pub_id that references the pub_id column of the publishers table. The referential integrity constraint on titles.pub_id requires that every value that is inserted into titles.pub_id must have a corresponding value in publishers.pub_id.

The query and its query plan are:

```
1> use pubs3
1> set showplan on
1> insert into titles values ("AB1234", "Abcdefg", "test", "9999", 9.95,
1000.00, 10, null, getdate(),1)

QUERY PLAN FOR STATEMENT 1 (at line 1).

4 operator(s) under root

The type of query is INSERT.

ROOT:EMIT Operator

        |INSERT Operator
        |  The update mode is direct.
        |
        |    |SCAN Operator
        |    |  FROM CACHE
        |
        |    |DIRECT RI FILTER Operator has 1 children.
        |    |
        |    |    |SCAN Operator
        |    |    |  FROM TABLE
        |    |    |  publishers
        |    |    |  Index : publishers_6240022232
        |    |    |  Forward Scan.
        |    |    |  Positioning by key.
        |    |    |  Index contains all needed columns. Base table will not be
                     read.
        |    |    |  Keys are:
        |    |    |    pub_id ASC
        |    |    |  Using I/O Size 2 Kbytes for index leaf pages.
        |    |    |  With LRU Buffer Replacement Strategy for index leaf pages.
        |
        |  TO TABLE
        |  titles
        |  Using I/O Size 2 Kbytes for data pages.
```

In the query plan, the insert operator's left child operator is a cache scan, which returns the row of values to be inserted into titles. The insert operator's right child is a direct ri filter operator. The direct ri filter operator executes a scan of the publishers table to find a row with a value of pub_id that matches the value of pub_id to be inserted into titles. If a matching row is found, the direct ri filter operator allows the insert to proceed, but if a matching value of pub_id is not found in publishers, the direct ri filter operator aborts the command. In this example, the direct ri filter can check and enforce the referential integrity constraint on titles for each row that is inserted, as it is inserted.

The next example shows a direct ri filter operating in a different mode, together with a deferred ri filter operator:

```
1> use pubs3
1> set showplan on
1> update publishers set pub_id = '0001'

QUERY PLAN FOR STATEMENT 1 (at line 1).

13 operator(s) under root

The type of query is UPDATE.

ROOT:EMIT Operator

       |UPDATE Operator
       |  The update mode is deferred_index.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  publishers
       |   |  Table Scan.
       |   |  Forward Scan.
       |   |  Positioning at start of table.
       |   |  Using I/O Size 2 Kbytes for data pages.
       |   |  With LRU Buffer Replacement Strategy for data pages.
       |
       |   |DIRECT RI FILTER Operator has 1 children.
       |   |
       |   |   |INSERT Operator
       |   |   |  The update mode is direct.
       |   |   |
       |   |   |   |SQFILTER Operator has 2 children.
       |   |   |   |
       |   |   |   |   |SCAN Operator
       |   |   |   |   |  FROM CACHE
```

```
|    |    |    |
|    |    |    |  Run subquery 1 (at nesting level 0).
|    |    |    |
|    |    |    |QUERY PLAN FOR SUBQUERY 1 (at nesting level 0 and at
                line 0).
|    |    |    |
|    |    |    |   Non-correlated Subquery.
|    |    |    |   Subquery under an EXISTS predicate.
|    |    |    |
|    |    |    |    |SCALAR AGGREGATE Operator
|    |    |    |    | Evaluate Ungrouped ANY AGGREGATE.
|    |    |    |    | Scanning only up to the first qualifying row.
|    |    |    |    |
|    |    |    |    |    |SCAN Operator
|    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |  titles
|    |    |    |    |    |  Table Scan.
|    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |  Positioning at start of table.
|    |    |    |    |    |  Using I/O Size 2 Kbytes for data pages.
|    |    |    |    |    |  With LRU Buffer Replacement strategy for data
                             pages.
|    |    |    |
|    |    |    |  END OF QUERY PLAN FOR SUBQUERY 1.
|    |    |
|    |    |  TO TABLE
|    |    |  Worktable1.
|
|    |DEFERRED RI FILTER Operator has 1 children.
|    |
|    |    |SQFILTER Operator has 2 children.
|    |    |
|    |    |    |SCAN Operator
|    |    |    |  FROM TABLE
|    |    |    |  Worktable1.
|    |    |    |  Table Scan.
|    |    |    |  Forward Scan.
|    |    |    |  Positioning at start of table.
|    |    |    |  Using I/O Size 2 Kbytes for data pages.
|    |    |    |  With LRU Buffer Replacement Strategy for data pages.
|    |    |
|    |    |  Run subquery 1 (at nesting level 0).
|    |    |
|    |    |  QUERY PLAN FOR SUBQUERY 1 (at nesting level 0 and at line 0).
|    |    |
|    |    |   Non-correlated Subquery.
```

```
|   |   |    Subquery under an EXISTS predicate.
|   |   |
|   |   |    |SCALAR AGGREGATE Operator
|   |   |    |  Evaluate Ungrouped ANY AGGREGATE.
|   |   |    |  Scanning only up to the first qualifying row.
|   |   |    |
|   |   |    |    |SCAN Operator
|   |   |    |    |  FROM TABLE
|   |   |    |    |  publishers
|   |   |    |    |  Index : publishers_6240022232
|   |   |    |    |  Forward Scan.
|   |   |    |    |  Positioning by key.
|   |   |    |    |  Index contains all needed columns. Base table will
                     not be read.
|   |   |    |    |  Keys are:
|   |   |    |    |    pub_id ASC
|   |   |    |    |  Using I/O Size 2 Kbytes for index leaf pages.
|   |   |    |    |  With LRU Buffer Replacement Strategy for index leaf
                     pages.
|   |   |
|   |   |  END OF QUERY PLAN FOR SUBQUERY 1.
|
|  TO TABLE
|  publishers
|  Using I/O Size 2 Kbytes for data pages.
```

The referential integrity constraint on *titles* requires that for every value of titles.pub_id there must exist a value of publishers.pub_id. However, this example query is changing the values of publisher.pub_id, so a check must be made to maintain the referential integrity constraint. The example query can change the value of publishers.pub_id for several rows in publishers, so a check to make sure that all of the values of titles.pub_id still exist in publisher.pub_id cannot be done until all rows of publishers have been processed. This example calls for deferred referential integrity checking: as each row of publishers is read, the update operator calls upon the direct ri filter operator to search titles for a row with the same value of pub_id as the value that is about to be changed. If a row is found, it indicates that this value of pub_id must still exist in publishers to maintain the referential integrity constraint on titles, so the value of pub_id is inserted into WorkTable1.

After all of the rows of publishers have been updated, the update operator calls upon the deferred ri filter operator to execute its subquery to verify that all of the values in Worktable1 still exist in publishers: The left child operator of the deferred ri filter is a scan which reads the rows from Worktable1 and the right child is a sq filter operator that executes an existence subquery to check for a matching value in publishers. If a matching value is not found, the command is aborted.

The examples in this section used simple referential integrity constraints, between only two tables. Adaptive Server allows up to 192 constraints per table, so it can generate much more complex query plans. When multiple constraints must be enforced, there is still only a single direct ri filter or deferred ri filter operator in the query plan, but these operators can have multiple subplans, one for each constraint that must be enforced.

join operators

Adaptive Server provides four primary join strategies: NestedLoopJoin, MergeJoin, HashJoin, and NaryNestedJoin, which is a variant of NestedLoopJoin. In versions earlier than 15.0, NestedLoopJoin was the primary join strategy. MergeJoin was also available, but was, by default, not enabled.

Each join operator is described in further detail below. A general description of the each algorithm is provided. These descriptions give a high-level overview of the processing required for each join strategy.

NestedLoopJoin

NestedLoopJoin, the simplest join strategy, is a binary operator with the left child forming the outer data stream and the right child forming the inner data stream. For every row from the outer data stream, the inner data stream is opened. Often, the right child is a scan operator. Opening the inner data stream effectively positions the scan on the first row that qualifies all of the searchable arguments. The qualifying row is returned to the NestedLoopJoin's parent operator. Subsequent calls to the join operator continue to return qualifying rows from the inner stream. After the last qualifying row from the inner stream is returned for the current outer row, the inner stream is closed. A call is made to get the next qualifying row from the outer stream. The values from this row provide the searchable arguments used to open and position the scan on the inner stream. This process continues until the NestedLoopJoin's left child returns `End Of Scan`.

```
1> -- Collect all of the title ids for books written by "Bloom".
2> select ta.title_id
```

```
3>       from titleauthor ta, authors a
4> where a.au_id = ta.au_id
5>       and au_lname = "Bloom"
6> go

QUERY PLAN FOR STATEMENT 1 (at line 2).

3 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |NESTED LOOP JOIN Operator (Join Type: Inner Join)
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  authors
       |   |  a
       |   |  Index : aunmind
       |   |  Forward Scan.
       |   |  Positioning by key.
       |   |  Keys are:
       |   |    au_lname ASC
       |   |  Using I/O Size 2 Kbytes for index leaf pages.
       |   |  With LRU Buffer Replacement Strategy for index leaf pages.
       |   |  Using I/O Size 2 Kbytes for data pages.
       |   |  With LRU Buffer Replacement Strategy for data pages.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  titleauthor
       |   |  ta
       |   |  Using Clustered Index.
       |   |  Index : taind
       |   |  Forward Scan.
       |   |  Positioning by key.
       |   |  Keys are:
       |   |    au_id ASC
       |   |  Using I/O Size 2 Kbytes for data pages.
       |   |  With LRU Buffer Replacement Strategy for data pages.
```

In this example, the authors table is being joined with the titleauthor table. A NestedLoopJoin strategy has been chosen. The NestedLoopJoin operator's type is "Inner Join." First, the authors table is opened and positioned on the first row (using the aunmind index) containing an l_name value of "Bloom." Then, the titleauthor table is opened and positioned on the first row with an au_id equal to the au_id value of the current authors' row using the clustered index "taind." If there is no useful index for lookups on the inner stream, then the optimizer may generate a reformatting strategy.

Generally, a NestedLoopJoin strategy is effective when there is a useful index available for qualifying the join predicates on the inner stream.

MergeJoin

The MergeJoin operator is a binary operator. The left and right children are the outer and inner data streams, respectively. Both data streams must be sorted on the MergeJoin's key values. First, a row from the outer stream is fetched. This initializes the MergeJoin's join key values. Then, rows from the inner stream are fetched until a row with key values that match or are greater than (less than if key column is descending) is encountered. If the join key matches, the qualifying row is passed on for additional processing, and a subsequent next call to the MergeJoin operator continues fetching from the currently active stream. If the new values are greater than the current comparison key, these values are used as the new comparison join key while fetching rows from the other stream. This process continues until one of the data streams is exhausted.

Generally, the MergeJoin strategy is effective when a scan of the data streams requires that most of the rows must be processed, and that, if any of the input streams are large, they are already sorted on the join keys.

```
1> -- Collect all of the title ids for books written by "Bloom".
2> select ta.title_id
3>       from titleauthor ta, authors a
4> where a.au_id = ta.au_id
5>       and au_lname = "Bloom"
6> go

QUERY PLAN FOR STATEMENT 1 (at line 2).

    STEP 1
        The type of query is EXECUTE.
        Executing a newly cached statement.

QUERY PLAN FOR STATEMENT 1 (at line 2).
```

```
4 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |MERGE JOIN Operator (Join Type: Inner Join)
       | Using Worktable2 for internal storage.
       |  Key Count: 1
       |  Key Ordering: ASC
       |
       |   |SORT Operator
       |   | Using Worktable1 for internal storage.
       |   |
       |   |   |SCAN Operator
       |   |   |  FROM TABLE
       |   |   |  authors
       |   |   |  a
       |   |   |  Index : aunmind
       |   |   |  Forward Scan.
       |   |   |  Positioning by key.
       |   |   |  Keys are:
       |   |   |    au_lname ASC
       |   |   |  Using I/O Size 2 Kbytes for index leaf pages.
       |   |   |  With LRU Buffer Replacement Strategy for index leaf pages.
       |   |   |  Using I/O Size 2 Kbytes for data pages.
       |   |   |  With LRU Buffer Replacement Strategy for data pages.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  titleauthor
       |   |  ta
       |   |  Index : auidind
       |   |  Forward Scan.
       |   |  Positioning at index start.
       |   |  Using I/O Size 2 Kbytes for index leaf pages.
       |   |  With LRU Buffer Replacement Strategy for index leaf pages.
       |   |  Using I/O Size 2 Kbytes for data pages.
       |   |  With LRU Buffer Replacement Strategy for data pages.
```

In this example, a sort operator is the left child or outer stream. The data source for the sort operator is the authors table. The sort operator is required because the authors table has no index on au_id that would otherwise provide the necessary sorted order. A scan of the titleauthor table is the right child/inner stream. The scan uses the auidind index, which provides the necessary ordering for the MergeJoin strategy.

A row is fetched from the outer stream (the authors table is the original source) to establish an initial join key comparison value. Then rows are fetched from the titleauthor table until a row with a join key equal to or greater than the comparison key is found.

Inner stream rows with matching keys are stored in a cache in case they need to be refetched. These rows are refetched when the outer stream contains duplicate keys. When a titleauthor.au_id value that is greater than the current join key comparison value is fetched, then the MergeJoin operator starts fetching from the outer stream until a join key value equal to or greater than the current titleauthor.au_id value is found. The scan of the inner stream resumes at that point.

The MergeJoin operator's showplan output contains a message indicating what worktable will be used for the inner stream's backing store. The worktable is written to if the inner rows with duplicate join keys no longer fits in cached memory. The width of a cached row is limited to 64KB.

HashJoin

The HashJoin operator is a binary operator. The left child generates the build input stream. The right child generates the probe input stream. The build set is generated by completely draining the build input stream when the first row is requested from the HashJoin operator. Every row is read from the input stream and hashed into an appropriate bucket using the hash key. If there is not enough memory to hold the entire build set, then a portion of it spills to disk. This portion is referred to as a *hash partition* and should not be confused with table partitions. A hash partition consists of a collection of hash buckets. After the entire left child's stream has been drained, the probe input is read.

Each row from the probe set is hashed. A lookup is done in the corresponding build bucket to check for rows with matching hash keys. This occurs if the build set's bucket is memory resident. If it has been spilled, the probe row is written to the corresponding spilled probe partition. When a probe row's key matches a build row's key, then the necessary projection of the two row's columns is passed up for additional processing.

Spilled partitions are processed in subsequent recursive passes of the HashJoin algorithm. New hash seeds are used in each pass so that the data will be redistributed across different hash buckets. This recursive processing continues until the last spilled partition is completely memory resident. When a hash partition from the build set contains many duplicates, the HashJoin operator reverts back to NestedLoopJoin processing.

Generally, the HashJoin strategy is good in cases where most of the rows from the source sets must be processed and there are no inherent useful orderings on the join keys or there are no interesting orderings that can be promoted to calling operators (for example, an order by clause on the join key). HashJoins perform particularly well if one of the data sets is small enough to be memory resident. In this case, no spilling occurs and no I/O is needed to perform that HashJoin algorithm.

```
1> -- Collect all of the title ids for books written by "Bloom".
2> select ta.title_id
3>       from titleauthor ta, authors a
4> where a.au_id = ta.au_id
5>       and au_lname = "Bloom"

QUERY PLAN FOR STATEMENT 1 (at line 2).

3 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |HASH JOIN Operator (Join Type: Inner Join)
       | Using Worktable1 for internal storage.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  authors
       |   |  a
       |   |  Index : aunmind
       |   |  Forward Scan.
       |   |  Positioning by key.
       |   |  Keys are:
       |   |    au_lname ASC
       |   |  Using I/O Size 2 Kbytes for index leaf pages.
       |   |  With LRU Buffer Replacement Strategy for index leaf pages.
       |   |  Using I/O Size 2 Kbytes for data pages.
       |   |  With LRU Buffer Replacement Strategy for data pages.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  titleauthor
       |   |  ta
       |   |  Index : auidind
       |   |  Forward Scan.
       |   |  Positioning at index start.
```

```
|    |  Using I/O Size 2 Kbytes for index leaf pages.
|    |  With LRU Buffer Replacement Strategy for index leaf pages.
|    |  Using I/O Size 2 Kbytes for data pages.
|    |  With LRU Buffer Replacement Strategy for data pages.
```

In this example, the source of the build input stream is an index scan of author.aunmind.

Only rows with an au_lname value of "Bloom" are returned from this scan. These rows are then hashed on their au_id value and placed into their corresponding hash bucket. After the initial build phase is completed, the probe stream is opened and scanned. Each row from the source index, titleauthor.auidind, is hashed on the au_id column. The resulting hash value is used to determine which bucket in the build set should be searched for matching hash keys. Each row from the build set's hash bucket is compared to the probe row's hash key for equality. If the row matches, then the titleauthor.au_id column is returned to the emit operator.

The HashJoin operator's showplan output contains a message indicating what worktable will be used for the spilled partition's backing store. The input row width is limited to 64KB.

NaryNestedLoopJoin operator

The NaryNestedLoopJoin strategy is never evaluated or chosen by the optimizer. It is an operator that is constructed during code generation. If the compiler finds series of two or more left-deep NestedLoopJoins, it attempts to transform them into an NaryNestedLoopJoin operator. Two additional requirements allow for transformation scan; each NestedLoopJoin operator has an "inner join" type and the right child of each NestedLoopJoin is a scan operator. A restrict operator is permitted above the scan operator.

NaryNestedLoopJoin execution has a performance benefit over the execution of a series of NestedLoopJoin operators. The example below demonstrates this. There is one fundamental difference between the two methods of execution. With a series of NestedLoopJoin, a scan may eliminate rows based on searchable argument values initialized by an earlier scan. That scan may not be the one that immediately preceded the failing scan. With a series of NestedLoopJoins, the previous scan would be completely drained although it has no effect on the failing scan. This could result in a significant amount of needless I/O. With NaryNestedLoopJoins, the next row fetched comes from the scan that produced the failing searchable argument value, which is far more efficient.

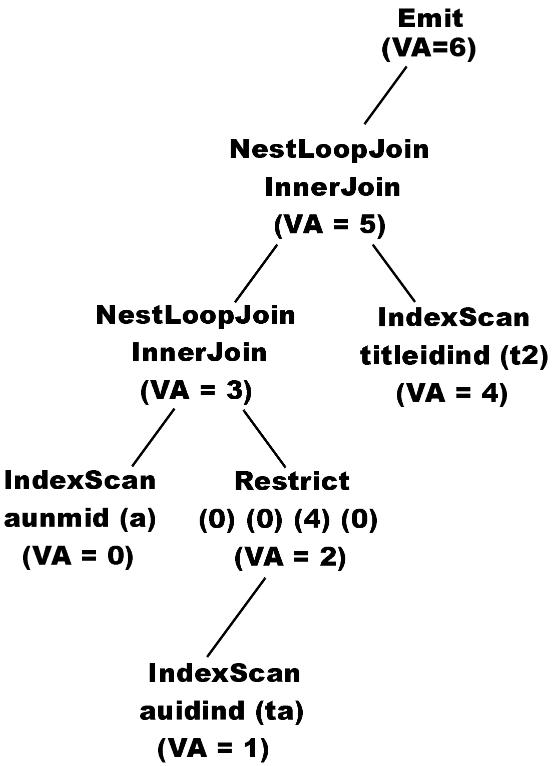
```
1> -- Collect the author id and name for all authors with the
```

```
2> -- last name "Bloom" and who have a listed title and the
3> -- author id is the same as the title_id.
4> select a.au_id, au_fname, au_lname
5>     from titles t, titleauthor ta, authors a
6> where a.au_id = ta.au_id
7>     and ta.title_id = t.title_id
8>     and a.au_id = t.title_id
9>     and au_lname = "Bloom"

5 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |NARY NESTED LOOP JOIN Operator has 3 children.
       |
       |    |SCAN Operator
       |    |  FROM TABLE
       |    |  authors
       |    |  a
       |    |  Index : aunmind
       |    |  Forward Scan.
       |    |  Positioning by key.
       |    |  Keys are:
       |    |    au_lname ASC
       |    |  Using I/O Size 2 Kbytes for index leaf pages.
       |    |  With LRU Buffer Replacement Strategy for index leaf pages.
       |    |  Using I/O Size 2 Kbytes for data pages.
       |    |  With LRU Buffer Replacement Strategy for data pages.
       |
       |    |RESTRICT Operator
       |    |
       |    |    |SCAN Operator
       |    |    |  FROM TABLE
       |    |    |  titleauthor
       |    |    |  ta
       |    |    |  Index : auidind
       |    |    |  Forward Scan.
       |    |    |  Positioning by key.
       |    |    |  Keys are:
       |    |    |    au_id ASC
       |    |    |  Using I/O Size 2 Kbytes for index leaf pages.
       |    |    |  With LRU Buffer Replacement Strategy for index leaf pages.
       |    |    |  Using I/O Size 2 Kbytes for data pages.
       |    |    |  With LRU Buffer Replacement Strategy for data pages.
```

```
|
|     |SCAN Operator
|     |  FROM TABLE
|     |  titles
|     |  t
|     |  Using Clustered Index.
|     |  Index : titleidind
|     |  Forward Scan.
|     |  Positioning by key.
|     |  Keys are:
|     |    title_id ASC
|     |  Using I/O Size 2 Kbytes for data pages.
|     |  With LRU Buffer Replacement Strategy for data pages.
```

Figure 2-3 depicts a series of NestedLoopJoins.

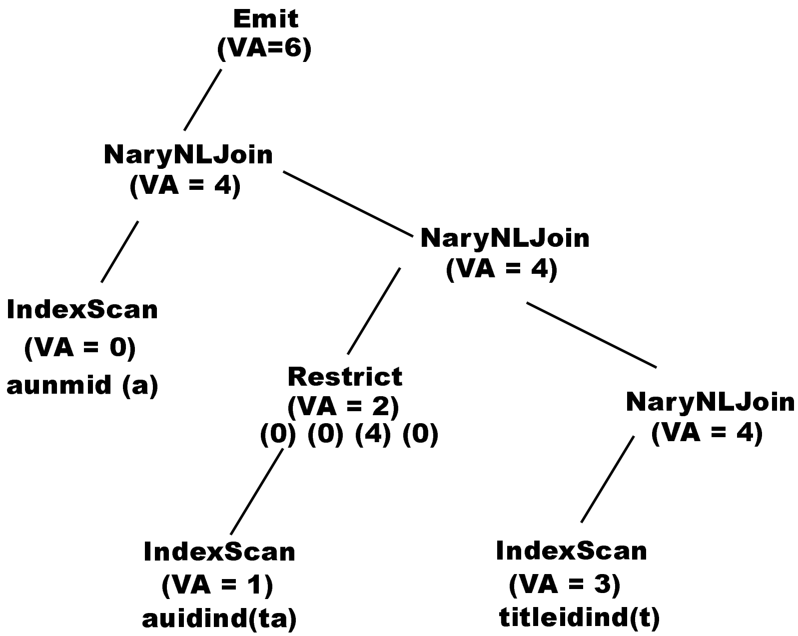
Figure 2-3: Emit operator tree with NestedLoopJoins



All query processor operators are assigned a virtual address. The lines in Figure 2-3 with `VA =` report the virtual address for a given operator.

The effective join order is authors, titleauthor, titles. A restrict operator is the parent operator of the scan on titleauthors. This plan is transformed into the NaryNestedLoopJoin plan below:

Figure 2-4: NaryNestedLoopJoin operator



The transformation retains the original join order of authors, titleauthor, and titles. In this example, the scan of titles has two searchable arguments on it—ta.title_id = t.title_id and a.au_id = t.title_id. So, the scan of titles fails because of the searchable argument value established by the scan of titleauthor or it fails because of the searchable argument value established by the scan of authors. If no rows are returned from a scan of titles because of the searchable argument value set by the scan of authors, there is no point in continuing the scan of titleauthor. For every row fetched from titleauthor, the scan of titles fails. It is only when a new row is fetched from authors that the scan of titles might succeed. This is why NaryNestedLoopJoins have been implemented; they eliminate the useless draining of tables that have no impact on the rows returned by successive scans. In the example, the NaryNestedLoopJoin operator closes the scan of titleauthor, fetches a new row from authors, and repositions the scan of titleauthor based on the au_id fetched from authors. Again, this can be a significant performance improvement as it eliminates the needless draining of the titleauthor table and the associated I/O that could occur.

Distinct operators

There are three operators that can be used to enforce distinctness: GroupSorted (Distinct), SortOp (Distinct), and HashDistinctOp. They are all unary operators. Each has advantages and disadvantages. The optimizer chooses an efficient distinct operator with respect to its use within the entire query plan's context.

See Table 1-6 on page 24 for a list and description of all query processor operators.

GroupSorted (Distinct) operator

The GroupSorted (Distinct) operator can be used to apply distinctness. It requires that the input stream is already sorted on the distinct columns. It reads a row from its child operator and initializes the current distinct columns' values to be filtered. The row is returned to the parent operator. When the group sorted operator is called again to fetch another row, it fetches another row from its child and compares the values to the current cached values. If the value is a duplicate, then the row is discarded and the child is called again to fetch a new row. This process continues until a new distinct row is found. The distinct columns' values for this row are cached and will be used later to eliminate nondistinct rows. The current row is returned to the parent operator for further processing.

The GroupSorted (Distinct) operator returns a sorted stream. The fact that it returns a sorted and distinct data stream are properties that the optimizer can exploit to improve performance in additional upstream processing. The GroupSorted (Distinct) operator is a nonblocking operator. It returns a distinct row to its parent as soon as it is fetched. It does not require that the entire input stream is processed before it can start returning rows. The following query collects distinct last and first author's names.

```
1> select distinct au_lname, au_fname
2> from authors
3> where au_lname = "Bloom"

QUERY PLAN FOR STATEMENT 1 (at line 2).

2 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |GROUP SORTED Operator
```

```
|Distinct
|
|    |SCAN Operator
|    |  FROM TABLE
|    |  authors
|    |  Index : aunmind
|    |  Forward Scan.
|    |  Positioning by key.
|    |  Index contains all needed columns. Base table will not be read.
|    |  Keys are:
|    |    au_lname ASC
|    |  Using I/O Size 2 Kbytes for index leaf pages.
|    |  With LRU Buffer Replacement Strategy for index leaf pages.
```

The SortOp (Distinct) operator is chosen in this query plan to apply the distinct property because the scan operator is returning rows in sorted order for the distinct columns au_lname and au_fname. By using the GroupSorted operator here, there is no I/O and minimal CPU overhead.

The GroupSorted (Distinct) operator can also be used to implement vector aggregation. See "Vector aggregation operators" on page 68 for more information. The showplan output prints the line `Distinct` to indicate that this GroupSorted (Distinct) operator is implementing the distinct property.

SortOp (Distinct) operator

The SortOp (Distinct) operator is a unary operator. It does not require that its input stream is already sorted on the distinct key columns. It is a blocking operator that drains its child operator's stream and sorts the rows as they are read. A distinct row is returned to the parent operator after all rows have been sorted. Rows are returned sorted on the distinct key columns. An internal worktable is used as a backing store in case the input set does not fit entirely in memory.

```
1> select distinct au_lname, au_fname
2> from authors
3> where city = "Oakland"

2 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |SORT Operator
       | Using Worktable1 for internal storage.
```

```
       |
       |     |SCAN Operator
       |     |  FROM TABLE
       |     |  authors
       |     |  Table Scan.
       |     |  Forward Scan.
       |     |  Positioning at start of table.
       |     |  Using I/O Size 2 Kbytes for data pages.
       |     |  With LRU Buffer Replacement Strategy for data pages.
```

The scan of the authors table does not return rows sorted on the distinct key columns. This requires that a SortOp (Distinct) operator be used rather than a GroupSorted (Distinct) operator. The sort operator's distinct key columns are au_lname and au_fname. The showplan output indicates that Worktable1 is used for disk storage in case the input set does not fit entirely in memory.

HashDistinctOp operator

The HashDistinctOp operator does not require that its input set be sorted on the distinct key columns. It is a nonblocking operator. Rows are read from the child operator and are hashed on the distinct key columns. This determines the row's bucket position. The corresponding bucket is searched to see if the key already exists. The row is discarded if it contains a duplicate key and another row is fetched from the child operator. The row is added to the bucket if no duplicate distinct key already exists and the row is passed up to the parent operator for further processing. Rows are not returned sorted on the distinct key columns.

The HashDistinctOp operator is generally used when the input set is not already sorted on the distinct key columns or when the optimizer is not able to exploit the ordering coming out of the distinct processing later in the plan.

```
1> select distinct au_lname, au_fname
2> from authors a
3> where city = "Oakland"
4> go

QUERY PLAN FOR STATEMENT 1 (at line 1).

2 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

       |HASH DISTINCT Operator
       | Using Worktable1 for internal storage.
```

```
|
|     |SCAN Operator
|     |  FROM TABLE
|     |  authors
|     |  a
|     |  Table Scan.
|     |  Forward Scan.
|     |  Positioning at start of table.
|     |  Using I/O Size 2 Kbytes for data pages.
|     |  With LRU Buffer Replacement Strategy for data pages.
```

In this example, the output of the authors table scan is not sorted. The optimizer can choose either a SortOp (Distinct) or HashDistinctOp strategy. The ordering provided by a SortOp (Distinct) strategy is not useful anywhere else in the plan, so the optimizer will probably choose a HashDistinctOp strategy. The optimizer's decision is ultimately based on cost estimates. The HashDistinctOp is typically less expensive for unsorted input streams as it is a sieve that can eliminate rows on the fly for resident partitions. The SortOp (Distinct) operator cannot eliminate any rows until the entire data set has been sorted.

The showplan output for the HashDistinctOp operator reports that Worktable1 will be used. A worktable is needed in case the distinct row result set cannot fit in memory. In that case, partially processed groups will be spilled to disk.

Vector aggregation operators

There are two unary operators used for vector aggregation. They are the GroupSortedOp (aggregation mode), the HashVectorAgOp, and the GroupInsertingOp operators.

See Table 1-6 on page 24 for a list and description of all query processor operators.

GroupSortedOp (Aggregation) operator

The GroupSortedOp (Aggregation) operator is a simple variant of the GroupSorted (Distinct) operator described in "GroupSorted (Distinct) operator" on page 65. The GroupSortedOp (Aggregation) operator requires that the input set is sorted on the group by columns. The algorithm is very similar. A row is read from the child operator. If the row is the start of a new vector, then its grouping columns are cached and the aggregation results are initialized. If the row belongs to the current group being processed, the aggregate functions are applied to the aggregate results. When the child operator returns a row that starts a new group or `End Of Scan`, the current vector and its aggregated values are returned to the parent operator.

This is a nonblocking operator similar to the GroupSorted (Distinct) operator with one difference. The first row in theGroupSortedOp (Aggregation) operator is returned after an entire group is processed, where the first row in the GroupSorted (Distinct) operator is returned at the start of a new group. This example collects a list of all cities with the number of authors that live in each city.

```
1> select city, total_authors = count(*)
2>     from authors
3>     group by city
4> plan
5> "(group_sorted
6>      (sort (scan authors))
7> )"
8> go

QUERY PLAN FOR STATEMENT 1 (at line 3).
Optimized using the Abstract Plan in the PLAN clause.

3 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

       |GROUP SORTED Operator
       |  Evaluate Grouped COUNT AGGREGATE.
       |
       |   |SORT Operator
       |   | Using Worktable1 for internal storage.
       |   |
       |   |   |SCAN Operator
```

```
    |    |    |  FROM TABLE
    |    |    |  authors
    |    |    |  Table Scan.
    |    |    |  Forward Scan.
    |    |    |  Positioning at start of table.
    |    |    |  Using I/O Size 2 Kbytes for data pages.
    |    |    |  With LRU Buffer Replacement Strategy for data pages.
```

In this query plan, the scan of authors does not return rows in grouping order. A sort operator is applied to order the stream based on the grouping column city. At this point, a GroupSortedOp (Aggregation) operator can be applied to evaluate the count() aggregate.

The GroupSortedOp (Aggregation) operator showplan output reports the aggregate functions being applied as:

```
|  Evaluate Grouped COUNT AGGREGATE.
```

HashVectorAgOp operator

The HashVectorAgOp operator is a blocking operator. All rows from the child operator must be processed before the first row from the HashVectorAgOp operator can be returned to its parent operator. Other than this, the algorithm is similar to the HashDistinctOp operator’s algorithm.

Rows are fetched from the child operator. Each row is hashed on the query’s grouping columns. The bucket that is hashed is searched to see if the vector already exists.

If the group by values do not exist, the vector is added and the aggregate values are initialized using this first row. If the group by values do exist, the current row is aggregated to the existing values. This example collects a list of all cities with the number of authors that live in each city.

```
1> select city, total_authors = count(*)
2>     from authors
3>     group by city
4> go

QUERY PLAN FOR STATEMENT 1 (at line 3).

2 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator
```

```
|HASH VECTOR AGGREGATE Operator
|  GROUP BY
|  Evaluate Grouped COUNT AGGREGATE.
| Using Worktable1 for internal storage.
|
|    |SCAN Operator
|    |  FROM TABLE
|    |  authors
|    |  Table Scan.
|    |  Forward Scan.
|    |  Positioning at start of table.
|    |  Using I/O Size 2 Kbytes for data pages.
|    |  With LRU Buffer Replacement Strategy for data pages.
```

In this query plan, the HashVectorAgOp operator reads all of the rows from its child operator, which is scanning the authors table. Each row is checked to see if there is already an entry bucket entry for the current city value. If there is not, a hash entry row is added with the new city grouping value and the count result is initialized to 1. If there is already a hash entry for the new row's city value, the aggregation function is applied. In this case, the count result is incriminated.

The showplan output prints a group by message specifically for the HashVectorAgOp operator, then prints the grouped aggregation messages:

```
|  Evaluate Grouped COUNT AGGREGATE.
```

The showplan output reports what worktable will be used to store spilled groups and unprocessed rows:

```
| Using Worktable1 for internal storage.
```

GroupInsertingOp

The GroupInsertingOp is a blocking operator. All rows from the child operator must be processed before the first row can be returned from the GroupInsertingOp.

The GroupInsertingOp used in earlier versions of Adaptive Server for generating grouped tables. It is limited to 31 or fewer columns in the group by clause. The operator starts by creating a work table with a clustered index of the grouping columns. As each row is fetched from the child, a lookup into the work table is done based on the grouping columns. If no row is found, then the row is inserted. This effectively creates a new group and initializes its aggregate values. If a row is found, then the new aggregate values are updated based on evaluating the new values. The GroupInsertingOp has the side effect of returning rows ordered by the grouping columns.

```
1> select city, total_authors = count(*)
2>    from authors
3>    group by city
4> plan
5> “(group_inserting (i_scan auidind authors ))”
6> go
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using the Abstract Plan in the PLAN clause.

STEP 1
The type of query is SELECT.

2 operator(s) under root

|ROOT:EMIT Operator
|
|   |GROUP INSERTING Operator
|   | GROUP BY
|   | Evaluate Grouped COUNT AGGREGATE
|   | Using Worktable1 for internal storage.
|   |
|   |   |SCAN Operator
|   |   | FROM TABLE
|   |   | authors
|   |   | Table Scan.
|   |   | Forward Scan.
|   |   | Positioning at start of table.
|   |   | Using I/O Size 2 Kbytes for data pages.
|   |   | With LRU Buffer Replacement Strategy for data pages.
```

In this example, the group inserting operator starts by building a worktable with a clustered index keyed on the city column. The group inserting operator proceeds to drain the authors table. For each row, a lookup is done on the city value. If there is no row in the aggregation worktable with the current city value, then the row is inserted. This creates a new group for the current city value with an initialized count value. If the row for the current city value is found, then an evaluation is done to increment the count aggregate value.

compute by message

processing is done in the emit operator. It requires that the emit operator's input stream be sorted according to any order by requirements in the query. The processing is similar to what is done in the GroupSortedOp (aggregation mode) operator. Each row read from the child is checked to see if it starts a new group. If it does not, the aggregate functions are applied as appropriate to the query's requested groups. If a new group is started, the current group and its aggregated values are returned to the user. A new group is then started and its aggregate values are initialized from the new row's values. This example collects an ordered list of all cities and reports a count of the number of entries for each city after the city list.

```
1> select city
2>     from authors
3>     order by city
4>     compute count(city) by city
5> go

QUERY PLAN FOR STATEMENT 1 (at line 3).

2 operator(s) under root

The type of query is SELECT.
Emit with Compute semantics

ROOT:EMIT Operator

       |SORT Operator
       | Using Worktable1 for internal storage.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  authors
       |   |  Table Scan.
       |   |  Forward Scan.
       |   |  Positioning at start of table.
```

```
        |    |  Using I/O Size 2 Kbytes for data pages.
        |    |  With LRU Buffer Replacement Strategy for data pages.
```

In this example, the emit operator's input stream is sorted on the city attribute. For each row, the compute by count value is incremented. When a new city value is fetched, the current city's values and associated count value is returned to the user. The new city value becomes the new compute by grouping value and its count is initialized to one.

Union operators

union all operator

The union all operator merges several compatible input streams without performing any duplicate elimination. Every data row that enters the union all operator is included in the operator's output stream.

The union all operator is a nary operator that displays this message:

```
UNION ALL OPERATOR  has N children.
```

<*N*> is the number of input streams into the operator.

This example demonstrates the use of union all:

```
1> select * from sysindexes where id < 100
2> union all
3> select * from sysindexes where id > 200
4> go

QUERY PLAN FOR STATEMENT 1 (at line 1).

  STEP 1
The type of query is SELECT.


3 operator(s) under root

  |ROOT:EMIT Operator
  |
  |   |UNION ALL Operator has 2 children.
  |   |
```

```
|   |   |SCAN Operator
|   |   | FROM TABLE
|   |   | sysindexes
|   |   | Using Clustered Index.
|   |   | Index : csysindexes
|   |   | Forward Scan.
|   |   | Positioning by key.
|   |   | Keys are:
|   |   |  id ASC
|   |   | Using I/O Size 2 Kbytes for index leaf pages.
|   |   | With LRU Buffer Replacement Strategy for index leaf pages.
|   |   | Using I/O Size 2 Kbytes for data pages.
|   |   | With LRU Buffer Replacement Strategy for data pages.
|   |
|   |   |SCAN Operator
|   |   | FROM TABLE
|   |   | sysindexes
|   |   | Using Clustered Index
|   |   | Index : csysindexes
|   |   | Forward scan.
|   |   | Positioning by key.
|   |   | Keys are:
|   |   |  id ASC
|   |   | Using I/O Size 2 Kbytes for index leaf pages.
|   |   | With LRU Buffer Replacement Strategy for index leaf pages.
|   |   | Using I/O Size 2 Kbytes for data pages.
|   |   | With LRU Buffer Replacement Strategy for data pages.
```

The union all operator starts by fetching all rows from its leftmost child. In this example, it returns all of the sysindexes rows with an id < 100. As each child operator's datastream is emptied, the union all operator moves on to the child operator immediately to its right. This stream is opened and emptied. This continues until the last (the Nth) child operator is emptied.

merge union operator

The merge union operator performs a union all operation on several sorted compatible data streams and eliminates duplicates within these streams.

The merge union operator is a nary operator that displays this message:

```
MERGE UNION OPERATOR has <N> children.
```

<***N***> is the number of input streams into the operator.

hash union

The hash union operator uses Adaptive Server hashing algorithms to simultaneously perform a union all operation on several data streams and hash-based duplicate elimination.

The hash union operator is a nary operator that displays this message:

```
HASH UNION OPERATOR has <N> children.
```

<N> is the number of input streams into the operator.

It also displays the name of the worktable it uses, in this format:

```
HASH UNION OPERATOR Using Worktable  <X>  for internal
storage.
```

This worktable is used by the hash union operator to temporarily store data for the current iteration that cannot be processed in the memory currently available.

This example demonstrates the use of hash union:

```
select * from sysindexes
union
select * from sysindexes

QUERY PLAN FOR STATEMENT 1 (at line 8).
Executed in parallel by coordinating process and 2 worker processes.

6 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |SORT Operator
    | Using Worktable2 for internal storage.
    |
    |    |EXCHANGE Operator
    |    | Executed in parallel by 2 Producer and 1 Consumer processes.

    |    |
    |    |    |EXCHANGE:EMIT Operator
    |    |    |
    |    |    |    |HASH UNION Operator has 2 children.
    |    |    |    | Using Worktable1 for internal storage.
    |    |    |    |    |SCAN Operator
    |    |    |    |    |  FROM TABLE
```

```
|    |    |    |    |  sysindexes
|    |    |    |    |  Table Scan.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning at start of table.
|    |    |    |    |  Using I/O Size 2 Kbytes for data pages.
|    |    |    |    |  With LRU Buffer Replacement Strategy for data
|    |    |    |    |    pages.
|    |
|    |    |    |    |SCAN Operator
|    |    |    |    |  FROM TABLE
|    |    |    |    |  sysindexes
|    |    |    |    |  Table Scan.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning at start of table.
|    |    |    |    |  Using I/O size 2 Kbytes for data pages.
|    |    |    |    |  With LRU Buffer Replacement Strategy for data
|    |    |    |    |    pages.
```

ScalarAggOp operator

The ScalarAggOp operator keeps track of running information about an input data stream, such as the number of rows in the stream, or the maximum value of a given column in the stream.

The ScalarAggOp operator prints a list of up to 10 messages describing the scalar aggregation operations it executes. The message has the following format:

```
Evaluate Ungrouped  <Type of Aggregate> Aggregate
```

<Type of Aggregate> can be any of the following: count, sum, average, min, max, any, once-unique, count-unique, sum-unique, average-unique, or once.

The following query performs a ScalarAggOp (in other words, unwrapped) aggregation on the authors table in the pubs2 database:

```
1> use pubs2
2> go
1> set showplan on
2> go
1> select count(*) from authors
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).

2 operator(s) under root
```

```
The type of query is SELECT.

ROOT:EMIT Operator

       |SCALAR AGGREGATE Operator
       |  Evaluate Ungrouped COUNT AGGREGATE.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  authors
       |   |  Index : aunmind
       |   |  Forward Scan.
       |   |  Positioning at index start.
       |   |  Index contains all needed columns. Base table will not be read.
       |   |  Using I/O Size 4 Kbytes for index leaf pages.
       |   |  With LRU Buffer Replacement Strategy for index leaf pages.


-----------
         23

(1 row affected)
```

The ScalarAggOp message indicates that the query to be executed is an ungrouped count aggregation.

restrict operator

The restrict operator is a unary operator that evaluates expressions based on column values. The restrict operator is associated with multiple column evaluations lists that can be processed before fetching a row from the child operator, after fetching a row from the child operator, or to compute the value of virtual columns after fetching a row from the child operator.

sort operator

The sort operator has only one child operator within the query plan. Its role is to generate an output data stream from the input stream, using a specified sorting key.

The sort operator may execute a streaming sort when possible, but may also have to store results temporarily into a worktable. The sort operator displays the worktable's name in this format:

```
Using Worktable<N>  for internal storage.
```

where <***N***> is a numeric identifier for the worktable within the showplan output.

Here is an example of a simple query plan using a sort operator and a worktable:

```
1> use pubs2
2> go
1> set showplan on
2> go
1> select au_id from authors order by postalcode
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).

2 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

|SORT Operator
| Using Worktable1 for internal storage.
|
|   |SCAN Operator
|   |  FROM TABLE
|   |  authors
|   |  Table Scan.
|   |  Forward Scan.
|   |  Positioning at start of table.
|   |  Using I/O Size 4 Kbytes for data pages.
|   |  With LRU Buffer Replacement Strategy for data pages.

au_id
----------------------
807-91-6654
527-72-3246
722-51-5454
712-45-1867
341-22-1782
899-46-2035
998-72-3567
172-32-1176
```

```
486-29-1786
427-17-2319
846-92-7186
672-71-3249
274-80-9391
724-08-9931
756-30-7391
724-80-9391
213-46-8915
238-95-7766
409-56-7008
267-41-2394
472-27-2349
893-72-1158
648-92-1872

(23    rows affected)
```

The sort operator drains its child operator and sorts the rows. In this case, it sorts each row fetched from the authors table using the postalcode attribute. If all of the rows fit into memory, then no data is spilled to disk. But, if the input data's size exceeds the available buffer space, then sorted runs are spilled to disk. These runs are recursively merged into larger sorted runs until there are fewer runs than there are available buffers to read and merge the runs with.

store operator

The store operator is used to create a worktable, fill it, and possibly create an index on it. As part of the execution of a query plan, the worktable is used by other operators in the plan. A sequencer operator guarantees that the plan fragment corresponding to the worktable and potential index creation is executed before other plan fragments that use the worktable. This is important when a plan is executed in parallel, because execution processes operate asynchronously.

Reformatting strategies use the store operator to create a worktable with a clustered index on it.

If the store operator is used for a reformatting operation, it prints this message:

```
Worktable <X> created, in <L> locking mode for
reformatting.
```

The locking mode **<*L*>** has to be one of "allpages," "datapages," or "datarows."

The store operator also prints this message:

```
Creating clustered index.
```

If the store operator is not used for a reformatting operation, it prints this message:

```
Worktable <X> created, in <L> locking mode.
```

The locking mode *<L>* has to be one of “allpages,” “datapages”, or “datarows.”

The following example applies to the store operator, as well as to the sequencer operator.

```
1> select*from tab1e a, tab2 b where a.c4 = b.c4 and a.c2 < 10
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using the Abstract Plan in the PLAN clause.
STEP 1
  The type of query is SELECT.

  7 operator(s) under root

   |ROOT:EMIT Operator
   |
   |   |SEQUENCER Operator has 2 children.
   |   |
   |   |   |STORE Operator
   |   |   | Worktable1 created, in allpages locking mode, for REFORMATTING.
   |   |   | Creating clustered index.
   |   |   |
   |   |   |   |INSERT Operator
   |   |   |   | The update mode is direct.
   |   |   |   |
   |   |   |   |   |SCAN Operator
   |   |   |   |   | FROM TABLE
   |   |   |   |   | bigun
   |   |   |   |   | b
   |   |   |   |   | Table Scan.
   |   |   |   |   | Forward Scan.
   |   |   |   |   | Positioning at start of table.
   |   |   |   |   | Using I/O Size 2 Kbytes for data pages.
   |   |   |   |   | With LRU Buffer Replacement Strategy for data pages.
   |   |   |   |
   |   |   |   | TO TABLE
   |   |   |   | Worktable1.
   |   |
   |   |   |NESTED LOOP JOIN (Join Type: Inner Join)
```

```
|   |   |
|   |   |   |SCAN Operator
|   |   |   | FROM TABLE
|   |   |   | bigun
|   |   |   | a
|   |   |   | Table Scan.
|   |   |   | Forward Scan.
|   |   |   | Positioning at start of table.
|   |   |   | Using I/O Size 2 Kbytes for data pages.
|   |   |   | With LRU Buffer Replacement Strategy for data pages.
|   |   |
|   |   |   |SCAN Operator
|   |   |   | FROM TABLE
|   |   |   | Worktable1.
|   |   |   | Using Clustered Index.
|   |   |   | Forward Scan.
|   |   |   | Positioning key.
|   |   |   | Using I/O Size 2 Kbytes for data pages.
|   |   |   | With LRU Buffer Replacement Strategy for data pages.
```

In the example plan shown above, the STORE operator is used in a reformatting strategy. It is located directly below the SEQUENCER operator in the leftmost child of the SEQUENCER operator.

The STORE operator creates Worktable1, which is filled by the INSERT operator below it. The STORE operator then creates a clustered index on Worktable1. The index is built on the join key “b.c4”.

sequencer operator

The sequencer operator is a nary operator used to sequentially execute each the child plans below it. The sequencer operator is used in reformatting plans, and certain aggregate processing plans.

The sequencer operator executes each of its child subplans, except for the rightmost one. Once all the left child subplans are executed, the rightmost subplan is executed.

The sequencer operator displays this message:

```
SEQUENCER operator has N children.
```

Notice the query plan from the section immediately above the store operator.

```
1> select * from tab1 a, tab2 b where a.c4 - b.c4 and a.c2 < 10
```

```
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using the Abstract Plan in the PLAN clause.

  STEP 1
    The type of query is SELECT.

    7 operator(s) under root

     |ROOT:EMIT Operator
     |
     |   |SEQUENCER Operator has 2 children.
     |   |
     |   |   |STORE Operator
     |   |   | Worktable1 created, in allpages locking mode, for REFORMATTING.
     |   |   | Creating clustered index.
     |   |   |
     |   |   |   |INSERT Operator
     |   |   |   | The update mode is direct.
     |   |   |   |
     |   |   |   |   |SCAN Operator
     |   |   |   |   | FROM TABLE
     |   |   |   |   | tab2
     |   |   |   |   | b
     |   |   |   |   | Table Scan.
     |   |   |   |   | Forward Scan.
     |   |   |   |   | Positioning at start of table.
     |   |   |   |   | Using I/O Size 2 Kbytes for data pages.
     |   |   |   |   | With LRU Buffer Replacement Strategy for data pages.
     |   |   |   |
     |   |   |   | TO TABLE
     |   |   |   | Worktable1.
     |   |
     |   |   |NESTED LOOP JOIN Operator (Join Type: Inner Join)
     |   |   |
     |   |   |   |SCAN Operator
     |   |   |   | FROM TABLE
     |   |   |   | tab1
     |   |   |   | a
     |   |   |   | Table Scan.
     |   |   |   | Forward Scan.
     |   |   |   | Positioning at start of table.
     |   |   |   | Using I/O Size 2 Kbytes for data pages.
     |   |   |   | With LRU Buffer Replacement Strategy for data pages.
     |   |   |
     |   |   |   |SCAN Operator
```

```
|   |   |   | FROM TABLE
|   |   |   | Worktable1.
|   |   |   | Using Clustered Index.
|   |   |   | Forward Scan.
|   |   |   | Positioning by key.
|   |   |   | Using I/O Size 2 Kbytes for data pages.
|   |   |   | With LRU Buffer Replacement Strategy for data pages.
```

In this example, the SEQUENCER operator is used to implement a reformatting strategy. The leftmost branch of the SEQUENCER operator creates a clustered index on Worktable1. This branch is executed and closed before the SEQUENCER operator proceeds on to the next child operator. When the SEQUENCER operator arrives at the rightmost child, it opens it and begins to drain it, returning rows back to its parent operator. The design intent of the SEQUENCER operator is for operators in the rightmost branch to take advantage of worktables created in the preceding outer branches of the SEQUENCER operator. In this example, Worktable1 is used in a nested-loop join strategy. The scan of Worktable1 is positioned by a key on its clustered index for each row that comes from the outer scan of tab1.

remote scan operator

The remote scan operator sends a SQL query to a remote server for execution. It then processes the results returned by the remote server, if any. The remote scan operator displays the formatted text of the SQL query it handles.

The remote scan operator has 0 or 1 child operators.

scroll operator

The scroll operator encapsulates the functionality of scrollable cursors in Adaptive Server. Scrollable cursors may be insensitive, meaning that they display a snapshot of their associated data, taken when the cursor is opened, or semi-sensitive, meaning that the next rows to be fetched are retrieved from the live data.

The scroll operator is a unary operator that displays this message:

```
SCROLL OPERATOR ( Sensitive Type: <T>)
```

The type may be "insensitive" or "semi-sensitive."

This is an example of a plan featuring an insensitive scrollable cursor:

```
1> use pubs2
2> go
1> declare CI insensitive scroll cursor for
2> select au_lname, au_id from authors
3> go
1> set showplan on
2> go
1> open CI
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).

       STEP 1
          The type of query is OPEN CURSOR CI.


QUERY PLAN FOR STATEMENT 1 (at line 2).

2 operator(s) under root

The type of query is DECLARE CURSOR.

ROOT:EMIT Operator

       |SCROLL Operator (Sensitive Type: Insensitive)
       |     Using Worktable1 for internal storage.
       |
       |   |SCAN Operator
       |   |  FROM TABLE
       |   |  authors
       |   |  Table Scan.
       |   |  Forward Scan.
       |   |  Positioning at start of table.
       |   |  Using I/O Size 4 Kbytes for data pages.
       |   |  With LRU Buffer Replacement Strategy for data pages.
```

The scroll operator is the child operator of the root emit operator, and its only child is the scan operator on the authors table. The scroll operator message specifies that the CI cursor is insensitive.

Scrollable cursor rows are initially cached memory. Worktable1 is used as a backing store for this cache when the amount of data processed exceeds the cache's physical memory limits.

rid join operator

The rid join operator is a binary operator that joins two data streams, based on row IDs generated for the same source table. Each data row in a SQL table is associated with a unique row ID or RID. A rid-join can be thought of as a special case of a self-join query. The left child fills a worktable with the set of uniquely qualifying RIDs. The RIDs are the result of applying a distinct filter to the RIDs returned from two or more disparate index cases of the same source table.

The rid join operator is used to implement the general-or strategy. The general-or strategy is often used when a query's predicate contains a collection of disjunctions that can be qualified by different indexes on the same table. In this case, each index is scanned based on the predicates that can be qualified by that index. For each index row that qualifies, a RID is returned. The returned RIDs are processed for uniqueness so that the same row will not be returned twice. This could happen if two or more of the disjuncts qualify the same row. The rid join operator inserts the unique RIDs into a worktable. The worktable of unique RIDs is passed to the scan operator in the rid-join's right branch. The access methods are capable of iteratively fetching the next RID to be processed directly from the worktable and looking up the associated row. This row is then returned to the rid join parent operator.

The rid join operator displays this message:

```
Using Worktable <N> for internal storage.
```

This worktable is used to store the unique RIDs generated from the left child.

The following example demonstrates the showplan output for the rid join operator.

```
1> select * from tab1 a where a.c1 = 10 or a.c3 = 10

QUERY PLAN FOR STATEMENT 1 (at line 2).

  STEP 1
The type of query is SELECT.

6 operator(s) under root.

   |ROOT:EMIT Operator
   |
   |   |RID JOIN Operator
   |   | Using Worktable2 for internal storage.
   |   |
   |   |   |HASH UNION Operator has 2 children.
```

```
|   |   | Key Count: 1
|   |   |
|   |   |   |SCAN Operator
|   |   |   | FROM TABLE
|   |   |   | tab1
|   |   |   | a
|   |   |   | Index:tab1idx
|   |   |   | Forward Scan.
|   |   |   | Positioning by key.
|   |   |   | Index contains all needed columns. Base table will not be read.
|   |   |   | Keys are:
|   |   |   | c1 ASC
|   |   |   | Using I/O Size 2 Kbytes for index leaf pages.
|   |   |   | With LRU Buffer Replacement Strategy for index leaf pages.
|   |   |
|   |   |   |SCAN Operator
|   |   |   | FROM TABLE
|   |   |   | tab1
|   |   |   | a
|   |   |   | Index:tab1idx2
|   |   |   | Forward Scan.
|   |   |   | Positioning by key.
|   |   |   | Index contains all needed columns. Base table will not be read.
|   |   |   | Keys are:
|   |   |   |  c3 ASC
|   |   |   | Using I/O Size 2 Kbytes for index leaf pages.
|   |   |   | With LRU Buffer Replacement Strategy for index leaf pages.
|   |
|   |   |RESTRICT Operator
|   |   |
|   |   |   |SCAN Operator
|   |   |   | FROM TABLE
|   |   |   | tab1
|   |   |   | a
|   |   |   | Using Dynamic Index.
|   |   |   | Forward Scan.
|   |   |   | Positioning by Row IDentifier (RID).
|   |   |   | Using I/O Size 2 Kbytes for data pages.
|   |   |   | With LRU Buffer Replacement Strategy for data pages.
```

In this example, the index "tab1idx" is scanned to get all RIDs from tab1 that have a c1 value of 10. The index "tab1idx2" is scanned to get all RIDs from tab1 that have a c3 value of 10. The HASH UNION operator is used to eliminate duplicate RIDs. There will be duplicate RIDs for any tab1 row(s) where both c1 and c3 rows have a value of 10. The RID JOIN operator inserts all of the returned rows into Worktable2. Worktable2 is passed to the scan of tab1 after it has been completely filled. The access methods fetch the first RID, look up the associated row, and return it to the RID JOIN operator. On subsequent calls to the tab1's scan operator, the access methods fetch the next RID to be processed and return its associated row.

sqfilter operator

The sqfilter operator is a nary operator that executes subqueries. Its leftmost child represents the outer query, and the other children represent query plan fragments associated with one or more subqueries.

The leftmost child generates correlation values that are substituted into the other child plans.

The sqfilter operator displays this message:

```
SQFILTER Operator has <N> children.
```

This example illustrates the use of sqfilter.

```
select pub_name from publishers
where pub_id =
(select distinct titles.pub_id from titles
   where publishers.pub_id = titles.pub_id
   and price > $1000)
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
4 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

   |SQFILTER Operator has 2 children.
   |
   |   |SCAN Operator
   |   |  FROM TABLE
   |   |  publishers
   |   |  Table Scan.
   |   |  Forward Scan.
```

```
|   |  Positioning at start of table.
|   |  Using I/O Size 8 Kbytes for data pages.
|   |  With LRU Buffer Replacement Strategy for data pages.
|
| Run subquery 1 (at nesting level 1)
|
|  QUERY PLAN FOR SUBQUERY 1 (at nesting level 1 and at line 3)
|
|  Correlated Subquery
|  Subquery under an EXPRESSION predicate.
|
|   |SCALAR AGGREGATE Operator
|   |  Evaluate Ungrouped ONCE-UNIQUE AGGREGATE
|   |
|   |   |SCAN Operator
|   |   |  FROM TABLE
|   |   |  titles
|   |   |  Table Scan.
|   |   |  Forward Scan.
|   |   |  Postitioning at start of table.
|   |   |  Using I/O Size 8 Kbytes for data pages.
|   |   |  With LRU Buffer Replacement Strategy for data pages.
|
| END OF QUERY PLAN FOR SUBQUERY 1
```

The sqfilter operator has 2 children in this example. The leftmost child is the query's outer block. It is a simple scan of the publishers table. The right child is used to evaluate the query's subquery. The sqfilter will fetch rows from the outer block. For every row from the outer block, it will invoke the right child to evaluate the subquery. If the subquery evaluates to TRUE, then a row will be returned to the sqfilter's parent operator.

exchange operator

The exchange operator is a unary operator that encapsulates parallel processing of Adaptive Server SQL queries. It can be located almost anywhere in a query plan. It divides the query plan into plan fragments. A plan fragment is a query plan tree that is rooted at an emit or exchange:emit operator and has leaves that are scan or exchange operators. A serial plan is a plan fragment that is executed by a single process.

An exchange operator's child operator is always an exchange:emit operator. The exchange:emit operator is the root of a new plan fragment. An exchange operator has an associated server process that acts as a local execution coordinator for the exchange operator's worker processes. It is called the Beta process. The worker processes execute the plan fragment as directed by the parent exchange operator and its Beta process. The plan fragment is often executed in a parallel fashion, using two or more processes. The exchange operator and Beta process coordinate the activities including the exchange of data between the fragment boundaries.

The topmost plan fragment, rooted at an emit operator rather than an exchange:emit operator, is executed by the Alpha process. The Alpha process is a consumer process associated with the user connection. The Alpha process is the global coordinator of all of the query plan's worker processes. It is responsible for initially setting up all of the plan fragment's worker processes and eventually freeing them. It manages and coordinates all of the fragment's worker processes in the case of an exception.

The exchange operator displays this message:

```
Executed in parallel by N producer and P consumer processes.
```

The number of producers refers to the number of worker processes that execute the plan fragment located beneath the exchange operator. The number of consumers refers to the number of worker processes that execute the plan fragment that contains the exchange operator. The consumers process the data passed to them by the producers. Data is exchanged between the producer and consumer processes through a pipe set up in the exchange operator. The producer's exchange:emit operator writes rows into the pipe while consumers read rows from this pipe. The pipe mechanism is responsible for synchronizing producer writes and consumer reads such that no data is lost.

This example illustrates a parallel query in the master database against the system table sysmessages:

```
1> use master
2> go
1> set showplan on
2> go
1> select count(*) from sysmessages (parallel 4)
2> go

QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using the forced options (internally generated Abstract Plan).
Executed in parallel by coordinating process and 4 worker processes.

4 operator(s) under root
```

```
The type of query is SELECT.

ROOT:EMIT Operator

        |SCALAR AGGREGATE Operator
        |  Evaluate Ungrouped COUNT AGGREGATE.
        |
        |   |EXCHANGE Operator
        |   |Executed in parallel by 4 Producer and 1 Consumer processes.

        |   |
        |   |   |EXCHANGE:EMIT Operator
        |   |   |
        |   |   |   |SCAN Operator
        |   |   |   |  FROM TABLE
        |   |   |   |  sysmessages
        |   |   |   |  Table Scan.
        |   |   |   |  Forward Scan.
        |   |   |   |  Positioning at start of table.
        |   |   |   |  Executed in parallel with a 4-way hash scan.
        |   |   |   |  Using I/O Size 4 Kbytes for data pages.
        |   |   |   |  With LRU Buffer Replacement Strategy for data pages.

-----------
7597

(1     row affected)
```

There are two plan fragments in this example. The first fragment in any plan, parallel or not, is always rooted by an EMIT operator. The first fragment in this example consists of the EMIT, SCALAR AGGREGATE, and EXCHANGE operators. This first fragment is always executed by the single Alpha process. In this example, it also acts as the Beta process responsible for managing the EXCHANGE operator's worker processes.

The second plan fragment is rooted at the EXCHANGE:EMIT operator. Its only child operator is the SCAN operator. The SCAN operator is responsible for scanning the sysmessages table. Note that the scan is executed in parallel:

```
Executed in parallel with a 4-way hash scan
```

This indicates that each worker process will process approximately a quarter of the table. Pages will be assigned to the worker processes based on having the data page ID.

The EXCHANGE:EMIT operator writes data rows to the consumer(s) by writing to a pipe created by its parent EXCHANGE operator. In this example, the pipe is a four-to-one demultiplexer. There are several pipe types that perform quite different behaviors.

Instead-of trigger operators

There are two operators associated with the instead-of triggers feature. They are the INSTEAD-OF TRIGGER operator and the CURSOR SCAN operator. The instead-of trigger feature uses pseudo tables which allow the user to apply specific actions for inserts, deletes, and updates on views that would otherwise have been ambiguous.

instead-of trigger operator

The instead-of trigger operator only appears in query plans for INSERT, DELETE, or UPDATE statements on a view which has an instead-of trigger created upon it. Its function is to create and fill the inserted and deleted pseudo tables that are used in the trigger to examine the rows that would have been modified by the original INSERT, DELETE, or UPDATE query. The only purpose of the query plan that contains the INSTEAD-OF TRIGGER operator is to fill the inserted and deleted tables -- the actual operation of the original SQL statement (INSERT, DELETE, or UPDATE) is never attempted on the view referenced in the statement. Rather, it is up to the trigger to perform the updates to the view's underlying tables based on the data available in the inserted and deleted pseudo tables.

The following is an example of the INSTEAD-OF TRIGGER operator's showplan output:

```
1> create table t12 (c0 int primary key, c1 int null, c2 int null)
. . .
1> create view t12view as select c1,c2 from t12
1> create trigger v12updtrg on t12view
2> instead of update as
3> select * from deleted
1> update t12view set c1 = 3

QUERY PLAN FOR STATEMENT 1 (at line 1).
```

```
  STEP 1
    The type of query is SELECT.

2 operator(s) under root

   |ROOT:EMIT Operator
   |
   |   |INSTEAD-OF TRIGGER Operator
   |   | Using Worktable1 for internal storage.
   |   | Using Worktable2 for internal storage.
   |   |
   |   |   |SCAN Operator
   |   |   | FROM TABLE
   |   |   | t12
   |   |   | Table Scan.
   |   |   | Forward Scan.
   |   |   | Positioning at start of table.
   |   |   | Using I/O Size 2 Kbytes for data pages.
   |   |   | With LRU Buffer Replacement Strategy for data pages.
```

In this example, the v12updtrig instead-of trigger is defined on the t12view. The update to the t12view results in the creation of the INSTEAD-OF TRIGGER operator. The INSTEAD-OF TRIGGER operator creates two worktables. Worktable1 and Worktable2 are used to hold the "inserted" and "deleted" rows respectively. These worktables are unique in that they will persist across statements. Trigger execution results in the following showplan lines getting printed.

```
QUERY PLAN FOR STATEMENT 1 (at line 3).

  STEP 1
    The type of query is SELECT.

1 operator(s) under root

  |ROOT:EMIT Operator
  |
  |   |SCAN Operator
  |   | FROM CACHE
```

The showplan statement output above is for the trigger's statement "select * from deleted". The rows to be deleted from the view were inserted into the "deleted" cache when the initial update statement was executed. Then, the trigger scans the table to report what rows would have been deleted from the t12view view.

CURSOR SCAN operator

The CURSOR SCAN operator only appears in positioned DELETE or UPDATE (that is, DELETE view-name where current of cursor-name) statements on a view that has an instead-of trigger created upon it. As such, it only appears as a child operator of the INSTEAD-OF TRIGGER operator. A positioned DELETE or UPDATE accesses only the row on which the cursor is currently positioned. The CURSOR SCAN operator reads the current row of the cursor directly from the EMIT operator of the query plan for the “fetch cursor” statement. These values are passed to the INSTEAD-OF TRIGGER operator to be inserted into the inserted and/or deleted pseudo tables.

```
1> declare curs1 cursor for select * from t12view
1> open curs1
1> fetch curs1
c1         c2
_________ ________
       1        2

(1 row affected)
1> set showplan on
1> update t12view set c1 = 3
2> where current of curs1

QUERY PLAN FOR STATEMENT (at line 1).

  STEP 1
    The type of query is SELECT.

2 operator(s) under root

  |ROOT:EMIT Operator
  |
  |   |INSTEAD-OF TRIGGER Operator
  |   | Using Worktable1 for internal storage.
  |   | Using Worktable2 for internal storage.
  |   |
  |   |   |CURSOR SCAN Operator
  |   |   | FROM EMIT OPERATOR
```

Note that the showplan output in this example is identical to that from the previous INSTEAD-OF TRIGGER operator example, with one exception. A CURSOR SCAN operator appears as the child operator of the INSTEAD-OF TRIGGER operator rather than a scan of the view’s underlying tables.

The CURSOR SCAN gets the values to be inserted into the pseudo tables by accessing the result of the cursor fetch. This is conveyed by the “FROM EMIT OPERATOR” message.

```
QUERY PLAN FOR STATEMENT 1 (at line 3).

  STEP 1
    The type of query is SELECT.

1 operator(s) under root

   |ROOT:EMIT Operator
   |
   |   |SCAN Operator
   |   | FROM CACHE
```

The showplan statement above is for the trigger’s statement. It is identical to the output in the INSTEAD-OF TRIGGER example.

CHAPTER 3 Displaying Query Optimization Strategies and Estimates

This chapter describes the messages printed by the set commands designed for query optimization.

set commands for text format messages

Either the query optimizer or the query execution layer can generate diagnostic output. To generate diagnostic output in text format, use this set option command:

```
set option
  {   {show | show_lop | show_managers | show_log_props |
       show_parallel | show_histograms | show_abstract_plan |
       show_search_engine | show_counters | show_best_plan |
       show_code_gen | show_pio_costing | show_lio_costing |
       show_pll_costing | show_elimination | show_missing_stats}
     {normal | brief | long | on | off} }...
```

Note Each option specified must be followed by a choice of normal, brief, long, on, or off. On and normal are equivalent. More than one option, and its corresponding choice, may be specified in a set option command, with each pair separated by a comma.

Table 3-1: Optimizer set commands for text format messages

Option	Definition
show	Shows a reasonable collection of details, where the collection depends on the choice of {normal | brief | long | on | off}.
show_lop	Shows the logical operators used.
show_managers	Shows data structure managers used during optimization.
show_log_props	Shows the logical properties evaluated.
show_parallel	Shows details of parallel query optimization.
show_histograms	Shows the processing of histograms associated with SARG/join columns.
show_abstract_plan	Shows the details of an abstract plan.
show_search_engine	Shows the details of the join-ordering algorithm.
show_counters	Shows the optimization counters.
show_best_plan	Shows the details of the best query plan selected by the optimizer.
show_code_gen	Shows details of code generation.
show_pio_costing	Shows estimates of physical input/output (reads/writes from/to the disk).
show_lio_costing	Shows estimates of logical input/output (reads/writes from/to memory).
show_pll_costing	Shows estimates relating to costing for parallel execution.
show_elimination	Shows partition elimination.
show_missing_stats	Shows details of useful statistics missing from SARG/join columns.

set commands for XML format messages

Diagnostics have been enhanced so that they can be sent out as an XML document. This makes it easier for front-end tools to interpret a document. You can use the native XPath query processor inside Adaptive Server to query this output if the XML option is enabled.

Either the query optimizer or the query execution layer can generate diagnostics output. To generate an XML document for the diagnostic output, use this set plan command:

```
set plan for
    {show_exec_xml, show_opt_xml, show_execio_xml,
    show_lop_xml, show_managers_xml, show_log_props_xml,
    show_parallel_xml, show_histograms_xml, show_final_plan_xml,
    show_abstract_plan_xml, show_search_engine_xml,
    show_counters_xml, show_best_plan_xml, show_pio_costing_xml,
    show_lio_costing_xml, show_elimination_xml}
    to {client | message} on
```

Option	Definition
show_exec_xml	Gets the compiled plan output in XML, showing each of the query plan operators.
show_opt_xml	Gets optimizer diagnostic output, which shows the different components such as logical operators, output from the managers, some of the search engine diagnostics, and the best query plan.
show_execio_xml	Gets the plan output along with estimated and actual IOs. show_execio_xml also includes the query text.
show_lop_xml	Gets the output logical operator tree in XML.
show_managers_xml	Shows the output of the different component managers during the preparation phase of the query optimizer.
show_log_props_xml	Shows the logical properties for a given equivalence class (one or more group of relations in the query).
show_parallel_xml	Shows the diagnostics related to the optimizer while generating parallel query plans.
show_histograms_xml	Shows diagnostics related to histograms and the merging of histograms.
show_final_plan_xml	Gets the plan output. Does not include the estimated and actual I/Os. show_final_plan_xml includes the query text.
show_abstract_plan_xml	Shows the generated abstract plan.
show_search_engine_xml	Shows diagnostics related to the search engine.
show_counters_xml	Shows plan object construction/destruction counters.
show_best_plan_xml	Shows the best plan in XML.
show_pio_costing_xml	Shows actual physical input/output costing in XML.
show_lio_costing_xml	Shows actual logical input/output costing in XML.
show_elimination_xml	Shows partition elimination in XML.
client	When specified, output is sent to the client. By default, this is understood to mean the error log. When traceflag 3604 is active, however, output is sent to the client connection.
message	When specified, output is sent to an internal message buffer.

To turn an option off, specify:

```
set plan for
    {show_exec_xml, show_opt_xml, show_execio_xml, show_lop_xml,
    show_managers_xml, show_log_props_xml, show_parallel_xml,
    show_histograms_xml,show_final_plan_xml
    show_abstract_plan_xml, show_search_engine_xml,
    show_counters_xml, show_best_plan_xml, show_pio_costing_xml,
    show_lio_costing_xml, show_elimination_xml} off
```

You need not specify the destination stream when turning the option off.

When message is specified, the client application must get the diagnostics from the buffer using a built-in function called showplan_in_xml(query_num).

query_num refers to the number of queries that are cached in the buffer. Currently, a maximum of 20 queries are cached in the buffer. The cache stops collecting query plans when it reaches 20 queries; it ignores the rest of the query plans. However, the message buffer continues to collect query plans. After 20 queries, you can only display the message buffer in its entirety by using a value of 0.

A value of -1 refers to the last XML doc in the cache; a value of 0 refers to the entire message buffer. This means that the legal values for *query_num* are not only 1 through 20, but also include -1 and 0.

The message buffer may overflow. If this occurs, there is no way to log all of the XML document, which may result in a partial and invalid XML document.

When the message buffer is accessed using showplan_in_xml, the buffer is emptied after execution.

You may want to use set textsize to set the maximum text size, as the XML document is printed as a text column and the document is truncated if the column is not large enough. For example, set the text size to 100000 bytes using:

```
set textsize 100000
```

When set plan is issued with off, all XML tracing is turned off if all of the trace options have been turned off. Otherwise, only specified options are turned off. Other options previously turned on are still valid and tracing continues on the specified destination stream. When you issue another set plan option, the previous options are joined with the current options, but the destination stream is switched unconditionally to a new one.

Using show_execio_xml to diagnose query plans

show_execio_xml includes diagnostic information that can be helpful for investigating problematic queries. The information show_execio_xml displays includes:

- The version level of the query plan. Each version of the plan is uniquely identified. This is the first version of the plan:

  ```
  <planVersion>1.0</planVersion>
  ```

- The statement number in a batch or stored procedure, along with the line number of the statement in the original text. This is statement number 2, but line number 6, in the query:

```
<statementNum>2</statementNum>
<lineNum>6</lineNum>
```

- The abstract plan for the query. For example, this is the abstract plan for the query select * from titles:

```
<abstractPlan>
        <![CDATA[>
                 ( i_scan titleidind titles ) ( prop titles ( parallel 1
) ( prefetch 8 ) ( lru ) )
]]>
        </abstractPlan>
```

- The logical IO, physical IO, and CPU costs:

```
 <costs>
    <lio> 2 </lio>
    <pio> 2 </pio>
    <cpu> 18 </cpu>
</costs>
```

You can estimate the total costs with this formula:

25 X *pio* + 2 X *lio* + 0.1 X *cpu*

- The estimated execution resource usage, including the number of threads and auxiliary scan descriptors used by the query plan.
- The number of plans the query engine viewed and the plans it determined were valid, the total time spent in the query engine (in milliseconds), the time it took to determine the first legal plan, and the amount of procedure cache used during the optimization process.

```
<optimizerMetrics>
    <optTimeMs>6</optTimeMs>
    <optTimeToFirstPlanMs>3</optTimeToFirstPlanMs>
    <plansEvaluated>1</plansEvaluated>
    <plansValid>1</plansValid>
    <procCacheBytes>140231</procCacheBytes>
</optimizerMetrics>
```

- The last time update statistics was run on the current table and whether the query engine used a hard-wired estimation constant for a given column that it could have estimated better if statistics were available. This section includes information about columns with missing statistics:

```
<optimizerStatistics>
    <statInfo>
        <objName>titles</objName>
        <columnStats>
```

```
            <column>title_id</column>
            <updateTime>Oct  5 2006  4:40:14:730PM</updateTime>
        </columnStats>
        <columnStats>
            <column>title</column>
            <updateTime>Oct  5 2006  4:40:14:730PM</updateTime>
        </columnStats>
    </statInfo>
</optimizerStatistics>
```

- An operator tree that includes table and index scans with information about cache strategies and IO sizes (inserts, updates, and deletes have the same information for the target table). The operator tree also shows whether updates are performed in “direct” or “deferred” mode. The exchange operator includes information about the number of producer and consumer processes the query used.

```
<TableScan>
    <VA>0</VA>
    <est>
        <rowCnt>18</rowCnt>
        <lio>2</lio>
        <pio>2</pio>
        <rowSz>218.5555</rowSz>
    </est>
    <varNo>0</varNo>
    <objName>titles</objName>
    <scanType>TableScan</scanType>
    <partitionInfo>
        <partitionCount>1</partitionCount>
    </partitionInfo>
    <scanOrder> ForwardScan </scanOrder>
    <positioning> StartOfTable </positioning>
    <dataIOSizeInKB>8</dataIOSizeInKB>
    <dataBufReplStrategy> LRU </dataBufReplStrategy>
</TableScan>
```

Usage scenarios

Scenario A

To send the execution plan XML to the client as trace output, use:

```
set plan for show_exec_xml to client on
```

Then run the queries for which the plan is wanted:

```
select id from sysindexes where id < 0
```

If dbcc traceon(3604) is set, trace information goes to the client's connection. If dbcc traceon (3605) is set, trace information goes to the error log.

Scenario B

To get the execution plan, use the showplan_in_xml built-in. You can get the output from the last query, or from any of the first 20 queries in a batch or stored procedure.

```
set plan for show_opt_xml to  message on
```

Run the query as:

```
select id from sysindexes where id < 0
select name from sysobjects where id > 0
go

select showplan_in_xml(0)
go
```

The example generates two XML documents as text streams. You can run an XPath query over this built-in as long as the XML option is enabled in Adaptive Server.

```
select xmlextract("/", showplan_in_xml(-1))
go
```

This allows the XPath query "/" to be run over the XML doc produced by the last query.

Scenario C

To set multiple options:

```
set plan for show_exec_xml, show_opt_xml to client on
go

select name from sysobjects where id > 0
go
```

This sets up the output from the optimizer and the query execution engine to send the result to the client, as is done in normal tracing.

```
set plan for show_exec_xml off
go
select name from sysobjects where id > 0
go
```

The optimizer's diagnostics are still available, as show_opt_xml is left on.

Scenario D

When running a set of queries in a batch, you can ask for the optimizer plan for the last query.

```
set plan for show_opt_xml to message on
```

```
go
declare @v int
select @v = 1
select name from sysobjects where id = @v
go

select showplan_in_xml(-1)
go
```

showplan_in_xml() can also be part of the same batch as it works the same way. Any message for the showplan_in_xml() built-in is ignored for logging.

To create a stored procedure:

```
create proc PP as
declare @v int
select @v = 1
select name from sysobjects where id = @v
go

exec P
go

select showplan_in_xml(-1)
go
```

If the stored procedure calls another stored procedure, and the called stored procedure compiles, and optimizer diagnostics are turned on, you get the optimizer diagnostics for the new set of statements as well. The same is true if show_execio_xml is turned on and only the called stored procedure is executed.

Scenario E

To query the output of the showplan_in_xml() for the query execution plan, which is an XML doc:

```
set plan for show_exec_xml to message on
go

select name from sysobjects
go

select  case when
'/Emit/Scan[@Label="Scan:myobjectss"]' xmltest
showplan_in_xml(-1)
then "PASSED" else "FAILED" end
go

set plan for show_exec_xml off
go
```

Scenario F

Use show_final_plan_xml to configure Adaptive Server to display the query plan as XML output. This output does not include the actual LIO costs, PIO costs, or the row counts. Once show_final_plan_xml is enabled, you can select the query plan from the last run query (which is query ID of -1). To enable show_final_plan_xml:

```
set plan for show_final_plan_xml to message on
```

Run your query, for example:

```
use pubs2
go
select * from titles
go
```

Select the query plan for the last query run using the showplan_in_xml parameter:

```
select showplan_in_xml(-1)
```

Permissions for *set* commands

The sa_role has full access to the set commands described above.

For other users, new set tracing permissions must be granted and revoked by the System Administrator to allow set option and set plan for XML, as well as dbcc traceon/off (3604,3605).

For more information, see the grant command description in *Adaptive Server Reference Manual: Commands*.

Tracing commands

Optimization tracing options (dbcc traceon/off(302,310,317)) from versions of Adaptive Server earlier than 15.0 are no longer supported.

dbcc traceon(3604) can be used to direct trace output to the client process that would otherwise go to the error log. dbcc traceon(3605) can be used to direct output to the error log as well as to the client process.

CHAPTER 4 Parallel Query Processing

This chapter provides an in-depth description of parallel query processing.

Vertical, horizontal, and pipelined parallelism

Adaptive Server supports horizontal and vertical parallelism for query execution. Vertical parallelism is the ability to run multiple operators at the same time by employing different system resources such as CPUs, disks, and so on. Horizontal parallelism is the ability to run multiple instances of an operator on the specified portion of the data.

The way you partition your data greatly affects how well horizontal parallelism works. The logical partitioning of data is useful in operational decision-support systems (DSS) queries where large volumes of data are being processed.

See Chapter 10, “Partitioning Tables and Indexes,” in the *Transact-SQL User’s Guide* and the section titled “Partitioning Tables for Performance” in Chapter 6, “Controlling Physical Data Placement,” of the *Performance and Tuning: Basics* guide for a more detailed discussion of partitioning on Adaptive Server. Understanding different types of partitioning is a prerequisite to understanding this chapter.

Adaptive Server also supports pipelined parallelism. Pipelining is a form of vertical parallelism in which intermediate results are piped to higher operators in a query tree. The output of one operator is used as input for another operator. The operator used as input can run at the same time as the operator feeding the data, which is an essential element in pipelined parallelism. Use parallelism only when multiple resources like disks and CPUs are available. Using parallelism can be detrimental if your system is not configured for resources that can work in tandem. In addition, data must be spread across disk resources in a way that closely ties the logical partitioning of the data with the physical partitioning on parallel devices. The biggest challenge for a parallel system is to control the correct granularity of parallelism. If parallelism is too finely grained, communication and synchronization overhead can offset any benefit that is obtained from parallel operations. Making parallelism too coarse does not permit proper scaling.

Queries that benefit from parallel processing

When Adaptive Server is configured for parallel query processing, the query optimizer evaluates each query to determine whether it is eligible for parallel execution. If it is eligible, and if the optimizer determines that a parallel query plan can deliver results faster than a serial plan, the query is divided into plan fragments that are processed simultaneously. The results are combined and delivered to the client in a shorter period of time than it would take to process the query serially as a single fragment.

Parallel query processing can improve the performance of:

- select statements that scan large numbers of pages but return relatively few rows, such as table scans or clustered index scans with grouped or ungrouped aggregates.
- Table scans or clustered index scans that scan a large number of pages, but have where clauses that return only a small percentage of rows.
- select statements that include union, order by, or distinct, since these query operations can make use of parallel sorting or parallel hashing.
- select statements where a reformatting strategy is chosen by the optimizer, since these can populate worktables in parallel and can make use of parallel sorting.
- join queries.

Commands that return large, unsorted result sets are unlikely to benefit from parallel processing due to network constraints. In most cases, results can be returned from the database faster than they can be merged and returned to the client over the network.

Parallel DMLs like insert, delete, and update are not supported and so do not benefit from parallelism.

Enabling parallelism

To configure Adaptive Server for parallelism, you must enable the number of worker processes and max parallel degree parameters.

To gain optimal performance, you must be aware of other configuration parameters that affect the quality of plans generated by Adaptive Server.

Setting the *number of worker processes*

Before you enable parallelism, you must first configure the number of worker processes (also referred to as threads) available for Adaptive Server by setting the configuration parameter number of worker processes. Make sure you configure a sufficient number of worker processes. Sybase recommends that you set the value for number of worker processes to one and a half times the total number required at peak load. You can calculate an approximate number using the max parallel degree configuration parameter, which indicates the total number of worker processes that can be used for any query. Depending on the number of connections to the Adaptive Server and the approximate number of queries that are run simultaneously, you can use this rule to roughly estimate the value for the number of worker processes that may be needed at any time:

[number of worker processes] = [max parallel degree] x [the number of concurrent connections wanting to run queries in parallel] x [1.5]

If the query processor has insufficient worker processes, the processor tries to adjust the query plan during runtime. If a minimal number of worker processes are required but unavailable, the query aborts with this error message:

```
Insufficient number of worker processes to execute the
parallel query. Increase the value of the configuration
parameter ‘number of worker processes’
```

To set the number of worker processes to 40:

```
sp_configure "number of worker processes", 40
```

Any runtime adjustment for the number of threads may have a negative effect on query performance. Adaptive Server always tries to optimize thread usage, but it may have already committed to a plan that needs increased resources, and therefore does not guarantee a linear scaledown when it runs with fewer threads.

Setting *max parallel degree*

Use the max parallel degree configuration parameter to configure the maximum amount of parallelism for a query. This parameter determines the maximum number of threads Adaptive Server uses when processing a given query. For example, to set max parallel degree to 10, enter:

```
sp_configure "max parallel degree", 10
```

Unlike versions of Adaptive Server earlier than 15.0, this parameter's value is not entirely enforced by the query optimizer. A complete enforcement process is expensive in terms of optimization time. Adaptive Server comes close to the desired setting of max parallel degree and exceeds it only for semantic reasons.

Setting *max resource granularity*

The value of max resource granularity configures the maximum percentage of system resources a query can use. As of version 15.0, max resource granularity affects only procedure cache. This parameter is set to 10% by default. However, it is not enforced at execution time; it is only a guide for the query optimizer. The query engine can avoid memory-intensive strategies, such as hash-based algorithms, when max resource granularity is set to a low value.

To set max resource granularity to 5%, enter:

```
sp_configure "max resource granularity", 5
```

Setting *max repartition degree*

Adaptive Server must dynamically repartition intermediate data to match the partitioning scheme of another operand or to perform an efficient partition elimination. The configuration parameter max repartition degree controls the amount of dynamic repartitioning Adaptive Server can do. If the value of max repartition degree is too high, the number of intermediate partitions becomes too large and the system becomes flooded with worker processes that compete for resources, which eventually degrades performance. The value for max repartition degree enforces the maximum number of partitions created for any intermediate data. Repartitioning is a CPU-intensive operation. The value of max repartition degree should not exceed the total number of Adaptive Server engines.

If all tables and indexes are unpartitioned, Adaptive Server uses the value for max repartition degree to provide the number of partitions to create as a result of repartitioning the data. When the value is set to 1, which is the default case, the value of max repartition degree is set to the number of online engines.

Use max repartition degree when using the force option to perform a parallel scan on a table or index.

```
select * from customers (parallel)
```

For example, if the customers table is unpartitioned and the force option is used, Adaptive Serve tries to find the inherent partitioning degree of that table or index, which in this case is 1. It uses the number of engines configured for the server, or whatever degree is best based on the number of pages in the table or index that does not exceed the value of max repartition degree.

To set max repartition degree to 5:

```
sp_configure "max repartition degree", 5
```

Setting *max scan parallel degree*

The max scan parallel degree configuration parameter is used only for backward compatibility, when the data in a partitioned table or index is highly skewed. If the value of this parameter is greater than 1, Adaptive Server uses this value to do a hash-based scan. The value of max scan parallel degree cannot exceed the value of max parallel degree.

Setting *prod-consumer overlap* factor

This parameter affects how much pipelined parallelism can be created in a query plan. The default value is 20%, which means that if two operators in a parent-child relationship are run by separate worker processes, there is a 20% overlap. The remaining 80% of the operation is sequential. This affects the way in which Adaptive Server costs two plan fragments. Consider the example of a scan operator under a grouping operation. In such a case, if the scan operator takes *N1* seconds and grouping operations take *N2* seconds, the response time of the two operators is:

```
0.2 * max (N1, N2) + 0.8 * (N1 + N2)
```

In setting this parameter, consider the number of online engines on which Adaptive Server is running and the complexity of the queries to be run. As a general rule, use thread resources to scan on multiple partitions first. Then, if there are unused thread resources, use them to speed up vertical pipelined parallelism. Do not exceed a value of 50.

Setting *min pages for parallel scan*

This parameter controls which tables and indices may be accessed in parallel. If the number of pages in a table is below this value, the table is accessed serially. The default value is 200 pages; page size is not relevant. Although the tables and indices of the table are accessed serially, Adaptive Server tries to repartition the data, if that is appropriate, and to use parallelism above the scans, if that is appropriate.

Setting *max query parallel degree*

This parameter does what max parallel degree otherwise does for a query; that is, it defines the number of worker processes to use for a given query. This parameter is relevant only if you do not want to enable parallelism globally. You must configure the number of worker processes to a value greater than zero, but max query parallel degree must be set to 1.

When max query parallel degree is set to a value greater than 1, queries are not compiled to use parallelism. Instead, it allows you to specify parallel hints, using Abstract Plans to compile one or more queries using parallelism.

Use use parallel *N* to define how much parallelism is to be used for a given query. Alternatively, use create plan to specify the query and the number of worker processes to use for it.

Controlling parallelism at the session level

The set options let you restrict the degree of parallelism on a session basis, in stored procedures, or in triggers. These options are useful for tuning experiments with parallel queries and can also be used to restrict noncritical queries to run in serial, so that worker processes remain available for other tasks. The set options are summarized in the following table.

Table 4-1: Session-level parallelism control parameters

Parameter	Function
parallel_degree	Sets the maximum number of worker processes for a query in a session, stored procedure, or trigger. Overrides the max parallel degree configuration parameter, but must be less than or equal to the value of max parallel degree.
scan_parallel_degree	Sets the maximum number of worker processes for a hash-based scan during a specific session, stored procedure, or trigger. Overrides the max scan parallel degree configuration parameter and must be less than or equal to the value of max scan parallel degree.
resource_granularity	Overrides the global value max resource granularity and sets it to a session specific value, which influences whether Adaptive Server uses memory-intensive operations.
repartition_degree	Sets the value of max repartition degree for a session. This is the maximum degree to which any intermediate data stream will be repartitioned for semantic purposes.

If you specify a value that is too large for any of the set options, the value of the corresponding configuration parameter is used, and a message reports the value that is in effect. While set parallel_degree, set scan_parallel_degree, set repartition_degree, or set resource_granularity is in effect during a session, the plans for any stored procedures that you execute are not placed in the procedure cache. Procedures executed with these set options in effect may produce less than optimal plans.

set command examples

This example restricts all queries started in the current session to 5 worker processes:

```
set parallel_degree 5
```

While this command is in effect, any query on a table with more than 5 partitions cannot use a partition-based scan.

To remove the session limit, use:

```
set parallel_degree 0
```

or

```
set scan_parallel_degree 0
```

To run subsequent queries in serial mode, use:

```
set parallel_degree 1
```

or

```
set scan_parallel_degree 1
```

To set resource granularity to 25% of the total resources available in the system, use:

```
set resource_granularity 25
```

The same is true for repartition degree as well; you can set it to a value of 5. It cannot, however, exceed the value of max parallel degree.

```
set repartition_degree 5
```

Controlling query parallelism

The parallel extension to the from clause of a select command allows users to suggest the number of worker processes used in a select statement. The degree of parallelism that you specify cannot be more than the value set with sp_configure or the session limit controlled by a set command. If you specify a higher value, the specification is ignored, and the optimizer uses the set or sp_configure limit.

The syntax for the select statement is:

select ...

from *tablename* [([index *index_name*]
[parallel [*degree_of_parallelism* | 1]]
[prefetch *size*] [lru|mru])] ,
tablename [([index *index_name*]
[parallel [*degree_of_parallelism* | 1]]
[prefetch *size*] [lru|mru])] ...

Query-level parallel clause examples

To specify the degree of parallelism for a single query, include `parallel` after the table name. This example executes in serial:

```
select * from huge_table (parallel 1)
```

This example specifies the index to use in the query, and sets the degree of parallelism to 2:

```
select * from huge_table (index ncix parallel 2)
```

Using parallelism selectively

Not all queries benefit from parallelism. In general, the optimizer determines which queries will not benefit from parallelism and attempts to run them serially. When the query processor makes errors in such cases, it is usually because of skewed statistics or incorrect costing as a result of imperfect modeling. Experience will show you whether queries are running better or worse, and you can decide to keep parallel on or off.

If you choose to keep parallel on, and have identified the queries you want to run in serial mode, you can attach an abstract plan hint, as follows:

```
select count(*) from sysobjects
plan "(use parallel 1)"
```

The same effect is achieved by creating a query plan:

```
create plan "select count(*) from sysobjects"
"use parallel 1"
```

If, on the other hand, you notice that parallelism is resource-intensive or that it does not generate query plans that perform well, use it selectively. To enable parallelism for selected complex queries:

1. Set the number of worker processes to a number greater than zero, based on the guidelines in “Setting the number of worker processes” on page 109. For example, to configure 10 worker processes, execute:

   ```
   sp_configure “number of worker processes”, 10
   ```

2. Then set max query parallel degree to a value greater than 1. As a starting point, you could set it to what you would have used for max parallel degree:

   ```
   sp_configure “max query parallel degree”, 10
   ```

3. The preferred way to force a query to use a parallel plan is to use the abstract plan syntax

   use parallel *N*

   where *N* is less than the value of max query parallel degree.

   To write a query that uses a maximum of 5 threads, use:

```
select count (*), S1.id from sysobjects S1, sysindexes S2
where S1.id = S2.id
group by S1.id
plan
“(use parallel 5)”
```

This query tells the optimizer to use 5 worker processes, if it can. the only drawback to this approach is that the actual queries in the application must be altered. To avoid this, use create plan:

```
create plan
“select count(*), S1.id from sysobjects S1, sysindexes S2
where S1.id = S2.id
group by S1.id”
“(use parallel 5)”
```

Use this command to turn the abstract plan load option on globally:

sp_configure “abstract plan load”, 1

See Chapter 8, “Creating and Using Abstract Plans,” for more information about using abstract plans.

Using parallelism with large numbers of partitions

The information in this section also applies when partitioning is configured for manageability, and in a situation where partitions are created on physical or logical devices that exhibit little or no parallelism.

For the purposes of this discussion, you have decided to partition a table using range partitioning that represents each week of a year. The issue here is that the query optimizer does not know how the underlying disk system will respond to a 52-way parallel scan. The optimizer needs to figure out the best way to scan the table. If there are enough worker processes configured, the optimizer will use 52 threads to scan the table, which may well cause serious performance issues and be even slower than a serial scan.

To prevent this, first find out exactly how much parallelism is supported. If you know the devices that are used for this table, you can use the following command on a UNIX system, where the underlying device is called */dev/xx*:

```
time dd if=/dev/xx of=/dev/null bs=2k skip=8 count = 102400 &
```

Assume that time records as *x*.

Now run two of the same commands concurrently:

```
time dd if=/dev/xx of=/dev/null bs=2k skip=8 count = 102400 &
time dd if=/dev/xx of=/dev/null bs=2k skip=8 count = 102400 &
```

This time, assume that time is *y*. In a linear scale-up, *x* is the same as *y*, which is probably impossible to achieve. The following identity may suffice:

$$x <= y <= (N*x)/k$$

Where *N* is the number of simultaneous sessions started and *k* is a constant that identifies an acceptable improvement level. A good approximation of *k* might be 1.4, which says that parallel scan is allowed as long as it delivers 40% better metrics than a serial scan.

Table 4-2: Parallel scan metrics

Number of threads	Perf metrics	Acceptable for k=1.4
1	200s	
2	245s	245 <= (200*2)/1.4; i.e. 245<=285.71
4	560s	560 <= (200*4)/1.4; i.e. 560<=571.42
5	725s	725 <= (200*5)/1.4; i.e. 725<=714.28

Table 4-2 shows that the disk subsystem did not perform well after four concurrent access; the performance numbers went below the acceptable limit established by *k*. In general, read enough data blocks to allow for any skewed readings.

Having established that 4 threads is optimal, provide this hint by binding it to the object using sp_chgattribute in this way:

sp_chgattribute <*tablename*>, “plldegree”, 4

This tells the query optimizer to use a maximum of 4 threads. It may choose less than four threads if it does not find enough resources. The same mechanism can be applied to an index. For example, if an index called auth_ind exists on authors and you want to use two threads to access it, use this command:

```
sp_chgattribute "authors.auth_ind", "plldegree", 4
```

You must run sp_chgatttribute from the current database.

When parallel query results differ

When a query does not include scalar aggregates or require a final sorting step, a parallel query might return results in a different order from the same query run in serial, and subsequent executions of the same query in parallel might return results in different orders. The relative speed of the different worker processes leads to differences in result-set ordering. Each parallel scan behaves differently, due to pages already in cache, lock contention, and so forth. Parallel queries always return the same set of results, just not in the same order. If you need a dependable ordering of results, use order by or run the query in serial mode.

In addition, due to the pacing effects of multiple worker processes reading data pages, two types of queries accessing the same data may return different results when an aggregate or a final sort is not done. They are:

- Queries that use set rowcount
- Queries that select a column into a local variable without sufficiently restrictive query clauses

Queries that use *set rowcount*

The set rowcount option stops processing from continuing after a certain number of rows are returned to the client. With serial processing, the results are consistent in repeated executions as long as the query plans are the same. In serial mode, given the same query plan, the same rows are returned in the same order for a given rowcount value, because a single process reads the data pages in the same order every time. With parallel queries, the order of the results and the set of rows returned can differ, because worker processes may access pages sooner or later than other processes. To get consistent results, you must either use a clause that performs a final sort step or run the query in serial.

Queries that set local variables

This query sets the value of a local variable in a select statement:

```
select @tid = title_id from titles
where type = "business"
```

The where clause matches multiple rows in the titles table, so the local variable is always set to the value from the last matching row returned by the query. The value is always the same in serial processing, but for parallel query processing, the results depend on which worker process finishes last. To achieve a consistent result, use a clause that performs a final sort step, execute the query in serial mode, or add clauses so that the query arguments select only single rows.

Understanding parallel query plans

The key to understanding parallel query processing in Adaptive Server is to understand the basic building blocks in a parallel query plan.

Note See Chapter 2, “Using showplan,” which explains how to display a query plan in a text-based format for each SQL statement in a batch or stored procedure.

A compiled query plan contains a tree of execution operators that closely resembles the relational semantics of the query. Each query operator implements a relational operation using a specific algorithm. For example, a query operator called nested-loop join implements the relational join operation. In Adaptive Server, the primary operator for parallelism is the exchange operator. It is a control operator and does not implement any relational operation. The purpose of an exchange operator is to create new worker processes that can handle a fragment of the data. During optimization, Adaptive Server strategically places the exchange operator to create operator tree fragments that can run in parallel. All operators found below the exchange operator (down to the next exchange operator) are executed by worker threads that clone the fragment of the operator tree to produce data in parallel. The exchange operator can then redistribute this data to the parent operator above it in the query plan. The exchange operator handles the pipelining and rerouting of data.

In the following sections, the word *degree* is used in two different contexts. When “degree N” of a table or index is referred to, it references the number of partitions contained in a table or index. When the “degree of an operation” or “the degree of a configuration parameter” is referred to, it references the number of partitions generated in the intermediate data stream.

The following example shows how operators in the query processor work in serial with the following query run in the pubs2 database. The table titles is hash-partitioned three ways on the column pub_id.

```
select * from titles
QUERY PLAN FOR STATEMENT 1 (at line 1).

1 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

     |SCAN Operator
     |  FROM TABLE
     |  titles
     |  Table Scan.
     |  Forward Scan.
     |  Positioning at start of table.
     |  Using I/O Size 2 Kbytes for data pages.
     |  With LRU Buffer Replacement Strategy for data
        pages.
```

As this example illustrates, the titles table is being scanned by the scan operator, the details of which can be seen in the showplan output. The emit operator reads the data from the scan operator and sends it to the client application. A given query can create an arbitrarily complex tree of such operators.

When parallelism turned on, Adaptive Server can perform a simple scan in parallel using the exchange operator above the scan operator. exchange produces three worker processes (based on the three partitions), each of which scans the three disjointed parts of the table and sends the output to the consumer process. The emit operator at the top of the tree does not know that the scans are done in parallel.

Example A:

```
select * from titles
Executed in parallel by coordinating process and 3 worker processes.

4 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 3 Producer and 1 Consumer processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |RESTRICT Operator
    |   |   |
    |   |   |   |SCAN Operator
    |   |   |   |  FROM TABLE
    |   |   |   |  titles
    |   |   |   |  Table Scan.
    |   |   |   |  Forward Scan.
    |   |   |   |  Positioning at start of table.
    |   |   |   |  Executed in parallel with a 3-way partition scan.
    |   |   |   |  Using I/O Size 2 Kbytes for data pages.
    |   |   |   |  With LRU Buffer Replacement Strategy for data pages.
```

Note the presence of an operator called Exchange:Emit. This is an operator that is placed under an Exchange operator to funnel data. The exchange operator is described in detail in “exchange operator” on page 122.

Adaptive Server parallel query execution model

One of the key components of the parallel query execution model is the exchange operator. You can see it in the showplan output of a query.

exchange operator

The exchange operator marks the boundary between a producer and a consumer operator (the operators below the exchange operator produce data and those above it consume data). In an earlier example (Example A) that showed parallel scan of the titles table (`select * from titles`), the exchange:emit and the scan operator produce data. This is shown briefly.

```
select * from titles

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 3 Producer and 1 Consumer
          processes.
    |
    |    |EXCHANGE:EMIT Operator
    |    |
    |    |    |RESTRICT Operator
    |    |    |
    |    |    |    |SCAN Operator
    |    |    |    |  FROM TABLE
    |    |    |    |  titles
    |    |    |    |  Table Scan.
```

In this example, one consumer process reads data from a pipe (which is used as a medium to transfer data across process boundaries) and hands it off to the emit operator, which in turn routes the result to the client. The exchange operator also spawns worker processes, which are called producer threads. The exchange:emit operator is responsible for writing the data into a pipe managed by the exchange operator.

Figure 4-1: Binding of thread to plan fragments in query plan

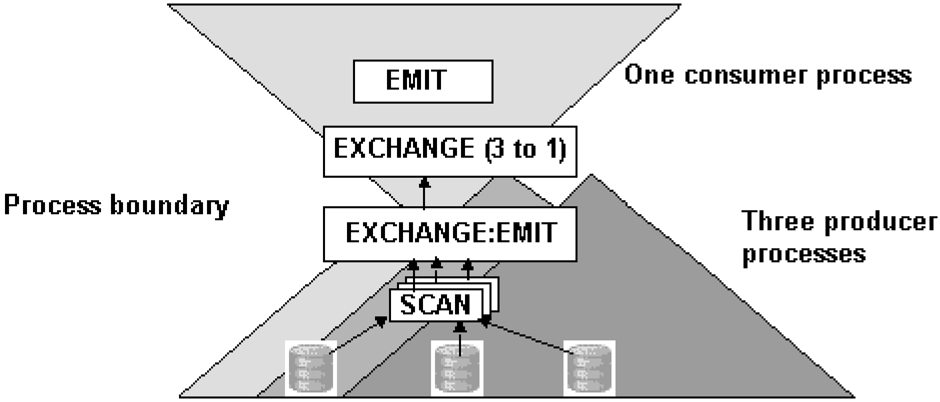


Figure 4-1 shows the process boundary between a producer and a consumer task. There are two plan fragments in this query plan. The plan fragment with the scan and the exchange:emit operators are being cloned three ways and then a three-to-one exchange operator writes it into a pipe. The emit operator and the exchange operator are run by a single process, which means there is a single clone of that plan fragment.

Pipe management

The four types of pipes managed by the exchange operator are distinguished by how they split and merge data streams. You can determine which type of pipe is being managed by the exchange operator by looking at its description in the showplan output, where the number of producers and consumers are shown. The four pipe types are described below.

Many-to-one

In this case, the exchange operator spawns multiple producer threads and has one consumer task that reads the data from a pipe, to which multiple producer threads write. The exchange operator in the previous example implements a many-to-one exchange. A many-to-one exchange operator can be order-preserving and this technique is employed particularly when doing a parallel sort for an order by clause and the resultant data stream merged to generate the final ordering. The showplan output shows more than one producer process and one consumer process.

```
|EXCHANGE Operator (Merged)
        |Executed in parallel by 3 Producer and 1
        Consumer processes
```

One-to-many

In this case, there is one producer and multiple consumer threads. The producer thread writes data to multiple pipes according to a partitioning scheme devised at query optimization and then routes data to each of these pipes. Each consumer thread reads data from one of the assigned pipes. This kind of data split can preserve the ordering of the data. The showplan output shows one producer process and more than one consumer processes.

Many-to-many

Many-to-many means that there are multiple producers and multiple consumers. Each producer writes to multiple pipes, and each pipe has multiple consumers. Each stream is written to a pipe. Each consumer thread reads data from one of the assigned pipes.

```
|EXCHANGE Operator (Repartitioned)
   |Executed in parallel by 3 Producer and 4
    Consumer processes
```

Replicated exchange operators

In this case, the producer thread writes all of its data to each pipe that the exchange operator configures. The producer thread makes a number of copies of the source data (the number is specified by the query optimizer) equal to the number of pipes in the exchange operator. Each consumer thread reads data from one of the assigned pipes. The showplan output shows this as follows:

```
|EXCHANGE (Replicated)
    |Executed in parallel by 3 Producers and 4
    Consumer processes
```

Worker process model

A parallel query plan is composed of different operators, at least one of which is an exchange operator. At runtime, a parallel query plan is bound to a set of server processes that will, together, execute the query plan in a parallel fashion.

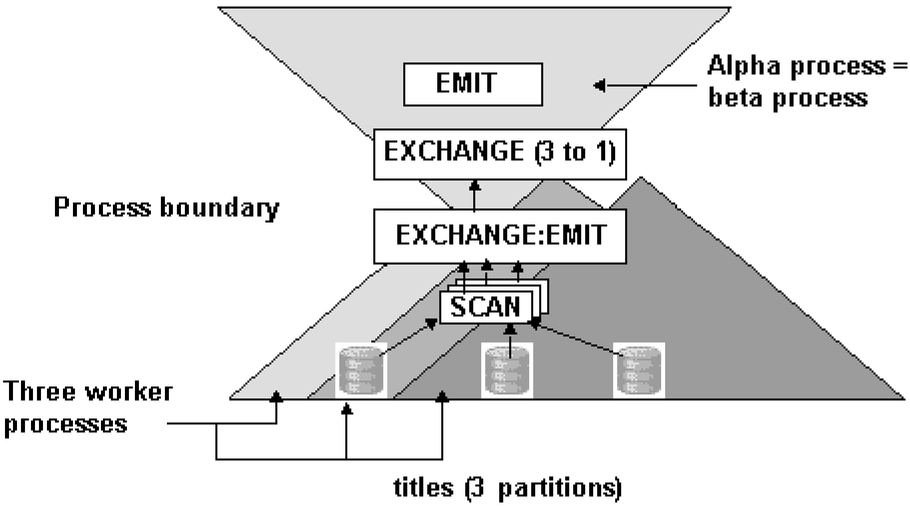
The server process associated with the user connection is called the *alpha process* because it is the source process from which parallel execution is initiated. In particular, each worker process involved in the execution of the parallel query plan is spawned by the alpha process.

In addition to spawning worker processes, the alpha process initializes all the worker processes involved in the execution of the plan, and creates and destroys the pipes necessary for worker processes to exchange data. The alpha process is, in effect, the global coordinator for the execution of a parallel query plan.

At runtime, Adaptive Server associates each exchange operator in the plan with a set of worker processes. The worker processes execute the query plan fragment located immediately below the exchange operator.

For the query in Example A, represented in "exchange operator" on page 122, the exchange operator is associated with three worker processes. Each worker process executes the plan fragment made of the exchange:emit operator and of the scan operator.

Figure 4-2: Query execution plan with one exchange operator

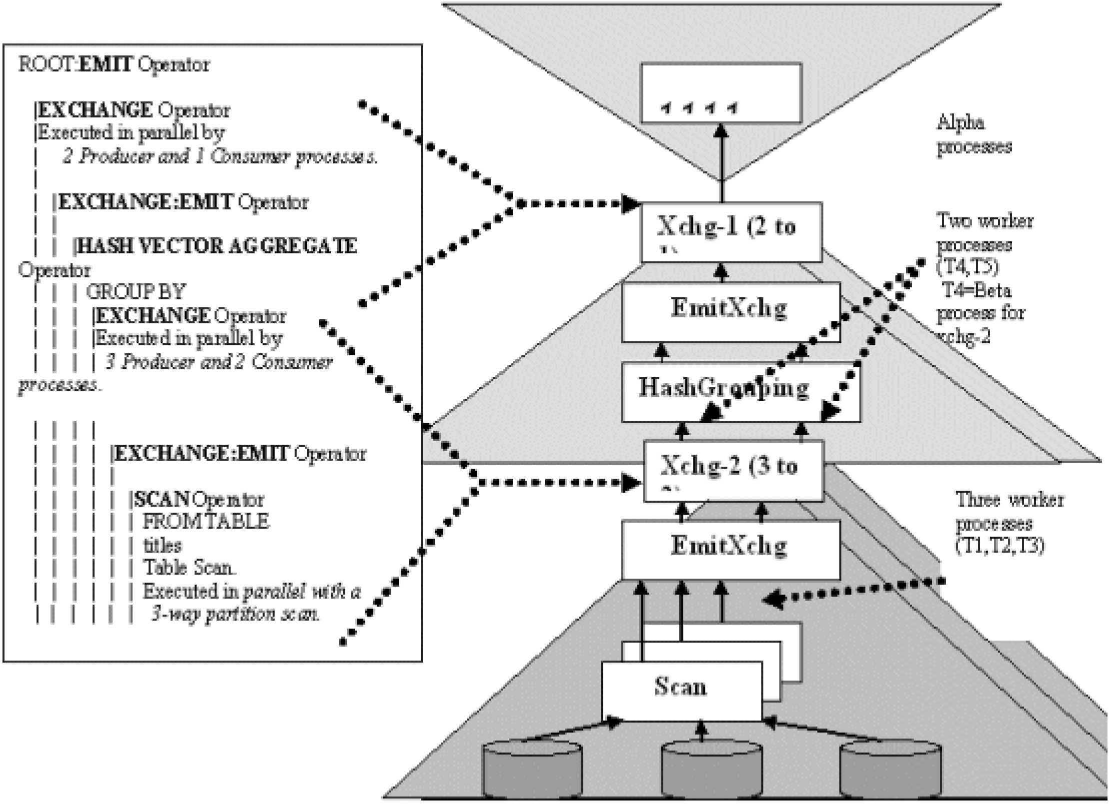


Each exchange operator is also associated with a server process named the *beta process*, which can be either the alpha process or a worker process. The beta process associated with a given exchange operator is the local coordinator for the execution of the plan fragment below the exchange operator. In the example above, the beta process is the same process as the alpha process, because the plan to be executed has only one level of exchange operators.

Next, use this query to illustrate what happens when the query plan contains multiple exchange operators.

```
select count(*),pub_id, pub_date
from titles
group by pub_id, pub_date
```

Figure 4-3: Query execution plan with two exchange operators



There are two levels of exchange operators marked as EXCHANGE-1 and EXCHANGE-2 in Figure 4-3. Worker process T4 is the beta process associated with the exchange operator EXCHANGE-2.

The function of the beta process is to locally orchestrate execution of the plan fragment below the exchange operator; it dispatches query plan information that is needed by the worker processes, and synchronizes the execution of the plan fragment.

A process involved in the execution of a parallel query plan that is neither the alpha process nor a beta process is called a *gamma process*.

A given parallel query plan is bound at runtime to a unique alpha process, to one or more beta processes, and to at least one gamma process. Any Adaptive Server parallel plan needs at least two different processes (alpha and gamma) to be executed in parallel.

To find out the mapping between exchange operators and worker processes, as well as to figure out which process is the alpha process, and which processes are the beta processes, use dbcc traceon(516).

Figure 4-4: Mapping between operators and processes

```
                ===== Thread to EXCHANGE map begins =====
ALFA thread spid:17
EXCHANGE = 2                                 (refers to EXCHANGE-2)
Comp Count = 2 Exec Count
          Range Adjustable
     Consumer:EXCHANGE = 5
Parent thread spid:34                        (refers to T4)
     Child thread 0: spid:37                 (refers to T1)
     Child thread 1: spid:38                 (refers to T2)
     Child thread 2: spid:36                 (refers to T3)
  Scheduling level:0
EXCHANGE = 5                                 (refers to EXCHANGE-1)
     Comp Count = 3 Exec Count = 3
Bounds Adjustable
     Consume:EXCHANGE = -1
     Parent thread spid:17                   (refers to Alpha)
          Child thread 0: spid:34            (refers to T4)
          Child thread 1: spid:35            (refers to T5)
  Scheduling level:0

                ===== Thread to EXCHANGE map ends =====
```

Using parallelism in SQL operations

You can partition tables or indexes in any way that best reflects the needs of your application. Sybase recommends that you put partitions on segments that use different physical disks so that enough I/O parallelism is present. For example, you can have a well-defined partition based on hashing of certain columns of a table or certain ranges or a list of values ascribed to a partition. Hash, range, and list partitions belong to the category of “semantic-based” partitioning—given a row, you can determine to which partition the row belongs.

Round-robin partitioning has no semantics associated with its partitioning. A row can occur in any of its partitions. The choice of columns to partition and the type of partitioning used can have a significant impact on the performance of the application. Partitions can be thought of as a low-cardinality index; the columns on which partitioning must be defined, are based on the queries in the application.

The query processing engine and its operators take advantage of the Adaptive Server partitioning strategy. Partitioning defined on table and indexes is called static partitioning. In addition, Adaptive Server *dynamically* repartitions data to match the needs for relational operations like joins, vector aggregation, distinct, union, and so on. Repartitioning is done in streaming mode and no storage is associated with it. Repartitioning is different from the alter table repartition command, where static repartitioning is done.

A query plan consists of query execution operators. In Adaptive Server, operators belong to one of two categories:

- Attribute-insensitive operators include scans, union alls, and scalar aggregation. They are not concerned about the underlying partitions.
- Attribute-sensitive operators (for example, join, distinct, union, and vector aggregation) allow for an operation on a given amount of data to be broken into a smaller number of operations on smaller fragments of the data using semantics-based partitioning. Afterwards, a simple union all provides the final result set. The union all is implemented using a many-to-one exchange operator.

The following sections discuss these two classes of operators. The examples in these sections use the following table with enough data to trigger parallel processing.

```
create table RA2(a1 int, a2 int, a3 int)
```

Parallelism of attribute-insensitive operation

This section discusses the attribute-insensitive operations, which include scans (serial and parallel), scalar aggregations, and union alls.

Table scan

For horizontal parallelism, either at least one of the tables in the query must be partitioned, or the configuration parameter max repartition degree must be greater than 1. If max repartition degree is set to 1, Adaptive Server uses the number of online engines as a hint. When Adaptive Server runs horizontal parallelism, it runs multiple versions of one or more operators in parallel. Each clone of an operator works on its partition, which can be statically created or dynamically built at execution.

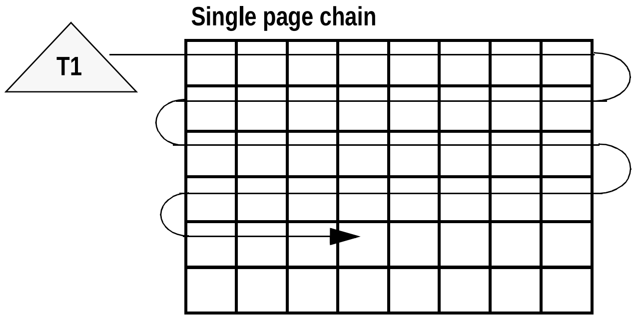
Serial table scan

The following example below shows the serial execution of a query where the table RA2 is scanned using the table scan operator. The result of this operation is routed to the emit operator, which forwards the result to the client.

```
select * from RA2
QUERY PLAN FOR STATEMENT 1 (at line 1).

1 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

      |SCAN Operator
      |  FROM TABLE
      |  RA2
      |  Table Scan.
      |  Forward Scan.
      |  Positioning at start of table.
      |  Using I/O Size 2 Kbytes for data pages.
      |  With LRU Buffer Replacement Strategy for data
         pages.
```

In versions earlier than 15.0, Adaptive Server did not try to scan an unpartitioned table in parallel using a hash-based scan unless a force option was used. Figure 4-5 shows a scan of an allpages-locked table executed in serial mode by a single task T1. The task follows the page chain of the table to read each page, while doing physical I/O if the needed pages are not in the cache.

Figure 4-5: Serial task scans data pages



Parallel table scan

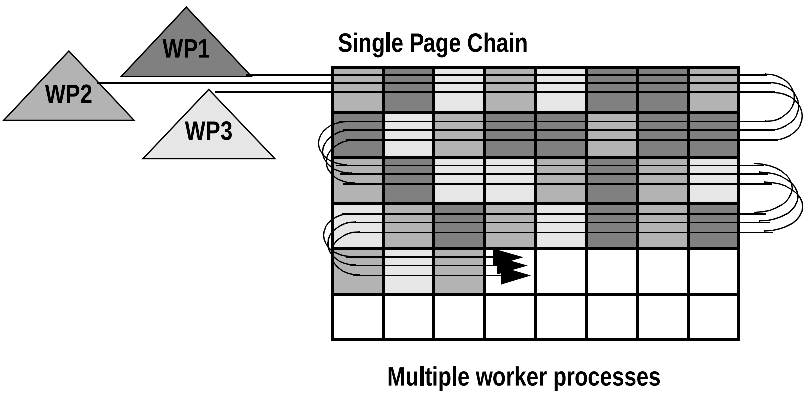
You can force a parallel table scan of an unpartitioned table using the Adaptive Server force option. In this case, Adaptive Server uses a hash-based scan.

Hash-based table scans

Figure 4-6 shows how three worker processes divide the work of accessing data pages from an allpages-locked table during a hash-based table scan. Each worker process performs a logical I/O on every page, but each process examines rows on one-third of the pages, as indicated by differently shaded lines. Hash-based table scans are used only if the user forces a parallel degree. See "Partition skew" on page 172 for more information.

With one engine, the query still benefits from parallel access because one work process can execute while others wait for I/O. If there are multiple engines, some of the worker processes can be running simultaneously.

Figure 4-6: Multiple worker processes scans unpartitioned table



Hash-based scans increase the logical I/O for the scan, since each worker process must access each page to hash on the page ID. For a data-only-locked table, hash-based scans hash either on the extent ID or the allocation page ID, so that only a single worker process scans a page and logical I/O does not increase.

Partitioned-based table scans

If you partition this table as follows:

```
alter table RA2 partition by range(a1, a2)
(p1 values <= (500,100), p2 values <= (1000, 2000))
```

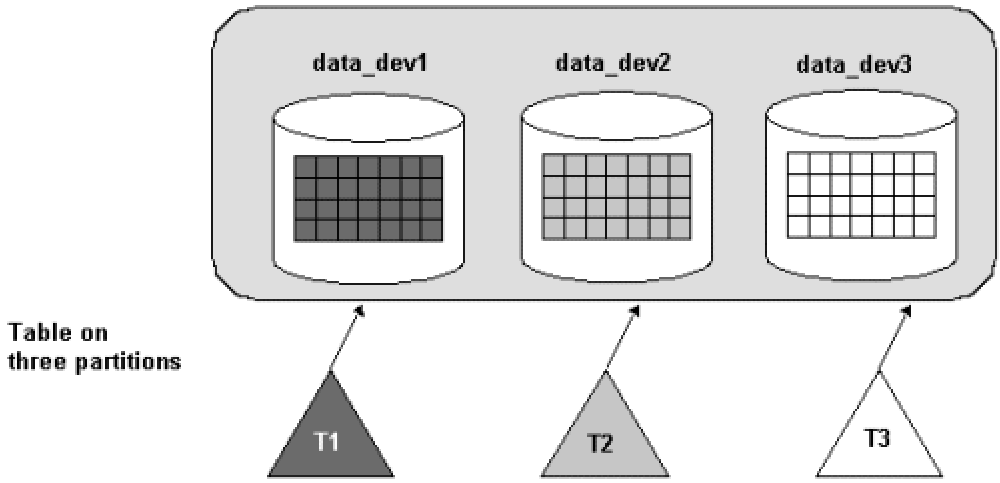
When the following query, Adaptive Server may choose a parallel scan of the table. Parallel scan is chosen only if there are sufficient pages to scan and the partition sizes are similar enough that the query will benefit from parallelism.

```
select * from RA2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

3 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1 Consumer
        processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |SCAN Operator
    |   |   |  FROM TABLE
    |   |   |  RA2
    |   |   |  Table Scan.
    |   |   |  Forward Scan.
    |   |   | Positioning at start of table.
    |   |   | Executed in parallel with a 2-way
    |   |   |  partition scan.
    |   |   | Using I/O Size 2 Kbytes for data pages.
    |   |   |  With LRU Buffer Replacement Strategy
    |   |   |   for data pages.
```

After partitioning the table, showplan output includes two additional opeators, exchange and exchange:emit. This query includes two worker processes, each of which scans a given partition and passes the data to the exchange:emit operator, as illustrated in Figure 4-1.

Figure 4-7 shows how a query scans a table that has three partitions on three physical disks. With a single engine, this query can benefit from parallel processing because one worker process can execute while others sleep, waiting for I/O or waiting for locks held by other processes to be released. If multiple engines are available, the worker processes can run simultaneously on multiple engines. Such a configuration can perform extremely well.

Figure 4-7: Multiple worker processes access multiple partitions



Index scan

Indexes, like tables, can be partitioned or unpartitioned. Local indexes inherit the partitioning strategy of the table. Each local index partition scans data in only one partition. Global indexes have a different partitioning strategy from the base table; they reference one or more partitions. The following sections describe the index configurations supported by Adaptive Server.

Global nonclustered indexes

Adaptive Server supports global indexes that are nonclustered and unpartitioned for all table partitioning strategies. Global indexes are supported for compatibility with Adaptive Server versions earlier than 15.0; they are also useful in OLTP environments. The index and the data partitions can reside on the same or different storage areas.

Noncovered scan of global nonclustered index using hashing

To create an unpartitioned global nonclustered index on table RA2, which is partitioned by range, enter:

```
create index RA2_NC1 on RA2(a3)
```

The next query has a predicate that uses the index key of a3 as follows:

```
select * from RA2 where a3 > 300
QUERY PLAN FOR STATEMENT 1 (at line 1).
. . . . . . . . . . . . . . .
The type of query is SELECT.

ROOT:EMIT Operator

        |EXCHANGE Operator (Merged)
        |Executed in parallel by 3 Producer and 1
         Consumer processes.
        |
        |   |EXCHANGE:EMIT Operator
        |   |
        |   |   |SCAN Operator
        |   |   | FROM TABLE
        |   |   | RA2
        |   |   | Index : RA2_NC1
        |   |   | Forward Scan.
        |   |   | Positioning by key.
        |   |   | Keys are:
        |   |   | a3 ASC
        |   |   | Executed in parallel with a 3-way
                    hash scan.
        |   |   | Using I/O Size 2 Kbytes for index
                    leaf pages.
        |   |   | With LRU Buffer Replacement Strategy
                   for index leaf pages.
        |   |   | Using I/O Size 2 Kbytes for data
                   pages.
        |   |   | With LRU Buffer Replacement Strategy
                   for data pages.
```

In the above example, Adaptive Server uses an index scan using the index RA2_NC1 using three producer threads spawned by the exchange operator. Each of the producer threads scans all of the qualifying leaf pages and uses a hashing algorithm on the row ID of the qualifying data and accesses the data pages to which it belongs. The parallelism in this case is exhibited at the data page level.

Figure 4-8: Hash-based parallel scan of global nonclustered index

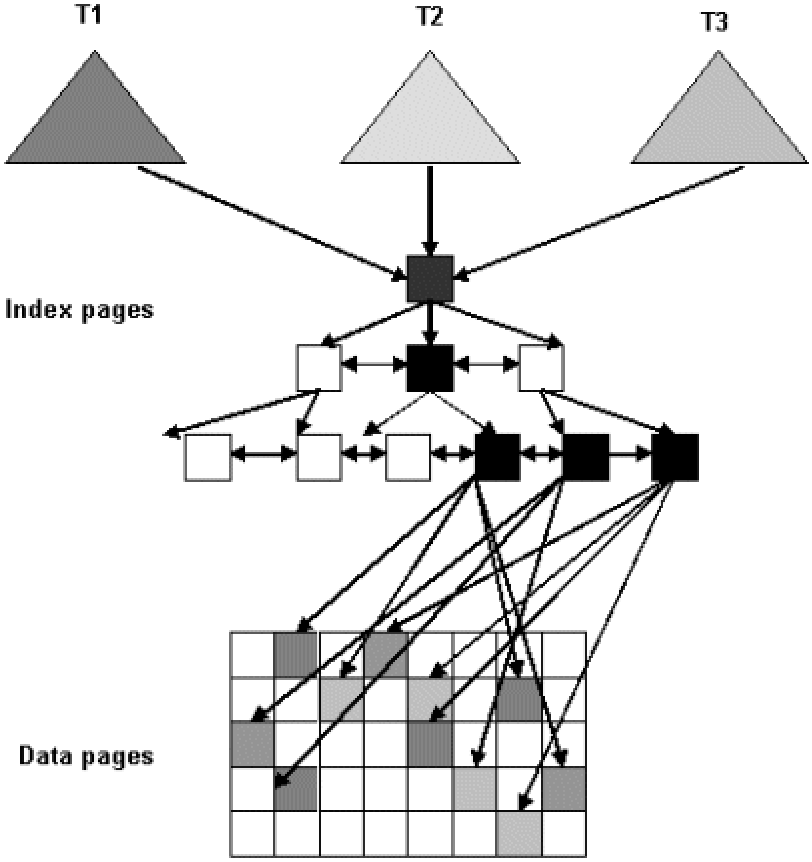
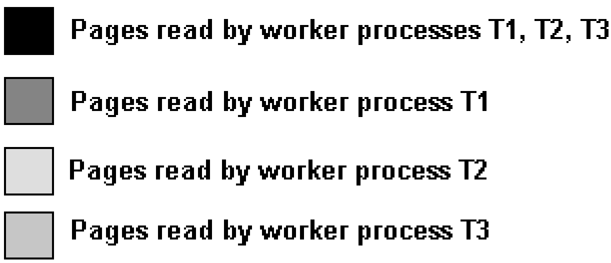


Figure 4-9: Legend for Figure 2-8



If the query does not need to access the data page, then it will not execute in parallel. However, in the current scheme, the partitioning columns must be added to the query; therefore, it becomes a noncovered scan:

```
select a3 from RA2 where a3 > 300

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.
3 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1 Consumer
processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |SCAN Operator
    |   |   |  FROM TABLE
    |   |   |  RA2
    |   |   |  Index : RA2_NC1
    |   |   |  Forward Scan.
    |   |   |  Positioning by key.
    |   |   |  Keys are:
    |   |   |    a3 ASC
    |   |   |  Executed in parallel with a 2-way hash
                scan.
    |   |   |  Using I/O Size 2 Kbytes for index leaf
                pages.
    |   |   |  With LRU Buffer Replacement Strategy for
               index leaf pages.
    |   |   |  Using I/O Size 2 Kbytes for data pages.
    |   |   |  With LRU Buffer Replacement Strategy for
               data pages.
```

Covered scan using nonclustered global index

If there is a nonclustered index that includes the partitioning column, there is no reason for Adaptive Server to access the data pages and the query executes in serial:

```
create index RA2_NC2 on RA2(a3,a1,a2)

select a3 from RA2 where a3 > 300

QUERY PLAN FOR STATEMENT 1 (at line 1).

1 operator(s) under root
```

```
The type of query is SELECT.

ROOT:EMIT Operator

     | SCAN Operator
     | FROM TABLE
     | RA2
     | Index : RA2_NC2
     |  Forward Scan.
     |  Positioning by key.
     |  Index contains all needed columns. Base table
        will not be read.
     |  Keys are:
     |    a3 ASC
     |  Using I/O Size 2 Kbytes for index leaf pages.
     |  With LRU Buffer Replacement Strategy for index
       leaf pages.
```

Clustered index scans

With a clustered index on an all-pages-locked (APL) table, a hash-based scan strategy is not permitted. The only allowable strategy is a partitioned scan. Adaptive Server uses a partitioned scan if that is the right thing to do. For a data-only-locked (DOL) table, a clustered index is usually a placement index, which behaves as a nonclustered index. All discussions pertaining to a nonclustered index on an APL table apply to a clustered index on a DOL table as well.

Local indexes

Adaptive Server supports clustered and nonclustered local indexes.

Clustered indexes on partitioned tables

Local clustered indexes allow multiple threads to scan each data partition in parallel, which can greatly improve performance. To take advantage of this parallelism, use a partitioned clustered index. On a local index, data is sorted separately within each partition. The information in each data partition conforms to the boundaries established when the partitions were created, which makes it possible to enforce unique index keys across the entire table.

Unique, clustered local indexes have the following restrictions:

- Index columns must include all partition columns.
- Partition columns must have the same order as the index definition's partition key.
- Unique, clustered local indexes cannot be included on a round-robin table with more than one partition.

Nonclustered indexes on partitioned tables

Adaptive Server supports local, nonclustered indexes on partitioned tables.

There is, however, a slight difference when using local indexes. When doing a covered index scan of a local nonclustered index, Adaptive Server can still use a parallel scan because the index pages are partitioned as well.

To illustrate the difference, a local nonclustered index is created in the following example.

```
create index RA2_NC2L on RA2(a3,a1,a2) local index

select a3 from RA2 where a3 > 300

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

3 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

     |EXCHANGE Operator (Merged)
     |Executed in parallel by 2 Producer and 1 Consumer
processes.

     |
     |   |EXCHANGE:EMIT Operator
     |   |
     |   |   |SCAN Operator
     |   |   |  FROM TABLE
     |   |   |  RA2
     |   |   |  Index : RA2_NC2L
     |   |   |  Forward Scan.
     |   |   |  Positioning by key.
     |   |   |  Index contains all needed columns. Base
                    table will not be read.
     |   |   |  Keys are:
     |   |   |    a3 ASC
     |   |   |  Executed in parallel with a 2-way
                 partition scan.
     |   |   |  Using I/O Size 2 Kbytes for index leaf
                    pages.
     |   |   |  With LRU Buffer Replacement Strategy
                    for index leaf pages.
```

Sometimes, Adaptive Server chooses a hash-based scan on a local index. This occurs when a different parallel degree is needed or when the data in the partition is skewed such that a hash-based parallel scan is preferred.

Scalar aggregation

The Transact-SQL scalar aggregation operation can be done in serial or in parallel.

Two-phased scalar aggregation

In a parallel scalar aggregation, the aggregation operation is performed in two phases, using two scalar aggregate operators. In the first phase, the lower scalar aggregation operator performs aggregation on the data stream. The result of scalar aggregation from the first phase is merged using a many-to-one exchange operator, and this stream is aggregated a second time.

In case of a count(*) aggregation, the second phase aggregation performs a scalar sum. This is highlighted in the showplan output of the next example.

```
select count(*) from RA2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

5 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |SCALAR AGGREGATE Operator
    |  Evaluate Ungrouped SUM OR AVERAGE AGGREGATE.
    |
    |    |EXCHANGE Operator (Merged)
    |    |Executed in parallel by 2 Producer and 1
               Consumer processes.

    |    |
    |    |    |EXCHANGE:EMIT Operator
    |    |    |
    |    |    |    |SCALAR AGGREGATE Operator
    |    |    |    |  Evaluate Ungrouped COUNT AGGREGATE.
    |    |    |    |
    |    |    |    |    |SCAN Operator
```

```
|    |    |    |    |  FROM TABLE
|    |    |    |    |  RA2
|    |    |    |    |  Table Scan.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning at start of table.
|    |    |    |    |  Executed in parallel with a
                          2-way partition scan.
|    |    |    |    |  Using I/O Size 2 Kbytes for data
                       pages.
|    |    |    |    |  With LRU Buffer Replacement
                           Strategy for data pages.
```

Serial aggregation

Adaptive Server may also choose to do the aggregation in serial. If the amount of data to be aggregated is not enough to guarantee a performance advantage, a serial aggregation may be the preferred technique. In case of a serial aggregation, the result of the scan is merged using a many-to-one exchange operator. This is shown in the example below, where a selective predicate has been added to minimize the amount of data flowing into the scalar aggregate operator. In such a case, it probably does not make sense to do the aggregation in parallel.

```
select count(*) from RA2 where a2 = 10
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

4 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |SCALAR AGGREGATE Operator
    |  Evaluate Ungrouped COUNT AGGREGATE.
    |
    |    |EXCHANGE Operator (Merged)
    |    |Executed in parallel by 2 Producer
             and 1 Consumer processes.

    |    |
    |    |    |EXCHANGE:EMIT Operator
    |    |    |
    |    |    |    |SCAN Operator
    |    |    |    |  FROM TABLE
```

```
|    |    |    |  RA2
|    |    |    |  Table Scan.
|    |    |    |  Forward Scan.
|    |    |    |  Positioning at start of table.
|    |    |    |  Executed in parallel with a 2-way
                     partition scan.
|    |    |    |  Using I/O Size 2 Kbytes for data
                     pages.
|    |    |    |  With LRU Buffer Replacement
                     Strategy for data pages.
```

union all

union all operators are implemented using a physical operator by the same name. union all is a fairly simple operation and it pays to parallelize it only when there is a lot of data being moved through it.

Parallel *union all*

The only condition to generating a parallel union all is that each of its operands must be of the same degree, irrespective of the type of partitioning they have. The following example shows a union all operator being processed in parallel. The position of the exchange operator above the union all operator signifies that it is being processed by multiple threads.

A new table, HA2, is taken to illustrate this next example.

```
create table HA2(a1 int, a2 int, a3 int)
partition by hash(a1, a2) (p1, p2)

select * from RA2
union all
select * from HA2
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1 Consumer
     processes.
```

```
          |
          |    |EXCHANGE:EMIT Operator
          |    |
          |    |    |UNION ALL Operator has 2 children.
          |    |    |
          |    |    |    |SCAN Operator
          |    |    |    |  FROM TABLE
          |    |    |    |  RA2
          |    |    |    |  Table Scan.
 . . . . . . . . . . . . . . . . . . .
          |    |    |    |  Executed in parallel with a 2-way
                            partition scan.
 . . . . . . . . . . . . . . . . . . .
          |    |    |
          |    |    |    |SCAN Operator
          |    |    |    |  FROM TABLE
          |    |    |    |  HA2
          |    |    |    |  Table Scan.
      . . . . . . . . . . . . . . . . . . .
          |    |    |    |  Executed in parallel with a 2-way
                            partition scan.
```

Serial *union all*

In the next example, the data from each side of the union operator is restricted by selective predicates on either side. The amount of data being sent through the union all operator is small enough that Adaptive Server decides not to run them in parallel. Instead, each scan of the tables RA2 and HA2 are organized by putting 2-to-1 exchange operators on each side of the union. The resultant operands are then processed in parallel by the union all operator. This is illustrated in the next query.

```
select * from RA2
where a2 > 2400
union all
select * from HA2
where a3 in (10,20)
Executed in parallel by coordinating process and 4
worker processes.

7 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator
```

```
|UNION ALL Operator has 2 children.
|
|   |EXCHANGE Operator (Merged)
|   |Executed in parallel by 2 Producer and 1
        Consumer processes.

|   |
|   |   |EXCHANGE:EMIT Operator
|   |   |
|   |   |   |SCAN Operator
|   |   |   |  FROM TABLE
|   |   |   |  RA2
|   |   |   |  Table Scan.
|   |   |   |  Executed in parallel with a 2-way
                 partition scan.
|
|   |EXCHANGE Operator (Merged)
|   |Executed in parallel by 2 Producer and 1
        Consumer processes.

|   |
|   |   |EXCHANGE:EMIT Operator
|   |   |
|   |   |   |SCAN Operator
|   |   |   |  FROM TABLE
|   |   |   |  HA2
|   |   |   |  Table Scan.
|   |   |   |  Executed in parallel with a 2-way
                 partition scan.
```

Parallelism of attribute-sensitive operation

This section discusses issues involving the attribute-sensitive operations, which includes such operations as joins, vector aggregations, and unions.

join

If two tables are joined in parallel, Adaptive Server tries to use semantics-based partitioning to make the join more efficient, depending on the amount of data being joined and the type of partitioning that each of the operands have. If the amount of data to be joined is small, but the number of pages to scan for each of the tables is quite significant, Adaptive Server serializes the parallel streams from each side and the join is done in serial mode. In this case, the query optimizer determines that it is suboptimal to run a join operation in parallel. In general, one or both of the operands used for the join operators may be any intermediate operator, like another join or a grouping operator, but the examples used show only scans as operands.

Tables with same useful partitioning

The partitioning of each operand of a join is useful only with respect to the join predicate. If two tables have the same partitioning, and the partitioning columns are a subset of the join predicate, then the tables are said to be equipartitioned. For example, if you create another table, RB2, which is partitioned similarly to that of RA2, using the following DDL command:

```
create table RB2(b1 int, b2 int, b3 int)
partition by range(b1,b2)
(p1 values <= (500,100), p2 values <= (1000, 2000))
```

Then join RB2 with RA2; the scans and the join can be done in parallel without additional repartitioning. Adaptive Server can join the first partition of RA2 with the first partition of RB2, then join the second partition of RA2 with the second partition of RB2. This is called an equipartitioned join and is possible only if the two tables join on columns a1, b1 and a2, b2 as shown below:

```
select * from RA2, RB2
where a1 = b1 and a2 = b2 and a3 < 0

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

7 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

     |EXCHANGE Operator (Merged)
     |Executed in parallel by 2 Producer
         and 1 Consumer processes.

     |
```

```
|    |EXCHANGE:EMIT Operator
|    |
|    |    |NESTED LOOP JOIN Operator
              (Join Type: Inner Join)
|    |    |
|    |    |    |RESTRICT Operator
|    |    |    |
|    |    |    |    |SCAN Operator
|    |    |    |    |  FROM TABLE
|    |    |    |    |  RB2
|    |    |    |    |  Table Scan.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning at start of table.
|    |    |    |    |  Executed in parallel with a
                         2-way partition scan.
|    |    |
|    |    |    |RESTRICT Operator
|    |    |    |
|    |    |    |    |SCAN Operator
|    |    |    |    |  FROM TABLE
|    |    |    |    |  RA2
|    |    |    |    |  Table Scan.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning at start of table.
|    |    |    |    |  Executed in parallel with a
                         2-way partition scan.
```

The exchange operator is shown above the nested-loop-join. This implies that it spawns two producer threads: the first scans the first partition of RA2 and RB2 and performs the nested-loop join; the second scans the second partition of RA2 and RB2 to do the nested-loop join. The two threads merge the results using a many-to-one (in this case, two-to-one) exchange operator.

One of the tables with useful partitioning

In this example, the table RB2 is repartitioned to a three-way hash partitioning on column b1 using the alter table command.

```
alter table RB2 partition by hash(b1) (p1, p2, p3)
```

Now, take a slightly modified join query as shown below:

```
select * from RA2, RB2 where a1 = b1
```

The partitioning on table RA2 is not useful because the partitioned columns are not a subset of the joining columns (that is, given a value for the joining column a1, you cannot say the partition to which it belongs). However, the partitioning on RB2 is helpful because it matches the joining column b1 of RB2. In this case, the query optimizer repartitions table RA2 to match the partitioning of RB2 by using hash partitioning on column a1 of RA2 (the joining column, which is followed by a three-way merge join). The many-to-many (2-to-3) exchange operator above the scan of RA2 does this dynamic repartitioning. The exchange operator above the merge join operator merges the result using a many-to-one (3-to-1 in this case) exchange operator. The showplan output for this query is shown in the following example:

```
select * from RA2, RB2 where a1 = b1

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 5
worker processes.

10 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator
    |EXCHANGE Operator (Merged)
    |Executed in parallel by 3 Producer and 1 Consumer
       processes.

    |
    |    |EXCHANGE:EMIT Operator
    |    |
    |    |    |MERGE JOIN Operator (Join Type: Inner
                 Join)
    |    |    | Using Worktable3 for internal storage.
    |    |    |  Key Count: 1
    |    |    |  Key Ordering: ASC
    |    |    |
    |    |    |    |SORT Operator
    |    |    |    |Using Worktable1 for internal storage.
    |    |    |    |
    |    |    |    |    |EXCHANGE Operator (Repartitioned)
    |    |    |    |    |Executed in parallel by 2 Producer
                          and 3 Consumer processes.

    |    |    |    |    |
    |    |    |    |    |    |EXCHANGE:EMIT Operator
    |    |    |    |    |    |
```

```
|    |    |    |    |    |    |RESTRICT Operator
|    |    |    |    |    |    |
|    |    |    |    |    |    |    |SCAN Operator
|    |    |    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |    |    |  RA2
|    |    |    |    |    |    |    |  Table Scan.
|    |    |    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |    |    |  Positioning at start
                                      of table.
|    |    |    |    |    |    |    |  Executed in parallel
                                      with a 2-way
                                      partition scan.
|    |    |
|    |    |    |SORT Operator
|    |    |    |Using Worktable2 for internal storage.
|    |    |    |
|    |    |    |    |SCAN Operator
|    |    |    |    |  FROM TABLE
|    |    |    |    |  RB2
|    |    |    |    |  Table Scan.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning at start of table.
|    |    |    |    |  Executed in parallel with a
                         3-way partition scan.
```

Both tables with useless partitioning

The next example uses a join where the native partitioning of the tables on both sides is useless. The partitioning on table RA2 is on columns (a1,a2) and that of RB2 is on (b1). The join predicate is on different sets of columns, and the partitioning for both tables does not help at all. One option is to dynamically repartition both sides of the join. By repartitioning table RA2 using a M-to-N (2-to-3) exchange operator. Adaptive Server chooses column a3 of table RA2 for repartitioning, as it is involved in the join with table RB2. For identical reasons, table RB2 is also repartitioned three ways on column b3. The repartitioned operands of the join are equipartitioned with respect to the join predicate, which means that the corresponding partitions from each side will join. In general, when repartitioning needs to be done on both sides of the join operator, Adaptive Server employs a hash-based partitioning scheme.

```
select * from RA2, RB2 where a3 = b3

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 8
worker processes.

12 operator(s) under root

The type of query is SELECT.
```

```
ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 3 Producer and 1 Consumer
        processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |MERGE JOIN Operator
                (Join Type: Inner Join)
    |   |   | Using Worktable3 for internal storage.
    |   |   | Key Count: 1
    |   |   | Key Ordering: ASC
    |   |   |
    |   |   |   |SORT Operator
    |   |   |   |Using Worktable1 for internal
                   storage.
    |   |   |   |
    |   |   |   |   |EXCHANGE Operator (Repartitioned)
    |   |   |   |   |Executed in parallel by 2
                      Producer and 3 Consumer
                      processes.

    |   |   |   |   |
    |   |   |   |   |   |EXCHANGE:EMIT Operator
    |   |   |   |   |   |
    |   |   |   |   |   |   |RESTRICT Operator
    |   |   |   |   |   |   |
    |   |   |   |   |   |   |   |SCAN Operator
    |   |   |   |   |   |   |   |  FROM TABLE
    |   |   |   |   |   |   |   |  RA2
    |   |   |   |   |   |   |   |  Table Scan.
    |   |   |   |   |   |   |   |  Forward Scan.
    |   |   |   |   |   |   |   |  Positioning at
                                       start of table.
    |   |   |   |   |   |   |   |  Executed in
                                           parallel with
                                           a 2-way
                                           partition scan.
    |   |   |
    |   |   |   |SORT Operator
    |   |   |   |Using Worktable2 for internal
                    storage.
    |   |   |   |
```

```
|    |    |    |    |EXCHANGE Operator (Repartitioned)
|    |    |    |    |Executed in parallel by 3
                       Producer and 3 Consumer
                       processes.

|    |    |    |    |
|    |    |    |    |    |EXCHANGE:EMIT Operator
|    |    |    |    |    |
|    |    |    |    |    |    |SCAN Operator
|    |    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |    |  RB2
|    |    |    |    |    |    |  Table Scan.
|    |    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |    |  Positioning at start
                                  of table.
|    |    |    |    |    |    |  Executed in parallel
                                     with a 3-way
                                      partition scan.
```

In general, all joins, including nested-loop, merge, and hash joins, behave in a similar way. nested-loop joins display one exception, which is that the inner side of a nested-loop join cannot be repartitioned. This limitation occurs because, in the case of a nested-loop join, a column value for the joining predicate is pushed from the outer side to the inner side.

Replicated *join*

A replicated join is useful when an index nested-loop join needs to be used. Consider the case where a large table has a useful index on the joining column, but useless partitioning, and joins to a small table that is either partitioned or not partitioned. The small table can be replicated N ways to that of the inner table, where N is the number of partitions of the large table. Each partition of the large table is joined with the small table and, because no exchange operator is needed on the inner side of the join, an index nested-loop join is allowed.

```
create table big_table(b1 int, b2 int, b3 int)
partition by hash(b3) (p1, p2)

create index big_table_nc1 on big_table(b1)

create table small_table(s1 int, a2 int, s3 int)

select * from small_table, big_table
where small_table.s1 = big_table.b1
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 3
worker processes.
```

```
7 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1
        Consumer processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |NESTED LOOP JOIN Operator (Join Type:
                Inner Join)
    |   |   |
    |   |   |   |EXCHANGE Operator (Replicated)
    |   |   |   |Executed in parallel by 1 Producer
                    and 2 Consumer processes.

    |   |   |   |
    |   |   |   |   |EXCHANGE:EMIT Operator
    |   |   |   |   |
    |   |   |   |   |   |SCAN Operator
    |   |   |   |   |   |  FROM TABLE
    |   |   |   |   |   |  small_table
    |   |   |   |   |   |  Table Scan.
    |   |   |
    |   |   |   |SCAN Operator
    |   |   |   |  FROM TABLE
    |   |   |   |  big_table
    |   |   |   |  Index : big_table_nc1
    |   |   |   |  Forward Scan.
    |   |   |   |  Positioning by key.
    |   |   |   |  Keys are:
    |   |   |   |    b1 ASC
    |   |   |   |  Executed in parallel with a
                       2-way hash scan.
```

Parallel reformatting

Parallel reformatting is especially useful when you are working with a nested-loop join. Usually, reformatting refers to materializing the inner side of a nested join into a worktable, then creating an index on the joining predicate. With parallel queries and nested-loop join, there is another reason to do reformatting when there is no useful index on the joining column or nested-loop join is the only viable option for a query because of the server/session/query level settings. This is an important option for Adaptive Server. The outer side may have useful partitioning and, if not, it can be repartitioned to create that useful partitioning. But for the inner side of a nested-loop join, any repartitioning means that the table must be reformatted into a worktable that uses the new partitioning strategy. The inner scan of a nested-loop join must then access the worktable.

In this next example, partitioning for tables RA2 and RB2 is on columns (a1, a2) and (b1, b2) respectively. The query is run with merge and hash join turned off for the session.

```
select * from RA2, RB2 where a1 = b1 and a2 = b3

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 12
worker processes.

17 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |SEQUENCER Operator has 2 children.
    |
    |   |EXCHANGE Operator (Merged)
    |   |Executed in parallel by 4 Producer
            and 1 Consumer processes.

    |   |
    |   |   |EXCHANGE:EMIT Operator
    |   |   |
    |   |   |   |STORE Operator
    |   |   |   |  Worktable1 created, in allpages
                      locking mode, for REFORMATTING.
    |   |   |   |  Creating clustered index.
    |   |   |   |
    |   |   |   |   |INSERT Operator
    |   |   |   |   |  The update mode is direct.
    |   |   |   |   |
```

```
|   |   |   |   |   |EXCHANGE Operator
                        (Repartitioned)
|   |   |   |   |   |Executed in parallel by
                         2 Producer and 4
                         Consumer processes.
|   |   |   |   |   |
|   |   |   |   |   |   |EXCHANGE:EMIT Operator
|   |   |   |   |   |   |
|   |   |   |   |   |   |   |RESTRICT Operator
|   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |SCAN Operator
|   |   |   |   |   |   |   |   |  FROM TABLE
|   |   |   |   |   |   |   |   |  RB2
|   |   |   |   |   |   |   |   |  Table Scan.
|   |   |   |   |   |   |   |   |  Executed in
                                      parallel
                                      with a
                                      2-way
                                      partition
                                      scan.
|   |   |   |   |
|   |   |   |   |  TO TABLE
|   |   |   |   |  Worktable1.
|
|   |EXCHANGE Operator (Merged)
|   |Executed in parallel by 4 Producer
        and 1 Consumer processes.

|   |
|   |   |EXCHANGE:EMIT Operator
|   |   |
|   |   |   |NESTED LOOP JOIN Operator
                (Join Type: Inner Join)
|   |   |   |
|   |   |   |   |EXCHANGE Operator (Repartitioned)
|   |   |   |   |Executed in parallel by 2
                    Producer and 4 Consumer
                    processes.
|   |   |   |   |
|   |   |   |   |   |EXCHANGE:EMIT Operator
|   |   |   |   |   |
|   |   |   |   |   |   |RESTRICT Operator
|   |   |   |   |   |   |
|   |   |   |   |   |   |   |SCAN Operator
|   |   |   |   |   |   |   |  FROM TABLE
|   |   |   |   |   |   |   |  RA2
```

```
|    |    |    |    |    |    |    |  Table Scan.
|    |    |    |    |    |    |    |  Executed in
                                          parallel with
                                          a 2-way
                                          partition scan.
|    |    |    |    |SCAN Operator
|    |    |    |    |  FROM TABLE
|    |    |    |    |  Worktable1.
|    |    |    |    |  Using Clustered Index.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning by key.
```

Note the presence of a sequence operator. This operator executes all of its child operators but the last, before executing the last child operator. In this case, it executes the first child operator, which reformats table RB2 into a worktable using a four-way hash partitioning on columns b1 and b3. The table RA2 is also repartitioned four ways to match the stored partitioning of the worktable.

Serial join

Sometimes, it may not make sense to run a join in parallel because of the amount of data that needs to be joined. If you run a query similar to that of the earlier join queries, but now have predicates on each of the tables (RA2 and RB2) such that the amount of data to be joined is not enough, the join may be done in serial mode. In such a case, it does not matter how these tables are partitioned. The query still benefits from scanning the tables in parallel.

```
select * from RA2, RB2 where a1=b1 and a2 = b2
and a3 =  0 and  b2 = 20



QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 4
worker processes.

11 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |MERGE JOIN Operator (Join Type: Inner Join)
    | Using Worktable3 for internal storage.
    |  Key Count: 1
    |  Key Ordering: ASC
    |
    |   |SORT Operator
```

```
|    | Using Worktable1 for internal storage.
|    |
|    |    |EXCHANGE Operator (Merged)
|    |    |Executed in parallel by 2 Producer and
              1 Consumer processes.

|    |    |
|    |    |    |EXCHANGE:EMIT Operator
|    |    |    |
|    |    |    |    |RESTRICT Operator
|    |    |    |    |
|    |    |    |    |    |SCAN Operator
|    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |  RA2
|    |    |    |    |    |  Table Scan.
|    |    |    |    |    |  Executed in parallel with
                              a 2-way partition scan.
|    |SORT Operator
|    |Using Worktable2 for internal storage.
|    |
|    |    |EXCHANGE Operator (Merged)
|    |    |Executed in parallel by 2 Producer and
              1 Consumer processes.

|    |    |
|    |    |    |EXCHANGE:EMIT Operator
|    |    |    |
|    |    |    |    |RESTRICT Operator
|    |    |    |    |
|    |    |    |    |    |SCAN Operator
|    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |  RB2
|    |    |    |    |    |  Table Scan.
|    |    |    |    |    |  Executed in parallel with
                                a 2-way partition scan.
```

Semijoins

Semijoins, which result from flattening of in/exist subqueries, behave the same way as regular inner joins. However, replicated joins are not used for semijoins, because an outer row can match more than one time in such a situation.

Outer joins

In terms of parallel processing for outer joins, replicated joins are not considered. Everything else behaves in a similar way as regular inner joins. One other point of difference is that no partition elimination is done for any table in an outer join that belongs to the outer group.

Vector aggregation

Vector aggregation refers to queries with group-bys. There are different ways Adaptive Server can perform vector aggregation. The actual algorithms are not described here; only the technique for parallel evaluation is shown in the following sections.

In-partitioned vector aggregation

If any base or intermediate relation requires a grouping and is partitioned on a subset, or the same columns as that of the columns in the group by clause, the grouping operation can be done in parallel on each of the partition and the resultant grouped streams merged using a simple N-to-1 exchange. This is because a given group cannot appear in more than one stream. The same goes for grouping over any SQL query as long as you use semantics-based partitioning on the grouping columns or a subset of them. This method of parallel vector aggregation is called in-partitioned aggregation.

The following query uses a parallel in-partitioned vector aggregation since range partitioning is defined on the columns a1 and a2, which also happens to be the column on which the aggregation is needed.

```
select count(*), a1, a2 from RA2 group by a1,a2
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

4 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and
        1 Consumer processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |HASH VECTOR AGGREGATE Operator
    |   |   |  GROUP BY
    |   |   |  Evaluate Grouped COUNT AGGREGATE.
    |   |   | Using Worktable1 for internal storage.
    |   |   |
    |   |   |   |SCAN Operator
    |   |   |   |  FROM TABLE
    |   |   |   |  RA2
```

```
|   |   |   |  Table Scan.
|   |   |   |  Forward Scan.
|   |   |   |  Positioning at start of table.
|   |   |   |  Executed in parallel with a 2-way
                   partition scan.
|   |   |   |  Using I/O Size 2 Kbytes for data
                   pages.
|   |   |   |  With LRU Buffer Replacement
                    Strategy for data pages.
```

Repartitioned vector aggregation

Sometimes, the partitioning of the table or the intermediate results may not be useful for the grouping operation. It may still be worthwhile to do the grouping operation in parallel by repartitioning the source data to match the grouping columns, then applying the parallel vector aggregation. Such a scenario is shown below, where the partitioning is on columns (a1, a2), but the query requires a vector aggregation on column a1.

```
select count(*), a1 from RA2 group by a1

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 4
worker processes.

6 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1 Consumer
processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |HASH VECTOR AGGREGATE Operator
    |   |   |  GROUP BY
    |   |   |  Evaluate Grouped COUNT AGGREGATE.
    |   |   | Using Worktable1 for internal storage.
    |   |   |
    |   |   |   |EXCHANGE Operator (Repartitioned)
    |   |   |   |Executed in parallel by 2 Producer
                     and 2 Consumer processes.

    |   |   |   |
```

```
|    |    |    |    |EXCHANGE:EMIT Operator
|    |    |    |    |
|    |    |    |    |    |SCAN Operator
|    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |  RA2
|    |    |    |    |    |  Table Scan.
|    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |  Positioning at start of
                                table.
|    |    |    |    |    |  Executed in parallel with
                                 a 2-way partition scan.
```

Two-phased vector aggregation

For the query in the previous example, repartitioning may be expensive. Another possibility is to do a first level of grouping, merge the data using a N-to-1 exchange operator, then do another level of grouping. This is called a *two-phased* vector aggregation. Depending on the number of duplicates for the grouping column, Adaptive Server can reduce the cardinality of the data streaming through the N-to-1 exchange, then the second level of grouping becomes relatively inexpensive.

```
select count(*), a1 from RA2 group by a1

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

5 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

    |HASH VECTOR AGGREGATE Operator
    |  GROUP BY
    |  Evaluate Grouped SUM OR AVERAGE AGGREGATE.
    | Using Worktable2 for internal storage.
    |
    |    |EXCHANGE Operator (Merged)
    |    |Executed in parallel by 2 Producer and
             1 Consumer processes.
    |    |
    |    |    |EXCHANGE:EMIT Operator
    |    |    |
    |    |    |    |HASH VECTOR AGGREGATE Operator
    |    |    |    |  GROUP BY
    |    |    |    |  Evaluate Grouped COUNT AGGREGATE.
```

```
      |   |   |   | Using Worktable1 for internal
                        storage.
      |   |   |   |
      |   |   |   |   |SCAN Operator
      |   |   |   |   |  FROM TABLE
      |   |   |   |   |  RA2
      |   |   |   |   |  Table Scan.
      |   |   |   |   |  Executed in parallel with
                           a 2-way partition scan.
```

There are two vector aggregate operators—the name two-phase vector aggregation.

Serial vector aggregation

As with some of the earlier examples, if the amount of data flowing into the grouping operator is restricted by using a predicate, executing that query in parallel may not make much sense. In such a case, the partitions are scanned in parallel and an N-to-1 exchange operator is used to serialize the stream followed by a serial vector aggregation:

```
select count(*), a1, a2 from RA2
where a1 between 100 and 200
group by a1, a2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and
     2 worker processes.

4 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

   |HASH VECTOR AGGREGATE Operator
   |  GROUP BY
   |  Evaluate Grouped COUNT AGGREGATE.
   | Using Worktable1 for internal storage.
   |
   |   |EXCHANGE Operator (Merged)
   |   |Executed in parallel by 2 Producer and 1
           Consumer processes.
   |   |
   |   |   |EXCHANGE:EMIT Operator
   |   |   |
   |   |   |   |SCAN Operator
   |   |   |   |  FROM TABLE
```

```
        |   |   |   |  RA2
        |   |   |   |  Positioning at start of table.
        |   |   |   |  Executed in parallel with a 2-way
                            partition scan.
```

You cannot always group on the partitioning columns, or take advantage of a table that is already partitioned on the grouping columns. The query optimizer determines if it is better to repartition and perform the grouping in parallel, or merge the data stream in a partitioned table and do the grouping in serial or a two-phased aggregation.

distinct

Think of queries with distinct operations as grouped vector aggregation without the aggregation part. For example:

```
select distinct a1, a2 from RA2
```

is same as:

```
select a1, a2 from RA2 group by a1, a2
```

All of the methodologies that are applicable to vector aggregates are applicable here as well.

Queries with an *in* list

Adaptive Server uses an optimized technique to handle an in list. This is a common SQL construct. So, a construct like:

```
col in (value1, value2,..valuek)
```

is same as:

```
col = value1 OR col = value2 OR .... col = valuek
```

The values in the in list are put into a special in-memory table and sorted for removal of duplicates.The table is then joined back with the base table using an index nested-loop join. The following example illustrates this with two values in the in list that correspond to two values in the or list:

```
SCAN Operator
FROM OR List
OR List has up to 2 rows of OR/IN values.

select * from RA2 where a3 in (1425, 2940)

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
      worker processes.

6 operator(s) under root
```

```
The type of query is SELECT.

ROOT:EMIT Operator

   |EXCHANGE Operator (Merged)
   |Executed in parallel by 2 Producer and 1
        Consumer processes.

   |
   |   |EXCHANGE:EMIT Operator
   |   |
   |   |   |NESTED LOOP JOIN Operator (Join Type:
                Inner Join)
   |   |   |
   |   |   |   |SCAN Operator
   |   |   |   |  FROM OR List
   |   |   |   |  OR List has up to 2 rows of OR/IN
                      values.
   |   |   |
   |   |   |   |RESTRICT Operator
   |   |   |   |
   |   |   |   |   |SCAN Operator
   |   |   |   |   |  FROM TABLE
   |   |   |   |   |  RA2
   |   |   |   |   |  Index : RA2_NC1
   |   |   |   |   |  Forward Scan.
   |   |   |   |   |  Positioning by key.
   |   |   |   |   |  Keys are:
   |   |   |   |   |    a3 ASC
   |   |   |   |   |  Executed in parallel with a
                         2-way hash scan.
```

Queries with *or* clauses

Adaptive Server takes a disjunctive predicate like an or clause and applies each side of the disjunction separately to qualify a set of row IDs (RIDs). The set of conjunctive predicates on each side of the disjunction must be indexable. Also, the conjunctive predicates on each side of the disjunction cannot have further disjunction within them; that is, it makes little sense to use an arbitrarily deep nesting of disjunctive and conjunctive clauses. In the next example, a disjunctive predicate is taken on the same column (you can have predicates on different columns as long as you have indexes that can do inexpensive scans), but the predicates may qualify an overlapping set of data rows. Adaptive Server uses the predicates on each side of the disjunction separately and qualifies a set of row IDs. These row IDs are then subjected to duplicate elimination.

```
select a3 from RA2 where a3 = 2955 or a3 > 2990
```

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

8 operator(s) under root

The type of query is SELECT.

ROOT:EMIT Operator

   |EXCHANGE Operator (Merged)
   |Executed in parallel by 2 Producer and 1
       Consumer processes.

   |
   |   |EXCHANGE:EMIT Operator
   |   |
   |   |   |RID JOIN Operator
   |   |   | Using Worktable2 for internal storage.
   |   |   |
   |   |   |   |HASH UNION Operator has 2 children.
   |   |   |   | Using Worktable1 for internal storage.
   |   |   |   |
   |   |   |   |   |SCAN Operator
   |   |   |   |   |  FROM TABLE
   |   |   |   |   |  RA2
   |   |   |   |   |  Index : RA2_NC1
   |   |   |   |   |  Forward Scan.
   |   |   |   |   |  Positioning by key.
   |   |   |   |   |  Index contains all needed
                          columns.Base table will not
                          be read.
   |   |   |   |   |  Keys are:
   |   |   |   |   |    a3 ASC
   |   |   |   |   |  Executed in parallel with a
                        2-way hash scan.
   |   |   |   |
   |   |   |   |   |SCAN Operator
   |   |   |   |   |  FROM TABLE
   |   |   |   |   |  RA2
   |   |   |   |   |  Index : RA2_NC1
   |   |   |   |   |  Forward Scan.
   |   |   |   |   |  Positioning by key.
   |   |   |   |   |  Index contains all needed
                          columns. Base table will
                          not be read.
```

```
|    |    |    |    |  Keys are:
|    |    |    |    |    a3 ASC
|    |    |    |    |  Executed in parallel with a
                         2-way hash scan.
|    |    |    |RESTRICT Operator
|    |    |    |
|    |    |    |    |SCAN Operator
|    |    |    |    |  FROM TABLE
|    |    |    |    |  RA2
|    |    |    |    |  Using Dynamic Index.
|    |    |    |    |  Forward Scan.
|    |    |    |    |  Positioning by Row IDentifier
                           (RID.)
|    |    |    |    |  Using I/O Size 2 Kbytes for
                           data pages.
|    |    |    |    |  With LRU Buffer Replacement
                            Strategy for data pages.
```

Two separate index scans are employed using the index RA2_NC1, which is defined on the column a3. The qualified set of row IDs are then checked for duplicate row IDs, and finally, joined back to the base table. Note the line `Positioning by Row Identifier (RID)`. You can use different indexes for each side of the disjunction, depending on what the predicates are, as long as they are indexable. One way to easily identify this is to run the query separately with each side of the disjunction to make sure that the predicates are indexable. Adaptive Server may not choose an index intersection if it seems more expensive than a single scan of the table.

Queries with an *order by* clause

If a query requires sorted output because of the presence of an order by clause, Adaptive Server can apply the sort in parallel. First it tries to avoid the sort if there is some inherent ordering available. If it is forced to do the sort, it sees if the sort can be done in parallel. To do that, it may repartition an existing data stream or it may use the existing partitioning scheme, then apply the sort to each of the constituent streams. The resultant data is merged using an N-to-1 order, preserving the exchange operator.

```
select * from RA2 order by a1, a2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

4 operator(s) under root

The type of query is SELECT.
```

```
ROOT:EMIT Operator

   |EXCHANGE Operator (Merged)
   |Executed in parallel by 2 Producer and
        1 Consumer processes.

   |
   |   |EXCHANGE:EMIT Operator
   |   |
   |   |   |SORT Operator
   |   |   | Using Worktable1 for internal storage.
   |   |   |
   |   |   |   |SCAN Operator
   |   |   |   |  FROM TABLE
   |   |   |   |  RA2
   |   |   |   |  Index : RA2_NC2L
   |   |   |   |  Forward Scan.
   |   |   |   |  Positioning at index start.
   |   |   |   |  Executed in parallel with a
                       2-way partition scan.
```

Depending upon the volume of data to be sorted, and the available resources, Adaptive Server may repartition the data stream to a higher degree than the current degree of the stream, so that the sort operation is faster. This depends on whether the benefit obtained from doing the sort in parallel far outweighs the overheads of repartitioning.

Subqueries

When a query contains a subquery, Adaptive Server uses different methods to reduce the cost of processing the subquery. Parallel optimization depends on the type of subquery:

- Materialized subqueries – parallel query methods are not considered for the materialization step.
- Flattened subqueries – parallel query optimization is considered only when the subquery is flattened to a regular inner join or a semijoin.
- Nested subqueries – parallel operations are considered for the outermost query block in a query containing a subquery; the inner, nested queries always execute serially. This means that all tables in nested subqueries are accessed serially. In the following example, the table RA2 is accessed in parallel, but the result is that the table is serialized using a 2-to-1 exchange operator before accessing the subquery. The table RB2 inside the subquery is accessed in parallel.

```
select count(*) from RA2 where not exists
(select * from RB2 where RA2.a1 = b1)

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

8 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

    |SCALAR AGGREGATE Operator
    |  Evaluate Ungrouped COUNT AGGREGATE.
    |
    |   |SQFILTER Operator has 2 children.
    |   |
    |   |   |EXCHANGE Operator (Merged)
    |   |   |Executed in parallel by 2 Producer
                and 1 Consumer processes.

    |   |   |
    |   |   |   |EXCHANGE:EMIT Operator
    |   |   |   |
    |   |   |   |   |RESTRICT Operator
    |   |   |   |   |
    |   |   |   |   |   |SCAN Operator
    |   |   |   |   |   |  FROM TABLE
    |   |   |   |   |   |  RA2
    |   |   |   |   |   |  Index : RA2_NC2L
    |   |   |   |   |   |  Forward Scan.
    |   |   |   |   |   |  Executed in parallel with
                              a 2-way partition scan.
    |   |
    |   |  Run subquery 1 (at nesting level 1).
    |   |
    |   |  QUERY PLAN FOR SUBQUERY 1 (at nesting
              level 1 and at line 2).
    |   |
    |   |   Correlated Subquery.
    |   |   Subquery under an EXISTS predicate.
    |   |
    |   |   |SCALAR AGGREGATE Operator
    |   |   |  Evaluate Ungrouped ANY AGGREGATE.
```

```
    |    |    |  Scanning only up to the first
                     qualifying row.
    |    |    |
    |    |    |    |SCAN Operator
    |    |    |    |  FROM TABLE
    |    |    |    |  RB2
    |    |    |    |  Table Scan.
    |    |    |    |  Forward Scan.
    |    |
    |    |  END OF QUERY PLAN FOR SUBQUERY 1.
```

The following example shows an in subquery flattened into a semijoin. Actually, Adaptive Server does even better; it converts this into an inner join to provide greater flexibility in shuffling the tables in the join order. As seen below, the table RB2, which was originally in the subquery, is now being accessed in parallel.

```
select * from RA2 where a1 in (select b1 from RB2)

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 5
worker processes.

10 operator(s) under root


The type of query is SELECT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 3 Producer and 1 Consumer
processes.

    |
    |    |EXCHANGE:EMIT Operator
    |    |
    |    |    |MERGE JOIN Operator (Join Type: Inner Join)
    |    |    | Using Worktable3 for internal storage.
    |    |    |  Key Count: 1
    |    |    |  Key Ordering: ASC
    |    |    |
    |    |    |    |SORT Operator
    |    |    |    | Using Worktable1 for internal
                         storage.
    |    |    |    |
    |    |    |    |    |SCAN Operator
```

```
|    |    |    |    |  FROM TABLE
|    |    |    |    |  RB2
|    |    |    |    |  Table Scan.
|    |    |    |    |  Executed in parallel with a
                          3-way partition scan.
|    |    |
|    |    |    |SORT Operator
|    |    |    | Using Worktable2 for internal
                    storage.
|    |    |    |
|    |    |    |    |EXCHANGE Operator (Merged)
|    |    |    |    |Executed in parallel by 2
                       Producer and 3 Consumer
                       processes.

|    |    |    |    |
|    |    |    |    |    |EXCHANGE:EMIT Operator
|    |    |    |    |    |
|    |    |    |    |    |    |RESTRICT Operator
|    |    |    |    |    |    |
|    |    |    |    |    |    |    |SCAN Operator
|    |    |    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |    |    |  RA2
|    |    |    |    |    |    |    |  Index : RA2_NC2L
|    |    |    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |    |    |  Positioning at
                                          index start.
|    |    |    |    |    |    |    |  Executed in
                                              parallel with
                                              a 2-way
                                               partition scan.
```

select into clauses

Queries with select into clauses create a new table to store the query's result set. Adaptive Server optimizes the base query portion of a select into command in the same way it does a standard query, considering both parallel and serial access methods. A select into statement that is executed in parallel:

- Creates the new table using columns specified in the select into statement.
- Creates N partitions in the new table, where N is the degree of parallelism that the optimizer chooses for the insert operation in the query.
- Populates the new table with query results, using N worker processes.

- Unpartitions the new table, if no specific destination partitioning is required.

Performing a select into statement in parallel requires more steps than an equivalent serial query plan. This is a simple select into done in parallel:

```
select * into RAT2 from RA2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

4 operator(s) under root

The type of query is INSERT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1
       Consumer processes.

    |
    |   |EXCHANGE:EMIT Operator
    |   |
    |   |   |INSERT Operator
    |   |   |  The update mode is direct.
    |   |   |
    |   |   |   |SCAN Operator
    |   |   |   |  FROM TABLE
    |   |   |   |  RA2
    |   |   |   |  Table Scan.
    |   |   |   |  Forward Scan.
    |   |   |   |  Positioning at start of table.
    |   |   |   |  Executed in parallel with a 2-way
                      partition scan.
    |   |   |
    |   |   |  TO TABLE
    |   |   |  RAT2
    |   |   |  Using I/O Size 2 Kbytes for data
                  pages.
```

In this case, Adaptive Server does not try to increase the degree of the stream coming from the scan of table RA2 and uses it to do a parallel insert into the destination table. The destination table is initially created using round-robin partitioning of degree two. After the insert, the table is unpartitioned.

If the data set to be inserted is not big enough, Adaptive Server may choose to insert this data in serial. The scan of the source table can still be done in parallel. The destination table is then created as an unpartitioned table.

The select into clause has been enhanced to allow destination partitioning to be specified. In such a case, the destination table is created using that partitioning, and Adaptive Server finds the most optimal way to insert data. If the destination table must be partitioned the same way as the source data, and there is enough data to insert, the insert operator executes in parallel.

The next example shows the same partitioning for source and destination table, and demonstrates that Adaptive Server recognizes this scenario and chooses not to repartition the source data.

```
select * into new_table
partition by range(a1, a2)
(p1 values <= (500,100), p2 values <= (1000, 2000))
from RA2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 2
worker processes.

4 operator(s) under root


The type of query is INSERT.

ROOT:EMIT Operator

    |EXCHANGE Operator (Merged)
    |Executed in parallel by 2 Producer and 1 Consumer
processes.

    |
    |    |EXCHANGE:EMIT Operator
    |    |
    |    |    |INSERT Operator
    |    |    |  The update mode is direct.
    |    |    |
    |    |    |    |SCAN Operator
    |    |    |    |  FROM TABLE
    |    |    |    |  RA2
    |    |    |    |  Table Scan.
    |    |    |    |  Forward Scan.
    |    |    |    |  Positioning at start of table.
    |    |    |    |  Executed in parallel with a 2-way
```

```
                                   partition scan.
    |   |   |
    |   |   |  TO TABLE
    |   |   |  RRA2
    |   |   |  Using I/O Size 16 Kbytes for data
                    pages.
```

If the source partitioning does not match that of the destination table, the source data must be repartitioned. This is illustrated in the next example, where the insert is done in parallel using two worker processes after the data is repartitioned using a 2-to-2 exchange operator that converts the data from range partitioning to hash partitioning.

```
select * into HHA2
partition by hash(a1, a2)
(p1, p2)
from RA2

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 4
worker processes.

6 operator(s) under root


The type of query is INSERT.

ROOT:EMIT Operator

|EXCHANGE Operator (Merged)
|Executed in parallel by 2 Producer and 1
      Consumer processes.

|
|   |EXCHANGE:EMIT Operator
|   |
|   |   |INSERT Operator
|   |   |  The update mode is direct.
|   |   |
|   |   |   |EXCHANGE OperatorEXCHANGE Operator (
                Merged)
|   |   |   |Executed in parallel by 2 Producer
                and 2 Consumer processes.

|   |   |   |
|   |   |   |   |EXCHANGE:EMIT Operator
|   |   |   |   |
```

```
|    |    |    |    |    |SCAN Operator
|    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |  RA2
|    |    |    |    |    |  Table Scan.
|    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |  Positioning at start of table.
|    |    |    |    |    |  Executed in parallel with a
                                2-way partition scan.
|    |    |
|    |    |  TO TABLE
|    |    |  HHA2
|    |    |  Using I/O Size 16 Kbytes for data
                 pages.
```

insert/delete/update

insert, delete, and update operations are done in serial in Adaptive Server. However, tables other than the destination table used in the query to qualify rows to be deleted or updated can be accessed in parallel.

```
delete from RA2
where exists
(select * from RB2
where RA2.a1 = b1 and RA2.a2 = b2)

QUERY PLAN FOR STATEMENT 1 (at line 1).
Executed in parallel by coordinating process and 3
worker processes.

9 operator(s) under root

The type of query is DELETE.

ROOT:EMIT Operator

|DELETE Operator
|  The update mode is deferred.
|
|   |NESTED LOOP JOIN Operator (Join Type: Inner Join)
|   |
|   |   |SORT Operator
|   |   | Using Worktable1 for internal storage.
|   |   |
|   |   |   |EXCHANGE Operator (Merged)
|   |   |   |Executed in parallel by 3 Producer
                  and 1 Consumer processes.
```

```
|    |    |    |
|    |    |    |    |EXCHANGE:EMIT Operator
|    |    |    |    |
|    |    |    |    |    |RESTRICT Operator
|    |    |    |    |    |
|    |    |    |    |    |    |SCAN Operator
|    |    |    |    |    |    |  FROM TABLE
|    |    |    |    |    |    |  RB2
|    |    |    |    |    |    |  Table Scan.
|    |    |    |    |    |    |  Forward Scan.
|    |    |    |    |    |    |  Positioning at start of
                                    table.
|    |    |    |    |    |    |  Executed in parallel with
                                    a 3-way partition scan.
|    |    |    |    |    |    |  Using I/O Size 2 Kbytes
                                    for data pages.
|    |    |    |    |    |    |  With LRU Buffer Replacement
                                    Strategy for data pages.
|    |
|    |    |RESTRICT Operator
|    |    |
|    |    |    |SCAN Operator
|    |    |    |  FROM TABLE
|    |    |    |  RA2
|    |    |    |  Index : RA2_NC1
|    |    |    |  Forward Scan.
|    |    |    |  Positioning by key.
|    |    |    |  Keys are:
|    |    |    |    a3 ASC
|
|  TO TABLE
|  RA2
|  Using I/O Size 2 Kbytes for data pages.
```

The table RB2, which is being deleted, is scanned and deleted in serial. However, table RA2 was scanned in parallel. The same scenario is true for update or insert statements.

Partition elimination

One of the advantages of semantic partitioning is that the query processor may be able to take advantage of this and be able to disqualify partitions at compile time. This is possible for range, hash, and list partitions. With hash partitions, only equality predicates can be used, whereas for range and list partitions equality and in-equality predicates can be used to eliminate partitions. For example, consider table RA2 with its semantic partitioning defined on columns a1, a2 where (p1 values <= (500,100) and p2 values <= (1000, 2000)). If there are predicates on columns a1 or columns a1, a2, then it would be possible to do some partition elimination. For example:

```
select * from RA2 where a1 > 1500
```

does not qualify any data. This can be seen in the showplan output.

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
................................
|    |    |SCAN Operator
|    |    |  FROM TABLE
|    |    |  RA2
|    |    |  [ Eliminated Partitions : 1 2 ]
|    |    |  Index : RA2_NC2L
```

The phrase `Eliminated Partitions` identifies the partition in accordance with how it was created and assigns an ordinal number for identification. For table RA2, the partition represented by p1 where (a1, a2) <= (500, 100) is considered to be partition number one and p2 where (a1, a2) > (500, 100) and <= (1000, 2000) is identified as partition number two.

Consider an equality query on a hash-partitioned table where all keys in the hash partitioning have an equality clause. This can be shown by taking table HA2, which is hash-partitioned two ways on columns (a1, a2). The ordinal numbers refer to the order in which partitions are listed in the output of sp_help.

```
select * from HA2 where a1 = 10 and a2 = 20

QUERY PLAN FOR STATEMENT 1 (at line 1).
................................

|SCAN Operator
|  FROM TABLE
|  HA2
|  [ Eliminated Partitions : 1 ]
|  Table Scan.
```

Partition skew

Partition skew plays an important part in determining whether a parallel partitioned scan can be used. Adaptive Server partition skew is defined as the ratio of the size of the largest partition to the average size of a partition. Consider a table with four partitions of sizes 10, 20, 35, and 80 pages. The size of the average partition is (20 + 20 + 35 + 85)/4 = 40 pages. The biggest partition has 85 pages so partition skew is calculated as 85/40 = 2.125. In partitioned scans, the cost of doing a parallel scan is as expensive as doing the scan on the largest partition. Instead, a hash-based partition may turn out to be fast, as each worker process may hash on a page number or an allocation unit and scan its portion of the data. The penalty paid in terms of loss of performance by skewed partitions is not always at the scan level, but rather as more complex operators like several join operations are built over the data. The margin of error increases exponentially in such cases.

Partition skew can be easily found by running sp_help on a table:

```
sp_help HA2

........
name   type partition_type partitions  partition_keys
------ ------------------- ------------- -----------
HA2   base table        hash               2 a1, a2

partition_name partition_id pages       segment
create_date
------------------------- ----------- ----------- --
------------
--------------------------
HA2_752002679             752002679       324 default
Aug 10 2005  2:05PM
HA2_768002736             768002736       343 default
Aug 10 2005  2:05PM

Partition_Conditions
--------------------
NULL

Avg_pages   Max_pages   Min_pages   Ratio(Max/Avg)

Ratio(Min/Avg)
----------- ----------- ----------- ------------------
---------
---------------------------
333         343         324                    1.030030
```

```
0.972973
```

Alternatively, skew can be calculated by querying the systabstats system catalog, where the number of pages in each partition is listed.

Why queries do not run in parallel

Adaptive Server runs a query in serial when:

- There is not enough data to benefit from parallel access.
- The query contains no equijoin predicates like:

  ```
  select * from RA2, RB2
  where a1 > b1
  ```

- There are not enough resources, such as thread or memory, to run a query in parallel.
- Uses a covered scan of a global nonclustered index.
- Tables and indexes are accessed inside a nested subquery that cannot be flattened.

Runtime adjustment

If there are not enough worker processes available at runtime, the execution engine attempts to reduce the number of worker processes used by the exchange operators present in the plan.

It does so in two ways:

- First, by attempting to reduce the worker process usage of certain exchange operators in the query plan without resorting to serial recompilation of the query. Depending on the semantics of the query plan, certain exchange operators are adjustable and some are not. Some are limited in the way they can be adjusted.
- Parallel query plans need a minimum number of worker processes to run. When enough worker processes are not available, the query is recompiled serially. When recompilation is not possible, the query is aborted and the appropriate error message is generated.

Adaptive Server supports serial recompilation for these type of queries:

- All ad-hoc select queries, except for select into, alter table, and execute immediate queries.
- All stored procedures, except for select into and alter table queries.

Support for select into for ad-hoc and stored procedures will be available in a future release.

Recognizing and managing runtime adjustments

Adaptive Server provides two mechanisms to help you observe runtime adjustments of query plans:

- set process_limit_action allows you to abort batches or procedures when runtime adjustments take place.
- showplan prints an adjusted query plan when runtime adjustments occur, and showplan is effect.

Using *set process_limit_action*

The process_limit_action option to the set command lets you monitor the use of adjusted query plans at a session or stored procedure level. When you set process_limit_action to "abort," Adaptive Server records error 11015 and aborts the query, if an adjusted query plan is required. When you set process_limit_action to "warning," Adaptive Server records error 11014 but still executes the query. For example, this command aborts the batch when a query is adjusted at runtime:

```
set process_limit_action abort
```

By examining the occurrences of errors 11014 and 11015 in the error log, you can determine the degree to which Adaptive Server uses adjusted query plans instead of optimized query plans. To remove the restriction and allow runtime adjustments, use:

```
set process_limit_action quiet
```

See set in the *Reference Manual: Commands* for more information about process_limit_action.

Using *showplan*

When you use showplan, Adaptive Server displays the optimized plan for a given query before it runs the query. When the query plan involves parallel processing, and a runtime adjustment is made, showplan displays this message, followed by the adjusted query plan:

```
AN ADJUSTED QUERY PLAN IS BEING USED FOR STATEMENT 1
BECAUSE NOT ENOUGH WORKER PROCESSES ARE CURRENTLY
AVAILABLE.

ADJUSTED QUERY PLAN:
```

Adaptive Server does not attempt to execute a query when the set noexec is in effect, so runtime plans are never displayed while using this option.

Reducing the likelihood of runtime adjustments

To reduce the number of runtime adjustments, you must increase the number of worker processes that are available to parallel queries. You can do this either by adding more total worker processes to the system or by restricting or eliminating parallel execution for noncritical queries, as follows:

- Use set parallel_degree to set session-level limits on the degree of parallelism, or
- Use the query-level parallel 1 and parallel N clauses to limit the worker process usage of individual statements.

To reduce the number of runtime adjustments for system procedures, recompile the procedures after changing the degree of parallelism at the server or session level. See sp_recompile in the *Adaptive Server Reference Manual: Procedures* for more information.

CHAPTER 5 Controlling Optimization

This chapter describes query processing options that affect the query processor's choice of join order, index, I/O size, and cache strategy.

Special optimizing techniques

Being familiar with the information presented in the *Performance and Tuning: Basics* guide helps to understand the material in this chapter. Use caution, as the tools allow you to override the decisions made by the Adaptive Server query processor and can have an extreme negative effect on performance if misused. You should understand the impact on the performance of both your individual query and the possible implications for overall system performance.

Adaptive Server's advanced, cost-based query processor produces excellent query plans in most situations. But there are times when the query processor does not choose the proper index for optimal performance or chooses a suboptimal join order, and you need to control the access methods for the query. The options described in this chapter allow you that control.

In addition, while you are tuning, you may want to see the effects of a different join order, I/O size, or cache strategy. Some of these options let you specify query processing or access strategy without costly reconfiguration.

Adaptive Server provides tools and query clauses that affect query optimization and advanced query analysis tools that let you understand why the query processor makes the choices that it does.

Note This chapter suggests workarounds for certain optimization problems. If you experience these types of problems, please call Sybase Technical Support.

Specifying query processor choices

Adaptive Server lets you specify these optimization choices by including commands in a query batch or in the text of the query:

- The order of tables in a join
- The number of tables evaluated at one time during join optimization
- The index used for a table access
- The I/O size
- The cache strategy
- The degree of parallelism

In a few cases, the query processor fails to choose the best plan. In some of these cases, the plan it chooses is only slightly more expensive than the "best" plan, so you need to weigh the cost of maintaining forced options against the slower performance of a less than optimal plan.

The commands to specify join order, index, I/O size, or cache strategy, coupled with the query-reporting commands like statistics io and showplan, can help you determine why the query processor makes its choices.

Warning! Use the options described in this chapter with caution. The forced query plans may be inappropriate in some situations and may cause very poor performance. If you include these options in your applications, check query plans, I/O statistics, and other performance data regularly.

These options are generally intended for use as tools for tuning and experimentation, not as long-term solutions to optimization problems.

Specifying table order in *joins*

Adaptive Server optimizes join orders to minimize I/O. In most cases, the order that the query processor chooses does not match the order of the from clauses in your select command. To force Adaptive Server to access tables in the order they are listed, use:

```
set forceplan [on|off]
```

The query processor still chooses the best access method for each table. If you use forceplan and specify a join order, the query processor may use different indexes on tables than it would with a different table order, or it may not be able to use existing indexes.

You might use this command as a debugging aid if other query analysis tools lead you to suspect that the query processor is not choosing the best join order. Always verify that the order you are forcing reduces I/O and logical reads by using set statistics io on and comparing I/O both with and without forceplan.

If you use forceplan, your routine performance maintenance checks should include verifying that the queries and procedures that use it still require the option to improve performance.

You can include forceplan in the text of stored procedures.

set forceplan forces only join order, and not join type. There is no command for specifying the join type; you can disable merge joins at the server or session level.

You can disable hash joins at the session level. Also remember that an abstract plan allows full plan specification, including join order and join types.

See Chapter 8, "Creating and Using Abstract Plans," for more information about abstract plans.

See "Enabling and disabling merge joins" on page 193 for more information about merge joins.

Risks of using *forceplan*

Forcing join order has these risks:

- Misuse can lead to extremely expensive queries. Always test the query thoroughly with statistics io, and with and without forceplan.
- It requires maintenance. You must regularly check queries and stored procedures that include forceplan. Also, future versions of Adaptive Server may eliminate the problems that lead you to incorporate index forcing, so you should check all queries using forced query plans each time a new version is installed.

Things to try before using *forceplan*

Before you use forceplan:

- Check the showplan output to determine whether index keys are used as expected.
- Use dbcc traceon(302) or set option show normal to look for other optimization problems.
- Run update statistics on the index.
- Use update statistics to add statistics for search arguments on unindexed search clauses in the query, especially for search arguments that match minor keys in compound indexes.
- Use set option show_missing_stats on to look for column(s) that may need statistics.
- If the query joins more than four tables, use set table count to see if it results in an improved join order.

  See "Specifying the number of tables considered by the query processor" on page 181.

Specifying the number of tables considered by the query processor

Before version 15.0, Adaptive Server optimized joins by considering permutations of two to four times at a time. In version 15.0, the query processor is not limited in this way when considering permutations. Instead, the new search engine introduces a timeout mechanism to avoid excessive optimizing time. The table count setting discussed later in this section still has an effect on the initial join order looked at by the search engine, and thus affects the final join order when timeout does occur. If you suspect that an inefficient join order is being chosen when the search engine times out, you can still use the set table count option to increase the number of tables that are considered, which will affect the initial join order considered by the search engine in starting the permutation.

Adaptive Server optimizes joins by considering permutations of two to four tables at a time. If you suspect that an inefficient join order is being chosen for a join query, use the set table count option to increase the number of tables that are considered at the same time. The syntax is:

set table count *int_value*

Valid values are 0 though 8; 0 restores the default behavior.

For example, to specify 4-at-a-time optimization, use:

```
set table count 4
```

dbcc traceon(310) reports the number of tables considered at a time. See “dbcc traceon(310) and final query plan costs” on page 189 in the *Performance and Tuning: Monitoring and Analyzing for Performance* book for more information.

As you decrease the value, you reduce the chance that the query processor will consider all the possible join orders. Increasing the number of tables considered at one time during join ordering can greatly increase the time it takes to optimize a query.

Since the time it takes to optimize the query is increased with each additional table, the set table count option is most useful when the execution savings from improved join order outweighs the extra optimizing time. Some examples are:

- If you think that a more optimal join order can shorten total query optimization and execution time, especially for stored procedures that you expect to be executed many times once a plan is in the procedure cache
- When saving abstract plans for later use

Use statistics time to check parse and compile time and statistics io to verify that the improved join order is reducing physical and logical I/O.

If increasing the table count produces an improvement in join optimization, but increases the CPU time unacceptably, rewrite the from clause in the query, specifying the tables in the join order indicated by showplan output, and use forceplan to run the query. Your routine performance maintenance checks should include verifying that the join order you are forcing still improves performance.

Specifying an query index

You can specify the index to use for a query using the (index *index_name*) clause in select, update, and delete statements. You can also force a query to perform a table scan by specifying the table name. The syntax is:

select *select_list*
  from *table_name* [*correlation_name*]
    (index {*index_name* | *table_name* })
    [, *table_name* ...]
  where ...

delete *table_name*
  from *table_name* [*correlation_name*]
  (index {*index_name* | *table_name* }) ...

update *table_name* set *col_name* = *value*
  from *table_name* [*correlation_name*]
  (index {*index_name* | *table_name*})...

For example:

```
select pub_name, title
    from publishers p, titles t (index date_type)
    where p.pub_id = t.pub_id
    and type = "business"
    and pubdate > "1/1/93"
```

Specifying an index in a query can be helpful when you suspect that the query processor is choosing a suboptimal query plan. When you use this option:

- Always check statistics io for the query to see whether the index you choose requires less I/O than the query processor's choice.

- Test a full range of valid values for the query clauses, especially if you are tuning queries:
  - Tuning queries on tables that have skewed data distribution
  - Performing range queries, since the access methods for these queries are sensitive to the size of the range

Use this option only after testing to be certain that the query performs better with the specified index option. Once you include an index specification in a query, you should check regularly to be sure that the resulting plan is still better than other choices made by the query processor.

Note If a unclustered index has the same name as the table, specifying a table name causes the unclustered index to be used. You can force a table scan using select *select_list* from *tablename* (0).

Risks

Specifying indexes has these risks:

- Changes in the distribution of data could make the forced index less efficient than other choices.
- Dropping the index means that all queries and procedures that specify the index print an informational message indicating that the index does not exist. The query is optimized using the best alternative access method.
- Maintenance increases, since all queries using this option need to be checked periodically. Also, future versions of Adaptive Server may eliminate the problems that lead you to incorporate index forcing, so you should check all queries using forced indexes each time you install a new version.
- The index must exist at the time the query using it is optimized. You cannot create an index and then use it in a query in the same batch.

Things to try before specifying an index

Before specifying an index in queries:

- Check showplan output for the “Keys are” message to be sure that the index keys are being used as expected.

- Use dbcc traceon(302) or set option show normal to look for other optimization problems.
- Run update statistics on the index.
- If the index is a composite index, run update statistics on the minor keys in the index, if they are used as search arguments. This can greatly improve query processor cost estimates. Creating statistics for other columns frequently used for search clauses can also improve estimates.
- Use set option show_missing_stats on to look for column(s) that may need statistics.

Specifying I/O size in a query

If your Adaptive Server is configured for large I/Os in the default data cache or in named data caches, the query processor can decide to use large I/O for:

- Queries that scan entire tables
- Range queries using clustered indexes, such as queries using >, <, > *x* and < *y*, between, and like "*charstring %*"
- Queries that scan a large number of index leaf pages

If the cache used by the table or index is configured for 16K I/O, a single I/O can read up to eight pages simultaneously. Each named data cache can have several pools, each with a different I/O size. Specifying the I/O size in a query causes the I/O for that query to take place in the pool that is configured for that size. See the *System Administration Guide: Volume 2* for information on configuring named data caches.

To specify an I/O size that is different from the one chosen by the query processor, add the prefetch specification to the index clause of a select, delete, or update statement. The syntax is:

```
select select_list
   from table_name
     ( [index {index_name | table_name} ]
          prefetch size)
     [, table_name ...]
where ...
```

delete *table_name* from *table_name*
([index {*index_name* | *table_name*}]
prefetch *size*)
...

update *table_name* set *col_name* = *value*
from *table_name*
([index {*index_name* | *table_name*}]
prefetch *size*)
...

The valid prefetch size depends on the page size. If no pool of the specified size exists in the data cache used by the object, the query processor chooses the best available size.

If there is a clustered index on au_lname, this query performs 16K I/O while it scans the data pages:

```
select *
from authors (index au_names prefetch 16)
    where au_lname like "Sm%"
```

If a query normally performs large I/O, and you want to check its I/O performance with 2K I/O, you can specify a size of 2K:

```
select type, avg(price)
from titles (index type_price prefetch 2)
    group by type
```

Note Reference to large I/Os are on a 2K logical page size server. If you have an 8K page size server, the basic unit for the I/O is 8K. If you have a 16K page size server, the basic unit for the I/O is 16K.

Index type and large I/O size

When you specify an I/O size with prefetch, the specification can affect both the data pages and the leaf-level index pages. Table 5-1 shows the effects.

Table 5-1: Access methods and prefetching

Access method	Large I/O performed on
Table scan	Data pages
Clustered index	Data pages only, for allpages-locked tables Data pages and leaf-level index pages for data-only-locked tables
Nonclustered index	Data pages and leaf pages of nonclustered index

showplan reports the I/O size used for both data and leaf-level pages.

See "I/O Size Messages" on page 112 in the book *Performance and Tuning: Monitoring and Analyzing for Performance* for more information.

When *prefetch* specification is not followed

In most cases, when you specify an I/O size in a query, the query processor incorporates the I/O size into the query's plan. However, there are times when the specification cannot be followed, either for the query as a whole or for a single, large I/O request.

You cannot use large I/O for the query if:

- The cache is not configured for I/O of the specified size. The query processor substitutes the best size available.
- sp_cachestrategy has been used to disable large I/O for the table or index.

You cannot use large I/O for a single buffer if:

- Any of the pages included in that I/O request are in another pool in the cache.
- The page is on the first extent in an allocation unit. This extent holds the allocation page for the allocation unit, and only seven data pages.
- No buffers are available in the pool for the requested I/O size.

Whenever a large I/O cannot be performed, Adaptive Server performs 2K I/O on the specific page or pages in the extent that are needed by the query.

To determine whether the prefetch specification is followed, use showplan to display the query plan and statistics io to see the results on I/O for the query. sp_sysmon reports on the large I/Os requested and denied for each cache.

See "Data cache management" in the book *Performance and Tuning: Monitoring and Analyzing for Performance*.

setting *prefetch*

By default, a query uses large I/O whenever a large I/O pool is configured and the query processor determines that large I/O would reduce the query cost. To disable large I/O during a session, use:

```
set prefetch off
```

To reenable large I/O, use:

```
set prefetch on
```

If large I/O is turned off for an object using sp_cachestrategy, set prefetch on does not override that setting.

If large I/O is turned off for a session using set prefetch off, you cannot override the setting by specifying a prefetch size as part of a select, delete, or insert statement.

The set prefetch command takes effect in the same batch in which it is run, so you can include it in a stored procedure to affect the execution of the queries in the procedure.

Specifying cache strategy

For queries that scan a table's data pages or the leaf level of an unclustered index (covered queries), the Adaptive Server query processor chooses one of two cache replacement strategies: the fetch-and-discard (MRU) strategy or the LRU strategy.

See "Overview of cache strategies" on page 174 in the book *Performance and Tuning: Basics* for more information about these strategies.

The query processor may choose the MRU strategy for:

- Any query that performs table scans.
- A range query that uses a clustered index.
- A covered query that scans the leaf level of a nonclustered index.
- An inner table in a nested-loop join, if the inner table is larger than the cache.
- The outer table of a nested-loop join, since it needs to be read only once.
- Both tables in a MergeJoin.

To affect the cache strategy for objects:

- Specify lru or mru in a select, update, or delete statement
- Use sp_cachestrategy to disable or reenable the mru strategy

If you specify MRU strategy, and a page is already in the data cache, the page is placed at the MRU end of the cache, rather than at the wash marker.

Specifying the cache strategy affects only data pages and the leaf pages of indexes. Root and intermediate pages always use the LRU strategy.

In *select*, *delete*, and *update* statements

You can use lru or mru (fetch-and-discard) in a select, delete, or update command to specify the I/O size for the query:

select *select_list*
 from *table_name*
 (index *index_name* prefetch *size* [lru|mru])
 [, *table_name* ...]
where ...

delete *table_name* from *table_name* (index *index_name*
 prefetch *size* [lru|mru]) ...

update *table_name* set *col_name* = *value*
 from *table_name* (index *index_name*
 prefetch *size* [lru|mru]) ...

This query adds the LRU replacement strategy to the 16K I/O specification:

```
select au_lname, au_fname, phone
    from authors (index au_names prefetch 16 lru)
```

For more information about specifying a prefetch size, see “Specifying I/O size in a query” on page 184.

Controlling large I/O and cache strategies

Status bits in the sysindexes table identify whether a table or an index should be considered for large I/O prefetch or for MRU replacement strategy. By default, both are enabled. To disable or re-enable these strategies, use sp_cachestrategy. The syntax is:

sp_cachestrategy *dbname* , [*ownername*.]*tablename*
[, *indexname* | "text only" | "table only"
[, { prefetch | mru }, { "on" | "off"}]]

This command turns off the large I/O prefetch strategy for the au_name_index of the authors table:

```
sp_cachestrategy pubtune, authors, au_name_index,
   prefetch, "off"
```

This command re-enables MRU replacement strategy for the titles table:

```
sp_cachestrategy pubtune, titles, "table only",
   mru, "on"
```

Only a System Administrator or the object owner can change or view the cache strategy status of an object.

Getting information on cache strategies

To see the cache strategy that is in effect for a given object, execute sp_cachestrategy, with the database and object name:

```
sp_cachestrategy pubtune, titles
object name      index name       large IO MRU
---------------- ---------------- -------- --------
titles           NULL             ON       ON
```

showplan output shows the cache strategy used for each object, including worktables.

Asynchronous log service

ALS increases scalability in Adaptive Server and provides higher throughput in logging subsystems for high-end symmetric multiprocessor systems.

You cannot use ALS if you have fewer than 4 engines. If you try to enable ALS with fewer than 4 online engines an error message appears.

Enabling ALS

You can enable, disable, or configure ALS using the sp_dboption stored procedure.

```
sp_dboption <db Name>, "async log service",
"true|false"
```

Issuing a checkpoint

After issuing sp_dboption, you must issue a checkpoint in the database for which you are setting the ALS option:

```
sp_dboption "mydb", "async log service", "true"
use mydb
checkpoint
```

You can use the checkpoint to identify the one or more databases or use an all clause.

checkpoint [all | [dbname[, dbname[, dbname.....]]]

Disabling ALS

Before you disable ALS, make sure there are no active users in the database. If there are, you receive an error message when you issue the checkpoint:

```
sp_dboption "mydb", "async log service", "false"
use mydb
checkpoint
-------------
Error 3647: Cannot put database in single-user mode.
Wait until all users have logged out of the database and
issue a CHECKPOINT to disable "async log service".
```

If there are no active users in the database, this example disables ALS

```
sp_dboption "mydb", "async log service", "false"
use mydb
checkpoint
-------------
```

Displaying ALS

You can see whether ALS is enabled in a specified database by checking sp_helpdb.

```
sp_helpdb "mydb"
----------
mydb            3.0 MB sa              2
       July 09, 2002
       select into/bulkcopy/pllsort, trunc log on chkpt,
          async log service
```

For more information on these stored procedures, see “Changed system procedures” on page 193.

Understanding the user log cache (ULC) architecture

Adaptive Server's logging architecture features the user log cache, or ULC, by which each task owns its own log cache. No other task can write to this cache, and the task continues writing to the user log cache whenever a transaction generates a log record. When the transaction commits or aborts, or the user log cache is full, the user log cache is flushed to the common log cache, shared by all the current tasks, which is then written to the disk.

Flushing the ULC is the first part of a commit or abort operation. It requires the following steps, each of which can cause delay or increase contention:

1. Obtaining a lock on the last log page.
2. Allocating new log pages if necessary.
3. Copying the log records from the ULC to the log cache.

   The processes in steps 2 and 3 require you to hold a lock on the last log page, which prevents any other tasks from writing to the log cache or performing commit or abort operations.
4. Flush the log cache to disk.

   Step 4 requires repeated scanning of the log cache to issue write commands on dirty buffers.

   Repeated scanning can cause contention on the buffer cache spinlock to which the log is bound. Under a large transaction load, contention on this spinlock can be significant.

When to use ALS

You can enable ALS on any specified database that has at least one of the following performance issues, so long as your systems runs 4 or more online engines:

- Heavy contention on the last log page.

  You can tell that the last log page is under contention when the sp_sysmon output in the Task Management Report section shows a significantly high value. For example:

Table 5-2: Log page under contention

Task Management	per sec	per xact	count	% of total
Log Semaphore Contention	58.0	0.3	34801	73.1

- Underutilized bandwidth in the log device.

Note You should use ALS only when you identify a single database with high transaction requirements, since setting ALS for multiple database may cause unexpected variations in throughput and response times. If you want to configure ALS on multiple databases, first check that throughput and response times are satisfactory.

Using the ALS

Two threads scan the dirty buffers (buffers full of data not yet written to the disk), copy the data, and write it to the log. These threads are:

- The User Log Cache (ULC) flusher
- The Log Writer

ULC flusher

The ULC flusher is a system task thread that is dedicated to flushing the user log cache of a task into the general log cache. When a task is ready to commit, the user enters a commit request into the flusher queue. Each entry has a handle, by which the ULC flusher can access the ULC of the task that queued the request. The ULC flusher task continuously monitors the flusher queue, removing requests from the queue and servicing them by flushing ULC pages into the log cache.

Log writer

Once the ULC flusher has finished flushing the ULC pages into the log cache, it queues the task request into a wakeup queue. The log writer patrols the dirty buffer chain in the log cache, issuing a write command if it finds dirty buffers, and monitors the wakeup queue for tasks whose pages are all written to disk. Since the log writer patrols the dirty buffer chain, it knows when a buffer is ready to write to disk.

Changed system procedures

Two stored procedures are changed to enable ALS:

- sp_dboption adds an option that enables and disables ALS.
- sp_helpdb adds a column to display ALS.

For more general information about these stored procedures, see the *Reference Manual*.

Enabling and disabling merge joins

By default, merge joins are enabled, at the server level, for allrows mix and for allrows_dss optgoal, and are disabled at the server level for other optgoals, including allrows_oltp. When merge joins are disabled, the server only costs other join types that are not disabled. To enable merge joins server-wide, set enable merge join to 1. The pre-version 15.0 configuration enable sort-merge joins and JTC does not affect the new query processor.

The command set merge_join on overrides the server level to allow use of merge joins in a session or stored procedure.

To enable merge joins, use:

```
set merge_join on
```

To disable merge joins, use:

```
set merge_join off
```

For information on configuring merge joins server-wide, see the *System Administration Guide*.

Enabling and disabling hash joins

By default, hash joins are enabled only at allrows_dss optgoal. To override the server level to allow use of hash join in a session or stored procedure, use set hash_join on.

To enable hash joins, use:

```
set hash_join on
```

To disable hash joins, use:

```
set hash_join off
```

Enabling and disabling *join* transitive closure

With version 15.0, join transitive closure is always on and cannot be disabled. The search engine uses the timeout mechanism to avoid excessive optimization time. Although this setting no longer affects the actual use of transitive closure for the new query processor, it can still affect the initial join order that the search engine begins the permutation with when the timeout occurs. Thus, the following discussion is still useful when you suspect that a suboptimal join order is being chosen at timeout.

By default, join transitive closure is not enabled at the server level, since it can increase optimization time. You can enable join transitive closure at a session level with set jtc on. The session-level command overrides the server-level setting for the enable sort-merge joins and JTC configuration parameter.

For queries that execute quickly, even when several tables are involved, join transitive closure may increase optimization time with little improvement in execution cost. For example, with join transitive closure applied to this query, the number of possible joins is multiplied for each added table:

```
select * from t1, t2, t3, t4, ... tN
where t1.c1 = t2.c1
and t1.c1 = t3.c1
and t1.c1 = t4.c1
...
and t1.c1 = tN.c1
```

For joins on very large tables, however, the additional optimization time involved in costing the join orders added by join transitive closure may result in a join order that greatly improves the response time.

You can use set statistics time to see how long it takes to optimize the query. If running queries with set jtc on greatly increases optimization time, but also improves query execution by choosing a better join order, check the showplan or dbcc traceon(302, 310) output. Explicitly add the useful join orders to the query text. You can run the query without join transitive closure, and get the improved execution time, without the increased optimization time of examining all possible join orders generated by join transitive closure.

You can also enable join transitive closure and save abstract plans for queries that benefit. If you then execute those queries with loading from the saved plans enabled, the saved execution plan is used to optimize the query, making optimization time extremely short.

See *Performance and Tuning: Optimizer and Abstact Plans* for more information on using abstract plans and configuring join transitive closure server-wide.

Suggesting a degree of parallelism for a query

The parallel and *degree_of_parallelism* extensions to the from clause of a select command allow users to restrict the number of worker processes used in a scan.

For a parallel partition scan to be performed, the *degree_of_parallelism* must be equal to or greater than the number of partitions. For a parallel index scan, specify any value for the *degree_of_parallelism*.

The syntax for the select statement is:

```
select...
    [from {tablename}
       [(index index_name
          [parallel [degree_of_parallelism | 1]]
          [prefetch size] [lru|mru])],
       {tablename} [([index_name]
          [parallel [degree_of_parallelism | 1]
           [prefetch size] [lru|mru])] ...
```

Table 5-3 shows how to combine the index and parallel keywords to obtain serial or parallel scans.

Table 5-3: Optimizer hints for serial and parallel execution

To specify this type of scan:	Use this syntax:
Parallel partition scan	(index *tablename* parallel *N*)
Parallel index scan	(index *index_name* parallel *N*)
Serial table scan	(index *tablename* parallel 1)
Serial index scan	(index *index_name* parallel 1)
Parallel, with the choice of table or index scan left to the optimizer	(parallel *N*)
Serial, with the choice of table or index scan left to the optimizer	(parallel 1)

When you specify the parallel degree for a table in a merge join, it affects the degree of parallelism used for both the scan of the table and the merge join.

You cannot use the parallel option if you have disabled parallel processing either at the session level with the set parallel_degree 1 command or at the server level with the parallel degree configuration parameter. The parallel option cannot override these settings.

If you specify a *degree_of_parallelism* that is greater than the maximum configured degree of parallelism, Adaptive Server ignores the hint.

The optimizer ignores hints that specify a parallel degree if any of the following conditions is true:

- The from clause is used in the definition of a cursor.
- parallel is used in the from clause of an inner query block of a subquery, and the optimizer does not move the table to the outermost query block during subquery flattening.
- The table is a view, a system table, or a virtual table.
- The table is the inner table of an outer join.
- The query specifies exists, min, or max on the table.
- The value for the max scan parallel degree configuration parameter is set to 1.
- An unpartitioned clustered index is specified or is the only parallel option.
- A nonclustered index is covered.
- The query is processed using the OR strategy.
- The select statement is used for an update or insert.

Query level *parallel* clause examples

To specify the degree of parallelism for a single query, include parallel after the table name. This example executes in serial:

```
select * from titles (parallel 1)
```

This example specifies the index to be used in the query, and sets the degree of parallelism to 5:

```
select * from titles
    (index title_id_clix parallel 5)
where ...
```

To force a table scan, use the table name instead of the index name.

Optimization goals

Adaptive Server lets you choose a query optimization goal that best suits your query environment. The four optimization goals are:

- fastfirstrow – optimizes queries so that Adaptive Server returns the first few rows as quickly as possible.
- allrows_oltp – optimizes queries so that Adaptive Server uses a limited number of optimization criteria (described in “Optimization criteria” on page 199) to find a good query plan. allrows_oltp is most useful for purely OLTP queries.
- allrows_mixed – optimizes queries so that Adaptive Server uses most available optimization techniques, including merge_join and parallel, to find the best query plan. allrows_mixed, which is the default strategy, is most useful in a mixed-query environment.
- allrows_dss – optimizes queries so that Adaptive Server uses all available optimization techniques to find the best query plan, including hash join, advanced aggregates processing, and bushy tree plan. allrows_dss is most useful in a DSS environment.

Setting optimization goals

You can set the optimization goal at the server, session, or query level. The server-level optimization goal is overridden at the session level, which is overridden at the query level—making it possible to set a different optimization goal at each level.

At the server level

To set the optimization goal at the server level, you can:

- Use the sp_configure command
- Modify the optimization goal configuration parameter in the Adaptive Server configuration file

For example, to set the optimization level for the server to fastfirstrow, enter:

```
sp_configure "optimization goal", 0, "fastfirstrow"
```

At the session level

To set the optimization goal at the session level, use set plan optgoal. For example, to modify the optimization goal for the session to allrows, enter:

```
set plan optgoal allrows_oltp
```

To verify the current optimization goal at the session level, enter:

```
select @@optgoal
```

At the query level

To set the optimization goal at the query level, use the select or other DML command. For example, to change the optimization goal to allrows_oltp for the current query, enter:

```
select * from A order by A.a plan "(use optgoal allrows_oltp)"
```

At the query level only, you can specify the number of rows that Adaptive Server will return quickly when you set fastfirstrow as the optimization goal. For example, enter:

```
select * from A order by A.a plan "(use optgoal fastfirstrow 5)"
```

Some exceptions

In general, you can set query-level optimization goals using select, update, and delete statements. However:

- You cannot set query-level optimization goals in pure insert statements, although you can set optimization goals in select ... insert statements.
- fastfirstrow is relevant only for select statements; it incurs an error when used with other DML statements.

Optimization criteria

You can set specific optimization criteria for each session. The optimization criteria represent specific algorithms or relational techniques that may or may not be considered when Adaptive Server creates a query plan. By setting individual optimization criteria on or off, you can fine-tune the query plan for the current session.

Note Each optimization goal has default settings for each optimization criterion. Resetting optimization criteria may interfere with the default settings of the current optimization goal and produce an error message—although Adaptive Server will honor the new setting.

Sybase recommends that you set individual optimization criteria *only rarely and with caution* if it is necessary to fine-tune a particular query. Overriding optimization goal settings in this way can overly complicate query administration. Always set optimization criteria *after* setting any existing session level optgoal setting; an explicit optgoal setting could return an optimization criteria to its default value.

See "Default optimization criteria" on page 201 for more information.

Setting optimization criteria

Use the set command to enable or disable individual criteria.

For example, to enable the hash join algorithm, enter:

```
set hash_join 1
```

To disable the hash join algorithm, enter:

```
set hash_join 0
```

To enable one option and disable another, enter:

```
set hash_join 1, merge_join 0
```

Criteria descriptions

Most criteria described here decides whether a particular query engine operator can be used in the final plan chosen by the optimizer.

The optimization criteria are:

- hash_join – determines whether the Adaptive Server query processor may use the hash join algorithm. Hash joins may consume more runtime resources, but are valuable when the joining columns do not have useful indexes or when a relatively large number of rows satisfy the join condition, compared to the product of the number of rows in the joined tables.

- hash_union_distinct – determines whether the query processor may use the hash union distinct algorithm, which is not efficient if most rows are distinct.
- merge_join – determines whether the Adaptive Server query processor may use the merge join algorithm, which relies on ordered input. merge_join is most valuable when input is ordered on the merge key—for example, from an index scan. merge_join is less valuable if sort operators are required to order input.
- merge_union_all – determines whether the Adaptive Server query processor may use the merge algorithm for union all. merge_union_all maintains the ordering of the result rows from the union input. merge_union_all is particularly valuable if the input is ordered and a parent operator (such as merge join) benefits from that ordering. Otherwise, merge_union_all may require sort operators that reduce efficiency.
- merge_union_distinct – determines whether the query processor may use the merge algorithm for union. merge_union_distinct is similar to merge_union_all, except that duplicate rows are not retained. merge_union_distinct requires ordered input and provides ordered output.
- multi_table_store_ind – determines whether the query processor may use reformatting on the result of a multiple table join. Using multi_gt_store_ind may increase the use of worktables.
- nl_join – determines whether the Adaptive Server query processor may use the nested-loop-join algorithm.
- opportunistic_distinct_view – determines whether the query processor may use a more flexible algorithm when enforcing distinctness.
- parallel_query – determines whether the Adaptive Server query processor may use parallel query optimization.
- store_index – determines whether the query processor may use reformatting, which may increase the use of worktables.
- append_union_all – determines whether the query processor may use the append union all algorithm.
- bushy_search_space – determines whether the query processor may use bushy-tree-shaped query plans, which may increase the search space, but provide more query plan options to improve performance.
- distinct_hashing – determines whether the query processor may use a hashing algorithm to eliminate duplicates, which is very efficient when there are few distinct values compared to the number of rows.

- distinct_sorted – determines whether the Adaptive Server query processor may use a single-pass algorithm to eliminate duplicates. distinct_sorted relies on an ordered input stream, and may increase the number of sort operators if its input is not ordered.
- group-sorted – determines whether the query processor may use an on-the-fly grouping algorithm. group-sorted relies on an input stream sorted on the grouping columns, and it preserves this ordering in its output.
- distinct_sorting – determines whether the Adaptive Server query processor may use the sorting algorithm to eliminate duplicates. distinct_sorting is useful when the input is not ordered (for example, if there is no index) and the output ordering generated by the sorting algorithm could benefit; for example, in a merge join.
- group_hashing – determines whether the query processor may use a group hashing algorithm to process aggregates.
- index_intersection – determines whether the query processor may use the intersection of multiple index scans as part of the query plan in the search space.

The query processor will re-enable a default algorithm if all the algorithms of a relational operator are disabled. For example, if all join algorithms (nl_join, m_join, and h_join) are disabled, the query processor will enable nl_join.

The query processor can also re-enable nl_join for semantic reasons: for example, if the joining tables are not connected through equijoins.

Default optimization criteria

Each optimization goal – fastfirstrow, allrows_oltp, allrows_mixed, allrows_dss – has a default setting (on or off) for each optimization criterion. For example, the default setting for merge_join is off for fastfirstrow and allrows_oltp, and on for allrows_mixed and allrows_dss. See Table 5-4 for a list of default settings for each optimization criteria.

Sybase recommends that you reset the optimization goal and evaluate performance before changing optimization criteria. Change optimization criteria only when necessary to fine-tune a particular query.

Table 5-4: Default settings for optimization criteria

Optimization criteria	fastfirstrow	allrows_oltp	allrows_mixed	allrows_dss
append_union_all	1	1	1	1
bushy_search_space	0	0	0	1
distinct_sorted	1	1	1	1
distinct_sorting	1	1	1	1

Optimization criteria	fastfirstrow	allrows_oltp	allrows_mixed	allrows_dss
group_hashing	1	1	1	1
group_sorted	1	1	1	1
hash_join	0	0	0	1
hash_union_distinct	1	1	1	1
index_intersection	0	0	0	1
merge_join	0	0	1	1
merge_union_all	1	1	1	1
multi_gt_store_ind	0	0	0	1
nl_join	1	1	1	1
opp_distinct_view	1	1	1	1
parallel_query	1	0	1	1
store_index	1	1	1	1

Limiting optimization time

You can use the optimization timeout limit configuration parameter to restrict the amount of time Adaptive Server spends optimizing a query. optimization timeout limit specifies the amount of time Adaptive Server can spend optimizing a query as a percentage of the total time spent processing the query.

The timeout is activated only if:

- At least one complete plan has been retained as the best plan, and
- The optimization timeout limit has been exceeded.

Set optimization timeout limit at the server level using sp_configure. For example, to limit optimization time to 10 percent of total query processing time, enter:

```
sp_configure "optimization timeout limit", 10
```

To set optimization timeout limit at the session level, use:

```
set plan optimeoutlimit n
```

This command overrides the server setting.

The default value is 10 percent; you can specify any value from 1 to 1000.

At the server level, there is a separate configuration, sproc optimize timeout limit, for the server level default timeout value within stored procedure compilations. The default value is 40 percent; you can specify any value from 1 to 4000.

For more information about optimization timeout limit, see the chapter "Abstract Plans" in the *Query Processor* guide.

Controlling parallel optimization

The goal of executing queries in parallel is to get the fastest response time, even if it involves more total work from the server.

To enable and control parallel processing, Adaptive Server provides four configuration parameters:

- number of worker processes
- max parallel degree
- max resource granularity
- max repartition degree

With the exception of number of worker processes, each of these parameters can be set at the server and the session level. To view the current session-level value of a parameter, use the select command. For example, to view the current value of max resource granularity, enter:

```
select @@resource_granularity
```

Note When set or viewed at the session level, these parameters do not include "max."

Specifying the maximum number of worker processes

Use number of worker processes to specify the maximum number of worker processes that Adaptive Server can use at any one time for all simultaneously running parallel queries.

number of worker processes is a server-wide configuration parameter only; use sp_configure to set the parameter. For example, to set the maximum number of worker processes to 200, enter:

```
sp_configure "number of worker processes", 200
```

Specifying the number of worker processes available for parallel processing

Use max parallel degree to specify the maximum number of worker processes allowed per query. You can configure max parallel degree at the server or the session level.

For example, to set max parallel degree to 60 at the server level, enter:

```
sp_configure "max parallel degree", 60
```

To set max parallel degree to 60 at the session level, enter:

```
set parallel_degree 60
```

The value of max parallel degree must be equal to or less than the current value of number of worker processes. Setting max parallel degree to 1 turns off parallel processing—Adaptive Server scans all tables and indexes serially. To enable parallel partition scans, set this parameter equal to or greater than the number of partitions in the table you are querying.

Specifying the percentage of resources available to process a query

Use max resource granularity to specify the percentage of total memory that Adaptive Server can allocate to a single query. You can set the parameter at the server or session level.

For example, to set max resource granularity to 35 percent at the server level, enter:

```
sp_configure "max resource granularity", 35
```

To set max resource granularity to 35 percent at the session level, enter:

```
set resource_granularity 35
```

The value of this parameter can affect the query optimizer's choice of operators for a query. If max resource granularity is set low, many hash- and sort-based operators cannot be chosen. max resource granularity also affects the scheduling algorithm.

Specifying the number of worker processes available to partition a data stream

Use max repartition degree to suggest a number of worker processes that the query processor can use to partition a data stream. You can set max repartition degree at the server or query level.

Note The value of max repartition degree is a suggestion only; the query processor decides the optimal number.

---

max repartition degree is most useful when the tables being queried are not partitioned, but partitioning the resultant data stream may improve performance by allowing concurrent SQL operations.

For example, to set max repartition degree to 15 at the server level, enter:

```
sp_configure "max repartition degree", 15
```

To set max repartition degree to 15 at the session level, enter:

```
set repartition_degree 15
```

The value of max repartition degree must not exceed the current value of max parallel degree. Sybase recommends that you set the value of this parameter equal to or less than the number of CPUs or disk systems that can work in parallel.

Concurrency optimization for small tables

For data-only-locked tables of 15 pages or fewer, Adaptive Server does not consider a table scan if there is a useful index on the table. Instead, it always chooses the cheapest index that matches any search argument that can be optimized in the query. The locking required for an index scan provides higher concurrency and reduces the chance of deadlocks, although slightly more I/O may be required than for a table scan.

If concurrency on small tables is not an issue, and you want to optimize the I/O instead, you can disable this optimization with sp_chgattribute. This command turns off concurrency optimization for a table:

```
sp_chgattribute tiny_lookup_table,
   "concurrency_opt_threshold", 0
```

With concurrency optimization disabled, the query processor can choose table scans when they require fewer I/Os.

You can also increase the concurrency optimization threshold for a table. This command sets the concurrency optimization threshold for a table to 30 pages:

```
sp_chgattribute lookup_table,
   "concurrency_opt_threshold", 30
```

The maximum value for the concurrency optimization threshold is 32,767. Setting the value to -1 enforces concurrency optimization for a table of any size. It may be useful in cases where a table scan is chosen over indexed access, and the resulting locking results in increased contention or deadlocks.

The current setting is stored in systabstats.conopt_thld and is printed as part of optdiag output.

Changing locking scheme

Concurrency optimization affects only data-only-locked tables. Table 5-5 shows the effect of changing the locking scheme.

Table 5-5: Effects of alter table on concurrency optimization settings

Changing locking scheme from	Effect on stored value
Allpages to data-only	Set to 15, the default
Data-only to allpages	Set to 0
One data-only scheme to another	Configured value retained

CHAPTER 6

Using Statistics to Improve Performance

Accurate statistics are essential to query optimization. In some cases, adding statistics for columns that are not leading index keys also improves query performance. This chapter explains how and when to use the commands that manage statistics.

Statistics maintained in Adaptive Server

These key optimizer statistics are maintained in Adaptive Server:

- Statistics per partition: table row count; table page count. An unpartitioned table is considered to have one partition for the purposes of the systabstats catalog. Can be found in systabstats.
- Statistics per index: index row count; index height; index leaf page count. A local index has a separate systabstats row for each index partition. A global index, which is considered a partitioned index with one partition, has one systabstats row. Can be found in systabstats.

- Statistics per column: data distribution. Can be found in sysstatistics.
- Statistics per group of columns: density information. Can be found in sysstatistics.
- Statistics per partition
    - Column statistics: data distribution per column; density per group of columns. Can be found in sysstatistics.

Definitions

These definitions will help you to understand the material in this chapter.

Density

Density is a statistical measurement of the uniqueness of a given column's values.

Histogram

A histogram is a statistical representation of the distribution of values of a given column of the relation.

Importance of statistics

The Adaptive Server cost-based optimizer uses statistics about the tables, indexes, partitions, and columns named in a query to estimate query costs. It chooses the access method that the optimizer determines has the least cost. But this cost estimate cannot be accurate if statistics are not accurate.

Some statistics, such as the number of pages or rows in a table, are updated during query processing. Other statistics, such as the histograms on columns, are updated only when update statistics runs or when indexes are created.

If your query is performing slowly and you seek help from Technical Support or a Sybase newsgroup on the Internet, one of the first questions you are likely be asked is "Did you run update statistics?" You can use the optdiag command to see when update statistics was last run for each column on which statistics exist:

```
Last update of column statistics: Aug 31 2004
4:14:17:180PM
```

Another command you may need for statistics maintenance is delete statistics. Dropping an index does not drop the statistics for that index. If the distribution of keys in the columns changes after the index is dropped, but the statistics are still used for some queries, the outdated statistics can affect query plans.

Histogram statistics from a global index are more accurate than histogram statistics generated by a local index. For a local index, the statistics are created on each partition, and are then merged to create a global histogram using guesses as to how overlapping histogram cells from each partition should be combined. With a global index, the merge step, with merging estimates, does not occur. In most cases, there is no issue with update statistics on a local index. However, if there are significant estimation errors in queries involving partitioned tables, histogram accuracy can be improved by creating and dropping a global index on a column rather than updating the statistics on a local index.

Updating statistics

The update statistics command updates column-related statistics such as histograms and densities. Statistics must be updated on those columns where the distribution of keys in the index changes in ways that affect the use of indexes for your queries.

Running update statistics requires system resources. Like other maintenance tasks, it should be scheduled at times when the load on the server is light. In particular, update statistics requires table scans or leaf-level scans of indexes, may increase I/O contention, may use the CPU to perform sorts, and uses the data and procedure caches. Use of these resources can adversely affect queries running on the server if you run update statistics when usage is high.

Using the sampling feature can reduce resource requirements and allow more flexibility when running this task.

In addition, some update statistics commands require shared locks, which can block updates. See “Scan types, sort requirements, and locking” on page 226 for more information.

You can also configure Adaptive Server to automatically run update statistics at times that have minimal impact on the system resources. For more information, see “Automatically updating statistics” on page 213.

Adding statistics for unindexed columns

When you create an index, a histogram is generated for the leading column in the index. Examples in earlier chapters have shown how statistics for other columns can increase the accuracy of optimizer statistics.

You should consider adding statistics for virtually all columns that are frequently used as search arguments, as long as your maintenance schedule allows time to keep these statistics up to date.

In particular, adding statistics for minor columns of composite indexes can greatly improve cost estimates when those columns are used in search arguments or joins along with the leading index key.

update statistics commands

The update statistics commands create statistics if there are no statistics for a particular column, or replaces existing statistics. The statistics are stored in the system tables systabstats and sysstatistics. The syntax is:

update statistics *table_name*
[[partition *data_partition_name*] [(*column_list*)] |
index_name [partition *index_partition_name*]]
[using step values]
[with consumers = consumers] [, sampling=*percent*]

update index statistics
table_name [[partition *data_partition_name*] |
[*index_name* [partition *index_partition_name*]]]
[using step values]
[with consumers = consumers] [, sampling=*percent*]

update all statistics *table_name*
[partition *data_partition_name*]
[sp_configure *histogram tuning factor*, <*value*>

update table statistics
table_name [partition *data_partition_name*]

delete [shared] statistics *table_name*
[partition *data_partition_name*]
[(*column_name*[, *column_name*] ...)]

- For update statistics:
  - *table_name* – generates statistics for the leading column in each index on the table.

- *table_name index_name* – generates statistics for all columns of the index.
- *partition_name* – generates statistics for only this partition.
- *partition_name table_name* (*column_name*) – generates statistics for this column of this table on this partition.
- *table_name* (*column_name*) – generates statistics for only this column.
- *table_name* (*column_name*, *column_name*...) – generates a histogram for the leading column in the set, and multicolumn density values for the prefix subsets.
- *using step values* – identifies the number of steps used. The default is 20 steps. To change the default number of steps, use sp_configure.
- sampling = *percent* – the numeric value of the sampling percentage, such as 05 for 5%, 10 for 10%, and so on. The sampling integer is between zero (0) and one hundred (100).

- For update index statistics:
  - *table_name* – generates statistics for all columns in all indexes on the table.
  - *partition_name table_name* – generates statistics for all columns in all indexes for the table on this partition.
  - *table_name index_name* – generates statistics for all columns in this index.
- For update all statistics:
  - *table_name* – generates statistics for all columns of a table.
  - *table_name partition_name* – generates statistics for all columns of a table on a partition.
  - *using step values* – identifies the number of steps used. The default is 20 steps. To change the default number of steps, use sp_configure.

    A new option in sp_configure is histogram tuning factor, which allows superior selection of the number of histogram steps. The default value for histogram tuning factor is 20. See the *System Administration Guide* for information about sp_configure.

Using sampling for *update statistics*

The optimizer for Adaptive Server uses the statistics on a database to set up and optimize queries. To generate optimal results, the statistics must be as current as possible.

Run the update statistics commands against data sets, such as tables, to update information about the distribution of key values in specified indexes or columns, for all columns in an index, or for all columns in a table. The commands revise histograms and density values for column-level statistics. The results are then used by the optimizer to calculate the best way to set up a query plan.

update statistics requires table scans or leaf-level scans of indexes, may increase I/O contention, may use the CPU to perform sorts, and uses data and procedure caches. Use of these resources can adversely affect queries running on the server if you run update statistics when usage is high. In addition, some update statistics commands require shared locks, which can block updates.

To reduce I/O contention and resources, run update statistics using a sampling method, which can reduce the I/O and time when your maintenance window is small and the data set is large. If you are updating a large data set or table that is in constant use, being truncated and repopulated, you may want to do a statistical sampling to reduce the time and the size of the I/O. Because sampling does not update the density values, run a full update statistics prior to using sampling for an accurate density value.

Use caution with sampling since the results are not fully accurate. Balance changes to histogram values against the savings in I/O.

Sampling does not update the density if it was previously created by a non-sampling update statistics command. Since the density changes very slowly, replacing an accurate density with an approximation calculated by sampling usually does not improve the estimate. If the density was created by a sampling update statistics command, then it is updated. It is recommended that one non-sampling update statistics command is used to establish an accurate density, which can be followed by numerous sampling update statistics commands. In order to have sampling update statistics update the density, you must delete the column statistics before using update statistics with sampling.

When you are deciding whether or not to use sampling, consider the size of the data set, the time constraints you are working with, and if the histogram produced is as accurate as needed.

The percentage to use when sampling depends on your needs. Test various percentages until you receive a result that reflects the most accurate information on a particular data set.

Example:

```
update statistics authors(auth_id) with sampling = 5 percent
```

The server-wide sampling percent can be set using:

```
sp_configure 'sampling percent', 5
```

This command sets a server-wide sampling of 5% for update statistics that allows you to do the update statistics without the *sampling* syntax. The percentage can be between zero (0) and one hundred (100) percent.

Automatically updating statistics

The Adaptive Server cost-based query processor uses statistics for the tables, indexes, and columns named in a query to estimate query costs. Based on these statistics, the query processor chooses the access method it determines has the least cost. However, this cost estimate cannot be accurate if the statistics are not accurate. You can run update statistics to ensure that the statistics are current. However, running update statistics has an associated cost because it consumes system resources such as CPU, buffer pools, sort buffers, and procedure cache.

Instead of manually running update statistics at a certain time, you can set update statistics to run automatically when it best suits your site and avoid running it at times that hamper your system. The best time for you to run update statistics is based on the feedback from the datachange function. datachange also helps to ensure that you do not unnecessarily run update statistics. You can use these templates to determine the objects, schedules, priority, and datachange thresholds that trigger update statistics, which ensures that critical resources are used only when the query processor generates more efficient plans.

Because it is a resource-intensive task, base the decision to run update statistics on a specific set of criteria. Key parameters that can help you determine a good time to run update statistics include:

- How much the data characteristics changed since you last ran update statistics. This is known as the datachange parameter.

- Whether there are sufficient resources available to run update statistics. These include resources such as the number of idle CPU cycles and making sure that critical online activity does not occur during update statistics.

Data change is a key metric that helps you measure the amount of altered data since you last ran update statistics, and is tracked by the datachange function. Using this metric and the criteria for resource availability, you can automate the process of running update statistics. Job Scheduler includes a mechanism to automatically run update statistics. Job Scheduler also includes a set of customizable templates that determine when to run update statistics. These inputs include all parameters to update statistics, the datachange threshold values, and the time to run update statistics. Job Scheduler runs update statistics at a low priority so it does not affect critical jobs that are running concurrently.

What is the *datachange* function?

The datachange function measures the amount of change in the data distribution since update statistics last ran. Specifically, it measures the number of inserts, updates, and deletes that have occurred on the given object, partition, or column, and helps you determine if running update statistics would benefit the query plan.

The syntax for datachange is:

select datachange(*object_name*, *partition_name*, *colname*)

Where:

- *object_name* – is the object name. This object is assumed to be in the current database. This is a required parameter. It cannot be null.
- *partition_name* – is the data partition name. This can be a null value.
- *colname* – is the column name for which the datachange is requested. This can be a null value.

The datachange function requires all three parameters.

datachange is expressed as a percentage of the total number of rows in the table or partition (if the partition is specified). The percentage value can be greater than 100 percent because the number of changes to an object can be much greater than the number of rows in the table, particularly when the number of deletes and updates to a table is very high.

The following set of examples illustrate the various uses for the datachange function. The examples use the following:

- Object name is "O."
- Partition name is "P."
- Column name is "C."

Passing a valid object, partition, and column name

The value reported when you include the object, partition, and column name is determined by this equation: the datachange value for the specified column in the specified partition divided by the partitions's rowcount. The result is expressed as a percentage:

```
datachange = 100 * (data change value for column C/ rowcount (P))
```

Using null partition names

If you include a null partition name, the datachange value is determined by this equation: the sum of the datachange value for the column across all partitions divided by the rowcount of the table. The result is expressed as a percentage:

```
datachange = 100 * (Sum(data change value for (O, P(1-N) , C))/rowcount(O)
```

Where P(1-*N*) indicates that the value is summed over all partitions.

Using null column names

If you include null column names, the value reported by datachange is determined by this equation: the maximum value of the datachange for all columns that have histograms for the specified partition divided by the number of rows in the partition. The result is expressed as a percentage:

```
datachange = 100 * (Max(data change value for (O, P, Ci))/rowcount(P)
```

Where the value of *i* varies through the columns with histograms (for example, formatid 102 in sysstatistics).

Null partition and column names

If you include null partition and column names, the value of datachange is determined by this equation: the maximum value of the datachange for all columns that have histograms summed across all partitions divided by the number of rows in the table. The result is expressed as a percentage:

```
datachange = 100 * ( Max(data change value for (O, NULL, Ci))/rowcount(O)
```

Where *i* is 1 through the total number of columns with histograms (for example, formatid 102 in sysstatistics).

The following session illustrates datachange gathering statistics:

```
create table matrix(col1 int, col2 int)
go
insert into matrix values (234, 560)
go
update statistics matrix(col1)
```

```
go
insert into matrix values(34,56)
go
select datachange ("matrix", NULL, NULL)
go

------
50.000000
```

The number of rows in matrix is two. The amount of data that has changed since the last update statistics command is 1, so the datachange percentage is 100 * 1/2 = 50 percent.

datachange counters are all maintained in memory. These counters are periodically flushed to disk by the housekeeper or when you run sp_flushstats.

Configuring automatic *update statistics*

There are three methods for automatically updating statistics:

- Defining update statistics jobs with Job Scheduler
- Defining update statistics jobs as part of the self-management installation
- Creating user-defined scripts

Creating user-defined scripts is not discussed in this document.

Using Job Scheduler to update statistics

Job Scheduler includes the update statistics template, which you can use to create a job that runs update statistics on a table, index, column, or partition. The datachange function determines when the amount of change in a table or partition has reached the predefined threshold. You determine the value for this threshold when you configure the template.

Templates perform the following operations:

- Run update statistics on specific tables, partitions, indexes, or columns. The templates allow you to define the value for datachange that you want update statistics to run.

- Run update statistics at the server level, which configures Adaptive Server to sweep through the available tables in all databases on the server and update statistics on all the tables, based on the threshold you determined when creating your job.

Use the following steps to configure Job Scheduler to automate the process of running update statistics (the chapters listed are from the *Job Scheduler User's Guide*:

1 Install and set up Job Scheduler (described in Chapter 2, "Configuring and Running Job Scheduler").

2 Install the stored procedures required for the templates (described in Chapter 4, "Using Templates to Schedule Jobs").

3 Install the templates. Job Scheduler provides the templates specifically for automating update statistics (described in Chapter 4, "Using Templates to Schedule Jobs").

4 Configure the templates. The templates for automating update statistics are in the Statistics Management folder.

5 Schedule the job. After you have defined which index, column, or partition you want tracked, you can also create a schedule that determines when Adaptive Server runs the job, making sure that update statistics is run only when it does not impact performance.

6 Identify success or failure. The Job Scheduler infrastructure allows you to identify success or failure for the automated update statistic.

The template allows you to supply values for the various options of the update statistics command such as sampling percent, number of consumers, steps, and so on. Optionally, you can also provide threshold values for the datachange function, page count, and row count. If you include these optional values, they are used to determine when and if Adaptive Server should run update statistics. If the current values for any of the tables, columns, indexes, or partitions exceed the threshold values, Adaptive Server issues update statistics. Adaptive Server detects that update statistics has been run on a column. Any query referencing that table in the procedure cache is recompiled before the next execution.

When does Adaptive Server run *update statistics*?

There are many forms of the update statistics command (update statistics, update index statistics, and so on), and you can form the command in many ways depending on your needs.

You must specify three thresholds: rowcount, pagecount, and datachange. All the thresholds must be satisfied for update statistics to run. Although values of NULL or 0 are ignored, these values do not prevent the command from running.

Table 6-1 describes the circumstances under which Adaptive Server automatically runs update statistics, based on the parameter values you provide.

Table 6-1: When does Adaptive Server automatically run update statistics?

If the user	Action taken by Job Scheduler
Specifies a datachange threshold of zero or NULL	Runs update statistics at the scheduled time.
Specifies a datachange threshold greater than zero for a table only, and does not request the update index statistics form	Gets all the indexes for the table and gets the leading column for each index. If the datachange value for any leading column is greater than or equal to the threshold, run update statistics.
Specifies threshold values for the table and index but does not request the update index statistics form	Gets the datachange value for the leading column of the index. If the datachange value is greater than or equal to the threshold, runs update statistics.
Specifies a threshold value for a table only, and requests the update index statistics form	Gets all the indexes for the table and gets the leading column for each index. If the datachange value for any leading column exceeds the threshold, runs update statistics.
Specifies threshold values for table and index and requests the update index statistics form	Gets the datachange value for the leading column of the index. If the datachange value is greater than or equal to the threshold, runs update statistics.
Specifies threshold values for a table and one or more columns (ignores any indexes or requests for the update index statistics form)	Gets the datachange value for each column. If the datachange value for any column is greater than or equal to the threshold, runs update statistics.

The datachange function compiles the number of changes in a table and displays this as a percentage of the total number of rows in the table. You can use this compiled information to create rules that determine when Adaptive Server runs update statistics. The best time for this to happen can be based on any number of objectives:

- The percentage of change in a table
- Number of CPU cycles available
- During a maintenance window

After update statistics runs, the datachange counter is reset to zero. The count for datachange is tracked at the partition level (not the object level) for inserts and deletes and at the column level for updates.

Examples of updating statistics with *datachange*

You can write scripts that check for the specified amount of changed data at the column, table, or partition level. The time at which you decide to run update statistics can be based on a number of variables collected by the datachange function; CPU usage, percent change in a table, percent change in a partition, and so on.

In this example, the authors table is partitioned, and the user wants to run update statistics when the data changes to the city column in the author_ptn2 partition are greater than or equal to 50%:

```
select  @datachange = datachange("authors","author_ptn2", "city")
if @datachange >= 50
begin
        update statistics authors partition author_ptn2(city)
end
go
```

The user can also specify that the script is executed when the system is idle or any other parameters they see fit.

In this example, the user triggers update statistics when the data changes to the city column of the authors table are greater than or equal to 100% (the table in this example is not partitioned):

```
select  @datachange = datachange("authors",NULL, "city")
if @datachange > 100
begin
        update statistics authors (city)
end
go
```

Column statistics and statistics maintenance

Histograms are kept on a per-column basis, rather than on a per-index basis. This has certain implications for managing statistics:

- If a column appears in more than one index, update statistics, update index statistics, or create index updates the histogram for the column and the density statistics for all prefix subsets.

  update all statistics updates histograms for all columns in a table.

- Dropping an index does not drop the statistics for the index, since the optimizer can use column-level statistics to estimate costs, even when no index exists.

  To remove the statistics after dropping an index, you must explicitly delete them using delete statistics.

  If the statistics are useful to the query processor and to keep the statistics without having an index, use update statistics, specifying the column name, for indexes where the distribution of key values changes over time.

- Truncating a table does not delete the column-level statistics in sysstatistics. In many cases, tables are truncated and the same data is reloaded.

  Since truncate table does not delete the column-level statistics, you need not run update statistics after the table is reloaded, if the data is the same.

  If you reload the table with data that has a different distribution of key values, run update statistics.

- You can drop and re-create indexes without affecting the index statistics, by specifying "0" for the number of steps in the with statistics clause to create index. This create index command does not affect the statistics in sysstatistics:

  ```
  create index title_id_ix on titles(title_id)
      with statistics using 0 values
  ```

  This allows you to re-create an index without overwriting statistics that have been edited with optdiag.

- If two users attempt to create an index on the same table, with the same columns, at the same time, one of the commands may fail due to an attempt to enter a duplicate key value in sysstatistics.

- update statistics on a column in a partition of a multi-partition table will update the statistics for that partition, but also has the side effect of updating the global histogram for that column. This is done by merging the histograms for that column from each partition in a row-weighted fashion to arrive at a global histogram for the column.

- Updating statistics on a multi-partitioned table for a column, without specifying a partition, updates the statistics for each partition of the table for that column, and, as a last step, merges the partition histograms for the column to create a global histogram for the column.

- The optimizer only uses the global histograms for a multi-partitioned table during compilation, and does not read the partition histograms. This approach avoids the overhead of merging partition histograms at compilation time, and instead performs any merging work at DDL time.

Creating and updating column statistics

Creating statistics on unindexed columns can improve the performance of many queries. The optimizer can use statistics on any column in a where or having clause to help estimate the number of rows from a table that match the complete set of query clauses on that table.

Adding statistics for the minor columns of indexes and for unindexed columns that are frequently used in search arguments can greatly improve the optimizer's estimates.

Maintaining a large number of indexes during data modification can be expensive. Every index for a table must be updated for each insert and delete to the table, and updates can affect one or more indexes.

Generating statistics for a column without creating an index gives the optimizer more information to use for estimating the number of pages to be read by a query, without the processing expense of index updates during data modification.

The optimizer can apply statistics for any columns used in a search argument of a where or having clause and for any column named in a join clause.

Use these commands to create and maintain statistics:

- update statistics, when used with the name of a column, generates statistics for that column without creating an index on it.

  The optimizer can use these column statistics to more precisely estimate the cost of queries that reference the column.

- update index statistics, when used with an index name, creates or updates statistics for all columns in an index.

  If used with a table name, it updates statistics for all indexed columns.

- update all statistics creates or updates statistics for all columns in a table.

Good candidates for column statistics are:

- Columns frequently used as search arguments in where and having clauses

- Columns included in a composite index, and which are not the leading columns in the index, but which can help estimate the number of data rows that need to be returned by a query

When additional statistics may be useful

To determine when additional statistics are useful, run queries using set option commands and set statistics io. If there are significant discrepancies between the "rows to be returned" and I/O estimates displayed by set commands and the actual I/O displayed by statistics io, examine these queries for places where additional statistics can improve the estimates. Look especially for the use of default density values for search arguments and join columns.

The set option show_missing_stats command prints the names of columns that could have used histograms, and groups of columns that could have used multi-attribute densities. This is particularly useful in pointing out where additional statistics can be useful.

Example 1

```
1> set option show_missing_stats long
2> go
1> dbcc traceon(3604)
2> go

DBCC execution completed. If DBCC printed error messages, contact a
user with System Administrator (SA) role.

1> select * from part, partsupp
2> where p_partkey = ps_partkey and p_itemtype = ps_itemtype
3> go

NO STATS on column part.p_partkey
NO STATS on column part.p_itemtype
NO STATS on column partsupp.pa_itemtype
NO STATS on density set for E={p_partkey, p_itemtype}
NO STATS on density set for F={ps_partkey, ps_itemtype}
- - - - - - - - - - - - - - -
(200 rows affected)
```

You can get the same information using the show_final_plan_xml option. Note that the set plan uses the client option and traceflag 3604 to get the output on the client side. This differs from the way the message option of set plan is used.

Example 2

```
1> dbcc traceon(3604)
2> go

DBCC execution completed. If DBCC printed error messages, contact a
user with System Administrator (SA) role.

1> set plan for show_final_plan_xml to client on
2> go
```

```
1> select * from part, partsupp
2> where p_partkey = ps_partkey and p_itemtype = ps_itemtype
3> go
```


```
<?xml version="1.0" encoding="UTF-8"?>
<query>
        <planVersion> 1.0 </planVersion>
- - - - - - - - - - - - - - - - - -
<optimizerStatistics>
    <statInfo>
        <objName>part</objName>
        <missingHistogram>
            <column>p_partkey</column>
            <column>p_itemtype</column>
        </missingHistogram>
        <missingDensity>
            <column>p_partkey</column>
            <column>p_itemtype</column>
        </missingDensity>
    </statInfo>
    <statInfo>
<objName>partsupp</objName>
        <missingHistogram>
            <column>ps_partkey</column>
            <column>ps_itemtype</column>
        </missingHistogram>
        <missingDensity>
            <column>ps_partkey</column>
            <column>ps_itemtype</column>
        </missingDensity>
    </statInfo>
</optimizerStatistics>
```


Use update statistics on part and partsupp to create statistics on p_partkey and p_itemtype, thus creating a histogram on the leading column (p_partkey) and the density (p_partkey, p_itemtype). Create a histogram on p_itemtype as well. Use these commands:

```
1> update statistics part(p_partkey, p_itemtype)
2> go
1> update statistics part(p_itemtype)
2> go
```

Since partsupp has a histogram on ps_partkey, you can create a histogram on ps_itemtype and a density on (ps_itemtype, ps_partkey). The columns used for density may be unordered.

```
1> update statistics partsupp(ps_itemtype, ps_partkey)
2> go
```

If this procedure is successful, you will not see the “NO STATS” messages shown in Example 1 when you run the query again.

Adding statistics for a column with *update statistics*

This command adds statistics for the price column in the titles table:

```
update statistics titles (price)
```

This command specifies the number of histogram steps for a column:

```
update statistics titles (price)
   using 50 values
```

This command adds a histogram for the titles.pub_id column and generates density values for the prefix subsets pub_id; pub_id, pubdate; and pub_id, pubdate, title_id:

```
update statistics titles(pub_id, pubdate, title_id)
```

However, this command does not create a histogram on `pubdate` and `title_id`, since a separate update statistics command is needed for every column for which a histogram is desired.

Note Running update statistics with a table name updates histograms and densities for leading columns for indexes only; it does not update the statistics for unindexed columns. To maintain these statistics, run update statistics and specify the column name, or run update all statistics.

Adding statistics for minor columns with *update index statistics*

To create or update statistics on all columns in an index, use update index statistics. The syntax is:

update index statistics
table_name [[partition *data_partition_name*] |
[*index_name* [partition *index_partition_name*]]]
[using step values]
[with consumers = consumers] [, sampling = *percent*]

Adding statistics for all columns with *update all statistics*

To create or update statistics on all columns in a table, use update all statistics. The syntax is:

```
update all statistics table_name
[partition data_partition_name]
```

Choosing step numbers for histograms

By default, each histogram has 20 steps, which provides good performance and modeling for columns that have an even distribution of values. A higher number of steps can increase the accuracy of I/O estimates for:

- Columns with a large number of highly duplicated values
- Columns with unequal or skewed distribution of values
- Columns that are queried using leading wildcards in like queries

The histogram tuning factor default of 20 automatically chooses a step value between the current requested step value (default 20) and the increased steps due to the factor (20 * 20 = 400) so that Adaptive Server will automatically choose the optimal steps value to compensate for the above cases. Overriding the step values should take into account the larger number of steps already introduced by the histogram tuning factor.

Note If your database was updated from a pre-11.9 version of the server, the number of steps defaults to the number of steps that were used on the distribution page.

Disadvantages of too many steps

Increasing the number of steps beyond what is needed for good query optimization can degrade Adaptive Server performance, largely due to the amount of space that is required to store and use the statistics. Increasing the number of steps:

- Increases the disk storage space required for sysstatistics

- Increases the cache space needed to read statistics during query optimization
- Requires more I/O, if the number of steps is very large

During query optimization, histograms use space borrowed from the procedure cache. This space is released as soon as the query is optimized.

Choosing a step number

If your table has 5000 rows, and one value in the column that has only one matching row, you may need to request 5000 steps to get a histogram that includes a frequency cell for every distinct value. The actual number of steps is not 5000; it is either the number of distinct values plus one (for dense frequency cells) or twice the number of values plus one (for sparse frequency cells).

The sp_configure option histogram tuning factor automatically chooses a larger number of steps, within parameters, when there are a large number of highly duplicated values.

The default value of the histogram tuning factor has been changed, in 15.0, to 20. If the requested step count is 50, then update statistics can create up to 20 * 50 = 1000 steps. This larger number of steps is used only if histogram distribution is skewed with a number of domain values that are highly duplicated. However, for a unique column, update statistics still uses only 50 steps to represent the histogram. To most efficiently use histograms, specify a relatively low number of steps and allow the histogram tuning factor to determine whether more steps would be useful for optimization. For example, instead of specifying 1000 steps with a default step count of 1000 to be used by all histograms, it is better to specify 50 default steps and a histogram tuning factor of 20. This allows Adaptive Server to determine the best step count, within the range of 50 to 1000 steps, with which to represent the distribution.

Scan types, sort requirements, and locking

Table 6-2 shows the types of scans performed during update statistics, the types of locks acquired, and when sorts are needed.

Table 6-2: Scans, sorts, and locking during update statistics

update statistics specifying	Scans and sorts performed	Locking
Table name		
Allpages-locked table	Table scan, plus a leaf-level scan of each nonclustered index	Level 1; shared intent table lock, shared lock on current page
Data-only-locked table	Table scan, plus a leaf-level scan of each nonclustered index and the clustered index, if one exists	Level 0; dirty reads
Table name and clustered index name		
Allpages-locked table	Table scan	Level 1; shared intent table lock, shared lock on current page
Data-only-locked table	Leaf level index scan	Level 0; dirty reads
Table name and nonclustered index name		
Allpages-locked table	Leaf level index scan	Level 1; shared intent table lock, shared lock on current page
Data-only-locked table	Leaf level index scan	Level 0; dirty reads
Table name and column name		
Allpages-locked table	Table scan; creates a worktable and sorts the worktable	Level 1; shared intent table lock, shared lock on current page
Data-only-locked table	Table scan; creates a worktable and sorts the worktable	Level 0; dirty reads

Sorts for unindexed or non-leading columns

For unindexed columns and columns that are not the leading columns in indexes, Adaptive Server performs a serial table scan, copying the column values into a worktable. It then sorts the worktable to build the histogram. The sort is performed in serial, unless the with consumers clause is specified.

See Chapter 9, “Parallel Sorting” in *Performance and Tuning: Optimizer and Abstract Plans* for information on parallel sort configuration requirements.

Locking, scans, and sorts during *update index statistics*

The update index statistics command generates a series of update statistics operations that use the same locking, scanning, and sorting as the equivalent index-level and column-level command. For example, if the salesdetail table has a nonclustered index named sales_det_ix on salesdetail(stor_id, ord_num, title_id), this command:

```
update index statistics salesdetail
```

performs these update statistics operations:

```
update statistics salesdetail sales_det_ix
update statistics salesdetail (ord_num)
update statistics salesdetail (title_id)
```

Locking, scans and sorts during *update all statistics*

The update all statistics commands generate a series of update statistics operations for each index on the table, followed by a series of update statistics operations for all unindexed columns.

Using the *with consumers* clause

The with consumers clause for update statistics is designed for use on partitioned tables on Redundant Array of Independent Disks (RAID) devices, which appear to Adaptive Server as a single I/O device, but can produce the high throughput required for parallel sorting. See Chapter 9, “Parallel Sorting” in *Performance and Tuning: Optimizer and Abstract Plans* for more information.

Reducing *update statistics* impact on concurrent processes

Since update statistics uses dirty reads (transaction isolation level 0) for data-only-locked tables, you can execute it while other tasks are active on the server; it does not block access to tables and indexes. Updating statistics for leading columns in indexes requires only a leaf-level scan of the index, and does not require a sort, so updating statistics for these columns does not affect concurrent performance very much.

However, updating statistics for unindexed and non-leading columns, which require a table scan, worktable, and sort can affect concurrent processing.

- Sorts are CPU-intensive. Use a serial sort, or a small number of worker processes to minimize CPU utilization. Alternatively, you can use execution classes to set the priority for update statistics.

  See “Using Engines and CPUs” in *Performance and Tuning: Basics*.

- The cache space required for merging sort runs is taken from the data cache, and some procedure cache space is also required. Setting the number of sort buffers to a low value reduces the space used in the buffer cache.

  If number of sort buffers is set to a large value, it takes more space from the data cache, and may also cause stored procedures to be flushed from the procedure cache, since procedure cache space is used while merging sorted values. There are approximately 100 bytes of procedure cache needed for every row that can fit into the sort buffers specified. For example, if 500 2K sort buffers are specified, and about 200 rows fit into each 2K buffer, then 200 * 100 * 500 bytes of procedure cache are needed to support the sort. This example requires about 5000 2K procedure cache buffers, if the entire 500 data cache buffers are filled by a sort run.

Creating the worktables for sorts also uses space in tempdb.

Using the *delete statistics* command

In versions of Adaptive Server earlier than 11.9, dropping an index removed the distribution page for the index. As of version 11.9.2, maintaining column-level statistics is under explicit user control, and the optimizer can use column-level statistics even when an index does not exist. The delete statistics command allows you to drop statistics for specific columns.

If you create an index and then decide to drop it because it is not useful for data access, or because of the cost of index maintenance during data modifications, you must determine:

- Whether the statistics on the index are useful to the optimizer.
- Whether the distribution of key values in the columns for this index are subject to change over time as rows are inserted and deleted.

If the distribution of key values changes, run update statistics periodically to maintain useful statistics.

This example deletes the statistics for the price column in the titles table:

```
delete statistics titles(price)
```

Note delete statistics only removes rows from sysstatistics; it does not remove rows from systabstats. The rows in systabstats that described partition row counts, cluster ratios, page counts, etc. cannot be deleted. However, if optdiag simulate statistics is used add any simulated systabstats rows to sysstatistics, then those rows are deleted.

When row counts may be inaccurate

Row count values for the number of rows, number of forwarded rows, and number of deleted rows may be inaccurate, especially if query processing includes many rollback commands. If workloads are extremely heavy, and the housekeeper wash task does not run often, these statistics are more likely to be inaccurate.

Running update statistics corrects counts in systabstats.

Running dbcc checktable or dbcc checkdb updates these values in memory.

When the housekeeper wash task runs, or when you execute sp_flushstats, these values are saved in systabstats.

Note You must set the configuration parameter housekeeper free write percent to 1 or greater to enable housekeeper statistics flushing.

CHAPTER 7

Introduction to Abstract Plans

This chapter provides an overview of abstract plans.

Overview

Adaptive Server can generate an abstract plan for a query, and save the text and its associated abstract plan in the sysqueryplans system table. Using a rapid hashing method, incoming SQL queries can be compared to saved query text, and if a match is found, the corresponding saved abstract plan is used to execute the query.

An abstract plan describes the execution plan for a query using a language created for that purpose. This language contains operators to specify the choices and actions that can be generated by the optimizer. For example, to specify an index scan on the titles table, using the index title_id_ix, the abstract plan says:

```
(i_scan title_id_ix titles)
```

To use this abstract plan with a query, you can modify the query text and add a PLAN clause:

```
select * from titles where title_id = “On Liberty”
plan
“(i_scan title_id_ix titles)”
```

This alternative has the shortcoming of requiring a change to the SQL text; however, the method described in the first paragraph, that is, the sysqueryplans-based way to give the abstract plan of a query, does not involve changing the query text.

Abstract plans provide a means for System Administrators and performance tuners to protect the overall performance of a server from changes to query plans. Changes in query plans can arise due to:

- Adaptive Server software upgrades that affect optimizer choices and query plans
- New Adaptive Server features that change query plans
- Changing tuning options such as the parallel degree, table partitioning, or indexing

The main purpose of abstract plans is to provide a means to capture query plans before and after major system changes. The sets of before-and-after query plans can be compared to determine the effects of changes on your queries. Other uses include:

- Searching for specific types of plans, such as table scans or reformatting
- Searching for plans that use particular indexes
- Specifying full or partial plans for poorly-performing queries
- Saving plans for queries with long optimization times

Abstract plans provide an alternative to options that must be specified in the batch or query in order to influence optimizer decisions. Using abstract plans, you can influence the optimization of a SQL statement without having to modify the statement syntax. While matching query text to stored text requires some processing overhead, using a saved plan reduces query optimization overhead.

Managing abstract plans

A full set of system procedures allows System Administrators and Database Owners to administer plans and plan groups. Individual users can view, drop, and copy the plans for the queries that they have run.

See Chapter 10, “Managing Abstract Plans with System Procedures,”

Relationship between query text and query plans

For most SQL queries, there are many possible query execution plans. SQL describes the desired result set, but does not describe how that result set should be obtained from the database. Consider a query that joins three tables, such as this:

```
select t1.c11, t2.c21
from t1, t2, t3
where t1.c11 = t2.c21
and t1.c11 = t3.c31
```

There are many different possible join orders, and depending on the indexes that exist on the tables, many possible access methods, including table scans, index scans, and the reformatting strategy. Each join may use either a nested-loop join or a merge join. These choices are determined by the optimizer's query costing algorithms, and are not included in or specified in the query itself.

When you capture the abstract plan, the query is optimized in the usual way, except that the optimizer also generates an abstract plan, and saves the query text and abstract plan in sysqueryplans.

Limits of options for influencing query plans

Adaptive Server provides other options for influencing optimizer choices:

- Session-level options such as set forceplan to force join order or set parallel_degree to specify the maximum number of worker processes to use for the query
- Options that can be included in the query text to influence the index choice, cache strategy, and parallel degree

There are some limitations to using set commands or adding hints to the query text:

- Not all query plan steps can be influenced, for example, subquery attachment
- Some query-generating tools do not support the in-query options or require all queries to be vendor-independent

Full versus partial plans

Abstract plans can be full plans, describing all query processing steps and options, or they can be partial plans. A partial plan might specify that an index is to be used for the scan of a particular table, without specifying other access methods. For example:

```
select t1.c11, t2.c21
from t1, t2, t3
where t1.c11 = t2.c21
and t1.c11 = t3.c31
plan
"(i_scan t3_c31_ix t3)"
```

The full abstract plan includes:

- The join type, nl_join for nested-loop joins, m_g_join for merge joins, or h_join for hash joins.
- The join order.
- The type of scan, t_scan for table scan or i_scan for index scan.
- The name of the index chosen for the tables that are accessed via an index scan.
- The scan properties: the parallel degree, I/O size, and cache strategy for each table in the query.

The abstract plan for the query above specifies the join order, the access method for each table in the query, and the scan properties for each table:

```
select t1.c11, t2.c21
from t1, t2, t3
where t1.c11 = t2.c21
and t1.c11 = t3.c31
plan
"(i_scan t3_c31_ix t3)"

(nl_join ( nl_join
    ( t_scan t2 )
    ( i_scan t1_c11_ix t1 )
    )
    ( i_scan t3_c31_ix t3 )
)
( prop t3
    ( parallel 1 )
    ( prefetch 16 )
    ( lru )
```

```
)
( prop t1
    ( parallel 1 )
    ( prefetch 16 )
    ( lru )
)
( prop t2
    ( parallel 1 )
    ( prefetch 16 )
    ( lru )
)
```

If the abstract plan dump mode is on, the query text and the abstract plan pair are saved in sysqueryplans:

```
select t1.c11, t2.c21
from t1, t2, t3
where t1.c11 = t2.c21
and t1.c11 = t3.c31
plan
“(i_scan t3_c31_ix t3)”
```

Creating a partial plan

When abstract plans are captured, full abstract plans are generated and stored. You can write partial plans to affect only a subset of the optimizer choices. If the query above had not used the index on t3, but all other parts of the query plan were optimal, you could create a partial plan for the query using the create plan command. This partial plan specifies only the index choice for t3:

```
create plan
"select t1.c11, t2.c21
from t1, t2, t3
where t1.c11 = t2.c21
and t1.c11 = t3.c31"
"( i_scan t3_c31_ix t3 )"
```

You can also create abstract plans with the plan clause for select, delete, update, and other commands that can be optimized. If the AP dump mode is on, the query text and AP pair are saved in sysqueryplans:

See “Creating plans using SQL” on page 247.

Abstract plan groups

When you first install Adaptive Server, there are two abstract plan groups:

- ap_stdout, used by default for capturing plans
- ap_stdin, used by default for plan association

A System Administrator can enable server-wide plan capture to ap_stdout, so that all query plans for all queries are captured. Server-wide plan association uses queries and plans from ap_stdin. If some queries require specially-tuned plans, they can be made available server-wide.

A System Administrator or Database Owner can create additional plan groups, copy plans from one group to another, and compare plans in two different groups.

The capture of abstract plans and the association of abstract plans with queries always happens within the context of the currently-active plan group. Users can use session-level set commands to enable plan capture and association.

Some of the ways abstract plan groups can be used are:

- A query tuner can create abstract plans in a group created for testing purposes without affecting plans for other users on the system
- Using plan groups, “before” and “after” sets of plans can be used to determine the effects of system or upgrade changes on query optimization.

See Chapter 8, “Creating and Using Abstract Plans,” for information on enabling the capture and association of plans.

How abstract plans are associated with queries

When an abstract plan is saved, all white space (tabs, multiple spaces, and returns, except for returns that terminate a --style comment) in the query is trimmed to a single space, and a hash-key value is computed for the white-space trimmed SQL statement. The trimmed SQL statement and the hash key are stored in sysqueryplans along with the abstract plan, a unique plan ID, the user’s ID, and the ID of the current abstract plan group.

When abstract plan association is enabled, the hash key for incoming SQL statements is computed, and this value is used to search for the matching query and abstract plan in the current association group, with the corresponding user ID. The full association key of an abstract plans consists of:

- The user ID of the current user
- The group ID of the current association group
- The full query text

Once a matching hash key is found, the full text of the saved query is compared to the query to be executed, and used if it matches.

The association key combination of user ID, group ID and query text means that for a given user, there cannot be two queries in the same abstract plan group that have the same query text, but different query plans.

CHAPTER 8

Creating and Using Abstract Plans

This chapter provides an overview of the commands used to capture abstract plans and to associate incoming SQL queries with saved plans. Any user can issue session-level commands to capture and load plans during a session, and a System Administrator can enable server-wide abstract plan capture and association. This chapter also describes how to specify abstract plans using SQL.

Using *set* commands to capture and associate plans

At the session level, any user can enable and disable capture and use of abstract plans with the set plan dump and set plan load commands. The set plan replace command determines whether existing plans are overwritten by changed plans.

Enabling and disabling abstract plan modes takes effect at the end of the batch in which the command is included (similar to showplan). Therefore, change the mode in a separate batch before you run your queries:

```
set plan dump on
go
/*queries to run*/
go
```

Any set plan commands used in a stored procedure do not affect the procedure (except those statements affected by deferred compilation) in which they are included, but remain in effect after the procedure completes.

Enabling plan capture mode with *set plan dump*

The set plan dump command activates and deactivates the capture of abstract plans. You can save the plans to the default group, ap_stdout, by using set plan dump with no group name:

```
set plan dump on
```

To start capturing plans in a specific abstract plan group, specify the group name. This example sets the group dev_plans as the capture group:

```
set plan dump dev_plans on
```

The group that you specify must exist before you issue the set command. The system procedure sp_add_qpgroup creates abstract plan groups; only the System Administrator or Database Owner can create an abstract plan group. Once an abstract plan group exists, any user can dump plans to the group. See "Creating a group" on page 286 for information on creating a plan group.

To deactivate the capturing of plans, use:

```
set plan dump off
```

You do not need to specify a group name to end capture mode. Only one abstract plan group can be active for saving or matching abstract plans at any one time. If you are currently saving plans to a group, you must turn off the plan dump mode, and re-enable it for the new group, as shown here:

```
set plan dump on /*save to the default group*/
go
/*some queries to be captured */
go
set plan dump off
go
set plan dump dev_plans on
go
/*additional queries*/
go
```

The use of the use database command while set plan dump is in effect disables plan dump mode.

Associating queries with stored plans

The set plan load command activates and deactivates the association of queries with stored abstract plans.

To start the association mode using the default group, ap_stdin, use the command:

```
set plan load on
```

To enable association mode using another abstract plan group, specify the group name:

```
set plan load test_plans on
```

Only one abstract plan group can be active for plan association at one time. If plan association is active for a group, you must deactivate the current group and start association for the new group, as shown here:

```
set plan load test_plans on
go
/*some queries*/
go
set plan load off
go
set plan load dev_plans on
go
```

The use of the use database command while set plan load is in effect disables plan load mode.

Using replace mode during plan capture

While plan capture mode is active, you can choose whether to have plans for the same query replace existing plans by enabling or disabling set plan replace. This command activates plan replacement mode:

```
set plan replace on
```

You do not specify a group name with set plan replace; it affects the current active capture group.

To disable plan replacement:

```
set plan replace off
```

The use of the use database command while set plan replace is in effect disables plan replace mode.

When to use replace mode

When you are capturing plans, and a query has the same query text as an already-saved plan, the existing plan is not replaced unless replace mode is enabled. If you have captured abstract plans for specific queries, and you are making physical changes to the database that affect optimizer choices, you need to replace existing plans for these changes to be saved.

Some actions that might require plan replacement are:

- Adding or dropping indexes, or changing the keys or key ordering in indexes
- Changing the partitioning on a table
- Adding or removing buffer pools
- Changing configuration parameters that affect query plans

For plans to be replaced, plan load mode should not be enabled in most cases. When plan association is active, any plan specifications are used as inputs to the optimizer. For example, if a full query plan includes the prefetch property and an I/O size of 2K, and you have created a 16K pool and want to replace the prefetch specification in the plan, do not enable plan load mode.

You may want to check query plans and replace some abstract plans as data distribution changes in tables, or after rebuilds on indexes, updating statistics, or changing the locking scheme.

Using *dump*, *load*, and *replace* modes simultaneously

You can have both plan dump and plan load mode active simultaneously, with or without replace mode active.

Using *dump* and *load* to the same group

If you have enabled dump and load to the same group, without replace mode enabled:

- If a valid plan exists for the query, it is loaded and used to optimize the query.
- If a plan exists that is not valid (for example, because an index has been dropped), a new plan is generated and used to optimize the query, but is not saved.

- If the plan is a partial plan, a full plan is generated, but the existing partial plan is not replaced
- If a plan does not exist for the query, a plan is generated and saved.

With replace mode also enabled:

- If a valid plan exists for the query, it is loaded and used to optimize the query.
- If the plan is not valid, a new plan is generated and used to optimize the query, and the old plan is replaced.
- If the plan is a partial plan, a complete plan is generated and used, and the existing partial plan is replaced. The specifications in the partial plan are used as input to the optimizer.
- If a plan does not exist for the query, a plan is generated and saved.

Using *dump* and *load* to different groups

If you have dump enabled to one group, and load enabled from another group, without replace mode enabled:

- If a valid plan exists for the query in the load group, it is loaded and used. The plan is saved in the dump group, unless a plan for the query already exists in the dump group.
- If the plan in the load group is not valid, a new plan is generated. The new plan is saved in the dump group, unless a plan for the query already exists in the dump group.
- If the plan in the load group is a partial plan, a full plan is generated and saved in the dump group, unless a plan already exists. The specifications in the partial plan are used as input to the optimizer.
- If there is no plan for the query in the load group, the plan is generated and saved in the dump group, unless a plan for the query exists in the dump group.

With replace mode active:

- If a valid plan exists for the query in the load group, it is loaded and used.
- If the plan in the load group is not valid, a new plan is generated and used to optimize the query. The new plan is saved in the dump group.

- If the plan in the load group is a partial plan, a full plan is generated and saved in the dump group. The specifications in the partial plan are used as input to the optimizer.
- If a plan does not exist for the query in the load group, a new plan is generated. The new plan is saved in the dump group.

set plan exists check option

The exists check mode can be used during query plan association to speed performance when users require abstract plans for fewer than 20 queries from an abstract plan group. If a small number of queries require plans to improve their optimization, enabling exists check mode speeds execution of all queries that do not have abstract plans, because they do not check for plans in sysqueryplans.

When set plan load and set exists check are both enabled, the hash keys for up to 20 queries in the load group are cached for the user. If the load group contains more than 20 queries, exists check mode is disabled. Each incoming query is hashed; if its hash key is not stored in the abstract plan cache, then there is no plan for the query and no search is made. This speeds the compilation of all queries that do not have saved plans.

The syntax is:

set plan exists check {on | off}

You must enable load mode before you enable plan hash-key caching.

A System Administrator can configure server-wide plan hash-key caching with the configuration parameter abstract plan cache. To enable server-wide plan caching, use:

```
sp_configure "abstract plan cache", 1
```

Using other *set* options with abstract plans

You can combine other set tuning options with set plan dump and set plan load.

Using *showplan*

When showplan is turned on, and abstract plan association mode has been enabled with set plan load, showplan prints the plan ID of the matching abstract plan at the beginning of the showplan output for the statement:

```
QUERY PLAN FOR STATEMENT 1 (at line 1).
Optimized using an Abstract Plan (ID : 832005995).
```

If you run queries using the plan clause added to a SQL statement, showplan displays:

```
Optimized using the Abstract Plan in the PLAN clause.
```

Using *noexec*

You can use noexec mode to capture abstract plans without actually executing the queries. If noexec mode is in effect, queries are optimized and abstract plans are saved, but no query results are returned.

To use noexec mode while capturing abstract plans, execute any needed procedures (such as sp_add_qpgroup) and other set options (such as set plan dump) before enabling noexec mode. The following example shows a typical set of steps:

```
sp_add_qpgroup pubs_dev
go
set plan dump pubs_dev on
go
set noexec on
go
select type, sum(price) from titles group by type
go
```

Using *fmtonly*

A similar behavior can be obtained for capturing plans in stored procedures without actually executing the stored procedures, using fmtonly set.

```
sp_add_qpgroup pubs_dev
go
set plan dump pubs_dev on
go
set fmtonly on
```

```
go
exec stored_proc(...)
go
```

Using *forceplan*

If set forceplan on is in effect, and query association is also enabled for the session, forceplan is ignored if a full abstract plan is used to optimize the query. If a partial plan does not completely specify the join order:

- First, the tables in the abstract plan are ordered, as specified.
- The remaining tables are ordered as specified in the from clause.
- The two lists of tables are merged.

Server-wide abstract plan capture and association modes

A System Administrator can enable server-wide plan capture, association, and replacement modes with these configuration parameters:

- abstract plan dump – enables dumping to the default abstract plans capture group, ap_stdout.
- abstract plan load – enables loading from the default abstract plans loading group, ap_stdin.
- abstract plan replace – when plan dump mode is also enabled, enables plan replacement.
- abstract plan cache – enables caching of abstract plan hash IDs; abstract plan load must also be enabled. See “set plan exists check option” on page 244 for more information.

By default, these configuration parameters are set to 0, which means that capture and association modes are off. To enable a mode, set the configuration value to 1:

```
sp_configure "abstract plan dump", 1
```

Enabling any of the server-wide abstract plan modes is dynamic; you do not have to reboot the server.

Server-wide capture and association allows the System Administrator to capture all plans for all users on a server. You cannot override he server-wide modes at the session level.

Creating plans using SQL

You can directly specify the abstract plan for a query by:

- Using the create plan command
- Adding the plan clause to select, insert...select, update, delete and return commands, and to if and while clauses

For information on writing plans, see Chapter 9, "Abstract Query Plan Guide."

Using *create plan*

The create plan command specifies the text of a query, and the abstract plan to save for the query.

This example creates an abstract plan:

```
create plan
    "select avg(price) from titles"
"(scalar_agg
    (i_scan type_price_ix titles)
)"
```

The plan is saved in the current active plan group. You can also specify the group name:

```
create plan
    "select avg(price) from titles"
"(scalar_agg
    (i_scan type_price_ix titles)
)"
into dev_plans
```

If a plan already exists for the specified query in the current plan group, or the plan group that you specify, you must first enable replace mode in order to overwrite the existing plan.

If you want to see the plan ID that is used for a plan you create, create plan can return the ID as a variable. You must declare the variable first. This example returns the plan ID:

```
create plan
    "select avg(price) from titles"
"(scalar_agg
    (i_scan type_price_ix titles)
)"
into dev_plans
and set @id

select @id
```

When you use create plan, the query in the plan is not executed. This means that:

- The text of the query is not parsed, so the query is not checked for valid SQL syntax.
- The plans are not checked for valid abstract plan syntax.
- The plans are not checked to determine whether they are compatible with the SQL text.

To guard against errors and problems, you should immediately execute the specified query with showplan enabled.

Using the *plan* clause

You can use the plan clause with the following SQL statements to specify the plan to use to execute the query:

- select
- insert...select
- delete
- update
- if
- while
- return

This example specifies the plan to use to execute the query:

```
select avg(price) from titles
    plan
"(scalar_agg
    (i_scan type_price_ix titles
)"
```

When you specify an abstract plan for a query, the query is executed using the specified plan. If you have showplan enabled, this message is printed:

```
Optimized using the Abstract Plan in the PLAN clause.
```

When you use the plan clause with a query, any errors in the SQL text, the plan syntax, and any mismatches between the plan and the SQL text are reported as errors. For example, this plan uses the wrong AP operator for the query:

```
/* wrong operator! */
select * from t1,t2
where c11 = c21
plan
"(union
 (t_scan t1)
 (t_scan t2)
)"
```

It returns the following message:

```
Abstract Plan (AP) Warning: An error occurred while applying the AP:
(union (t_scan t1) (t_scan2))
to the SQL query:
select * from t1, t2
where c11 = c21
Failed to apply the top operator 'union' of the following AP fragment:
(union (t_scan t1) (t_scan t2))
The query contains no union that matches the 'union' AP operator at this point.
The following template can be used as a basis for a valid AP:
(also_enforce (join (also_enforce (scan t1)) (also_enforce (scan t2)))
)
The optimizer will complete the compilation of this query; the query will be
executed normally.
```

Plans specified with the plan clause are saved in sysqueryplans only if plan capture is enabled. If a plan for the query already exists in the current capture group, you must enable replace mode in order to replace an existing plan.

CHAPTER 9 Abstract Query Plan Guide

This chapter covers some guidelines you can use in writing Abstract Plans.

Introduction

Abstract plans allow you to specify the desired execution plan of a query. Abstract plans provide an alternative to the session-level and query level options that force a join order, or specify the index, I/O size, or other query execution options. The session-level and query-level options are described in Chapter 8, "Creating and Using Abstract Plans."

There are several optimization decisions that cannot be specified with set commands or clauses included in the query text. Some examples are:

- Algorithms that implement a given relational operator; for example, NLJ versus MJ versus HJ or GroupSorted versus GroupHashing versus GroupInserting
- Subquery attachment
- The join order for flattened subqueries
- Reformatting

In many cases, including set commands or changing the query text is not always possible or desired. Abstract plans provide an alternative, more complete method of influencing optimizer decisions.

Abstract plans are relational algebra expressions that are not included in the query text. They are stored in a system catalog and associated to incoming queries based on the text of these queries.

Abstract plan language

The abstract plan language is a relational algebra that uses these operators:

- distinct – a logical operator describing duplicates elimination.
  - distinct_sorted – a physical operator describing available ordering-based duplicates elimination.
  - distinct_sorting – a physical operator describing sorting-based duplicates elimination.
  - distinct_hashing – a physical operator describing hashing-based duplicates elimination.
- group – a logical operator, describing vector aggregation.
  - group_sorted – a physical operator describing the available ordering-based vector aggregation.
  - group_hashing – a physical operator describing hashing-based vector aggregation.
  - group_inserting – a physical operator describing clustered index insertion-based vector aggregation.
- join – the generic join and a high-level logical join operator that describes inner, outer and existence joins, using nested-loop joins, merge joins, or hash joins.
  - nl_join – specifying a nested-loop join, including all inner, outer, and existence joins.
  - m_join – specifying a merge join, including inner and outer joins.
  - h_join – specifying a hash join, including all inner, outer, and existence joins.
- union – a logical union operator. It describes both the union and the union all SQL constructs.
  - append_union_all – a physical operator implementing union all. It appends the child result sets, one after the other.

    - merge_union_all – a physical operator implementing union all. It merges the child result sets on the subset of the projection that is ordered in each child, and preserves that ordering.
    - merge_union_distinct – a physical operator implementing UNION [DISTINCT]. A merge-based duplicates removal algorithm.
    - hash_union_distinct – a physical operator implementing UNION [DISTINCT]. A merge-based duplicates removal algorithm.
- scalar_agg – a logical operator, describing scalar aggregation.
- scan – a logical operator that transforms a stored table in a flow of rows, an abstract plan derived table. It allows partial plans that do not restrict the access method.
    - i_scan – a physical operator implementing scan. It directs the optimizer to use an index scan on the specified table.
    - t_scan – a physical operator implementing scan. It directs the optimizer to use a full table scan on the specified table.
    - m_scan – a physical operator implementing scan. It directs the optimizer to use a multi-index table scan on the specified table, either index union, index intersection, or both.
- store – a physical operator describing the materialization of an abstract plan derived table in a stored worktable.
- store_index – a physical operator describing the materialization of an abstract plan derived table in a clustered index stored worktable; the optimizer chooses the useful key columns.
- sort – a physical operator describing the sorting of an abstract plan derived table; the optimizer chooses the useful key columns.
- nested – a filter describing the placement and structure of nested subqueries.
- xchg – a physical operator describing the on-the-fly repartitioning of an abstract plan derived table, the abstract plan gives the target degree, but the optimizer chooses the useful target partitioning.

Additional abstract plan keywords are used for grouping and identification:

- sequence – groups the elements when a sequence requires multiple steps.
- hints – groups a set of hints for a partial plan.

- prop – introduces a set of scan properties for a table: prefetch, lru|mru and parallel.
- table – identifies a table when correlation names are used, and in subqueries or views.
- work_t – identifies a worktable.
- in – used with table to identify tables named in a subquery (subq) or view (view).
- subq – used under the nested operator to indicate the attachment point for a nested subquery, and to introduce the subqueries abstract plan.

All legacy abstract plan operators, such as g_join, are still accepted for their new counterparts.

Queries, access methods, and abstract plans

For any specific table, there can be several access methods for a specific query: index scans using different indexes, table scans, the OR strategy, and reformatting are some examples.

This simple query has several choices of access methods:

```
select * from t1
where c11 > 1000 and c12 < 0
```

The following abstract plans specify three different access methods:

- Use the index i_c11:

  ```
  (i_scan i_c11 t1)
  ```

- Use the index i_c12:

  ```
  (i_scan i_c12 t1)
  ```

- Do a full table scan:

  ```
  (t_scan t1)
  ```

- Do a multi-scan; that is, the union or intersection of several indices of the table, according to the complex clause (hence the more complex query used in this example):

```
select * from t1
where (c11 > 1000 or c12 < 0) and (c12 > 1000 or c112 < 0)
plan
"(m_scan t1)"
```

Abstract plans can be full plans, specifying all optimizer choices for a query, or can specify a subset of the choices, such as the index to use for a single table in the query, but not the join order for the tables. For example, using a partial abstract plan, you can specify that the query above should use some index and let the optimizer choose between i_c11 and i_c12, but not do a full table scan. The empty parentheses are used in place of the index name:

```
(i_scan () t1)
```

In addition, the query could use either 2K or 16K I/O, or be performed in serial or parallel.

Derived tables

A derived table is defined by the evaluation of a query expression and differs from a regular table in that it is neither described in system catalogs nor stored on disk. In Adaptive Server, a derived table may be a SQL derived table or an abstract plan derived table.

- A SQL derived table – defined by one or more tables through the evaluation of a query expression. A SQL derived table is used in the query expression in which it is defined and exists only for the duration of the query. For more information on SQL derived tables, see the *Transact-SQL User's Guide*.
- An abstract plan derived table – a derived table used in query processing, the optimization and execution of queries. An abstract plan derived table differs from a SQL derived table in that it exists as part of an abstract plan and is invisible to the end user.

Identifying tables

Abstract plans need to name all of a query's tables in a nonambiguous way, such that a table named in the abstract can be linked to its occurrence in the SQL query. In most cases, the table name is all that is needed. If the query qualifies the table name with the database and owner name, these are also needed to fully identify a table in the abstract plan. For example, this example used the unqualified table name:

```
select * from t1
```

The abstract plan also uses the unqualified name:

```
(t_scan t1)
```

If a database name and/or owner name are provided in the query:

```
select * from pubs2.dbo.t1
```

Then the abstract plan must also use the qualifications:

```
(t_scan pubs2.dbo.t1)
```

However, the same table may occur several times in the same query, as in this example:

```
select * from t1 a, t1 b
```

Correlation names, a and b in the example above, identify the two tables in SQL. In an abstract plan, the table operator associates each correlation name with the occurrence of the table:

```
(join
        (t_scan (table (a t1)))
        (t_scan (table (b t1)))
)
```

However, a briefer abstract plan, which uses only the correlation names, is also accepted:

```
(join
  (t_scan a)
  (t_scan b)
)
```

Table names can also be ambiguous in views and subqueries, so the table operator is used for tables in views and subqueries.

For subqueries, the in and subq operators qualify the name of the table with its syntactical containment by the subquery. The same table is used in the outer query and the subquery in this example:

```
select *
from t1
where c11 in (select c12 from t1 where c11 > 100)
```

The abstract plan identifies them unambiguously:

```
(join
    (t_scan t1)
    (i_scan i_c11_c12 (table t1 (in (subq 1))))
)
```

For views, the in and view operators provide the identification. The query in this example references a table used in the view:

```
create view v1
```

```
as
select * from t1 where c12 > 100
select t1.c11 from t1, v1
    where t1.c12 = v1.c11
```

Here is the abstract plan:

```
(join
    (t_scan t1)
    (i_scan i_c12 (table t1 (in (view v1))))
)
```

In abstract plans generated by Adaptive Server, the view or subquery-qualified table names are generated only for the tables where they are needed to remove name ambiguity. For other tables, only the name is generated.

In abstract plans created by the user, view or subquery-qualified tables names are required in case of ambiguity; both syntaxes are accepted otherwise.

Identifying indexes

The i_scan operator requires two operands, the index name and the table name, as shown here:

```
(i_scan i_c12 t1)
```

To specify that some index should be used, without specifying the index, substitute empty parenthesis for the index name:

```
(i_scan () t1)
```

Specifying join order

Adaptive Server performs joins of three or more tables by joining two of the tables, and joining the “abstract plan derived table” from that join to the next table in the join order. This abstract plan derived table is a flow of rows, as from an earlier nested-loop join in the query execution.

This query joins three tables:

```
select *
from t1, t2, t3
where c11 = c21
```

```
and c12 = c31
and c22 = 0
and c32 = 100
```

This example shows the binary nature of the join algorithm, using g_join operators. The plan specifies the join order t2, t1, t3:

```
(join
    (join
        (scan t2)
        (scan t1)
    )
    (scan t3)
)
```

The results of the t2-t1 join are then joined to t3. The scan operator in this example leaves the choice of table scan or index scan up to the optimizer.

Shorthand notation for joins

In general, a *N*-way left deep nested loops join, with the order t1, t2, t3..., tN-1, *tN* is described by:

```
(join
    (join
        ...
            (join
                (join
                    (scan t1)
                    (scan t2)
                )
                (scan t3)
            )
        ...
        (scan tN-1)
    )
    (scan tN)
)
```

This notation can be used as shorthand for the nl_join, nl_g_join, and m_g_join operators:

```
(nl_join
    (scan t1)
    (scan t2)
    (scan t3)
    ...
    (scan tN-1)
```

```
        (scan tN)
)
```

Join order examples

The optimizer could select among several plans for this three-way join query:

```
select *
from t1, t2, t3
where c11 = c21
    and c12 = c31
    and c22 = 0
    and c32 = 100
```

Here are a few examples:

- Use c22 as a search argument on t2, join with t1 on c11, then with t3 on c31:

  ```
  (nl_join
      (i_scan i_c22 t2)
      (i_scan i_c11 t1)
      (i_scan i_c31 t3)
  )
  ```

- Use the search argument on t3, and the join order t3, t1, t2:

  ```
  (nl_join
      (i_scan i_c32 t3)
      (i_scan i_c12 t1)
      (i_scan i_c21 t2)
  )
  ```

- Do a full table scan of t2, if it is small and fits in cache, still using the join order t3, t1, t2:

  ```
  (nl_join
      (i_scan i_c32 t3)
      (i_scan i_c12 t1)
      (t_scan t2)
  )
  ```

- If t1 is very large, and t2 and t3 individually qualify a large part of t1, but together a very small part, this plan specifies a STAR join:

  ```
  (nl_join
      (i_scan i_c22 t2)
      (i_scan i_c32 t3)
  ```

```
            (i_scan i_c11_c12 t1)
        )
```

The join operators are generic in that they implement any of the outer joins, inner joins, and existence joins; the optimizer chooses the correct join semantics according to the query semantics.

Match between execution methods and abstract plans

There are some limits to join orders and join types, depending on the type of query. One example is outer joins, such as:

```
select *
from t1 left join t2
on c11 = c21
```

Adaptive Server requires the outer member of the outer join to be the outer table during join processing. Therefore, this abstract plan is illegal:

```
(join
    (scan t2)
    (scan t1)
)
```

Attempting to use this plan results in an error message, the AP application fails, and the optimizer makes the best attempt to complete the compilation of the query.

Specifying join order for queries using views

You can use abstract plans to enforce the join order for merged views. This example creates a view. This view performs a join of t2 and t3:

```
create view v2
as
select *
from t2, t3
where c22 = c32
```

This query performs a join with the t2 in the view:

```
select * from t1, v2
where c11 = c21
    and c22 = 0
```

This abstract plan specifies the join order t2, t1, t3:

```
(nl_join
    (scan t2)
```

```
        (scan t1)
        (scan t3)
)
```

Since the table names are not ambiguous, the view qualification is not needed. However, the following abstract plan is also legal and has the same meaning:

```
(nl_join
     (scan (table t2(in(view v2))))
     (scan t1)
     (scan (table t3 (in (view v2))))
)
```

This example joins with *t3* in the view:

```
select * from t1, v2
where c11 = c31
    and c32 = 100
```

This plan uses the join order t3, t1, t2:

```
(g_join
    (scan t3)
    (scan t1)
    (scan t2)
)
```

This is an example where abstract plans can be used, if needed, to affect the join order for a query, when set forceplan cannot.

Specifying the join type

Adaptive Server can perform either nested-loop, merge, or hash joins. The join operator leaves the optimizer free to choose the best join algorithm, based on costing. To specify a nested-loop join, use the nl_join operator; for a merge join, use the m_join operator, and for a hash join, use the h_join operator. Abstract plans captured by Adaptive Server always include the operator that specifies the algorithm, and not the join operator.

This query specifies a join between t1 and t2:

```
select * from t1, t2
    where c12 = c21 and c11 = 0
```

This abstract plan specifies a nested-loop join:

```
(nl_join
```

```
        (i_scan i_c11 t1)
        (i_scan i_c21 t2)
    )
```

The nested-loop plan uses the index i_c11to limit the scan using the search clause, and then performs the join with t2, using the index on the join column.

This merge-join plan uses different indexes:

```
    (m_join
        (i_scan i_c12 t1)
        (i_scan i_c21 t2)
    )
```

The merge join uses the indexes on the join columns, i_c12 and i_c21, for the merge keys. This query performs a full-merge join and no sort is needed.

A merge join could also use the index on i_c11 to select only the matching rows, but then a sort is needed to provide the needed ordering.

```
    (m_join
        (sort
            (i_scan i_c11 t1)
        )
        (i_scan i_c21 t2)
    )
```

Finally, this plan does a hash join and a full table scan on the inner side:

```
    (h_join
       (i_scan i_c11 t1)
       (t_scan t2)
    )
```

Specifying partial plans and hints

There are cases when a full plan is not needed. For example, if the only problem with a query plan is that the optimizer chooses a table scan instead of using a nonclustered index, the abstract plan can specify only the index choice, and leave the other decisions to the optimizer.

The optimizer could choose a table scan of t3 rather than using i_c31 for this query:

```
    select *
```

```
from t1, t2, t3
where c11 = c21
    and c12 < c31
    and c22 = 0
    and c32 = 100
```

The following plan, as generated by the optimizer, specifies join order t2, t1, t3. However, the plan specifies a table scan of t3:

```
(nl_join
    (i_scan i_c22 t2)
    (i_scan i_c11 t1)
    (t_scan t3)
)
```

This full plan could be modified to specify the use of i_c31 instead:

```
(nl_join
    (i_scan i_c22 t2)
    (i_scan i_c11 t1)
    (i_scan i_c31 t3)
)
```

However, specifying only a partial abstract plan is a more flexible solution. As data in the other tables of that query evolves, the optimal join order can change. The partial plan can specify just one partial plan item. For the index scan of t3, the partial plan is simply:

```
(i_scan i_c31 t3)
```

The optimizer chooses the join order and the access methods for t1 and t2.

Abstract plans are partial by using logical operators instead of physical operators. For example, the following abstract plan is partial, although it covers the whole query, as it lets the optimizer choose the join algorithms and the access methods:

```
(join
   (scan t1)
   (scan t2)
   (scan t3)
)
```

Partial plans may also be incomplete at the top, in that the root of the abstract plan may cover just a part of the query. If this is the case, the optimizer completes the plan:

```
(nl_join
   (t_scan t1)
   (t_scan t2)
```

```
)
```

However, the plan fragment given in an abstract plan needs to be complete down to the leafs. For example, the following abstract plan, which reads "`hash join t1 outer to something`" is illegal.

```
(h_join
   (t_scan t1)
   ()
)
```

Grouping multiple hints

There may be cases where more than one plan fragment is needed. For example, you might want to specify that some index should be used for each table in the query, but leave the join order up to the optimizer. When multiple hints are needed, they can be grouped with the hints operator:

```
(hints
    (i_scan () t1)
    (i_scan () t2)
    (i_scan () t3)
)
```

In this case, the role of the hints operator is purely syntactic; it does not affect the ordering of the scans.

There are no limits on what may be given as a hint. Partial join orders may be mixed with partial access methods. This hint specifies that t2 is outer to t1 in the join order, and that the scan of t3 should use an index, but the optimizer can choose the index for t3, the access methods for t1 and t2, and the placement of t3 in the join order:

```
(hints
    (g_join
        (scan t2)
        (scan t1)
    )
    (i_scan () t3)
)
```

Inconsistent and illegal plans using hints

It is possible to describe inconsistent plans using hints, such as this plan that specifies contradictory join orders:

```
(hints
```

```
        (g_join
            (scan t2)
            (scan t1)
        )
        (g_join
            (scan t1)
            (scan t2)
        )
    )
```

When the query associated with the plan is executed, the query cannot be compiled, and an error is raised.

Other inconsistent hints do not raise an exception, but may use any of the specified access methods. This plan specifies both an index scan and a table scan for the same table:

```
    (hints
        (t_scan t3)
        (i_scan () t3)
    )
```

In this case, either method may be chosen, the behavior is indeterminate.

Creating abstract plans for subqueries

Subqueries are resolved in several ways in Adaptive Server, and the abstract plans reflect the query execution steps:

- Materialization – the subquery is executed and results are stored in a worktable or internal variable. See “Materialized subqueries” on page 266.
- Flattening – the query is flattened into a join with the tables in the main query. See “Flattened subqueries” on page 266.
- Nesting – the subquery is executed once for each outer query row. See “Nested subqueries” on page 268.

Abstract plans do not allow the choice of the basic subquery resolution method. This is a rule-based decision and cannot be changed during query optimization. Abstract plans, however, can be used to influence the plans for the outer and inner queries. In nested subqueries, abstract plans can also be used to choose where the subquery is nested in the outer query.

Materialized subqueries

This query includes a non correlated subquery that can be materialized:

```
select *
from t1
where c11 = (select count(*) from t2)
```

The first step in the abstract plan materializes the scalar aggregate in the subquery. The second step uses the result to scan t1:

```
( sequence
    (scalar_agg
        (i_scan i_c21 t2)
    )
    (i_scan i_c11 t1)
)
```

Flattened subqueries

Some subqueries can be flattened into joins. The g_join and nl_g_join operators leave it to the optimizer to detect when an existence join is needed. For example, this query includes a subquery introduced with exists:

```
select * from t1
where c12 > 0
    and exists (select * from t2
            where t1.c11 = c21
                and c22 < 100)
```

The semantics of the query require an existence join between t1 and t2. The join order t1, t2 is interpreted by the optimizer as a semijoin, with the scan of t2 stopping on the first matching row of t2 for each qualifying row in t1:

```
(join
    (scan t1)
    (scan t2)
)
```

The join order t2, t1 requires other means to guarantee the duplicate elimination:

```
(join
    (distinct
       (scan t2)
    )
    (scan t1)
```

```
)
```

Using this abstract plan, the optimizer can decide to use:

- A unique index on t2.c21, if one exists, with a regular join.
- The unique reformatting strategy, if no unique index exists. In this case, the query will probably use the index on c22 to select the rows into a worktable.
- The duplicate elimination sort optimization strategy, performing a regular join and selecting the results into the worktable, then sorting the worktable.

The abstract plan does not need to specify the creation and scanning of the worktables needed for the last two options.

For more information on subquery flattening, see “Flattened subqueries” on page 266.

Example of changing the join order in a flattened subquery

The query can be flattened to an existence join:

```
select *
from t1, t2
where c11 = c21
    and c21 > 100
    and exists (select * from t3
        where c31 != t1.c11)
```

The “!=” correlation can make the scan of t3 rather expensive. If the join order is t1, t2, the best place for t3 in the join order depends on whether the join of t1 and t2 increases or decreases the number of rows, and therefore, the number of times that the expensive table scan needs to be performed. If the optimizer fails to find the right join order for t3, the following abstract plan can be used when the join reduces the number of times that t3 must be scanned:

```
(nl_join
    (scan t1)
    (scan t2)
    (scan t3)
)
```

If the join increases the number of times that t3 needs to be scanned, this abstract plan performs the scans of t3 before the join:

```
(nl_join
```

```
        (scan t1)
        (scan t3)
        (scan t2)
    )
```

Nested subqueries

Nested subqueries can be explicitly described in abstract plans:

- The abstract plan for the subquery is provided.
- The location at which the subquery attaches to the main query is specified.

Abstract plans allow you to affect the query plan for the subquery, and to change the attachment point for the subquery in the outer query.

The nested operator specifies the position of the subquery in the outer query. Subqueries are “nested over” a specific abstract plan derived table. The optimizer chooses a spot where all the correlation columns for the outer query are available, and where it estimates that the subquery needs to be executed the least number of times.

The following SQL statement contains a correlated expression subquery:

```
select *
from t1, t2
where c11 = c21
    and c21 > 100
    and c12 = (select c31 from t3
                where c32 = t1.c11)
```

The abstract plan shows the subquery nested over the scan of t1:

```
(nl_join
    (nested
        (i_scan i_c12 t1)
        (subq
            (scalar_agg
                (scan t3)
            )
        )
    )
    (i_scan i_c21 t2)
)
```

Aggregation is described in Chapter 2, “Using showplan.” The scalar_agg abstract plan operator is necessary because all abstract plans, even partial ones, need to be complete down to the leafs.

Subquery identification and attachment

Subqueries in the SQL query are matched against abstract plan subqueries using their underlying tables. As tables are unambiguously identified, so are the subqueries. For example:

```
select
   (select c11 from t1 where c12 = t3.c32), c31
from t3
where
   c32 > (select c22 from t2 where c21 = t3.c31)
plan
"(nested
    (nested
        (t_scan t3)
        (subq
             (i_scan i_c11_c12 t1)
   )
)
    (subq
        (i_scan i_c21 t2)
   )
)"
```

However, when table names are ambiguous, the identity of the subquery is needed to solve the table name ambiguity.

Subqueries are identified with numbers, in the order of their leading opened parenthesis “(“.

This example has two subqueries; both refer to table t1:

```
select 1
from t1
where
   c11 not in (select c12 from t1)
   and c11 not in (select c13 from t1)
```

In the abstract plan, the subquery which projects out of `c12` is named “1” and the subquery which projects out of `c13` is named “2”.

```
(nested
    (nested
        (t_scan t1)
```

```
                (subq
                   (scalar_agg
                        (i_scan i_c11_c12 (table t1 (in (subq 1))))
                   )
                )
            )
            (subq
                (scalar_agg
                    (i_scan i_c13 (table t1 (in (subq 2))))
                )
            )
        )
```

In this query, the second subquery is nested in the first:

```
select * from t1
where c11 not in
    (select c12 from t1
     where c11 not in
     (select c13 from t1)
```

In this case, the subquery that projects out of c12 is also named "1" and the subquery that projects out of c13 is also named "2".

```
(nested
   (t_scan t1
   (subq
      (scalar_agg
         (nested
            (i_scan i_c12 (table t1 (in (subq 1))))
            (subq
               (scalar_agg
                  (i_scan i_c21 (table t1 (in (subq 2))))
               )
            )
         )
      )
   )
)
```

More subquery examples: reading ordering and attachment

The nested operator has the abstract plan derived table as the first operand and the nested subquery as the second operand. This allows an easy vertical reading of the join order and subquery placement:

```
select *
from t1, t2, t3
```

```
where c12 = 0
    and c11 = c21
    and c22 = c32
    and 0 < (select c21 from t2 where c22 = t1.c11)
```

In the plan, the join order is t1, t2, t3, with the subquery nested over the scan of t1:

```
(nl_join
    (nested
        (i_scan i_c11 t1)
        (subq
            (t_scan (table t2 (in (subq 1)))
        )
    )
    (i_scan i_c21 t2)
    (i_scan i_c32 t3)
)
```

Modifying subquery nesting

If you modify the attachment point for a subquery, you must choose a point at which all of the correlation columns are available.This query is correlated to two of the tables in the outer query:

```
select *
from t1, t2, t3
where c12 = 0
    and c11 = c21
    and c22 = c32
    and 0 < (select c31 from t3 where c31 = t1.c11
                    and c32 = t2.c22)
```

This plan uses the join order t1, t2, t3, with the subquery nested over the t1-t2 join:

```
(nl_join
    (nested
        (nl_join
            (i_scan i_c11_c12 t1)
            (i_scan i_c22 t2)
        )
        (subq
            (t_scan (table t3 (in (subq 1))))
        )
    )
    (i_scan i_c32 t3)
```

```
)
```

Since the subquery requires columns from both outer tables, it would be incorrect to nest it over the scan of t1 or the scan of t2; such errors are silently corrected during optimization.

However, the following abstract plan makes the legal request to nest the subquery over the three tables join:

```
(nested
  (nl_join
    (i_scan i_c11_c12 t1)
    (i_scan i_c22 t2)
    (i_scan i_c32 t3)
  )
  (subq
    (t_scan (table t3 (in (subq 1))))
  )
)
```

Abstract plans for materialized views

In most cases, view processing merges the view definition in the main query. There are, however, cases when a view needs to be materialized, as in the case of a self-join:

```
create view v3(cc31, sum_c32)
as
select c31, sum(c32)
from t3
group by c31

select *
from v3 a, v3 b
where a.c31 = b.c31
```

In such a case, the abstract plan exposes the worktable and the store operator that materializes it. The two scans of the worktable are identified through their correlation names:

```
(sequence
  (store
    (group_sorted
      (i_scan i_c31 t3)
    )
  )
```

```
    (m_join
    (sort
      (t_scan (work_t (a Worktable)))
    ( sort
      (t_scan (work_t (b Worktable)))
    )
    )
)
```

The handling of vector aggregation in an abstract plan is described in the next section.

Abstract plans for queries containing aggregates

This query returns a scalar aggregate:

```
select max(c11) from t1
```

There is a physical operator that implements scalar aggregation, hence, the optimizer has no choice. However, choosing an index on c11 allows the MAX() optimization:

```
(scalar_agg
  (i_scan ic11 t1)
)
```

Since the scalar aggregate is the top abstract plan operator, removing it and using the following partial plan has the same outcome:

```
(i_scan ic11 t1)
```

As was discussed in the section on subqueries, the scalar_agg abstract plan is typically needed when it is part of a subquery and the abstract plan must cover the parent query as well.

Vector aggregation is different, in that there are several physical operators to implement the group logical operator, which means that the optimizer has a choice to make. Thus, the abstract plan can force it.

```
select max(c11)
from t1
group by c12
```

The following abstract plan examples force each of the three vector aggregation algorithms:

Note group_sorted requires an ordering on the grouping column, so it needs to use an index.

```
(group_sorted
  (i_scan i_c12 t1)
)
(group_hashing
  (t_scan t1)
)

(group_inserting
  (t_scan t1)
)
```

Abstract plans for queries containing unions

The union abstract plan operator describes plans for SQL queries that contain unions:

```
select*
from
  t1,
  (select * from t2
  union
  select * from t3
 ) u(u1, u2)
where c11=u1
plan
"(nl_join
 (union
  (t_scan t2)
  (t_scan t3)
 )
 (i_scan i_c11 t1)
)"
```

There are two types of UNION in SQL: UNION DISTINCT and UNION [ALL]. UNION [ALL] is the default.

The m_union_distinct and h_union_distinct abstract plan operators force the merge or hash-based UNION DISTINCT duplicates removal. It is illegal to use them with a UNION ALL. The merge-based algorithm needs, from each of the union children, an ordering covering all union projection columns.

In the following example, the needed ordering is provided, for the first child, by the `(c11, c12)` composite index and, for the second child, by the sort.

```
select c11, c12 from t1
union distinct
select c21, c22 from t2
plan
"(m_union distinct
 (i_scan i_c11_c12 t1)
 (sort
  (t_scan t2)
 )
)"
```

The union_all and m_union_all abstract plan operators force the append- or merge-based UNION ALL. It is illegal to use them with a UNION DISTINCT. The merge algorithm needs no ordering for itself; it makes any useful ordering from the children available to the parent.

In the following example, the ordering provided by the two i_scan operators is made available, by their m_union_all parent, to the m_join above.

```
select *
from
  t1,
  (select c21, c22 from t2
   union
   select c31, c32 from t3
) u(u1, u2)
where c11=u1
plan
"(m_join
 (m_union_all
   (i_scan i_c21 t2)
   (i_scan i_c31 t3)
 )
 (i_scan i_c11 t1)
)"
```

Using abstract plans when queries need ordering

An ordering is needed either explicitly, in an ORDER BY query, or implicitly by merge-based operators such as m_join, m_union_distinct, and group_sorted.

An ordering is produced either explicitly, by the sort abstract plan operator (the optimizer build the sort key on all columns known to need an ordering), or implicitly by an i_scan on the indexed columns.

All merge-based operators that require ordering preserve it in their results for a parent that also requires it.

In the following example, the i_scan of t1 provides the ordering needed by the m_join. The i_scan of t2, and the sort over t3's scan, provides the ordering needed by m_union_distinct. This ordering also provides the ordering needed by the m_join. Finally, no top sort is required as the ordering needed by ORDER BY is provided by the m_join.

```
select *
from
  t1,
  (select c21, c22 from t2
    union distinct
    select c31, c32 from t3
) u(u1, u2)
where c11=u1
order by c11, u2
plan
"(m_join
    (m_union_distinct
        (i_scan i_c21_c22 t2)
        (sort
            (t_scan t3)
        )
    )
    (i_scan i_c11 t1)
)"
```

Specifying the reformatting strategy

In this query, t2 is very large, and has no index:

```
select *
from t1, t2
```

```
where c11 > 0
    and c12 = c21
    and c22 = 0
```

The abstract plan that specifies the reformatting strategy on t2 is:

```
(nl_join
    (t_scan t1)
    (store_ind
        (t_scan t2)
    )
)
```

The store_ind abstract plan operator must be placed on the inner side of an nl_join. It can be placed over any abstract plan; there is no longer a single table scan limitation. The legacy `(scan (store... ))` syntax is still accepted.

Specifying the OR strategy

An OR strategy uses a set of index scans to limit the scan with each of the OR terms, then passes the resulting RIDs through a UnionDistinct operator to get, with a RidJoin from the table, the tuples corresponding to the unique RIDs.

The m_scan (multi-scan) abstract plan operator forces index union, hence the OR strategy:

```
select * from t1
where c11 > 10 or c12 > 100
plan
"(m_scan t1)"
```

When the *store* operator is not specified

Storing the stream of tuples into a worktable to meet the intra-operator needs of an algorithm (Sort, GroupInserting, and so on), is treated as a implementation detail of the algorithm and thus is not exposed in the abstract plan.

Abstract plans expose only the worktables created for inter-operator reasons, such as the self-joined materialized view. In such a case, none of the operators needs a work table. The cause is, rather, the global nature of the plan, of computing an intermediate derived table once and using it twice.

Abstract plans for parallel processing

Partitioned tables scanned in parallel produce partitioned streams of tuples. Different operators have specific needs for parallel processing. For instance, in all joins, either both children must be equi-partitioned or one child must be replicated.

The abstract plan xchg operator forces the optimizer to repartition, on-the-fly, in *n* ways, its child derived table. The abstract plan only gives the degree. The optimizer chooses the useful partitioning columns and style (hash, range, list, or round-robin).

In the following example, assume that t1 and t2 are hash partitioned two ways and three ways on the join columns, and i_c21 is a local index:

```
select *
from t1, t2
where c11=c21
```

The following abstract plan repartitions t1 three ways, does a three-way parallel nl_join, serializes the results, and returns a single data stream to the client:

```
(xchg 1
  (nl_join
    (xchg 3
      (t_scan t1)
    )
    (i_scan i_c21 t2)
  )
)
```

It is not necessary to specify t2's parallel scan. It is hash partitioned three ways, and, as it's joined with an xchg-3, no other plan would be legal.

The following abstract plan scans and sorts t1 and t2 in parallel, as each is partitioned, then serializes them for the m_join:

```
(m_join
    (xchg 1
```

```
                (sort
                    (t_scan t1)
                )
            )
            (xchg 1
                (sort
                    (t_scan t2)
                )
            )
        )
        (prop t1 (parallel 2))
        (prop t2 (parallel 3))
```

The prop-parallel abstract plan construct is used to make sure that the optimizer chooses the parallel scan with the native degree.

Tips on writing abstract plans

Here are some additional tips for writing and using abstract plans:

- Look at the current plan for the query and at plans that use the same query execution steps as the plan you need to write. It is often easier to modify an existing plan than to write a full plan from scratch.
    - Capture the plan for the query.
    - Use sp_help_qplan to display the SQL text and plan.
    - Edit this output to generate a create plan command, or attach an edited plan to the SQL query using the plan clause.
- It is often best to specify partial plans for query tuning in cases where most optimizer decisions are appropriate, but only an index choice, for example, needs improvement.

  By using partial plans, the optimizer can choose other paths for other tables as the data in other tables changes.
- Once saved, abstract plans are static. Data volumes and distributions may change so that saved abstract plans are no longer optimal.

Subsequent tuning changes made by adding indexes, partitioning a table, or adding buffer pools may mean that some saved plans are not performing as well as possible under current conditions. Most of the time, you want to operate with a small number of abstract plans that solve specific problems.

Perform periodic plan checks to verify that the saved plans are still better than the plan that the optimizer would choose.

Comparing plans before and after

Abstract query plans can be used to assess the impact of an Adaptive Server software upgrade or system tuning changes on your query plans. You must save plans before the changes are made, perform the upgrade or tuning changes, and then save plans again and compare the plans. The basic set of steps is:

1. Enable server-wide capture mode by setting the configuration parameter abstract plan dump to 1. All plans are then captured in the default group, ap_stdout.
2. Allow enough time for the captured plans to represent most of the queries run on the system. You can check whether additional plans are being generated by checking whether the count of rows in the ap_stdout group in sysqueryplans is stable:

   ```
   select count(*) from sysqueryplans where gid = 2
   ```

3. Copy all plans from ap_stdout to ap_stdin (or some other group, if you do not want to use server-wide plan load mode), using sp_copy_all_qplans.
4. Drop all query plans from ap_stdout, using sp_drop_all_qplans.
5. Perform the upgrade or tuning changes.
6. Allow sufficient time for plans to be captured to ap_stdout.
7. Compare plans in ap_stdout and ap_stdin, using the diff mode parameter of sp_cmp_all_qplans. For example, this query compares all plans in ap_stdout and ap_stdin:

   ```
   sp_cmp_all_qplans ap_stdout, ap_stdin, diff
   ```

This displays only information about the plans that are different in the two groups.

Effects of enabling server-wide capture mode

When server-wide capture mode is enabled, plans for all queries that can be optimized are saved in all databases on the server. Some possible system administration impacts are:

- When plans are captured, the plan is saved in sysqueryplans and log records are generated. The amount of space required for the plans and log records depends on the size and complexity of the SQL statements and query plans. Check space in each database where users will be active.

  You may need to perform more frequent transaction log dumps, especially in the early stages of server-wide capture when many new plans are being generated.

- If users execute system procedures from the master database, and installmaster was loaded with server-wide plan capture enabled, then plans for the statements that can be optimized in system procedures are saved in master.sysqueryplans.

  This is also true for any user-defined procedures created while plan capture was enabled. You may want to provide a default database at login for all users, including System Administrators, if space in master is limited.

- The sysqueryplans table uses datarows locking to reduce lock contention. However, especially when a large number of new plans are being saved, there may be a slight impact on performance.

- While server-wide capture mode is enabled, using bcp saves query plans in the master database. If you perform bcp using a large number of tables or views, check sysqueryplans and the transaction log in master.

Time and space to copy plans

If you have a large number of query plans in ap_stdout, be sure there is sufficient space to copy them on the system segment before starting the copy. Use sp_spaceused to check the size of sysqueryplans, and sp_helpsegment to check the size of the system segment.

Copying plans also requires space in the transaction log.

sp_copy_all_qplans calls sp_copy_qplan for each plan in the group to be copied. If sp_copy_all_qplans fails at any time due to lack of space or other problems, any plans that were successfully copied remain in the target query plan group.

Abstract plans for stored procedures

For abstract plans to be captured for the SQL statements that can be optimized in stored procedures:

- The procedures must be created while plan capture or plan association mode is enabled. (This saves the text of the procedure in sysprocedures.)
- The procedure must be executed with plan capture mode enabled, and the procedure must be read from disk, not from the procedure cache.

This sequence of steps captures the query text and abstract plans for all statements in the procedure that can be optimized:

```
set plan dump dev_plans on
go
create procedure myproc as ...
go
exec myproc
go
```

If the procedure is in cache, so that the plans for the procedure are not being captured, you can execute the procedure with recompile. Similarly, once a stored procedure has been executed using an abstract query plan, the plan in the procedure cache is used so that query plan association does not take place unless the procedure is read from disk.

set fmtonly on could be used to capture plans for a stored procedure without actually executing the statements in a stored procedure.

Procedures and plan ownership

When plan capture mode is enabled, abstract plans for the statements in a stored procedure that can be optimized are saved with the user ID of the owner of the procedure.

During plan association mode, association for stored procedures is based on the user ID of the owner of the procedure, not the user who executes the procedure. This means that once an abstract query plan is created for a procedure, all users who have permission to execute the procedure use the same abstract plan.

Procedures with variable execution paths and optimization

Executing a stored procedure saves abstract plans for each statement that can be optimized, even if the stored procedure contains control-of-flow statements that can cause different statements to be run depending on parameters to the procedure or other conditions. If the query is run a second time with different parameters that use a different code path, plans for any statements that were optimized and saved by the earlier execution, and the abstract plan for the statement is associated with the query.

However, abstract plans for procedures do not solve the problem with procedures with statements that are optimized differently depending on conditions or parameters. One example is a procedure where users provide the low and high values for a between clause, with a query such as:

```
select title_id
from titles
where price between @lo and @hi
```

Depending on the parameters, the best plan could either be index access or a table scan. For these procedures, the abstract plan may specify either access method, depending on the parameters when the procedure was first executed. If abstract plans are saved while executing queries or stored procedures in tempdb, the abstract plans are lost if the server is rebooted.

For more information on optimization of procedures, see *Performance & Tuning: Optimizer*.

Ad hoc queries and abstract plans

Abstract plan capture saves the full text of the SQL statement and abstract plan association is based on the full text of the SQL query. If users submit ad hoc SQL statements, rather than using stored procedures or Embedded SQL, abstract plans are saved for each different combination of query clauses. This can result in a very large number of abstract plans.

If users check the price of a specific title_id using select statements, an abstract plan is saved for each statement. The following two queries each generate an abstract plan:

```
select price from titles where title_id = "T19245"
select price from titles where title_id = "T40007"
```

In addition, there is one plan for each user, that is, if several users check for the title_id "T40007", a plan is save for each user ID.

If such queries are included in stored procedures, there are two benefits:

- Only only one abstract plan is saved, for example, for the query:

  ```
  select price from titles where title_id =
  @title_id
  ```

- The plan is saved with the user ID of the user who owns the stored procedure, and abstract plan association is made based on the procedure owner's ID.

Using Embedded SQL, the only abstract plan is saved with the host variable:

```
select price from titles
where title_id = :host_var_id
```

CHAPTER 10

Managing Abstract Plans with System Procedures

This chapter provides an introduction to the basic functionality and use of the system procedures for working with abstract plans. For detailed information on each procedure, see the guide *Reference Manual: Procedures*.

System procedures for managing abstract plans

The system procedures for managing abstract plans work on individual plans or on abstract plan groups.

- Managing an abstract plan group
  - sp_add_qpgroup
  - sp_drop_qpgroup
  - sp_help_qpgroup
  - sp_rename_qpgroup
- Finding abstract plans
  - sp_find_qplan
- Managing individual abstract plans
  - sp_help_qplan

    - sp_copy_qplan
    - sp_drop_qplan
    - sp_cmp_qplans
    - sp_set_qplan
- Managing all plans in a group
    - sp_copy_all_qplans
    - sp_cmp_all_qplans
    - sp_drop_all_qplans
- Importing and exporting groups of plans
    - sp_export_qpgroup
    - sp_import_qpgroup

Managing an abstract plan group

You can use system procedures to create, drop, rename, and provide information about an abstract plan group.

Creating a group

sp_add_qpgroup creates and names an abstract plan group. Unless you are using the default capture group, ap_stdout, you must create a plan group before you can begin capturing plans. For example, to start saving plans in a group called dev_plans, you must create the group, then issue the set plan dump command, specifying the group name:

```
sp_add_qpgroup dev_plans
set plan dump dev_plans on
/*SQL queries to capture*/
```

Only a System Administrator or Database Owner can add abstract plan groups. Once a group is created, any user can dump or load plans from the group.

Dropping a group

sp_drop_qpgroup drops an abstract plan group.

The following restrictions apply to sp_drop_qpgroup:

- Only a System Administrator or Database Owner can drop abstract plan groups.
- You cannot drop a group that contains plans. To remove all plans from a group, use sp_drop_all_qplans, specifying the group name.
- You cannot drop the default abstract plan groups ap_stdin and ap_stdout.

This command drops the dev_plans plan group:

```
sp_drop_qpgroup dev_plans
```

Getting information about a group

sp_help_qpgroup prints information about an abstract plan group, or about all abstract plan groups in a database.

When you use sp_help_qpgroup without a group name, it prints the names of all abstract plan groups, the group IDs, and the number of plans in each group:

```
    sp_help_qpgroup
Query plan groups in database ‘pubtune’
 Group                           GID          Plans
 ------------------------------ ----------- -----------
 ap_stdin                                 1           0
 ap_stdout                                2           2
 p_prod                                   4           0
 priv_test                                8           1
 ptest                                    3          51
 ptest2                                   7         189
```

When you use sp_help_qpgroup with a group name, the report provides statistics about plans in the specified group. This example reports on the group ptest2:

```
sp_help_qpgroup ptest2
Query plans group 'ptest2', GID 7

 Total Rows  Total QueryPlans
```

```
 ----------- ----------------
         452              189
sysqueryplans rows consumption, number of query
plans per row count
 Rows        Plans
 ----------- -----------
           5           2
           3          68
           2         119
Query plans that use the most sysqueryplans rows
 Rows        Plan
 ----------- -----------
           5  1932533918
           5  1964534032
 Hashkeys
 -----------
         123
There is no hash key collision in this group.
```

When reporting on an individual group, sp_help_qpgroup reports:

- The total number of abstract plans, and the total number of rows in the sysqueryplans table.
- The number of plans that have multiple rows in sysqueryplans. They are listed in descending order, starting with the plans with the largest number of rows.
- Information about the number of hash keys and hash-key collisions. Abstract plans are associated with queries by a hashing algorithm over the entire query.

When a System Administrator or the Database Owner executes sp_help_qpgroup, the procedure reports on all of the plans in the database or in the specified group. When any other user executes sp_help_qpgroup, it reports only on plans that he or she owns.

sp_help_qpgroup provides several report modes. The report modes are:

Mode	Information returned
full	The number of rows and number of plans in the group, the number of plans that use two or more rows, the number of rows and plan IDs for the longest plans, and number of hash keys, and has-key collision information. This is the default report mode.
stats	All of the information from the full report, except hash-key information.
hash	The number of rows and number of abstract plans in the group, the number of hash keys, and hash-key collision information.

Mode	Information returned
list	The number of rows and number of abstract plans in the group, and the following information for each query/plan pair: hash key, plan ID, first few characters of the query, and the first few characters of the plan.
queries	The number of rows and number of abstract plans in the group, and the following information for each query: hash key, plan ID, first few characters of the query.
plans	The number of rows and number of abstract plans in the group, and the following information for each plan: hash key, plan ID, first few characters of the plan.
counts	The number of rows and number of abstract plans in the group, and the following information for each plan: number of rows, number of characters, hash key, plan ID, first few characters of the query.

This example shows the output for the counts mode:

```
sp_help_qpgroup ptest1, counts
Query plans group 'ptest1', GID 3

 Total Rows  Total QueryPlans
 ----------- ----------------
          48               19

Query plans in this group

Rows  Chars    hashkey    id         query
----- --------- ----------- ----------- ---------------------------
    3      623  1801454852   876530156 select title from titles ...
    3      576   476063777   700529529 select au_lname, au_fname...
    3      513   444226348   652529358 select au1.au_lname, au1....
    3      470   792078608   716529586 select au_lname, au_fname...
    3      430   789259291   684529472 select au1.au_lname, au1....
    3      425  1929666826   668529415 select au_lname, au_fname...
    3      421   169283426   860530099 select title from titles ...
    3      382   571605257   524528902 select pub_name from publ...
    3      355   845230887   764529757 delete salesdetail where ...
    3      347   846937663   796529871 delete salesdetail where ...
    2      379  1400470361   732529643 update titles set price =...
```

Renaming a group

A System Administrator or Database Owner can rename an abstract plan group with sp_rename_qpgroup. This example changes the name of the group from dev_plans to prod_plans:

```
sp_rename_qpgroup dev_plans, prod_plans
```

The new group name cannot be the name of an existing group.

Finding abstract plans

sp_find_qplan searches both the query text and the plan text to find plans that match a given pattern.

This example finds all plans where the query includes the string “from titles”:

```
sp_find_qplan "%from titles%"
```

This example searches for all abstract plans that perform a table scan:

```
sp_find_qplan "%t_scan%"
```

When a System Administrator or Database Owner executes sp_find_qplan, the procedure examines and reports on plans owned by all users. When other users execute the procedure, it searches and reports on only plans that they own.

To search just one abstract plan group, specify the group name with sp_find_qplan. This example searches only the test_plans group, finding all plans that use a particular index:

```
sp_find_qplan "%i_scan title_id_ix%", test_plans
```

For each matching plan, sp_find_qplan prints the group ID, plan ID, query text, and abstract plan text.

Managing individual abstract plans

You can use system procedures to print the query and text of individual plans, to copy, drop, or compare individual plans, or to change the plan associated with a particular query.

Viewing a plan

sp_help_qplan reports on individual abstract plans. It provides three types of reports that you can specify: brief, full, and list. The brief report prints only the first 78 characters of the query and plan; use full to see the entire query and plan, or list to display only the first 20 characters of the query and plan.

This example prints the default brief report:

```
        sp_help_qplan 588529130
gid         hashkey     id
----------- ----------- -----------
          8  1460604254   588529130
query
---------------------------------------------------------------
select min(price) from titles
plan
---------------------------------------------------------------
(plan
    (i_scan type_price titles)
    ()
)
(prop titles
    (parallel ...
```

A System Administrator or Database Owner can use sp_help_qplan to report on any plan in the database. Other users can only view the plans that they own.

sp_help_qpgroup reports on all plans in a group. For more information see "Getting information about a group" on page 287.

Copying a plan to another group

sp_copy_qplan copies an abstract plan from one group to another existing group. This example copies the plan with plan ID 316528161 from its current group to the prod_plans group:

```
sp_copy_qplan 316528161, prod_plans
```

sp_copy_qplan checks to make sure that the query does not already exist in the destination group. If a possible conflict exists, it runs sp_cmp_qplans to check plans in the destination group. In addition to the message printed by sp_cmp_qplans, sp_copy_qplan prints messages when:

- The query and plan you are trying to copy already exists in the destination group
- Another plan in the group has the same user ID and hash key
- Another plan in the group has the same hash key, but the queries are different

If there is a hash-key collision, the plan is copied. If the plan already exists in the destination group or if it would give an association key collision, the plan is not copied. The messages printed by sp_copy_qplan contain the plan ID of the plan in the destination group, so you can use sp_help_qplan to check the query and plan.

A System Administrator or the Database Owner can copy any abstract plan. Other users can copy only plans that they own. The original plan and group are not affected by sp_copy_qplan. The copied plan is assigned a new plan ID, the ID of the destination group, and the user ID of the user who ran the query that generated the plan.

Dropping an individual abstract plan

sp_drop_qplan drops individual abstract plans. This example drops the specified plan:

```
sp_drop_qplan 588529130
```

A System Administrator or Database Owner can drop any abstract plan in the database. Other users can drop only plans that they own.

To find abstract plan IDs, use sp_find_qplan to search for plans using a pattern from the query or plan, or sp_help_qpgroup to list the plans in a group.

Comparing two abstract plans

Given two plan IDs, sp_cmp_qplans compares two abstract plans and the associated queries. For example:

```
sp_cmp_qplans 588529130, 1932533918
```

sp_cmp_qplans prints one message reporting the comparison of the query, and a second message about the plan, as follows:

- For the two queries, one of:

    - The queries are the same.
    - The queries are different.
    - The queries are different but have the same hash key.
- For the plans:
    - The query plans are the same.
    - The query plans are different.

This example compares two plans where the queries and plans both match:

```
sp_cmp_qplans 411252620, 1383780087
The queries are the same.
The query plans are the same.
```

This example compares two plans where the queries match, but the plans are different:

```
sp_cmp_qplans 2091258605, 647777465
The queries are the same.
The query plans are different.
```

sp_cmp_qplans returns a status value showing the results of the comparison. The status values are shown in Table 10-1

Table 10-1: Return status values for sp_cmp_qplans

Return value	Meaning
0	The query text and abstract plans are the same.
+1	The queries and hash keys are different.
+2	The queries are different, but the hash keys are the same.
+10	The abstract plans are different.
100	One or both of the plan IDs does not exist.

A System Administrator or Database Owner can compare any two abstract plans in the database. Other users can compare only plans that they own.

Changing an existing plan

sp_set_qplan changes the abstract plan for an existing plan ID without changing the ID or the query text. It can be used only when the plan text is 255 or fewer characters.

```
sp_set_qplan 588529130, "(i_scan title_ix titles)"
```

A System Administrator or Database Owner can change the abstract plan for any saved query. Other users can modify only plans that they own.

When you execute sp_set_qplan, the abstract plan is not checked against the query text to determine whether the new plan is valid for the query, or whether the tables and indexes exist. To test the validity of the plan, execute the associated query.

You can also use create plan and the plan clause to specify the abstract plan for a query. See "Creating plans using SQL" on page 247.

Managing all plans in a group

These system procedures help manage groups of plans:

- sp_copy_all_qplans
- sp_cmp_all_qplans
- sp_drop_all_qplans

Copying all plans in a group

sp_copy_all_qplans copies all of the plans in one abstract plan group to another group. This example copies all of the plans from the test_plans group to the helpful_plans group:

```
sp_copy_all_qplans test_plans, helpful_plans
```

The helpful_plans group must exist before you execute sp_copy_all_qplans. It can contain other plans.

sp_copy_all_qplans copies each plan in the group by executing sp_copy_qplan, so copying a plan may fail for the same reasons that sp_copy_qplan might fail. See "Comparing two abstract plans" on page 292.

Each plan is copied as a separate transaction, and failure to copy any single plan does not cause sp_copy_all_qplans to fail. If sp_copy_all_qplans fails for any reason, and has to be restarted, you see a set of messages for the plans that have already been successfully copied, telling you that they exist in the destination group.

A new plan ID is assigned to each copied plan. The copied plans have the original user's ID. To copy abstract plans and assign new user IDs, you must use sp_export_qpgroup and sp_import_qpgroup. See "Importing and exporting groups of plans" on page 298.

A System Administrator or Database Owner can copy all plans in the database. Other users can copy only plans that they own.

Comparing all plans in a group

sp_cmp_all_qplans compares all abstract plans in two groups and reports:

- The number of plans that are the same in both groups
- The number of plans that have the same association key, but different abstract plans
- The number of plans that are present in one group, but not the other

This example compares the plans in ap_stdout and ap_stdin:

```
sp_cmp_all_qplans ap_stdout, ap_stdin
If the two query plans groups are large, this might take some
time.
Query plans that are the same
 count
 -----------
         338
Different query plans that have the same association key

 count
 -----------
          25
Query plans present only in group 'ap_stdout' :

 count
 -----------
           0
Query plans present only in group 'ap_stdin' :

 count
 -----------
           1
```

With the additional specification of a report-mode parameter, sp_cmp_all_qplans provides detailed information, including the IDs, queries, and abstract plans of the queries in the groups. The mode parameter lets you get the detailed information for all plans, or just those with specific types of differences.Table 10-2 shows the report modes and what type of information is reported for each mode.

Table 10-2: Report modes for sp_cmp_all_qplans

Mode	Reported information
counts	The counts of: plans that are the same, plans that have the same association key, but different groups, and plans that exist in one group, but not the other. This is the default report mode.
brief	The information provided by counts, plus the IDs of the abstract plans in each group where the plans are different, but the association key is the same, and the IDs of plans that are in one group, but not in the other.
same	All counts, plus the IDs, queries, and plans for all abstract plans where the queries and plans match.
diff	All counts, plus the IDs, queries, and plans for all abstract plans where the queries and plans are different.
first	All counts, plus the IDs, queries, and plans for all abstract plans that are in the first plan group, but not in the second plan group.
second	All counts, plus the IDs, queries, and plans for all abstract plans that are in the second plan group, but not in the first plan group.
offending	All counts, plus the IDs, queries, and plans for all abstract plans that have different association keys or that do not exist in both groups. This is the combination of the diff, first, and second modes.
full	All counts, plus the IDs, queries, and plans for all abstract plans. This is the combination of same and offending modes.

This example shows the brief report mode:

```
sp_cmp_all_qplans ptest1, ptest2, brief
```

```
If the two query plans groups are large, this might take some time.
Query plans that are the same

 count
 -----------
          39
Different query plans that have the same association key

 count
 -----------
```

```
          4

   ptest1    ptest2

 id1         id2
 ----------- -----------
   764529757  1580532664
   780529814  1596532721
   796529871  1612532778
   908530270  1724533177
Query plans present only in group 'ptest1' :

 count
 -----------
          3


 id
 -----------
   524528902
  1292531638
  1308531695

Query plans present only in group 'ptest2' :

 count
 -----------
          1


 id
 -----------
  2108534545
```

Dropping all abstract plans in a group

sp_drop_all_qplans drops all abstract plans in a group. This example drops all abstract plans in the dev_plans group:

```
sp_drop_all_qplans dev_plans
```

When a System Administrator or the Database Owner executes sp_drop_all_qplans, all plans belonging to all users are dropped from the specified group. When another user executes this procedure, it affects only the plans owned by that users.

Importing and exporting groups of plans

sp_export_qpgroup and sp_import_qpgroup copy groups of plans between sysqueryplans and a user table. This allows a System Administrator or Database Owner to:

- Copy abstract plans from one database to another on the same server
- Create a table that can be copied out of the current server with bcp, and copied into another server
- Assign different user IDs to existing plans in the same database

Exporting plans to a user table

sp_export_qpgroup copies all plans for a specific user from an abstract plan group to a user table. This example copies plans owned by the Database Owner (dbo) from the fast_plans group, creating a table called transfer:

```
sp_export_qpgroup dbo, fast_plans, transfer
```

sp_export_qpgroup uses select...into to create a table with the same columns and datatypes as sysqueryplans. If you do not have the select into/bulkcopy/pllsort option enabled in the database, you can specify the name of another database. This command creates the export table in tempdb:

```
sp_export_qpgroup mary, ap_stdout, "tempdb..mplans"
```

The table can be copied out using bcp, and copied into a table on another server. The plans can also be imported to sysqueryplans in another database on the same server, or the plans can be imported into sysqueryplans in the same database, with a different group name or user ID.

Importing plans from a user table

sp_import_qpgroup copies plans from tables created by sp_export_qpgroup into a group in sysqueryplans. This example copies the plans from the table tempdb.mplans into ap_stdin, assigning the user ID for the Database Owner:

```
sp_import_qpgroup "tempdb..mplans", dbo, ap_stdin
```

You cannot copy plans into a group that already contains plans for the specified user.

CHAPTER 11 Query Processing Metrics

Overview

Query processing (QP) metrics identify and compare empirical metric values in query execution. When a query is executed, it is associated with a set of defined metrics that are the basis for comparison in QP metrics.

Captured metrics include:

- CPU execution time – the time, in milliseconds, it takes to execute the query.
- Elapsed time – the time, in milliseconds, from after the compile to the end of the execution.
- Logical I/O – the number of logical I/O reads.
- Physical I/O – the number of physical I/O reads.
- Count – the number of times a query is executed.
- Abort count – the number of times a query is aborted by the resource governor due to a resource limit being exceeded.

Each metric, except count and abort count, has three values: minimum, maximum, and average.

Executing QP metrics

You can activate and use QP metrics at the server level or at the session level.

At the server level, use sp_configure with the enable metrics capture option. The QP metrics for ad hoc statements are captured directly into a system catalog, while the QP metrics for statements in a stored procedure are saved in a procedure cache. When the stored procedure or query in the statement cache is flushed, the respective captured metrics are written to the system catalog.

```
sp_configure "enable metrics capture", 1
```

At a session level, use set metrics_capture on/off.

```
set metrics_capture on/off
```

Accessing metrics

QP metrics are always captured in the default running group, which is group 1 in each respective database. Use sp_metrics 'backup' to move saved QP metrics from the default running group to a backup group. Access metric information using a select statement with order by against the sysquerymetrics view. See "sysquerymetrics view" on page 302 for details.

You can also use a data manipulation language (DML) statement to sort the metric information and identify the specific queries for evaluation. See Adaptive Server Enterprise *Component Integration Services User's Guide*, Chapter 2, "Understand Component Integration Services," for more information about DML commands.

sysquerymetrics view

Field	Definition
uid	User ID
gid	Group ID
id	Unique ID
hashkey	Hashkey over the SQL query text
sequence	Sequence number for a row when multiple rows are required for the text of the SQL
exec_min	Minimum execution time

Field	Definition
exec_max	Maximum execution time
exec_avg	Average execution time
elap_min	Minimum elapsed time
elap_max	Maximum elapsed time
elap_avg	Average elapsed time
lio_min	Minimum logical I/O
lio_max	Maximum logical I/O
lio_avg	Average logical I/O
pio_min	Minimum physical I/O
pio_max	Maximum physical I/O
pio_avg	Average physical I/O
cnt	Number of times the query has been executed
abort_cnt	Number of times a query is aborted by the resource governor when a resource limit is exceeded
qtext	Query text

Average values in this view are calculated using this formula:

```
new_avg = (old_avg * old_count + new_value )/ (old_count + 1) = old_avg +
round((new_value - old_avg)/(old_count + 1))
```

This is an example of the sysquerymetrics view:

select * from sysquerymetrics

```
uid   gid   hashkey   id   sequence   exec_min
exec_max   exec_avg   elap_min   elap_max   elap_avg   lio_min
lio_max   lio_avg   pio_min   pio_max   pio_avg   cnt   abort_cnt
qtext
----------- ----------- ----------- ----------- ----------- -----------
----------- ----------- ----------- ----------- ----------- -----------
----------- ----------- ----------- ----------- ----------- -----------
-------------------------------------------------------------------------
1   1   106588469   480001710   0   0
0   0   16   33   25   4
4   4   0   4   2   2   0
select distinct c1 from t_metrics1 where c2 in (select c2 from t_metrics2)
```

The above example displays a record for a SQL statement. The query text of the statement is select distinct c1 from t_metrics1 where c2 in (select c2 from t_metrics2). This statement has been executed twice so far (cnt = 2). The minimum elapsed time is 16 milliseconds, the maximum elapsed time is 33 milliseconds, and the average elapsed time is 25 milliseconds. All the execution times are 0, and this may be due to the CPU execution time being less than 1 millisecond. The maximum physical I/O is 4, which is consistent with the maximum logical I/O. However, the minimum physical I/O is 0 because data is already in cache in the second run. The logical I/O, at 4, should be static whether or not the data is in memory.

Using metrics

Use the information produced by QP metrics to identify:

- Query performance regression
- Most “expensive” query from a batch of running queries
- Most frequently run queries

When you have information on the queries that may be causing problems, you can tune the queries to increase efficiency.

For example, identifying and fine-tuning an expensive query may be more effective than tuning the cheaper ones in the same batch.

You can also identify the queries that are run most frequently, and fine-tune them to increase efficiency.

Turning on query metrics may involve extra I/O for every query being run, so there may be performance impact. However, also consider the benefits mentioned above. You may want to gather statistical information from monitoring tables instead of turning on metrics.

Both QP metrics and monitoring tables can be used to gather statistical information. However, you can use QP metrics instead of the monitoring tables to gather aggregated historical query information in a persistent catalog, rather than have transient information from the monitor tables.

Examples

You can use QP metrics to identify specific queries for tuning and possible regression on performance.

Identifying the most expensive statement

Typically, to find the most expensive statement as the candidate for tuning, sysquerymetrics provides CPU execution time, elapsed time, logical IO, and physical IO as options for measure. For example, a typical measure is based on logical IO. Use the following query to find the statements that incur too many IOs as the candidates for tuning:

select lio_avg, qtext from sysquerymetrics order by lio_avg

```
lio_avg qtext
-----------
-------------------------------------------------------
2
select c1, c2 from t_metrics1 where c1 = 333
4
select distinct c1 from t_metrics1 where c2 in (select c2 from t_metrics2)
6
select count(t_metrics1.c1) from t_metrics1, t_metrics2,
t_metrics3 where (t_metrics1.c2 = t_metrics2.c2 and
t_metrics2.c2 = t_metrics3.c2 and t_metrics3.c3 = 0)
164
select min(c1) from t_metrics1 where c2 in (select t_metrics2.c2 from
t_metrics2, t_metrics3 where (t_metrics2.c2 = t_metrics3.c2 and t_metrics3.c3
= 1))

(4 rows affected)
```

The best candidate for tuning can be seen in the last statement of the above results, which has the biggest value for average logical IO.

Identifying the most frequently used statement for tuning

If a query is used frequently, fine-tuning may improve its performance. Identify the most frequently used query using the select statement with order by:

select elap_avg, cnt, qtext from sysquerymetrics order by cnt

```
elap_avg cnt
qtext
----------- -----------
---------------------------------------------------
```

```
0         1
select c1, c2 from t_metrics1 where c1 = 333
16        2

select distinct c1 from t_metrics1 where c2 in (select c2 from t_metrics2)
24        3

select min(c1) from t_metrics1 where c2 in (select t_metrics2.c2 from
t_metrics2, t_metrics3 where (t_metrics2.c2 = t_metrics3.c2 and t_metrics3.c3
= 1))

78        4

select count(t_metrics1.c1) from t_metrics1, t_metrics2, t_metrics3 where
(t_metrics1.c2 = t_metrics2.c2 and t_metrics2.c2 = t_metrics3.c2 and
t_metrics3.c3 = 0)

(4 rows affected)
```

Identifying possible performance regression

In some cases, when a server is upgraded to a newer version, QP metrics may be useful for comparing performance. To identify queries that may have some degradation, use the following process:

1. Back up the QP metrics from the old server into a backup group:

   sp_metrics ‘backup’, ’@gid’

2. Enable QP metrics on the new server:

   sp_configure “enable metrics capture”, 1

3. Compare QP metrics output from the old and new servers to identify any queries that may have regression problems.

Clearing the metrics

Use sp_metrics ‘flush’ to flush all aggregated metrics in memory to the system catalog.The aggregated metrics for all statements in memory are zeroed out.

The syntax of removing QP metrics from the system catalog is:

sp_metrics ‘drop’, ‘@gid’ [, ‘@id’]

To remove one entry, use:

```
sp_metrics 'drop', '<gid>', '<id>'
```

You can also use filter to remove QP metrics from the system catalog, based on some metrics conditions. The syntax is:

```
sp_metrics 'filter', '@gid', [, '@predicate']
```

For example:

```
sp_metrics 'filter','1','lio_max < 100'
```

deletes all QP metrics in group 1 where lio_max < 100.

Restricting query metrics capture

There are four configuration parameters that set the query metrics threshold for capture into the catalog. These parameters are useful if you want to filter out trivial metrics before writing metrics information to the catalog. The syntax is:

```
sp_configure 'metrics lio max' | 'metrics pio max' |
'metrics elap max' | 'metrics exec max' , <value>
```

For example, the following will not capture those query plans for which lio is less than 10:

```
sp_configure 'metrics lio max', 10
```

Understanding *uid* in *sysquerymetrics*

The UID of sysquerymetrics is 0 when all table names in a query that are not qualified by user name are owned by the dbo.

Example 1

```
select * from t1 where cl = 1
```

t1 is owned by dbo and is shared by different users. 0 is the UID for the entry into sysquerymetrics no matter which user issues the query.

Example 2

```
select * from t2 where cl = 1
```

In this case, t2 is owned by *user1*. *user1*'s UID is used for the entry in sysquerymetrics, since t2 is unqualified and is not owned by the dbo.

Example 3

```
select * from u1.t3 where cl = 1
```

Here, t3 is owned by *u1* and is qualified by *u1*, so UID 0 is used.

This increases the sharing of metrics between user IDs to reduce the number of entries in sysqueryplans. Aggregation of metrics for identical queries with different user IDs is done automatically. Turn on Traceflag 15361 to use the UID of the user who issues the query.

Note QP metrics for INSERT...SELECT/UPDATE/DELETE are captured when at least one table is involved. CIS related queries and INSERT...VALUES statements are not included.

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