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Edward Pollack
Albany, New York, USA

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Printed on acid-free paper

To Theresa and Nolan, the best Player 2 and Player 3 (AKA family) I could ever have asked for!

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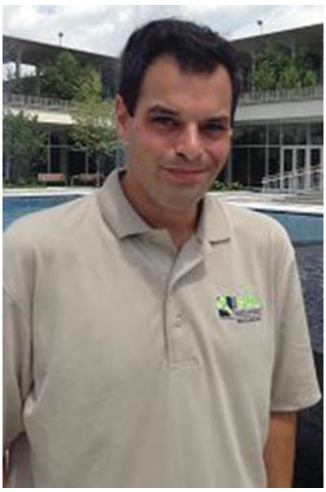

Edward Pollack has over 15 years of experience in database and systems administration, with a passion for performance optimization, database design, and making things go faster. He has spoken at many SQL Saturdays, 24 Hours of PASS, and PASS Summit. This led him to organize SQL Saturday Albany, which has become an annual event for New York's Capital Region.

In his free time, Ed enjoys video games, sci-fi and fantasy, traveling, and cooking exceptionally spicy foods. He lives in the subarctic icescape of Albany, NY with his wife Theresa, his son Nolan, and an impressive collection of video game-related plushies and figures.

About the Technical Reviewer

Kathi Kellenberger, known to the Structured Query Language (SQL) community as Aunt Kathi, is an independent SQL Server consultant associated with Linchpin People and an SQL Server MVP. She loves writing about SQL Server and has contributed to a dozen books as an author, coauthor, or technical editor. Kathi enjoys spending free time with family and friends, especially her five grandchildren. When she is not working or involved in a game of hide-and-seek or *Candy Land* with the kids, you may find her at the local karaoke bar. Kathi blogs at `www.auntkathisql.com`.

Acknowledgments

The SQL Server community is vast, made up of user groups, companies, professionals, colleges, and organizations that create a network of like-minded individuals all looking to further their knowledge, while at the same time helping others.

My interest in database administration was borne of some masochistic curiosity, but the resources to learn, grow, and share that knowledge were made possible by more people than I can count, each of whom has volunteered countless hours for the betterment of others.

Thank you to the Professional Association of SQL Server; the Capital Area SQL Server Group and its founders, Dan Bowlin and Joe Barth; to CommerceHub and Autotask, companies that have given me great amounts of professional freedom to explore database technologies in my free time; Matt Slocum, for organizing and letting me be a part of the Rochester SQL Saturday (the first I spoke at); Apress, for the opportunity to write and for the support throughout the process; my friends, who are always there for me no matter what life has thrown at us; to the many volunteers who organize, speak, write, blog, and otherwise improve the world in their free time; and to my family for having immense patience when I've come up with crazy ideas like this one.

Introduction

Dynamic SQL is often described in bits and pieces, often when a need for code arises and time is limited. This book is an opportunity to put as many of those fragments together into a meaningful journey, from defining the technology to delving into its deepest and most complex aspects. This is a dive into many topics that are extremely important when working with any database. It will intentionally delve deeper into performance optimization, application development, and security than may seem necessary.

What Is This Book?

This is meant to be a discussion of smart database design and architecture, with a focus on Dynamic SQL. If any topic that is covered in an aside feels incomplete, it is because there simply isn't room in these pages for a thorough analysis of all of them without losing focus on why you are here. Dynamic SQL is often underused, misused, or overused. The many tangents into other arenas of design and development serve as guides to keep you on track and emphasize the value of well-written database queries as well as ensuring that you use Dynamic SQL for the correct applications.

Each chapter delves into a specific topic and attempts to go into as much detail as possible, while also providing multiple examples to demonstrate it in the simplest way possible. If you have never written a line of Dynamic SQL, this will be an opportunity to learn, practice, and immediately apply it. If you already have experience in writing and using Dynamic SQL, this will be a chance to learn new applications while getting a refresher on those you have worked with in the past.

Intended Audience

Anyone with a healthy interest in database administration or development can benefit from the topics covered in this book. Each chapter starts out with basic definitions and examples, providing an easy entry point for professionals with any level of experience. The book transitions into more advanced techniques, allowing you to not only learn the basics of an important subject, but also to gain access to scripts and ideas that could be tested and used to solve problems you may face in your everyday experiences.

If you have a particular interest in database security or optimization, you will appreciate the focus on these topics in each chapter. SQL Injection gets an exhaustive review, with many different aspects and examples presented to ensure a thorough explanation of this important topic! Every chapter, regardless of topic, will reference performance whenever possible. It is an oft-made mistake that a database is designed with little data and few users, ignoring the possibility that it will one day grow into a behemoth. Reminders are placed throughout this book to consider query performance at all times, even when performance may seem "good enough".

Contacting the Author

We can only grow personally and professionally if we are willing to consider other viewpoints and revise our own to improve.

I love hearing from anyone who has ideas, questions, applications, video game recommendations, or criticism. Please contact me at `ed7@alum.rpi.edu` and let me know what I can do to improve the content of this book or address any questions or problems you may have.

CHAPTER 1

What Is Dynamic SQL?

TSQL is a scripting language that expands with each new release of SQL Server. Success in the world of database development and administration requires flexibility and the ability to adapt constantly to new situations, technologies, and demands. Many of the challenges you'll face are unknowns, or situations where you don't know exactly what kind of data you will be working with until runtime. Dynamic SQL is one of the best tools for solving problems in the face of unknowns.

Understanding Dynamic SQL

Dynamic SQL is quite simple to understand, and once you're acquainted with it, the number of applications you can use it for can become staggering. Dynamic SQL seeks to solve scenarios where you want to operate on one or many objects, but do not know all of the pertinent details as you write the code. Parameters can be passed into the code in order to persist sets of important values, but what do you do when the structure of the TSQL is defined by these values?

A Simple Example

Starting with a very simple `select` statement, we will build a starting point for understanding Dynamic SQL:

```
SELECT TOP 10 * FROM Person.Person;
```

This statement returns all columns of data for 10 rows in the table `Person.Person`. What if you wanted to select data from a table, but did not know the name of the table until runtime? How would you substitute the variable table name into the TSQL? Before answering that question, let's introduce Dynamic SQL by simply rewriting the above query so that you are executing it as a character string, rather than as standard TSQL:

```
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = 'SELECT TOP 10 * FROM Person.Person';
EXEC (@sql_command);
```

This example defines a character string called `@sql_command` that will be used to hold the Dynamic SQL. What is the Dynamic SQL? It's the string that you are building and then later executing. In this case, it is the same `SELECT` statement from above, with no alterations. After you set the `@sql_command`, it is then executed, providing the same results as above.

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The EXEC Statement

`EXEC` is used to execute `@sql_command`. `EXECUTE` may also be used. Other ways to execute Dynamic SQL will be presented later in this book, in response to the need for further flexibility or security. Remember to always put parentheses around the `@sql_command` string. Here's an example that omits the parentheses:

```
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = 'SELECT TOP 10 * FROM Person.Person';
EXEC @sql_command;
```

Failure to do so will result in a somewhat odd error:

```
Msg 2812, Level 16, State 62, Line 11
Could not find stored procedure 'SELECT TOP 10 * FROM Person.Person'.
```

The Dynamic SQL command string is treated by SQL Server as a stored procedure when there are no parentheses. Leave them out and you'll be unable to run your SQL string, receiving an error similar to the one above.

Data Types to Use

Note that `NVARCHAR(MAX)` is used as the data type for the command string. While you could use `VARCHAR`, you would potentially be losing data if any extended Unicode characters were in any of the objects you work with. The size could also be shortened, but if your command string becomes larger than that size, it will be truncated and your Dynamic SQL will become the source of confusing error messages or logical errors.

For consistency and reliability, use `NVARCHAR(MAX)` as the data type for your Dynamic SQL command strings.

Dynamic Execution Process

In order to understand how Dynamic SQL works and the various ways in which it can be applied to the many problems you'll encounter, it is important to consider how Dynamic SQL is built. In addition, becoming familiar with the execution process used by SQL Server in order to parse and run the string of TSQL will make using Dynamic SQL a much easier process.

All Dynamic SQL follows three basic steps:

1. Create a string variable that will store the Dynamic SQL. Any variable name may be used.
2. Build a command string and store it in this variable.
3. Execute the command string.

The benefit of storing the TSQL command as a string is that you are free to use any string manipulation commands on it, building it in one or many steps. Now to tackle your original problem: how to select data from a table that is not defined until runtime. To accomplish this, you remove `Person.Person` from the string and replace it with a variable that you defined above:

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @table_name NVARCHAR(100);
SELECT @table_name = 'Person.Person';
SELECT @sql_command = 'SELECT TOP 10 * FROM ' + @table_name;
EXEC (@sql_command);
```

The variable `@table_name` stores the name of the table you wish to query. Commonly, this would be passed in as a parameter, either from other stored procedures or an application that calls this directly. By building it into `@sql_command`, you gain the flexibility of querying any table you wish, without hard-coding it ahead of time. While this is a trivial example (how often will you want to select data in this fashion?), it provides the basis for thousands of applications, each of which can save immense time, resources, and complexity. Before diving further into the details of Dynamic SQL and its many uses, let's look at a more practical (and more complex) example of Dynamic SQL in action.

Dynamic SQL in Action

A common maintenance need is to run TSQL against many databases on a server. This maintenance could involve backing up databases, rebuilding indexes, reporting on critical data elements, or many other possibilities. If the database list never changes and no databases are ever renamed, you could hard-code names into each procedure and not worry about changing them in the future. This would work until the one day when you finally experience those inevitable changes—moving or renaming databases—which ultimately will break all of those valuable maintenance procedures. It's critical that your maintenance, monitoring, and reporting jobs operate with the highest level of reliability possible.

Listing 1-1 shows a common example of a statement that could be used to run a backup against a single database, storing it on a local drive.

Listing 1-1. Simple BACKUP Statement

```
BACKUP DATABASE AdventureWorks2014
TO DISK='E:\SQLBackups\AdventureWorks2014.bak'
WITH COMPRESSION;
```

This TSQL will back up the `AdventureWorks2014` database to the `SQLBackups` folder on the E drive, using compression. If you want to perform a custom database backup on a subset of databases that all begin with the text `AdventureWorks`, for example, you would need to build TSQL that could adapt to collect a list of all databases with that name, and then perform backups on each of them separately. The following TSQL shows one way that this could be accomplished, using Dynamic SQL.

Listing 1-2. Dynamic SQL Built to Back Up All Databases Starting with "AdventureWorks"

```
DECLARE @database_list TABLE
        (database_name SYSNAME);

INSERT INTO @database_list
        (database_name)
```

```
SELECT
      name
FROM sys.databases
WHERE name LIKE 'AdventureWorks%';

DECLARE @sql_command NVARCHAR(MAX);
DECLARE @database_name SYSNAME;

DECLARE database_cursor CURSOR LOCAL FAST_FORWARD FOR
SELECT database_name FROM @database_list
OPEN database_cursor
FETCH NEXT FROM database_cursor INTO @database_name;

WHILE @@FETCH_STATUS = 0
BEGIN
        SELECT @sql_command = '
        BACKUP DATABASE ' + @database_name + '
        TO DISK=''E:\SQLBackups\' + @database_name + '.bak''
        WITH COMPRESSION;'

        EXEC (@sql_command);

        FETCH NEXT FROM database_cursor INTO @database_name;
END

CLOSE database_cursor;
DEALLOCATE database_cursor;
```

This TSQL is certainly more complex than the first BACKUP statement that you looked at. Let's break it apart in order to understand what is going on here, and why it works. You'll then focus on the Dynamic SQL that provides the backbone of this set of statements.

1. Populate a table variable with a list of database names.
2. Go through a loop one time per database.
3. Build a Dynamic SQL command string that takes into account the current database name.
4. Execute the dynamic BACKUP statement.
5. Continue iterating through the loop until all relevant databases have been backed up.

You declare a number of variables here:

@database_list: Contains all databases that match the search criteria. In this case, any database that starts with the word AdventureWorks will be included.

@sql_command: This is the command string that will contain the Dynamic SQL statement.

@database_name: Holds the name of the database that is currently being backed up.

database_cursor: A cursor that will be used to iterate through all databases named in @database_list.

Much of this example is set up for the loop. The critical portion is where you substitute the database name and backup file name with `@database_name`. This allows you to generate a backup statement that will not only back up each database, regardless of how many there are, but will also name the backup file using that name. You could just as easily append additional information onto the file name, such as the date, time, or server name, if it were important.

Advantages of Dynamic SQL

There are many reasons why you would want to incorporate Dynamic SQL into your everyday arsenal of SQL Server tools. In addition, there are many specific challenges for which Dynamic SQL is the optimal solution. Discussing these scenarios will highlight why an entire book can be written on this topic.

Optional or Customized Search Criteria

Search boxes are one of the most common tools used in the development of web pages or applications. For simple searches, you may only need to pass in a single variable for evaluation. In more powerful web searches, you may be able to choose among many criteria, of which each could be evaluated with `AND` or `OR` conditions. While you could write a very long `SELECT` statement with left joins to every possible table involved, you would likely end up with an immense, inefficient, and unwieldy pile of TSQL. Instead, Dynamic SQL allows you to build a `SELECT` string that only queries the tables necessary to satisfy a given search.

Customizable Everything

Adding joins or `WHERE` clauses is only the beginning. With Dynamic SQL, any statement can be customized to provide greater flexibility to your code. Want to group by a column based on a dynamic search? The solution is to write the `GROUP BY` clause as Dynamic SQL, altering it to fit the needs of each specific situation. Want to generate row numbers for a data set, but won't know which columns to partition by or order by until runtime? No problem!

The previous example illustrated how you could use Dynamic SQL to customize a backup operation and customize the name of the backup file. Any conceivable TSQL statement can be altered to utilize Dynamic SQL, and in doing so, allow for greater flexibility in any number of day-to-day challenges.

Optimize SQL Performance

So far, Dynamic SQL has appeared to make things more complicated, adding the need for temporary variables, loops, and command strings. Despite the seemingly added complexity, this framework can allow you to reduce the size of the SQL statements that you typically execute and improve performance.

Dynamic SQL provides an opportunity to customize our statements to match performance needs. Removing excess objects, adjusting joins and subqueries, and reducing the size of a SQL statement can result in faster executions times and reduce resource consumption.

Generate Large Amounts of TSQL or Text, Fast!

Sometimes you'll need to execute large SQL statements that act on a set of many objects. Other times, you'll want to generate output text based on data stored in a specific set of tables. Perhaps you want to generate `SELECT` statements that will be used to gather reporting data from any number of sources.

Writing all of this TSQL by hand could take a very long time and lead to a significant opportunity for human error to occur as you trudge through a time-consuming, boring task. If the SQL statements involved are to be run on a regular basis, then preparing them in advance may be impossible, especially if the target tables or other objects involved can change on a regular basis.

Using Dynamic SQL, you can generate any amount of commands or text without limit. SQL Server will not tire of this process, no matter how dull it may seem. This is an opportunity to automate tedious tasks and reduce operator intervention in tasks that would end up being busy work. The result is that your job becomes easier and more fun, and you can focus on more important tasks that demand your attention!

Execute SQL Statements on Other Servers or Databases

A common challenge occurs when you want to run queries against other entities, but do not know ahead of time what all of those entities are. If those objects can vary or change at runtime, then Dynamic SQL is a great solution for managing these operations without having to hard-code object names that are likely to change over time. This reduces the chances of an application breaking after a software release, configuration change, or hardware upgrade.

Similarly, in these scenarios, you may have an application with code that runs in many locations, with references to servers, databases, or other objects that vary based on environment. Writing slightly different code in each environment would be inefficient and would result in significantly higher maintenance needs over time. It's far simpler to maintain configuration data and write code that processes those configurations, reading and writing to the database as needed. Dynamic SQL allows for that configuration data to be easily handled and acted upon, regardless of the complexity of the operations involved.

Do the Impossible!

Simply put, there are many tasks in SQL Server that would be extremely difficult, or seemingly impossible, without Dynamic SQL. Many common maintenance scenarios that need to iterate across database objects become trivially easy with Dynamic SQL.

Have you ever tried to `PIVOT` or `UNPIVOT` across a dynamic column list? The command is powerful, but it requires a definitive column list. If the list is not known until runtime, then the only way to get the data is to use Dynamic SQL to insert your customized column list into the statement and then execute it.

There will be many examples of interesting, useful, and fun ways in which Dynamic SQL can make very difficult tasks easy. Stay tuned and enjoy!

Dynamic SQL Considerations

As with any tool, Dynamic SQL shouldn't be used everywhere blindly, nor is it the solution to every database problem you'll encounter. With a discussion of any tool, it is imperative that you consider its challenges, pitfalls, and complexities prior to implementing it.

Apostrophes Can Break Strings

As you build Dynamic SQL commands, you incorporate other variables and strings into them. If any of these contain apostrophes, your command string will be broken. The resulting command will, if you are lucky, throw an error and not run. SQL injection is the process of using the variables in Dynamic SQL to intentionally close the string with an apostrophe, and then attempt to execute malicious code. If you do not cleanse all parameters and inputs prior to building the command statement, you risk introducing colossal security holes into your code.

It is imperative that whenever you use Dynamic SQL, you ensure that your inputs are clean and that unexpected symbols in your parameters have no negative effect on the code operation. Failure to do so can result in broken application code, unexpected behavior, or catastrophic security holes.

NULL Can Break Strings

`NULL` is a complicated state of affairs. As an absence of value, any attempt to concatenate a string with `NULL` will result in `NULL`. If the Dynamic SQL command string that you build is passed a parameter that is `NULL`, the entire statement will become `NULL`. The result will likely be TSQL that does absolutely nothing. This can lead to troubleshooting nightmares as it becomes unclear why a SQL statement appears to do nothing. Further, the search for the `NULL` parameter may be a daunting task if the statement in question has many inputs.

Difficult to Read and Debug

TSQL loses the benefits of color-coding that exist in SQL Server Management Studio when you write standard SQL in the text editor. Within apostrophes, much of the text will be red, including keywords, strings, and variable names. In addition, the error-checking that is performed as you type does not occur as effectively within a Dynamic SQL string. A simple typo that would be underlined in red normally will not be as apparent when it is within a string.

In order to combat these challenges, you must devise very well-written TSQL. In addition to writing very organized code, you have to be even more diligent when documenting your work. TSQL that may normally be trivially easy to understand can be harder to grasp when written as part of a string. Extra time and care must be used in order to ensure that when you revisit this code in the future, it is still easy to read and meaningful.

Dynamic SQL *always* compiles correctly. To SQL Server, it is simply a character string. The contents of it are not checked for syntax or object validity until runtime. Effective testing and debugging are the key to ensuring that the TSQL you write executes as you expect it to.

Permissions and Scope Are Different

Dynamic SQL statements are executed in their own scope. Variables defined within the string will not normally be available outside of it. In addition, Dynamic SQL is executed with the permissions of the user executing the overall TSQL code (stored procedure, job, etc…). It does not execute with the permissions of the owner of the stored procedure or the user who happened to be testing it recently.

In order to avoid unexpected errors, permissions conflicts, or other security concerns, it's important to consider what users will be running any code that includes Dynamic SQL. If you need to save data from a Dynamic SQL statement, or pass parameters in from outside, then that needs to be explicitly managed in order to get the desired effect.

Dynamic SQL Cannot Be Used in Functions

Simply put, you can use Dynamic SQL in stored procedures, ad-hoc TSQL, and jobs, but it is not allowed within functions. Any attempt to include Dynamic SQL within functions will result in an error:

```
Msg 443, Level 16, State 14, Procedure fn_test, Line 72
Invalid use of a side-effecting operator 'EXECUTE STRING' within a function.
```

SQL Server functions must be deterministic. Inputs and outputs must be in the form given in the function definition. Dynamic SQL by nature is non-deterministic, and therefore cannot be used within functions.

Dynamic SQL Style

Writing code that works is very important. Writing code that is easy to understand and maintainable is equally as important. As someone charged with the creation and upkeep of immense numbers of database objects, you must always consider how easy it will be to read, understand, troubleshoot, and upgrade these objects at any point in the future. Because Dynamic SQL tends to be harder to read, extra care should be taken to ensure that your TSQL is well-written, effectively documented, and that objects/variables are named according to reasonable conventions. These design considerations will save you considerable time, as well as show your colleagues that you care about their well-being and the future of your organization.

The rules of good Dynamic SQL design begin here, but will continue to be built on throughout the rest of this book. Consider any efforts on your part to write maintainable code, whether it utilizes Dynamic SQL or not.

Document Thoroughly

This is the mantra that is repeated to anyone who has ever written a line of code, a script, or a non-technical process. Your documentation explains how your code works and why it is written as it is, and it serves as a guide when changes are inevitably made. TSQL that may not normally warrant documentation will become harder to read when Dynamic SQL is applied. Consider creating additional documentation to supplement this added complexity.

The first and simplest way to document your work is to include a header at the top of your file. This header provides basic information on who created this code, some revision notes, its purpose, and a quick overview of how it works. Understanding the reasons behind why a stored procedure was created can be as useful as knowing how it works. More importantly, it is possible to discern the function of code by reading through it and scratching one's head a bit. It isn't possible to figure out the original request that spurred the creation of that code without either having some existing application knowledge that others may not have or asking other developers for help.

Consider the header for a simple backup script, shown in Listing 1-3.

Listing 1-3. Header Comments, Documenting a Hypothetical Backup Script

```
/*      9/8/2015 Edward Pollack
        Backup routing for AdventureWorks databases

        As a result of ticket T1234, logged on 8/20/2015, it became necessary
        to selectively back up a limited set of AdventureWorks databases via a
        SQL Server Agent job. The job can have its schedule adjusted as needed
        to fit the current needs of the business.

        Dynamic SQL is used to iterate through each database, performing the
        backup and naming the resulting file using the database name, date,
        time, and source server.    */
```

This header tells the reader the following:

1. The date that this code was written, to provide context as to when it came about.
2. The author, which allows future developers to know where to go with questions.
3. Background into why this was written and the problem that was being addressed.
4. A brief description of how it works and any special features that are used.

This short documentation block answers most of the common questions that a developer may have about your code. The things you might consider obvious while writing TSQL may not be so obvious to someone else reading this years later.

When writing code that involves Dynamic SQL, you must consider documenting thoroughly, but also not go overboard and explain every single line of TSQL. Let's take the backup routine from earlier and add some meaningful documentation to it.

Listing 1-4. Backup Script Sample, with Documentation Added

```
-- This will temporarily store the list of databases that we will back up below.
DECLARE @database_list TABLE
        (database_name SYSNAME);

INSERT INTO @database_list
        (database_name)
SELECT
        name
FROM sys.databases
WHERE name LIKE 'AdventureWorks%';
-- This WHERE clause may be adjusted to back up other databases besides those starting with
"AdventureWorks"

DECLARE @sql_command NVARCHAR(MAX);
DECLARE @database_name SYSNAME;
DECLARE @date_string VARCHAR(17) = CONVERT(VARCHAR, CURRENT_TIMESTAMP, 112) + '_' +
REPLACE(RIGHT(CONVERT(NVARCHAR, CURRENT_TIMESTAMP, 120), 8), ':', '');

-- Use a cursor to iterate through databases, one by one.
DECLARE database_cursor CURSOR FOR
SELECT database_name FROM @database_list
OPEN database_cursor
FETCH NEXT FROM database_cursor INTO @database_name;

WHILE @@FETCH_STATUS = 0 -- Continue looping until the cursor has reached the end of the
database list.
BEGIN
        -- Customize the backup file name to use the database name, as well as the date and time
        SELECT @sql_command = '
        BACKUP DATABASE ' + @database_name + '
        TO DISK=''E:\SQLBackups\' + @database_name + '_' + @date_string + '.bak'' WITH COMPRESSION;'
```

```
        EXEC (@sql_command);

        FETCH NEXT FROM database_cursor INTO @database_name;
END

-- Clean up our cursor object.
CLOSE database_cursor;
DEALLOCATE database_cursor;
```

This example shows the backup script from earlier with the addition of a timestamp on the file name. Documentation is added to explain each section. Note that the comments are short, simple, and explain the parts that I think may benefit from them. You don't have to waste time with obvious comments that would take up extra space and distract from the task at hand. For example, I'd never include a comment like this, unless I was looking for some misplaced comic relief:

```
-- This variable holds the database name.
DECLARE @database_name SYSNAME;
```

While amusing, my addition says nothing new. Whether it annoys or amuses, it doesn't provide any useful information that wasn't already obvious in the variable name.

Documentation is often like choosing pizza toppings. Everyone has their own style, and it would be foolish to try and settle on a single style that is appropriate in all environments for all objects. If you are writing more complex code, especially if it involves Dynamic SQL, consider being as thorough as possible. Your bit of extra work now will save someone immense time in the future!

Debugging Dynamic SQL

Dynamic SQL benefits from debugging more than the standard queries that you write. Since SQL Server will always compile Dynamic SQL statements successfully, it's important that you perform further testing on your code before executing it. Simple errors that would normally be obvious could easily be missed due to the lack of feedback in SQL Server Management Studio. In addition, your code will partially be obscured in a string, surrounded by apostrophes. The harder the code is to read, the harder it will be to debug and locate mistakes, whether they are syntax or logical mistakes.

The easiest and most effective way to test and debug Dynamic SQL is to replace the `EXEC` with `PRINT`. When the TSQL is executed, the command string will print out, rather than be executed immediately. The printout can then be copied into another editor window and reviewed for syntax, logic, spelling, and any other considerations you may have. Many common Dynamic SQL typos are the result of misplaced quotation marks, which become quickly apparent when moved into a new window. For example, consider the following short command string:

```
DECLARE @CMD NVARCHAR(MAX);
SELECT @CMD = 'SELLECT TOP 17 * FROM Person.Person';
EXEC (@CMD);
```

This statement will compile successfully, but throw the following error:

```
Msg 156, Level 15, State 1, Line 79
Incorrect syntax near the keyword 'TOP'.
```

The resulting error message is cryptic and tells you very little about what you did wrong. Print out the command string and paste it into an editor window, and the issue becomes obvious:

```
SELLECT TOP 17 * FROM Person.Person
```

SELECT is clearly misspelled, and in addition to being underlined in red in SQL Server Management Studio, it will not be highlighted in blue as a reserved keyword normally would be.

For larger blocks of TSQL, there is great value in adding a debug bit into the code. When @debug is 1, all statements will print, rather than execute. When @debug is 0, then statements will execute. This allows you to control all blocks of code with a single bit that can easily be configured at the top. It is far easier to flip this one bit than to constantly write PRINT statements and comment out execute statements whenever debugging becomes necessary. Listing 1-5 shows the backup script example from earlier, with a debug parameter added.

Listing 1-5. Backup Script Sample, with Debug Parameter Added

```
DECLARE @debug BIT = 1;

DECLARE @database_list TABLE
        (database_name SYSNAME);

INSERT INTO @database_list
        (database_name)
SELECT
        name
FROM sys.databases
WHERE name LIKE 'AdventureWorks%';
-- This WHERE clause may be adjusted to back up other databases besides those starting with
"AdventureWorks"

DECLARE @sql_command NVARCHAR(MAX);
DECLARE @database_name SYSNAME;
DECLARE @date_string VARCHAR(17) = CONVERT(VARCHAR, CURRENT_TIMESTAMP, 112) + '_' +
REPLACE(RIGHT(CONVERT(NVARCHAR, CURRENT_TIMESTAMP, 120), 8), ':', '');

-- Use a cursor to iterate through databases, one by one.
DECLARE database_cursor CURSOR FOR
SELECT database_name FROM @database_list
OPEN database_cursor
FETCH NEXT FROM database_cursor INTO @database_name;

WHILE @@FETCH_STATUS = 0 -- Continue looping until the cursor has reached the end of the
database list.
BEGIN
        -- Customize the backup file name to use the database name, as well as the date and
        time
        SELECT @sql_command = '
        BACKUP DATABASE ' + @database_name + '
        TO DISK=''E:\SQLBackups\' + @database_name + '_' + @date_string + '.bak''
        WITH COMPRESSION;'
```

```
        IF @debug = 1
                PRINT @sql_command
        ELSE
                EXEC (@sql_command);

        FETCH NEXT FROM database_cursor INTO @database_name;
END
-- Clean up our cursor object.
CLOSE database_cursor;
DEALLOCATE database_cursor;
```

With the addition of four lines of TSQL, you have allowed execution to be controlled by a single bit. By copying the print output into a new window and reviewing it, you can quickly confirm if it compiles successfully and looks correct.

Additionally, if the source of a problem is unclear, you can add `PRINT` statements into the code for some of your variables. For example, if you were unsure whether the `@date_string` was being populated correctly, you could print it out separately and verify that the value is what you expect:

```
PRINT '@date_string (line 20): ' + @date_string
```

This is a very simple debugging action, but by including the variable name and line number, you make the code easier to understand. If the results were still perplexing, you could split up the result further, printing the date and time portions of the variable separately. By breaking a problem into smaller, simpler pieces, debugging becomes a much easier task and one that causes far less frustration along the way.

When writing new Dynamic SQL, be sure to print the command string often, verifying that the resulting TQL is valid, both syntactically and logically.

Lastly, for any code that will take inputs from other applications (or an end user), remember to test all possibilities. Ensure that either the application or the TSQL checks and validates inputs as needed. What happens if an input contains a special character? What if it has an apostrophe, underscore, or escape character? If humans are allowed to manually enter text, assume they will make mistakes, enter garbage, blanks, special characters, or in some way do the unexpected. Account for this and you will prevent untold numbers of potential errors and greatly improve the security of your application.

Write Dynamic SQL Just Like Standard TSQL

Just because your Dynamic SQL is enclosed in a string does not mean that it should be written any differently than your usual statements. Whatever your normal standards are for capitalization, indentation, and spacing should be used equally here. Too often is a Dynamic SQL statement written as one long line of code, with no spaces, newlines, capitalizations, or breaks. The result is often unintelligible, and far more prone to mistakes. If you were to copy the debug text from a `PRINT` statement into a new window, the result should look precisely like the TSQL you would normally write.

Listing 1-6. Example of How to Annoy Future Developers with Poorly Formatted Dynamic SQL

```
DECLARE @CMD NVARCHAR(MAX) = ''; -- This will hold the final SQL to execute
DECLARE @first_name NVARCHAR(50) = 'Edward'; -- First name as entered in search box
SET @CMD = 'SELECT PERSON.FirstName,PERSON.LastName,PHONE.PhoneNumber,PTYPE.Name FROM
Person.Person PERSON INNER JOIN Person.PersonPhone PHONE ON PERSON.BusinessEntityID = PHONE.
BusinessEntityID INNER JOIN Person.PhoneNumberType PTYPE ON PHONE.PhoneNumberTypeID = PTYPE.
PhoneNumberTypeID WHERE PERSON.FirstName = ''' + @first_name + '''';
PRINT @CMD;
EXEC (@CMD);
```

String Sizes and Truncation

When you attempt to store a string in a variable that is not large enough to hold it, the string will be automatically truncated. The result will be incomplete data that will likely cause headaches later on in your code. Consider the following TSQL, which generates a timestamp and stores it in a string.

Listing 1-7. Example of Truncation when Generating a Timestamp String

```
DECLARE @date_string VARCHAR(10) = CONVERT(VARCHAR, CURRENT_TIMESTAMP, 112) + '_' +
REPLACE(RIGHT(CONVERT(NVARCHAR, CURRENT_TIMESTAMP, 120), 8), ':', '');
PRINT @date_string;
```

You expect a timestamp with the date (MMDDYYYY) and time (HHMMSS). What you instead get is a string that is cut off at 10 characters: `20150908_1`. Always declare variables that are large enough to hold any valid data that could be stored there. If you are unsure of the potential data size, erring on the side of caution and providing extra characters is not a bad decision. Seventeen characters are required to get the full text output expected in this example. What if you were considering adding milliseconds to the timestamp, but were not going to do so until a future software release? Make the `@date_string` larger now, and there will be no need to make further changes in order to account for that change. The cost is tiny, and the potential for errors in the future are reduced.

A more complex example of string truncation can occur when Dynamic SQL gets very, very large. If you write a command string that is greater than 8192 characters and are concatenating it with other strings (names, dates, input parameters, other Dynamic SQL strings, etc…), there is an implicit, undocumented risk of truncation. SQL Server will implicitly convert strings of different data types and sizes in an attempt to process them quickly and efficiently. The result will be a `NVARCHAR(MAX)` command string that seems to be truncated down to 8192 characters when executed. This truncation can be resolved in one of two ways:

1. Split the Dynamic SQL statement into multiple statements, each less than 8192 characters.

2. Change all parameters and variables involved in the command string to `NVARCHAR(MAX)`.

The first option can be difficult to guarantee. How do you split an extremely long command into pieces that are guaranteed to always be 8192 characters or less? The second option will always work when faced with this conundrum, and is an easy, inexpensive fix.

When working with very large Dynamic SQL, consider using `NVARCHAR(MAX)` for all scalar parameters involved in the construction of the command string to avoid inadvertent string truncation.

Management Studio Text Display

An unrelated, but somewhat similar, problem can occur when you print output directly to the text window. You will do this frequently, either to debug new TSQL or to manually execute Dynamic SQL that you have generated. By default, the text limit in the output window of SQL Server Management Studio is set to 256 characters. Any text printed from any SQL statements will be truncated at 256 characters, which will often be inconvenient.

This limit only affects output that you print to the results window and has no bearing on the string sizes when you execute a command string. The text limit has no effect on actual query execution. For the sake of debugging, it is advantageous to modify your SQL editor options to increase this limit to 8192 characters.

This setting can be found by navigating to Tools ➤ Options ➤ Query Results ➤ SQL Server ➤ Results to Text and modifying the maximum number of characters displayed in each column. See Figure 1-1 for an example.

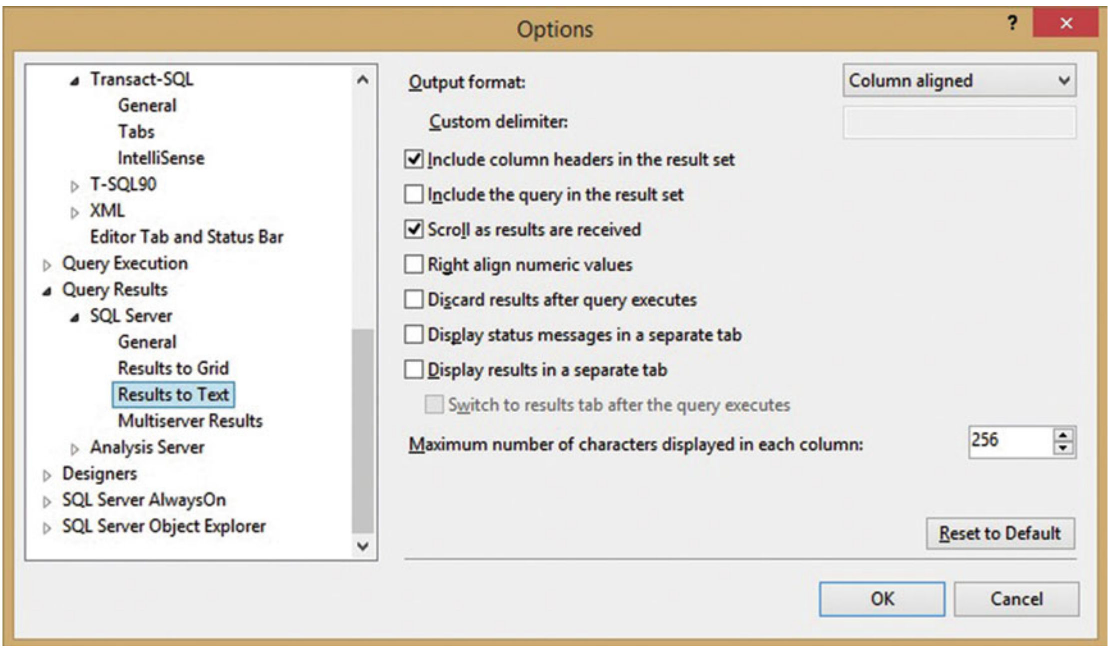


Figure 1-1. *Results to Text settings in SQL Server Management Studio*

Change 256 to 8192 and you'll have an easier time printing and debugging larger Dynamic SQL statements in the future.

Sp_executesql

Thus far, all Dynamic SQL statements have been executed using the EXEC keyword. This method of execution is simple, straightforward, and convenient for quick testing and debugging. Unfortunately, EXEC comes with a number of limitations and security concerns that encourage a better solution:

- EXEC is vulnerable to SQL injection and the effects of unexpected input. Escape characters and apostrophes can easily wreck a Dynamic SQL statement.
- There is no built-in way to manage input or output variables with EXEC.

- When using EXEC, it is unlikely that execution plans will be reused. This reuse of execution plans, known as parameter sniffing, is a useful feature and generally something you'll want to occur.

Each of these topics is covered in extensive detail later in this book and can be addressed using the system stored procedure sp_executesql, instead of EXEC.

The syntax for sp_executesql is straightforward:

```
sp_executesql N'SELECT COUNT(*) FROM Person.Person';
```

Whatever TSQL is provided in the string will be executed in the same way as the previous examples. The more common (and more useful) syntax is to store the command string in a variable and use EXEC in front of sp_executesql:

```
DECLARE @sql_command NVARCHAR(MAX) = 'SELECT COUNT(*) FROM Person.Person';
EXEC sp_executesql @sql_command;
```

All examples going forward use sp_executesql instead of EXEC. This is considered a best practice in SQL Server, and one that will improve the reliability, security, and performance of your Dynamic SQL.

In the world of databases, we rarely use the words "always" or "never". Oftentimes, the answer to a question is "it depends," followed by quite a bit of discussion. This is one of those rare scenarios where "always" is the best answer. When writing Dynamic SQL, *always* use sp_executesql and *never* use EXEC. The benefits far outweigh any inconvenience that you may face from using this new stored procedure.

Building Strings via Concatenation

There are two straightforward ways to combine strings in TSQL. The first is to use the + operator, which has been the method used thus far in this book. This is simple, easy and quick to implement, and intuitive.

Remember the brief introduction to how NULL can break strings? When piecing many strings together, if any one of them happens to be NULL, then the entire string output will become NULL as well. NULL + 1 is treated by SQL Server in a similar manner that infinity + 1 is handled by mathematics. You can combat this by using ISNULL or COALESCE, or by performing an explicit check of the variable for NULL and replacing it as needed. Consider the following Dynamic SQL queries.

Listing 1-8. Examples of String Concatenation Results when a Parameter Is NULL

```
DECLARE @schema VARCHAR(25) = NULL;
DECLARE @table VARCHAR(25) = 'Person';
DECLARE @sql_command VARCHAR(MAX);
SELECT @sql_command = 'SELECT COUNT(*) ' + 'FROM ' + @schema + '.' + @table;
PRINT @sql_command;
SELECT @sql_command = 'SELECT COUNT(*) ' + 'FROM ' + ISNULL(@schema, 'Person') + '.' + @table;
PRINT @sql_command;
SELECT @sql_command = 'SELECT COUNT(*) ' + 'FROM ' + CASE WHEN @schema IS NULL THEN 'Person'
ELSE @schema END + '.' + @table;
PRINT @sql_command;
```

The first query returns NULL. Since @schema is NULL, anything you concatenate with it will also become NULL. This will generally be undesired behavior, and you would immediately be confounded by a command string that does nothing or generates errors when executing.

The second query uses ISNULL to ensure that, if @schema is NULL, something will be returned in place of it. In this case, the Person schema is hard-coded there, which produced the same results as before. This required assumptions, though. In the event that you do not have a default value, you may be better served by throwing an error, rather than making up a value that may not be accurate. Alternatively, you could simply never allow @schema to be NULL, and exit immediately if it is.

The third query uses a CASE statement to replace NULL with the Person schema. This is the same result as the last query, although CASE provides some additional flexibility that you could utilize. If necessary, you could alter the structure of the query to account for missing variables, or have multiple code paths.

There is a second way to concatenate strings that can be beneficial under circumstances where the data types and values of the data are unpredictable. The built-in function CONCAT allows you to combine strings using the following syntax:

```
SELECT CONCAT ('SELECT COUNT(*) ', 'FROM ', 'Person.', 'Person');
```

Variables may be passed into this function as parameters as well:

```
DECLARE @schema NVARCHAR(25) = 'Person';
DECLARE @table NVARCHAR(25)= 'Person';
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = CONCAT ('SELECT COUNT(*) ', 'FROM ', @schema, '.', @table);
PRINT @sql_command
```

The results of both of these SQL statements will be the same:

```
SELECT COUNT(*) FROM Person.Person
```

CONCAT offers several features:

1. NULL parameters are always converted into empty strings.
2. The data type of the result is intelligently determined based on the inputs. NVARCHAR parameters will yield NVARCHAR results, VARCHAR will yield VARCHAR, and MAX inputs will yield an output of MAX size.
3. If all inputs are NULL, then the output will be an empty string of type VARCHAR(1).
4. It will attempt to convert different data types in the process of concatenation. This can be desirable with strings, but problematic when concatenating text and numeric. Adding a CAST or CONVERT to manage this will remove any doubts as to the accuracy of results.

Removing NULL may not be desired behavior, though! Oftentimes, if a parameter is unintentionally NULL, you may very well prefer that an error be thrown by the code than continue processing with dummy values. Utilize this feature only if removing NULLs is advantageous to your application.

CONCAT is a viable alternative to using the + operator. There are many other SQL Server string-manipulation functions that are useful when generating Dynamic SQL. We'll continue to use + for the duration of this book, but it's worth the time to quickly review a handful of useful string functions that may prove convenient:

> LTRIM, RTRIM: Removes any whitespace on the left (LTRIM) or right (RTRIM) of an expression. This can be useful when dealing with unpredictable inputs, or those that often have extra whitespaces attached to them:

```
DECLARE @string NVARCHAR(MAX) = '  This is a string with extra whitespaces   ';
SELECT @string;
SELECT LTRIM(@string);
SELECT RTRIM(@string);
```

The above TSQL returns the following:

```
"   This is a string with extra whitespaces   "
"This is a string with extra whitespaces   "
"   This is a string with extra whitespaces"
```

CHARINDEX: This will return the first instance of a search expression within a string. For example, if you wanted to return the first instance of dinosaur in a string, then this would do the trick:

```
DECLARE @string NVARCHAR(MAX) = 'The stegosaurus is my favorite dinosaur';
SELECT CHARINDEX('dinosaur', @string);
```

The result of this query would be 32, the starting character of the word dinosaur. An optional third parameter can specify where in the string to begin looking for the search string. CHARINDEX returns 0 if the search string isn't found.

STUFF: Allows you to insert a string into the middle of another string and optionally delete characters from the insertion point. This has many uses, and can be a convenient way to combine SQL statements, text output, or input parameters in desired combinations. Here are a few examples of how to use STUFF:

```
DECLARE @string NVARCHAR(MAX) = 'The stegosaurus is my favorite dinosaur';
SELECT STUFF(@string, 5, 0, 'purple ');
SELECT STUFF(@string, 5, 11, 't-rex');
SELECT STUFF(@string, 32, 8, 'animal!');
```

The first parameter is the text to be modified and the last is the string that is being inserted. The second is the insert point (what character position number within the string to insert into). The third parameter indicates how many characters will be deleted prior to the insertion (enter 0 if you don't want to delete any characters). The results of these queries are as follows:

```
"The purple stegosaurus is my favorite dinosaur"
"The t-rex is my favorite dinosaur"
"The stegosaurus is my favorite animal!"
```

REPLACE: Within a string, this will replace all occurrences of a text pattern with another. This is often useful for removing specific characters from a string, or for replacing undesirable parts of input strings with a standard or consistent segment of text. The behavior of REPLACE and STUFF can be very similar, so you can choose whichever is convenient for the task at hand:

```
DECLARE @string NVARCHAR(MAX) = CAST(CURRENT_TIMESTAMP AS NVARCHAR);
SELECT REPLACE(@string, ' ', '');
SELECT REPLACE(REPLACE(@string, ' ', ''), ':', '');
SELECT REPLACE(REPLACE(REPLACE(REPLACE(@string, ' ', ''), ':', ''), 'AM', ''), 'PM', '');
```

In these examples, you are stripping out a variety of characters from the current date/time string. A single REPLACE can be used to remove a specific character, or several can be used to remove additional characters as well. The first example replaces all spaces with empty strings, thereby removing them from the string. The second query also removes colons, and the final additionally removes AM or PM from the timestamp. This is a frequent tactic used when cleansing strings to be used in file names, labels, or a standard name for catalog data. The query results are as follows:

```
Sep1320152:40PM
Sep132015240PM
Sep132015240
```

SUBSTRING returns a segment of a string, based on a starting point and the number of characters to return. This can also be used to remove characters from a string, to extract a specific portion, or to return the beginning or end of a string.

```
DECLARE @string NVARCHAR(MAX) = CAST(CURRENT_TIMESTAMP AS NVARCHAR);
SELECT SUBSTRING(@string, 1, 3);
```

This example returns the three-letter month from the string:

```
Sep
```

REPLICATE repeats a string the number of times specified. This can be a quick way to generate a large volume of test text, or to create data when there are parts that are expected to repeat often.

```
SELECT 'Look, a robot' + REPLICATE('!', 50)
Look, a robot!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

The example is simple (outputting lots of exclamation marks), but consider the following example, where serial numbers are entered into a system, but should all have 20 digits (with leading zeroes):

```
DECLARE @serial_number NVARCHAR(MAX) = '91542278';
SELECT REPLICATE(0, 20 - LEN(@serial_number)) + @serial_number;
```

In this example, LEN returns the number of characters in the serial number. By subtracting that from 20, you can determine how many additional characters you need to reach 20. By replicating zeroes this many times, you can quickly pad the serial number with the appropriate number of zeroes. This tactic is also useful with ZIP codes, identification numbers, or any numeric values represented as strings, where leading zeroes could be omitted.

REVERSE is also a simple function that takes a string and reverses the characters. This can be useful if you are looking to operate on the end of the string (in reverse order) or to manage a list, starting at the end.

```
DECLARE @string NVARCHAR(MAX) = '123456789';
SELECT REVERSE(@string);
```

This quick example takes a number string and reverses it, which returns the expected result:

```
987654321
```

Notes on Apostrophes

Because Dynamic SQL is built within strings, it's important to carefully consider how to correctly use apostrophes when you build more complex string logic. For example, let's say you wanted to locate all people with a first name that started with Ed. Using Dynamic SQL, you would need to include some extra apostrophes to ensure the syntax is correct:

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @first_name NVARCHAR(20) = 'Ed';
SELECT @sql_command = '
SELECT
      *
FROM Person.Person
WHERE FirstName LIKE ''' + @first_name + '%''';
PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The resulting command string will look like this:

```
SELECT
      *
FROM Person.Person
WHERE FirstName LIKE 'Ed%'
```

Note that three apostrophes are used instead of one. Within a string, a pair of apostrophes is translated into a single apostrophe. Whenever you are working with strings within a Dynamic SQL command string, be sure to debug and print often to ensure that you're building valid TSQL and have not forgotten any string delimiters.

If there was a need to modify a string within a parameter within Dynamic SQL, the result would be the need for six apostrophes instead of two. If this sounds complicated, then use that complexity as a caution against developing an application that is more difficult to understand and maintain than is necessary.

Conclusion

Dynamic SQL is a powerful tool that is capable of executing complex requests quickly and efficiently. There are many database queries and tasks that would be very difficult to accomplish without the ability to customize queries on the fly. We will soon delve into greater detail on Dynamic SQL features, as well as provide many practical examples of how to effectively use it.

Before diving in, though, it is important to discuss security and the best practices for writing and maintaining Dynamic SQL. As with any tool, it can be used and misused, and knowing how to effectively utilize security will not only improve the quality of development, but will also help secure your existing applications and systems.

CHAPTER 2

Protecting Against SQL Injection

There are few SQL vulnerabilities as commonly exploited as SQL injection. This form of database attack has destroyed companies and ruined careers, and is a constant challenge for database administrators. As a database professional, data is your greatest asset, and it is your responsibility to guard it above all else. SQL injection is not limited only to Dynamic SQL, but is a technique that can be applied to many areas of SQL Server. Therefore, understanding and defending against it are the most important priorities when considering SQL Server security.

What Is SQL Injection?

SQL injection is when a hacker attempts to insert malicious TSQL into the parameters used in Dynamic SQL. Consider the example shown in Listing 2-1.

Listing 2-1. Dynamic SQL, Intro to SQL Injection

```
DECLARE @CMD NVARCHAR(MAX);
DECLARE @search_criteria NVARCHAR(1000);

SELECT @CMD = 'SELECT * FROM Person.Person
WHERE FirstName = ''';
SELECT @search_criteria = 'Edward';
SELECT @CMD = @CMD + @search_criteria;
SELECT @CMD = @CMD + '''';
PRINT @CMD;
EXEC sp_executesql @CMD;
```

We perform a search of `Person.Person` for anyone who has the first name of whatever `@search_criteria` was passed into this code. The resulting command string appears exactly as you'd expect it to:

```
SELECT * FROM Person.Person
WHERE FirstName = 'Edward'
```

Over time, this search is used by many, many people and is expanded to also search for people by last name, middle initial, title, e-mail address, and more! Eventually, someone with the last name of "O'Brien" tries to search for their records, as shown in Listing 2-2.

E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_2

Listing 2-2. Use of Input Value with an Apostrophe

```
DECLARE @CMD NVARCHAR(MAX);
DECLARE @search_criteria NVARCHAR(1000);

SELECT @CMD = 'SELECT * FROM Person.Person
WHERE LastName = ''';
SELECT @search_criteria = 'O''Brien';
SELECT @CMD = @CMD + @search_criteria;
SELECT @CMD = @CMD + '''';
EXEC sp_executesql @CMD;
```

The results are not what the user expected. Instead of getting their info, they get a SQL Server error:

```
Msg 102, Level 15, State 1, Line 322
Incorrect syntax near 'Brien'.
Msg 105, Level 15, State 1, Line 322
Unclosed quotation mark after the character string ''.
```

Returning to the command string and verifying that it looks correct, you would notice the following:

```
SELECT * FROM Person.Person
WHERE LastName = 'O'Brien'
```

The apostrophe within “O’Brien” broke the command string, closing the string after the “O” in “O’Brien”. Instead of receiving the expected data, your friend O’Brien receives a cryptic error and contacts your help desk to determine why this web application is broken. This is a best-case scenario of what could happen. The user shrugs and submits an incident to your organization to fix this bug so he can search for his information without odd error messages.

Let’s consider another example where the end user is more tech-savvy and a bit more malicious. She enters a string with apostrophes and are returned an error message. Instead of reporting the error to you, a light bulb goes off and she begins writing some TSQL of their own, as shown in Listing 2-3.

Listing 2-3. How a Hacker Can Begin to Use SQL Injection Against Unsecured Dynamic SQL

```
DECLARE @CMD NVARCHAR(MAX);
SELECT @CMD = 'SELECT * FROM Person.Person
WHERE LastName = ''';
SELECT @search_criteria = 'Smith'' OR 1 = 1 AND '''' = ''';
SELECT @CMD = @CMD + @search_criteria;
SELECT @CMD = @CMD + '''';
EXEC sp_executesql @CMD;
```

This sneaky user realized immediately that this site was vulnerable to SQL injection and began tinkering with search parameters until she found one that allowed her to extract all of the personal data from this table, and not just hers. By adding two apostrophes after `Smith`, the uninvited guest has returned to the main TSQL query and appended `OR 1 = 1` to the end. Finally, she adds some additional apostrophes to the end in order to complete the command string correctly and avoid syntactical errors. The resulting command string is as follows:

```
SELECT * FROM Person.Person
WHERE LastName = 'Smith' OR 1 = 1 AND '' = ''
```

The last name of Smith is irrelevant to the attack. By adding a condition that is always true, the hacker has effectively bypassed the WHERE clause and have gained access to all of the data in the table. In a single statement, this hacker has stolen tens of thousands of rows of personal data and began a data breach that would cause great harm to any organization targeted by it!

If a username and password prompt were managed via Dynamic SQL, then a similar attack would result in someone gaining access to a software application that they were not authorized to use. Consider the Dynamic SQL in Listing 2-4, which verifies a user's ID and password.

Listing 2-4. Dynamic SQL that Verifies a User/Password Combination

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @id INT = 3;
DECLARE @password NVARCHAR(128) = '';

SELECT @sql_command = '
SELECT
       *
FROM Person.Password
WHERE BusinessEntityID = ' + CAST(@id AS NVARCHAR(25)) + '
AND PasswordHash = ''' + @password + ''''

EXEC (@sql_command)
```

Any incorrect guess at a password will result in a failed login, and no results are returned. But what if a hacker tries to use SQL injection to bypass the login validation all together? The following string for @password would be all it would take to completely invalidate this security check:

```
''' OR 1 = 1 AND '''' = '''
```

By including an OR in the conditional, a malicious user could find ways to log in using any user, even the administrator. Since these logins may appear legitimate from the perspective of the application, it's possible that this attack could go unnoticed until it was too late.

Similarly, UNION ALL can allow additional data to be selected without triggering any errors, as shown in Listing 2-5.

Listing 2-5. Use of UNION ALL via SQL Injection to Collect Additional Secure Data

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @id INT = 3;
DECLARE @password NVARCHAR(128) = ''' UNION ALL SELECT * FROM Person.Password
WHERE '''' = ''';

SELECT @sql_command = '
SELECT
       *
FROM Person.Password
WHERE BusinessEntityID = ' + CAST(@id AS NVARCHAR(25)) + '
AND PasswordHash = ''' + @password + ''''

EXEC (@sql_command)
```

In this example, the original query is allowed to execute with a blank password, but an additional SELECT statement is appended, which returns the entire contents of the Password table. The resulting command string looks like this:

```
SELECT
        *
FROM Person.Password
WHERE BusinessEntityID = 3
AND PasswordHash = '' UNION ALL SELECT * FROM Person.Password WHERE '' = ''
```

This is a bit trickier to pull off as both tables need to be of the same structure in order to prevent syntax errors when the columns from the first table don't match the second. Given time, though, a hacker can figure out ways around this, such as adding dummy columns to the appended table, choosing specific columns, or using COLLATE to ensure that language and localization settings match up. Determining the names of tables in order to exploit them is a matter of guesswork here, but later on you will learn about ways in which a hacker can determine them through more covert means.

A similar attack involving a username/password scenario would be to use comments to remove the remainder of the TSQL so that the username is validated, but the password is not. This database schema is hypothetical, but the use case very common, as shown in Listing 2-6.

Listing 2-6. User/Password Verification Statement

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @username NVARCHAR(128) = 'edward';
DECLARE @password NVARCHAR(128) = 'my_password';

SELECT @sql_command = 'SELECT
        *
FROM dbo.password
WHERE username = ''' + @username + ''' AND Password = ''' + @password + '''';

EXEC(@sql_command);
```

An attacker may see that SQL injection is possible here and try to remove the password from the equation altogether by entering the following for their username:

```
'administrator'' --'
```

The resulting command string shows that the remainder of the WHERE clause is commented out, therefore bypassing the password check:

```
SELECT
        *
FROM dbo.password
WHERE username = 'administrator' --' AND Password = 'my_password'
```

An open comment delimiter, /* may be used in an attempt to bypass multi-line queries, or those that have some precautions in place.

For a skilled hacker, this would only be the beginning. From here, they could begin testing the structure of your database, learning the names of tables, stored procedures, views, and the security permissions granted to the user whom the application runs under. In order to do this, they would continue to rewrite their search box entry in an attempt to learn more, as shown in Listing 2-7.

Listing 2-7. Closing a Dynamic SQL String from an Input Parameter to Probe Schema Objects

```
DECLARE @CMD NVARCHAR(MAX);
DECLARE @search_criteria NVARCHAR(1000);

SELECT @CMD = 'SELECT * FROM Person.Person
WHERE LastName = ''';
SELECT @search_criteria = 'Smith''; SELECT * FROM sys.tables WHERE '''' = '''
SELECT @CMD = @CMD + @search_criteria;
SELECT @CMD = @CMD + '''';
EXEC sp_executesql @CMD;
```

After a bit of experimenting with apostrophes, the hacker has figured out how to close the search statement and start a new one of his own. By selecting data from `sys.tables`, he has now collected a list of all tables in the database. If he did not have access to system views, then guesswork would still yield some results as most databases have somewhat predictable object names. More guessing would result in more risk, as many failed TSQL statements or high activity from this search by a single user may eventually arouse suspicion. Unfortunately, most companies do not have the time or resources to vigilantly monitor and guard their web logs. Oftentimes, these vulnerabilities are discovered too late, after data has been stolen.

The hacker's next step would be to identify specific tables of interest: those with passwords, credit card numbers, or other valuable data. In addition, he can now run any SQL statements for which the application user has permissions without generating any further errors, as shown in Listing 2-8.

Listing 2-8. Using SQL Injection to Freely Gather Password Data

```
DECLARE @CMD NVARCHAR(MAX);
DECLARE @search_criteria NVARCHAR(1000);

SELECT @CMD = 'SELECT * FROM Person.Person
WHERE LastName = ''';
SELECT @search_criteria = 'Smith''; SELECT * FROM Person.Password WHERE '''' = '''
SELECT @CMD = @CMD + @search_criteria;
SELECT @CMD = @CMD + '''';
EXEC sp_executesql @CMD;
```

At this point, the hacker can have whatever data he can collect from the database. If you're lucky, then critical data will be encrypted, reducing the ability to immediately gain access to sensitive data. With this level of database access, though, the hacker may be able to collect enough additional information to access other systems and eventually decrypt that data. This is an excellent example of why highly privileged accounts, such as `sa`, should never be used in the context of an application login.

There is a single worst-case scenario that has played out many times in recent history. If the hacker was feeling destructive, he could use his newly found database access to delete data, truncate or drop tables, or even delete backup files from disk. How could he access files on disk? If `xp_cmdshell` is enabled on your server, then the hacker may be able to use it to access any data that is directly accessible from there. He could also potentially adjust server settings, change database and server security, add or remove users, and more. The limits at this point are restricted only by your imagination.

Disable `xp_cmdshell` on all database servers that could be accessed from outside of your internal network. As an additional safety measure, disable it anywhere that it isn't absolutely needed!

In addition to `xp_cmdshell`, other system stored procedures should have their security limited. `xp_regread`, `xp_regwrite`, `xp_servicecontrol`, `xp_loginconfig`, `sp_addextendedproc`, and many others can provide far more access to the server and operating system than you would ever want. Be sure to limit access to these so that any user who doesn't need them doesn't have them. Other functions that can be dangerous include `HOST_NAME()`, `OPENQUERY()`, `OPENROWSET()`, `SHUTDOWN`, and `KILL`.

Another scenario that has added further insult to injury has been the desire of hackers to profit off of their escapades. They may try to blackmail your company in an attempt to profit off of their efforts: "Pay up, or watch your precious data go up in flames!" More complicated situations have arisen when hackers attempt to cover their data theft by issuing a DDOS (distributed denial of service attack) attack. The influx of web/data requests overwhelm your web servers and distract you from their true intentions.

Additional SQL injection attacks have been documented in which the hacker did not steal data, drop tables, or otherwise make her presence immediately known. Instead, she would use the newfound access to modify web page code, inserting links to viruses, malware, or other malicious code that could exploit anyone visiting this web page. This expands the scope of the attack greatly and could result in significant damage, until the target realizes what has happened, removes the malicious code, and patches the original SQL injection target.

These scenarios are scary, but are far from a bedtime story gone wrong. We will spend the rest of this chapter discussing this nightmare situation, including the steps you can take to alleviate each and every mistake that led to the database server being infiltrated by an outside party.

Cleansing Inputs

The first step toward guarding against SQL injection is to ensure that all inputs are clean and that no invalid data can be passed in. This is a responsibility that is shared by developers (via code) and database administrators (via SQL). In an ideal environment, inputs are cleansed at all stages of execution. The web page or application that initially prompts for inputs should make efforts to ensure that invalid entries are not allowed. Some common methods are:

- Generate a custom error message for the user that indicates that invalid characters or text were entered.
- Strip out the invalid characters and allow execution to proceed.
- Define roles for input data and if the entry doesn't fit that specific format, throw an error to the user. For example, a birthdate could be in the form MMDDYYYY, and all other entries disallowed.
- Implement a software framework that automatically handles the cleansing of inputs for you.

These efforts will greatly enhance security and ensure that end users receive immediate feedback regarding the data they input. A good application will implement at least one, but likely several of these safeguards. A great application will implement all of them, regardless of those efforts seeming redundant or unnecessary. As a database professional, you'll want these protections, but cannot rely on them. It is your responsibility to ensure that all parameters that are passed into your TSQL are cleansed with the same level of diligence. Doing so on all layers of a software application ensures the highest level of protection in the event that mistakes are made.

SQL Server error messages should always be handled internally via code and never exposed to end users. Instead, provide them with a friendly error message and reporting instructions.

The simplest way to cleanse inputs is to directly address them at the start of the code. In an attempt to keep the sample code as easy to read as possible, we'll use stored procedures for any reusable code going forward. Listing 2-9 reconsiders the search from earlier and adds some basic input cleansing at the top.

Listing 2-9. Basic Input-Cleansing Search Procedure

```
CREATE PROCEDURE dbo.search_people
       (@search_criteria NVARCHAR(1000) = NULL) -- This comes from user input
AS
BEGIN
      SELECT @search_criteria = REPLACE(@search_criteria, '''', '''''');

      DECLARE @CMD NVARCHAR(MAX);

      SELECT @CMD = 'SELECT * FROM Person.Person
      WHERE LastName = ''';
      SELECT @CMD = @CMD + @search_criteria;
      SELECT @CMD = @CMD + '''';
      PRINT @CMD;
      EXEC sp_executesql @CMD;
END
GO

EXEC dbo.search_people 'Smith';
EXEC dbo.search_people 'O''Brien';
EXEC dbo.search_people ''' SELECT * FROM Person.Password; SELECT ''';
```

This stored procedure contains a single addition at the top: all instances of an apostrophe are replaced with a pair of apostrophes. This guarantees that if anyone enters apostrophes, they will not break the string and cause immediate errors or obvious SQL injection vulnerabilities. The results of each of the three executions are as follows:

```
SELECT * FROM Person.Person
         WHERE LastName = 'Smith'
SELECT * FROM Person.Person
         WHERE LastName = 'O''Brien'
SELECT * FROM Person.Person
         WHERE LastName = ''' SELECT * FROM Person.Password; SELECT '''
```

In the first example, `Smith` is entered and all people with the last name of Smith are returned as usual. When an `O'Brien` enters their last name, the apostrophe is doubled, his name is searched, and results are found normally, without any error messages. When any malicious users try to access passwords within the database, they are given an empty result set. Since the apostrophes are doubled in all cases, this string of attempted SQL injection turns into a harmless string with no holes in it.

SQL Server has a built-in function whose purpose is to ensure that string contents are correctly delimited. `QUOTENAME` takes two parameters: The string to be cleansed and the character that will be verified. The stored procedure in Listing 2-10 is similar to above, but the `REPLACE` operation has been updated to use `QUOTENAME` instead.

Listing 2-10. Input-Cleansing Search Procedure, Implemented Using QUOTENAME

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_people')
       DROP PROCEDURE search_people;
GO

CREATE PROCEDURE dbo.search_people
       (@search_criteria NVARCHAR(1000) = NULL) -- This comes from user input
AS
BEGIN
      DECLARE @CMD NVARCHAR(MAX);

      SELECT @CMD = 'SELECT * FROM Person.Person
      WHERE LastName = ';
      SELECT @CMD = @CMD + QUOTENAME(@search_criteria, '''');
      PRINT @CMD;
      EXEC sp_executesql @CMD;
END
GO
EXEC dbo.search_people 'Smith';
EXEC dbo.search_people 'O''Brien';
EXEC dbo.search_people ''' SELECT * FROM Person.Password; SELECT ''';
```

QUOTENAME handles the apostrophe cleansing for you, and as a result, you no longer need to wrap the last name portion of the command string in additional apostrophes. The output of this stored procedure is exactly the same as in the last example. Each name is correctly delimited with apostrophes to ensure that the search criteria will not cause any opportunities for errors to occur. In addition to apostrophes, QUOTENAME can be used to delimit square brackets ([,]), as well as a quotation mark (").

Parameterizing Dynamic SQL

Manually cleansing inputs using REPLACE or QUOTENAME is leaps and bounds better than having no protection at all. This will help prevent the most common SQL injection attacks, but is not perfect. Manual input cleansing ensures that certain character combinations are replaced with more desirable options, but they are still subject to your vigilance in escaping inputs everywhere they exist. This tends toward a manual process where the database developer must remember to correctly use REPLACE or QUOTENAME in conjunction with all Dynamic SQL statements.

A more reliable choice is to shift the responsibility from the developer to sp_executesql. This versatile stored procedure can accept input parameters, and in the process of doing so, will cleanse them automatically. Consider the new version of the stored procedure, as shown in Listing 2-11.

Listing 2-11. Parameterized Search Procedure

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_people')
       DROP PROCEDURE search_people;
GO
CREATE PROCEDURE dbo.search_people
       (@search_criteria NVARCHAR(50) = NULL) -- This comes from user input
```

```
AS
BEGIN
      DECLARE @CMD NVARCHAR(MAX);

      SELECT @CMD = 'SELECT * FROM Person.Person
      WHERE LastName = @search_criteria';
      PRINT @CMD;
      EXEC sp_executesql @CMD, N'@search_criteria
NVARCHAR(1000)', @search_criteria;
END
```

The syntax for parameterizing `sp_executesql` is broken into three parts:

- The command string to execute (`@CMD`)
- The parameter list, including data types for each (`N'@search_criteria NVARCHAR(1000)'`
- The parameters that are being passed in from the stored procedure (`@search_criteria`)

The results of this stored procedure are identical to each of the previous input cleansing examples. In this case, `sp_executesql` will handle the cleansing itself, ensuring that the inputs are correctly delimited, without the need from any further instruction from you. The parameter list may be stored as a separate variable as well. This can prove useful when there are many parameters, when you want to modify this list prior to execution, or when you want the `sp_executesql` command to be as short and clean as possible.

Listing 2-12. Parameterized Search Procedure Using a Separate Parameter Variable

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_people')
       DROP PROCEDURE search_people;
GO

CREATE PROCEDURE dbo.search_people
       (@search_criteria NVARCHAR(1000) = NULL) -- This comes from user input
AS
BEGIN
      DECLARE @CMD NVARCHAR(MAX);
      DECLARE @parameter_list NVARCHAR(MAX) = N'@search_criteria NVARCHAR(1000)';

      SELECT @CMD = 'SELECT * FROM Person.Person
      WHERE LastName = @search_criteria';
      PRINT @CMD;
      EXEC sp_executesql @CMD, @parameter_list, @search_criteria;
END
```

Notice the addition of the variable `@parameter_list`, which provides a separate place in which to store the list of input parameters. Adding this parameter is optional, but can help improve the readability of your Dynamic SQL execution statement.

Using `sp_executesql` and passing all parameters into it ensures that all inputs are properly delimited and that SQL injection will not be possible using those inputs.

The parameter list string (`@parameter_list`) contains all of the parameter names that correspond to the text within the Dynamic SQL command string. The input parameters (`@search_criteria`) correspond to the parameters that are being passed in from outside of the Dynamic SQL, listed individually. The parameter names in each list may be different, and the naming convention used is up to you. Exercise consistency, though, so that future developers are not left guessing with each line of TSQL.

How many parameters are allowed in an `sp_executesql` statement? The answer is based on the SQL Server built-in limit for parameters in a stored procedure. The limit for any stored procedure is 2100, but in the case of `sp_executesql`, the command string and parameter list count as parameters, leaving you with a 2098 parameter limit, which should be more than enough for even the wildest programmers!

The previous example illustrated a Dynamic SQL statement with a single parameter. Listing 2-13 shows how this would look with many parameters, naming the internal and external names differently.

Listing 2-13. Search Procedure with Multiple Optional Parameters

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_people')
    DROP PROCEDURE search_people;
GO

CREATE PROCEDURE dbo.search_people
        (@FirstName NVARCHAR(50) = NULL,
         @MiddleName NVARCHAR(50) = NULL,
         @LastName NVARCHAR(50) = NULL,
         @EmailPromotion INT = NULL)
AS
BEGIN
      DECLARE @CMD NVARCHAR(MAX);
      DECLARE @parameter_list NVARCHAR(MAX) = N'@FirstName NVARCHAR(50), @MiddleName
      NVARCHAR(50), @LastName NVARCHAR(50), @EmailPromotion INT';

      SELECT @CMD = 'SELECT * FROM Person.Person
      WHERE 1 = 1';
      IF @FirstName IS NOT NULL
              SELECT @CMD = @CMD + '
              AND FirstName = @FirstName'
      IF @MiddleName IS NOT NULL
              SELECT @CMD = @CMD + '
              AND MiddleName = @MiddleName'
      IF @LastName IS NOT NULL
              SELECT @CMD = @CMD + '
              AND LastName = @LastName'
      IF @EmailPromotion IS NOT NULL
              SELECT @CMD = @CMD + '
              AND EmailPromotion = @EmailPromotion';
      PRINT @CMD;
      EXEC sp_executesql @CMD, @parameter_list, @FirstName, @MiddleName, @LastName,
      @EmailPromotion;
END
```

There are a few interesting changes to the search proc here. First, there are now four parameters that are passed into the stored procedure. Note the syntax of the `sp_executesql` command: command string first, then the internal parameter list, and then each parameter passed in separately. It is important that the order of parameters in each list match; otherwise, you risk passing a first name in as a last name, or worse, passing a string where an integer is expected.

The second significant change in this stored procedure is that all parameters are optional. In order to facilitate this, "`WHERE 1 = 1`" is the first `WHERE` clause, followed by each parameter. This ensures that, if all parameters are `NULL`, you aren't left with a hanging `WHERE` keyword and no clauses following it; this would result in an error. Consider the following executions of the stored procedure:

```
EXEC dbo.search_people 'Edward', 'H', 'Johnson', 1
EXEC dbo.search_people 'Edward', NULL, NULL, 1
EXEC dbo.search_people
```

The first example provides values for all parameters and will return a single row from `Person.Person`. The TSQL command string will look like this:

```
SELECT * FROM Person.Person
       WHERE 1 = 1
                AND FirstName = @FirstName
                AND MiddleName = @MiddleName
                AND LastName = @LastName
                AND EmailPromotion = @EmailPromotion
```

The second example leaves the middle name and last name `NULL`, and the resulting command string is:

```
SELECT * FROM Person.Person
       WHERE 1 = 1
                AND FirstName = @FirstName
                AND EmailPromotion = @EmailPromotion
```

The final example provides no parameters, and illustrates the importance of the "`WHERE 1 = 1`" placeholder in order to maintain good syntax when you do not know what parameters (if any) will be supplied:

```
SELECT * FROM Person.Person
       WHERE 1 = 1
```

It is likely within any large application where the table you are searching contains thousands (or millions) of rows, that you would not want to allow an empty search like this. It is generally beneficial to require at least one search parameter, which prevents users from blindly returning everything. It is also worthwhile to limit the rows returned by the database to some relatively small number. Common defaults include 10, 25, 50, and 100, and this ensures that you never inadvertently allow users to query a table for millions of rows at one time.

Using `sp_executesql` is not enough to ensure protection against SQL injection. All parameters must explicitly be passed into `sp_executesql` as shown in the last few examples. If parameters are concatenated directly to the command string without passing them into `sp_executesql`, those inputs will be subject to SQL injection attacks by exploiting apostrophes as previously demonstrated, and as you will see in further examples later in this chapter. Always verify that there is no opportunity for users to have their search text directly incorporated into a command string without the appropriate input sanitation first!

Schema Name and Square Brackets

This convention applies to writing standard SQL as well as Dynamic SQL. When querying against dynamically defined database schema, such as tables, views, columns, or stored procedures, you can't parameterize the database objects. Without this protection, your TSQL is opened up to the potential for SQL injection attacks. Consider the TSQL search in Listing 2-14.

Listing 2-14. Dynamic Table Search with No SQL Injection Protection

```
DECLARE @table_name SYSNAME = 'ErrorLog';
DECLARE @CMD NVARCHAR(MAX);

SELECT @CMD = 'SELECT * FROM ' + @table_name;
PRINT @CMD;
EXEC sp_executesql @CMD;
```

When executed, this returns all rows in the table `ErrorLog`. As with the earlier examples, this search, which defines the table to be queried at runtime, can easily be targeted by SQL injection. The following sinister input for `@table_name` would result in the contents of `Person.Password` to be returned to the user, in addition to `ErrorLog`:

```
'ErrorLog; SELECT * FROM Person.Password WHERE '''' = ''''';
```

An easy defense against this is to explicitly include the schema name, even if it is the default. In addition, include square brackets around all objects, which will further delimit the SQL statement and restrict the ability.

Listing 2-15. Dynamic Table Search with Added Schema and Brackets

```
DECLARE @table_name SYSNAME = 'ErrorLog; SELECT * FROM Person.Password WHERE '''' = ''''';
DECLARE @CMD NVARCHAR(MAX);

SELECT @CMD = 'SELECT * FROM [dbo].[' + @table_name + ']';
PRINT @CMD;
EXEC sp_executesql @CMD;
```

Executing this new version will result in the following command string:

```
SELECT * FROM [dbo].[ErrorLog; SELECT * FROM Person.Password WHERE '' = '']
```

Executing that TSQL results in an error at runtime:

```
Msg 208, Level 16, State 1, Line 142
Invalid object name 'dbo.ErrorLog; SELECT * FROM Person.Password WHERE '' = '''.
```

Adding the schema and delimiting brackets caused that simple SQL injection attempt to fail. Assuming that the error message is caught by an application, and a friendly error returned, then the users will not know for certain what happened. This, of course, isn't foolproof, and very persistent hackers will continue entering attempts at command strings until they figure out the pattern and try this input:

```
'ErrorLog]; SELECT * FROM [Person].[Password'
```

By closing the square brackets and then reopening them with their table name, they've defeated the attempts to secure this query. While you could take further measures to complicate the command string to thwart a potential hacker, there would still be a security risk involved.

As stated earlier, any command string where all inputs are not parameterized using `sp_executesql` will be potentially vulnerable to SQL injection attacks. In general, avoid using database objects as Dynamic SQL parameters unless you are certain that there will be no external access to this system. Regardless of the audience, use `QUOTENAME` in order to properly delimit your parameters. While they cannot be passed in to `sp_executesql` directly, this will at least ensure that they cannot be exploited as shown previously.

For internal procedures to be used exclusively by DBAs or developers, these sorts of Dynamic SQL statements are reasonable, although caution should still be exercised. As soon as any unknown parties have access, such as non-technical departments, end users, or the Internet as a whole, the level of risk increases immensely. Always consider your audience before making stored procedures available to outside parties in any form, and ensure there is no way for them to exploit your code. Even if those procedures are internal and deemed safe, it is still important to utilize every security precaution and TSQL best practice. Seemingly unlikely events, such as rogue users, disgruntled employees, or social engineering attempts, happen far too often to be considered irrelevant under any conditions.

Effective Spacing

The example in Listing 2-6 showed a scenario where an attacker used comments to remove the password check in a login script. The primary cause of this vulnerability was the lack of parameterization or input sanitation, but a secondary cause was that the entire `WHERE` clause was on a single line.

I am unsure what possesses anyone to write Dynamic SQL mostly or all on a single line, but in addition to rendering it illegible, it also increases the ways in which SQL injection could be used to exploit a poorly written query. Writing Dynamic SQL with the same formatting and care that standard SQL is given will not only make it more maintainable, but will also remove a very simple SQL injection attack method from an attacker's arsenal.

Properly Type Inputs

In addition to sanitizing inputs, it is important to always use the correct data type for inputs. SQL injection specifically targets string inputs, in which apostrophes and malicious SQL can be inserted. Non-text data types, such as `BIT`, `INT`, or `DATETIME`, cannot be the target of SQL injection.

Some applications are written with all (or most) input parameters as strings, for convenience. When working with strings, there is no need to cast or convert them to strings when concatenating them with your Dynamic SQL command string. While this may reduce development time slightly, it increases the number of inputs in which SQL injection is theoretically possible.

If any data type is being evaluated that is not inherently a string, ensure that it is stored as a non-string at least until it has been passed into your stored procedure. Once execution has passed these parameters into TSQL, they can then be cast as strings and used in Dynamic SQL with no risk of SQL injection. If desired, string variables can be declared within a stored procedure, and then populated with the converted types from above. Since the conversion is internal to SQL Server and has no connection to outside of the stored procedure, it too is safe from SQL injection.

Always ensure that data is properly typed. Storing values as non-strings ensures that they cannot be the target of SQL injection.

Similarly, ensure that applications always verify inputs to ensure that they match the expected type. An integer that is passed into a TSQL statement as a string may allow arithmetic to be embedded safely in the string. If malicious users realize that they can replace `"5"` with `"5 + 1"`, then they will immediately begin to probe other non-string inputs to determine if they are converted blindly to strings. A parameter should be typed correctly from the moment it is entered by a user until it is consumed be a stored procedure. This prevents any opportunities for manipulation, in addition to reducing complexity and the chance that developers may make mistakes as a result of confusing data types.

Blind SQL Injection

Even if a hacker cannot gain complete access to the database server via SQL injection, they may still be able to use some query elements to slowly gain information about a server, its security settings, and data. This can be done through the SQL injection methods demonstrated previously, or by modifying URLs or other data that is passed directly to the application.

The simplest example of this attack is to modify an HTTP string in order to view data that would otherwise be inaccessible to the user, such as a user profile, personal pictures, or upcoming travel plans. This attack requires little or no TSQL knowledge, and therefore it is very common, and often one of the first attempts made against a web application. The defense against these attempts to steal data is to ensure that the web page itself does not allow URLs to be blindly modified. In addition, if user, client, or web browser data is verified with all requests to sensitive data, then denying unauthorized access becomes much easier.

If hackers can gain some SQL Server access via Dynamic SQL, but are limited by security restrictions, they can use their limited access to poke at the server and slowly discover limitations, security settings, data elements, and more. They will send requests in the form of `IF` statements that evaluate to true or false. Alternatively, the malicious users could ask questions that lead to error messages, and therefore determine the results by whether the statement throws an error or not. `TRY/CATCH` can be used to manage error messages, thereby reducing the impact of these queries on web or database logs. Delays can be used, as well, to help in diagnosing responses based on the time it takes for them to complete. Even if friendly errors are displayed, that information would confirm that they have enough access to query the server for information and succeed.

Listing 2-16 illustrates some simple examples of the sorts of blind SQL injection queries that might get targeted at a vulnerable server.

Listing 2-16. Example Queries that May Be Used in Blind SQL Injection Attacks

```
IF CURRENT_USER = 'dbo' SELECT 1 ELSE SELECT 0;

IF @@VERSION LIKE '%12.0%' SELECT 1 ELSE SELECT 0;

IF (SELECT COUNT(*) FROM Person.Person WHERE FirstName = 'Edward' AND LastName = 'Pollack') > 0
WAITFOR DELAY '00:00:05'
ELSE
WAITFOR DELAY '00:00:00';

BEGIN TRY
        DECLARE @sql_command NVARCHAR(MAX);
        SELECT @sql_command = 'SELECT COUNT(*) FROM dbo.password;'
        EXEC (@sql_command)
END TRY
BEGIN CATCH
        SELECT 0
END CATCH;
```

The first three examples use basic yes/no questions in an attempt to learn about the server. The last example is a bit sneaker and involves creating additional Dynamic SQL to probe database objects further without throwing database errors in the process. TRY/CATCH does not work if syntax errors are present, hence querying an invalid table would return error messages. Injecting or appending further Dynamic SQL allows an attacker to verify the existence of tables without causing syntax or parsing errors.

Blind SQL injection is a slower attack method, but it can over time reveal critical data about a system. Each query reveals a new piece of information, and with enough data, hackers may be able to alter/bypass security restrictions in order to execute queries in the same way as they would have if no security precautions were in place.

Detection and Prevention

Prevention is the optimal way to prevent SQL injection, but as with any large software system, there will be code that predates you and could contain security holes. How do we guard ourselves against existing threats, or those we have yet to identify?

Security Testing

It has become a regular security task for companies to have third-party vendors run penetration tests against their applications. This provides an opportunity for an unbiased external source to probe your environments for any of the common signs of SQL injection (or other vulnerabilities). Alternatively, these tests can be run internally if you have your own set of tools that are up to the task. This is an excellent way to find uncommon, old, or hidden vulnerabilities.

This sort of testing is often required in order to meet compliance standards, for example, with HIPAA (Health Insurance Portability and Accountability Act). If you work for a company or in an industry where sensitive data is stored by your software, conduct the necessary research to ensure that your security testing and verification are meeting your industry's compliance standards. Additional compliance may be necessary if you are doing business with customers in other countries.

The most common methods for detecting SQL injection vulnerabilities involve blindly populating application inputs with a variety of injection statements, in an attempt to generate application errors or coax unusual HTTP responses from a web page. For example, a set of valid searches is performed and the response time is measured. Next, SQL injection statements are supplied to the application. By comparing those response times, it is possible to determine if the injected SQL was executed or not.

Checking for error messages is also common. If a set of typical SQL injection statements can result in unusual application or SQL errors, then the possibility exists for further exploitation.

It is important to understand that while security companies possess a variety of tools as a method of defending you from SQL injection attacks, hackers also possess their own sets of similar tools. If any security vulnerability can be demonstrated, regardless of how improbable or obscure, it is likely that a hacker will also eventually discover and immediately take advantage of it.

Scanning of Application Traffic

Lightweight monitors can be put in place that will scan incoming traffic for unusual data patterns. For example, are common SQL commands or syntax being sent to your database servers from applications where only text is expected? Searching for semicolons, apostrophes, or TSQL keywords, such as `SELECT`, `WHERE`, and `FROM`, are effective ways to locate and manage the sources of hacking attempts.

While these scans can be very useful, their value is solely based on the ratio of valid information versus noise. The need to catch SQL injection attacks needs to be weighed against the potential that common SQL characters or keywords may be common amongst application traffic. Realistically, any application that is open to the Internet will be blindly targeted by hackers for common vulnerabilities.

If this is the case, then it is up to you to determine a baseline for an average day of traffic (without any actual attacks occurring). Once that is established, you can limit alerts to scenarios where suspicious activity is high enough to make you want to investigate further.

Log Review

Similar to monitoring network, application, or database traffic, you can regularly scan your web logs, application logs, or database error logs to determine if anything unusual or concerning is taking place. Similar searches can be made as with application traffic, and the results can be trended over time to produce an overview of SQL injection attempts, common targets, and sources.

Using this data, you can review the most common targets and ensure they are not vulnerable to SQL injection. In addition, you can analyze the sources of attacks to determine if any patterns exist. Many companies will block web traffic from specific countries, domains, or IP ranges, in order to remove risks while not affecting legitimate end user activity.

Note that password change requests are not logged by default, as a security precaution. As a result, if injected TSQL statements contain `sp_password`, they will evade the SQL Server logs (although they will still appear as normal in application or web logs). There are many available ways to audit password changes, a few of which will be covered in Chapter 4.

Code Review

All new application code should follow a review process by which an experienced developer reviews it, and all TSQL is reviewed by a DBA. If the database scripts include Dynamic SQL, it can be focused on, ensuring that no SQL injection vulnerabilities exist. Even if the review is quick and targeted, it is likely that any significant problems will be discovered and fixed. Even if only a single vulnerability were ever found, the process itself would be completely justified in its elimination.

For larger and older applications, a sequential reviews of existing code can provide an additional defense against attacks. While it may sound time consuming to review all existing code, you can greatly reduce the volume by filtering based on the presence of common mistakes. For example, for SQL injection review, you could specifically single out database scripts/objects and review only those that contain `EXEC`, `sp_executesql`, or `xp_cmdshell`.

Software Patching

Be sure to keep your servers up to date! In addition to SQL Server, stay current with service packs and patches for your operating system, application software, and any commonly used tools or frameworks. Vulnerabilities are discovered daily in many commonly used software products, and some could potentially allow unauthorized access to your data.

While SQL injection is typically associated with Dynamic SQL, it has been discovered in the past as a vulnerability where seemingly legitimate HTTP or command strings are passed from the web or another application directly to yours. The most readily available defense against unexpected attacks such as these is to regularly review application patch notes. If any relevant security holes are found, patch them immediately.

Limiting URL Length

As mentioned, it's possible for malicious SQL or application requests to be passed into an application via an HTTP request. Some web servers will not log the complete URL if it is too long. This is one possible way in which a hacker can probe your system for vulnerabilities without their actions being immediately noticed. They can create an unusually long URL with the hope that it will either be truncated, or not logged at all.

Most web servers allow you to set a limit on the allowable length of URL strings, and unless any applications require long URLs, setting that limit is beneficial. Although you can choose any limit, 2048 characters is common. As with security, only allow as much as is required for your application to operate normally (including future growth).

For example, in Microsoft IIS, when this limit is set, a longer URL will return a 404 error to the client with no further detail. The server logs, though, will include additional information as to why the request was blocked, so that you can identify potential threats:

```
404.10: Request Header Too Long

404.13: Content Length Too Long

404.14: URL Too Long

404.15: Query String Too Long
```

Use Views and/or Masking for Sensitive Data

When encrypted sensitive data needs to be accessed, such as with passwords or credit card numbers, consider only supplying permissions to views that provide the fewest fields necessary to service those queries. Denying direct access to critical tables removes the ability of hackers to access them, and therefore to use SQL injection to infiltrate them.

For example, a password table may have a variety of information that could not only give away password hash details, but also password policies, usernames, locked accounts, recent login times, and more. The application likely only needs access to the encrypted password (or hash) and positive identifying data (such as a user ID).

SQL Server 2016 includes a new security feature: *Dynamic Data Masking*. This can be extremely effective for any scenarios where part of sensitive data is needed, such as the last four digits of a social security number or credit card number. For users without the `UNMASK` permission, a predetermined segment of the sensitive data will be obscured. This added layer of data obfuscation provides an extra defense against an unauthorized user gaining the complete details of your important data.

Data masking, while convenient, is not intended to be a hardened security feature. As of SQL Server 2016 CTP 2.1, it is possible to partially unmask data using a `CAST` of the column to its underlying data type, which would partially defeat the process and revert it to default masking. There are a few other hacks available that involve joining masked tables to secondary tables and the data being unmasked as it is selected from the resulting join. These are very likely to be fixed in the public release of SQL Server 2016, but for the moment, they are legitimate concerns.

Despite these limitations, Dynamic Data Masking is another lock on the vault that is critical data, and one that will either dissuade hackers from proceeding, or slow them down enough that your security team has extra time to respond to the threat head-on. When only data validation is needed, not full access to that data, this is an excellent tool for providing only what is needed and nothing more.

Conclusion

SQL injection is one of the top vulnerabilities exploited throughout the entire process of application development. In fact, many governmental, corporate, and independent surveys have consistently flagged SQL injection as the #1 vulnerability in all of computing. This is clearly a very serious topic and one you must keep in mind on a regular basis as you design, develop, test, deploy, and maintain a software application.

The easiest and most effective way to protect against SQL injection is to be proactive and write secure TSQL and code. Consider how user inputs will be integrated into search parameters and ultimately database queries. Once those sensitive areas are located, address them with multiple levels of security. Implementing `sp_executesql` is a good start, but adding input verification, parameterization, and explicit schema references will be even more effective. Depending on your application, take as many additional steps as practical, as each will be another lock on the vault that is your data.

If the time and effort required for these additional steps is ever questioned by management, feel free to explain to them the vulnerabilities that you are addressing. List the potential threats and the consequences of them being realized. Security is often seen as an inconvenience, but it is your responsibility as the database professional to justify its necessity and ensure that your data is as secure as possible. Never let doing the “right” thing with regard to security be entangled with release dates, efficiency, or resources. The consequences of disregarding what are relatively simple development steps are too high to shrug off.

Chapter 4 discusses security in further detail. SQL injection is significant enough to warrant a separate and special place in the hierarchy of SQL Server security. Documenting your efforts and the threats they address will justify themselves in the long run.

CHAPTER 3

Large Scale Searching

One of the most common, versatile, and useful ways to implement Dynamic SQL is when performing complex searches. Consider your favorite web sites and the search functionality provided in each. For some, the search may be simple: You go to the single text box in the top-right corner, enter some text, and get your results. Other searches—such as searching for a hotel, flight, or car rental—can involve dozens (or more) of optional parameters. Dynamic SQL can allow you to pare down your search queries in order to only process what is needed. In addition, you can greatly customize the search, as well as the data returned. You can even analyze the input to determine the correct course of action, based on its structure.

Why Use Dynamic Searches?

Let's say you want to search through a table of products, but need to join this data to other tables along the way. Depending on the application, the number of tables could be small, or they could be immense. For the hotel search, you may very well need to join 50 tables if you wanted to query on every single possible search parameter. Listing 3-1 is an example of a relatively small product search that could benefit from the use of Dynamic SQL.

Listing 3-1. Search Stored Procedure, with Six Optional Parameters (No Dynamic SQL)

```
CREATE PROCEDURE dbo.search_products
@product_name NVARCHAR(50) = NULL, @product_number NVARCHAR(25) = NULL, @product_model
NVARCHAR(50) = NULL,   @product_subcategory NVARCHAR(50) = NULL, @product_sizemeasurecode
NVARCHAR(50) = NULL, @product_weightunitmeasurecode NVARCHAR(50) = NULL
AS
BEGIN
      SET NOCOUNT ON;

      SET @product_name = '%' + @product_name + '%';
      SET @product_number = '%' + @product_number + '%';
      SET @product_model = '%' + @product_model + '%';

      SELECT
             Product.Name AS product_name,
             Product.ProductNumber AS product_number,
             ProductModel.Name AS product_model_name,
             ProductSubcategory.Name AS product_subcategory_name,
             SizeUnitMeasureCode.Name AS size_unit_measure_code,
             WeightUnitMeasureCode.Name AS weight_unit_measure_code
```


E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_3

```
    FROM Production.Product
    LEFT JOIN Production.ProductModel
    ON Product.ProductModelID = ProductModel.ProductModelID
    LEFT JOIN Production.ProductSubcategory
    ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID
    LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
    ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
    LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
    ON Product.WeightUnitMeasureCode = WeightUnitMeasureCode.UnitMeasureCode
    WHERE (Product.Name LIKE @product_name OR @product_name IS NULL)
    AND (Product.ProductNumber LIKE @product_number OR @product_number IS NULL)
    AND (ProductModel.Name LIKE @product_model OR @product_model IS NULL)
    AND (ProductSubcategory.Name = @product_subcategory OR @product_subcategory IS NULL)
    AND (SizeUnitMeasureCode.Name = @product_sizemeasurecode OR @product_sizemeasurecode
    IS NULL)
    AND (WeightUnitMeasureCode.Name = @product_weightunitmeasurecode OR @product_
    weightunitmeasurecode IS NULL);
END
```

This stored procedure will search for products and has a variety of search options available for the users to choose from. Product name, product number, product model, product subcategory, size measure, and weight measure may all be provided or omitted from the user's input. It is assumed for this specific example that product name, product number, and product model are wildcard searches, hence the addition of `%` to each parameter after it is passed in. The other parameters are assumed to be selected from a pre-populated menu, ensuring that any values passed in will be exact, and therefore there is no need to make those into wildcard searches.

In the case of this search, we will always return the same six columns, regardless of the parameters passed in. As a result, we will `LEFT JOIN` all participating tables to ensure that we get a row per product, even if any join criteria are `NULL`. In order to ensure that no results are omitted for unused parameters, an additional check is added to all `WHERE` clauses such that, if the input is `NULL`, it will evaluate to true. The resulting logic allows you to choose one of the following:

- A parameter is passed in from user input and should be evaluated against the appropriate column. The `NULL` check evaluates to `FALSE` and has no bearing on this logic.
- A parameter is not passed in from the user, and therefore the comparison against it is irrelevant. Instead, the `NULL` check evaluates to true, which means the entire `WHERE` clause evaluates to `TRUE`.

The following three examples illustrate how this works:

```
EXEC dbo.search_products @product_number = 'BK-M18', @product_model = 'Mountain',
@product_subcategory = 'Mountain Bikes';
```

In this search, three parameters are provided and you will search for any product that has a product number that includes `BK-M18`, a product model that includes the word "Mountain" and must be in the sub-category of "Mountain Bikes". The other three parameters do not participate in the `WHERE` clause and are evaluated against the second `NULL` check instead. Ten results are returned that fit these specifications.

```
EXEC dbo.search_products @product_name = 'Mountain-500 Black, 48';
```

Here, the user knows exactly what they are looking for, and enter a specific product name. All other parameters are NULL and are discarded from the search logic. A single row is returned with the product they were searching for.

```
EXEC dbo.search_products;
```

In this last example, the user enters no search criteria and simply runs an empty search. The stored procedure allows this; every product is returned. All inputs are `NULL` and therefore they bypass the `WHERE` clause predicate.

In reviewing this stored procedure, it is accurate, returning the expected results, but it is also somewhat lengthy and evaluates quite a few `WHERE` clause predicates in order to accomplish its goals. The TSQL that is executed is very similar, regardless of what parameters are provided, which could be problematic when you are evaluating many parameters.

As business logic grows and becomes more complex over time, it is a given that these queries will also grow and increase in size and complexity. A simple `LEFT JOIN` on one column may no longer be enough to handle this new logic. `WHERE` clauses may have additional options attached to them, such as the ability to be wildcard searches, equality searches, include `AND`/`OR` logic, and more. While this stored procedure may continue to grow over time in order to encompass all of these new requirements, you definitely do not want the resulting TSQL that is executed to grow indefinitely. Performance will become problematic when you are joining dozens of tables, issuing subqueries, running existence checks, and issuing complex `WHERE` clauses. This is where Dynamic SQL comes in! See Listing 3-2 for an example of using parameters to limit joins.

Listing 3-2. Search Stored Procedure with Six Optional Parameters (Using Dynamic SQL)

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_products')
BEGIN
      DROP PROCEDURE dbo.search_products;
END
GO

CREATE PROCEDURE dbo.search_products
       @product_name NVARCHAR(50) = NULL, @product_number NVARCHAR(25) = NULL,
       @product_model NVARCHAR(50) = NULL,
       @product_subcategory NVARCHAR(50) = NULL, @product_sizemeasurecode NVARCHAR(50) = NULL,
       @product_weightunitmeasurecode NVARCHAR(50) = NULL
AS
BEGIN
       SET NOCOUNT ON;

       SET @product_name = '%' + @product_name + '%';
       SET @product_number = '%' + @product_number + '%';
       SET @product_model = '%' + @product_model + '%';

       DECLARE @sql_command NVARCHAR(MAX);
       DECLARE @parameter_list NVARCHAR(MAX) = '@product_name NVARCHAR(50),
       @product_number NVARCHAR(25),
       @product_model NVARCHAR(50), @product_subcategory NVARCHAR(50),
       @product_sizemeasurecode NVARCHAR(50),
       @product_weightunitmeasurecode NVARCHAR(50)';
```

```
	SELECT @sql_command = '
	SELECT
		Product.Name AS product_name,
		Product.ProductNumber AS product_number,
		ProductModel.Name AS product_model_name,
		ProductSubcategory.Name AS product_subcategory_name,
		SizeUnitMeasureCode.Name AS size_unit_measure_code,
		WeightUnitMeasureCode.Name AS weight_unit_measure_code
	FROM Production.Product
	LEFT JOIN Production.ProductModel
	ON Product.ProductModelID = ProductModel.ProductModelID
	LEFT JOIN Production.ProductSubcategory
	ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID
	LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
	ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
	LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
	ON Product.WeightUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
	WHERE 1 = 1'
	IF @product_name IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND Product.Name LIKE @product_name'
	IF @product_number IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND Product.ProductNumber LIKE @product_number'
	IF @product_model IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND ProductModel.Name LIKE @product_model'
	IF @product_subcategory IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND ProductSubcategory.Name = @product_subcategory'
	IF @product_sizemeasurecode IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND SizeUnitMeasureCode.Name = @product_sizemeasurecode'
	IF @product_weightunitmeasurecode IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND WeightUnitMeasureCode.Name = @product_weightunitmeasurecode'

	PRINT @sql_command;
	EXEC sp_executesql @sql_command, @parameter_list, @product_name, @product_number,
	@product_model, @product_subcategory, @product_sizemeasurecode,
	@product_weightunitmeasurecode
END
```

This stored procedure uses Dynamic SQL to provide you with complete control over the `WHERE` clause. Instead of there always being six checks on all columns, you now only include a check when the relevant parameter is supplied. Consider the first example from earlier:

```
EXEC dbo.search_products @product_number = 'BK-M18', @product_model = 'Mountain',
@product_subcategory = 'Mountain Bikes';
```

Earlier, the search used all six WHERE clause sections, one per parameter, even when the parameter was NULL. With the new Dynamic SQL version, the resulting command string will only include WHERE clause sections for parameters that are not NULL, as shown in Listing 3-3.

Listing 3-3. Output from the Stored Procedure in Listing 3-2

```
SELECT
       Product.Name AS product_name,
       Product.ProductNumber AS product_number,
       ProductModel.Name AS product_model_name,
       ProductSubcategory.Name AS product_subcategory_name,
       SizeUnitMeasureCode.Name AS size_unit_measure_code,
       WeightUnitMeasureCode.Name AS weight_unit_measure_code
FROM Production.Product
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID
LEFT JOIN Production.ProductSubcategory
ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID
LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
ON Product.WeightUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
WHERE 1 = 1
       AND Product.ProductNumber LIKE @product_number
       AND ProductModel.Name LIKE @product_model
       AND ProductSubcategory.Name = @product_subcategory
```

Note that only the necessary WHERE clause segments are included. WHERE 1 = 1 is always present, regardless of the input parameters. While it’s possible to add some logic to remove the need for the default WHERE clause, its inclusion comes at no significant cost and avoids adding any further complex logic to the growing stored procedure.

Custom Search Grids

At the moment, it may seem as though all this trouble to shrink the WHERE clause isn’t worth it, but this is only the beginning! The next logical step is to examine another common use case for large-scale searching: Custom search grids. In this slightly different search, the output columns are controlled by the user as well. Above, you returned the same six columns for every search, but this is an unlikely scenario for any large application that wants to incorporate any level of flexibility into its search functionality.

There are two fundamental ways in which to approach these types of searches. The first is to include all columns and joins in every query. The application can then pick and choose which are needed and which ones to discard. For this option, instead of selecting six output columns, you would add every possible one that could be requested by the end users in their custom results grid. For very small tables, this would be functional and relatively maintainable, but consider when there are immense numbers of possible columns to choose from, such as in the File Explorer window shown in Figure 3-1.

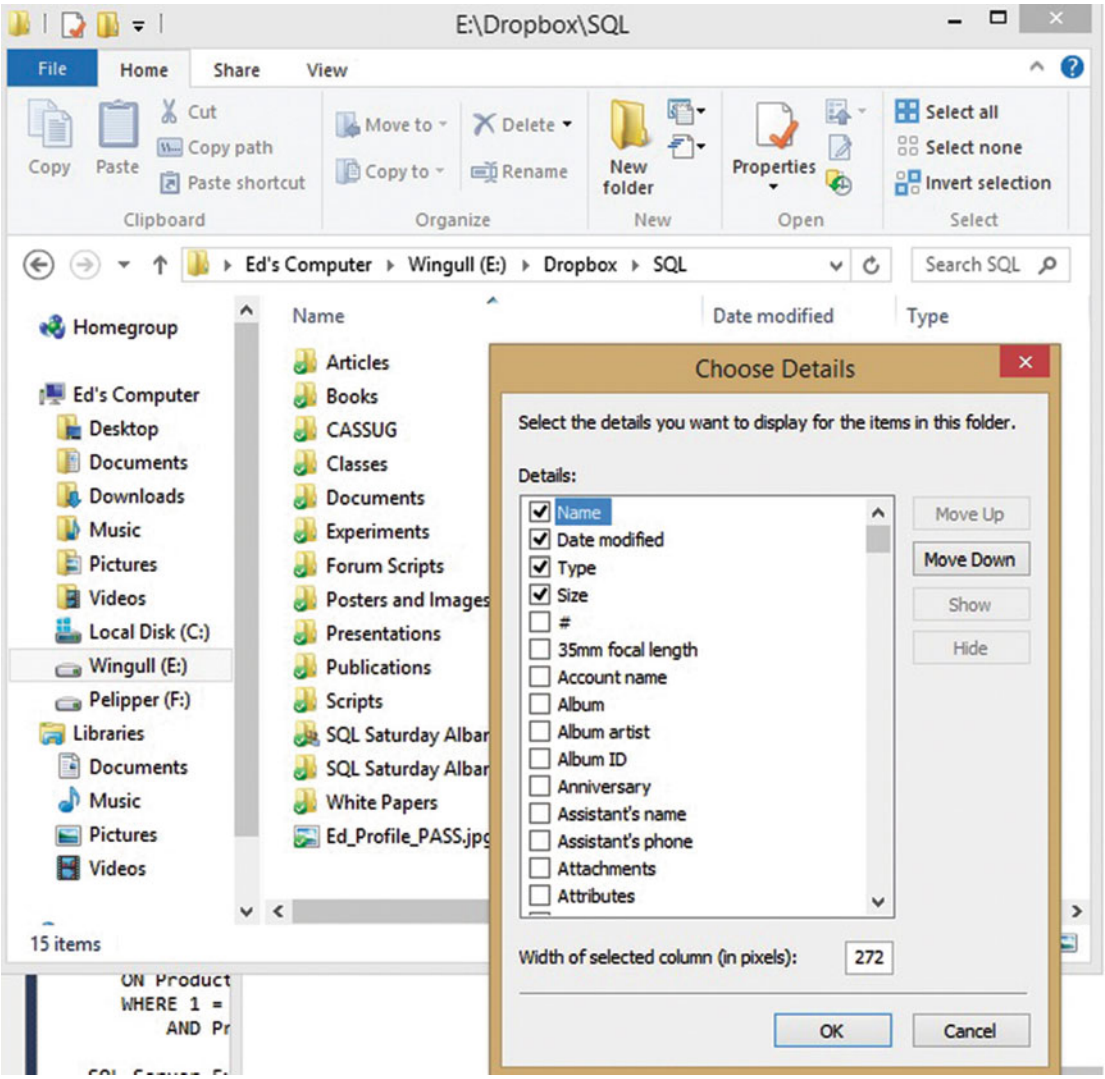


Figure 3-1. *Windows File Explorer column chooser*

In this column chooser, there are hundreds of columns to choose from, and the idea of always collecting all of this data, regardless of the user's needs, is quite scary. There are many file types for which only a small number of these choices would make sense to include, and collecting all of this data for every folder accessed would be inefficient and difficult to effective maintain.

If you were to apply this logic to the stored procedure and include all possible columns from each of the six tables you queried, you would have to list 38 columns to ensure that the end user had everything they could potentially need from these entities. If every table relating to products in AdventureWorks was added to the search query, the end result would contain hundreds of columns and be quite the challenge to ensure good performance. The downside of selecting everything extends to network IO, disk IO, memory, and server CPU, in addition to the performance of SQL Server in processing the query. All of this extra data would need to be moved from the database to the application before it could finally be sorted out and the extra columns removed from the data set.

The second and more versatile solution for implementing a search grid is to make each part of the query dynamic. In addition to the WHERE clause, make the joins and the columns selected dynamic. This ensures that the command string that you ultimately execute is relatively small, only reads from the tables you need, and only returns the columns you want. To keep this example easy to read, assume that the product name and product number will always be returned. There will also be a set of bits that can be passed in that will determine what other columns are chosen, which include some of the filter columns, as shown in Listing 3-4.

Listing 3-4. Search Grid Stored Procedure Using Dynamic SQL

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_products')
BEGIN
      DROP PROCEDURE dbo.search_products;
END

CREATE PROCEDURE dbo.search_products
       @product_name NVARCHAR(50) = NULL, @product_number NVARCHAR(25) = NULL,
       @product_model NVARCHAR(50) = NULL,
       @product_subcategory NVARCHAR(50) = NULL, @product_sizemeasurecode NVARCHAR(50) = NULL,
       @product_weightunitmeasurecode NVARCHAR(50) = NULL,
       @show_color BIT = 0, @show_safetystocklevel BIT = 0, @show_reorderpoint BIT = 0,
       @show_standard_cost BIT = 0,
       @show_catalog_description BIT = 0, @show_subcategory_modified_date BIT = 0,
       @show_product_model BIT = 0,
       @show_product_subcategory BIT = 0, @show_product_sizemeasurecode BIT = 0,
       @show_product_weightunitmeasurecode BIT = 0
AS
BEGIN
       SET NOCOUNT ON;
       -- Add "%" delimiters to parameters that will be searched as wildcards.
       SET @product_name = '%' + @product_name + '%';
       SET @product_number = '%' + @product_number + '%';
       SET @product_model = '%' + @product_model + '%';

       DECLARE @sql_command NVARCHAR(MAX);
       -- Define the parameter list for filter criteria
       DECLARE @parameter_list NVARCHAR(MAX) = '@product_name NVARCHAR(50),
       @product_number NVARCHAR(25),
       @product_model NVARCHAR(50), @product_subcategory NVARCHAR(50),
       @product_sizemeasurecode NVARCHAR(50),
       @product_weightunitmeasurecode NVARCHAR(50)';

       -- Generate the command string section for the SELECT columns
       SELECT @sql_command = '
       SELECT
              Product.Name AS product_name,
              Product.ProductNumber AS product_number,';
              IF @show_product_model = 1 SELECT @sql_command = @sql_command + '
                    ProductModel.Name AS product_model_name,';
```

```
        IF @show_product_subcategory = 1 SELECT @sql_command = @sql_command + '
              ProductSubcategory.Name AS product_subcategory_name,';
        IF @show_product_sizemeasurecode = 1 SELECT @sql_command = @sql_command + '
               SizeUnitMeasureCode.Name AS size_unit_measure_code,';
        IF @show_product_weightunitmeasurecode = 1 SELECT @sql_command =
        @sql_command + '
              WeightUnitMeasureCode.Name AS weight_unit_measure_code,';
        IF @show_color = 1 SELECT @sql_command = @sql_command + '
              Product.Color AS product_color,';
        IF @show_safetystocklevel = 1 SELECT @sql_command = @sql_command + '
              Product.SafetyStockLevel AS product_safety_stock_level,';
        IF @show_reorderpoint = 1 SELECT @sql_command = @sql_command + '
              Product.ReorderPoint AS product_reorderpoint,';
        IF @show_standard_cost = 1 SELECT @sql_command = @sql_command + '
              Product.StandardCost AS product_standard_cost,';
        IF @show_catalog_description = 1 SELECT @sql_command = @sql_command + '
              ProductModel.CatalogDescription AS productmodel_catalog_description,';
        IF @show_subcategory_modified_date = 1 SELECT @sql_command = @sql_command + '
              ProductSubcategory.ModifiedDate AS product_subcategory_modified_date';
-- In the event that there is a comma at the end of our command string, remove it
before continuing:
IF (SELECT SUBSTRING(@sql_command, LEN(@sql_command), 1)) = ','
       SELECT @sql_command = LEFT(@sql_command, LEN(@sql_command) - 1);
SELECT @sql_command = @sql_command + '
FROM Production.Product'
-- Put together the JOINs based on what tables are required by the search.
IF (@product_model IS NOT NULL OR @show_product_model = 1 OR
@show_catalog_description = 1)
       SELECT @sql_command = @sql_command + '
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID';
IF (@product_subcategory IS NOT NULL OR @show_subcategory_modified_date = 1 OR @show_
product_subcategory = 1)
       SELECT @sql_command = @sql_command + '
LEFT JOIN Production.ProductSubcategory
ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID';
IF (@product_sizemeasurecode IS NOT NULL OR @show_product_sizemeasurecode = 1)
       SELECT @sql_command = @sql_command + '
LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode';
IF (@product_weightunitmeasurecode IS NOT NULL OR @show_product_
weightunitmeasurecode = 1)
       SELECT @sql_command = @sql_command + '
LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
ON Product.WeightUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode'

SELECT @sql_command = @sql_command + '
WHERE 1 = 1'
-- Build the WHERE clause based on which tables are referenced and required by the
search.
```

```
	IF @product_name IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND Product.Name LIKE @product_name'
	IF @product_number IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND Product.ProductNumber LIKE @product_number'
	IF @product_model IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND ProductModel.Name LIKE @product_model'
	IF @product_subcategory IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND ProductSubcategory.Name = @product_subcategory'
	IF @product_sizemeasurecode IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND SizeUnitMeasureCode.Name = @product_sizemeasurecode'
	IF @product_weightunitmeasurecode IS NOT NULL
		SELECT @sql_command = @sql_command + '
		AND WeightUnitMeasureCode.Name = @product_weightunitmeasurecode'

	PRINT @sql_command;
	EXEC sp_executesql @sql_command, @parameter_list, @product_name, @product_number,
	@product_model, @product_subcategory, @product_sizemeasurecode,    @product_
	weightunitmeasurecode
END
GO

EXEC dbo.search_products @product_number = 'BK-M18', @product_model = 'Mountain', @product_
subcategory = 'Mountain Bikes';
EXEC dbo.search_products @product_name = 'Mountain-500 Black, 48';
EXEC dbo.search_products;
GO
```

The first change here is that there are ten new parameters that correspond to each column that can be added to the search results grid. This looks a bit haphazard, although an explicit parameter list is convenient for easy troubleshooting. Each is explicitly named and easy to understand and document. One alternative to the use of individual bits is to implement a bitmap and adjust individual bits within a single parameter. This reduces the parameter list from one per parameter down to one, but will also reduce readability and maintainability, as the parameter will now be a hexadecimal number instead of a set of bits. For example, if bit 1, bit 6, and bit 7 were selected, the resulting `VARBINARY` representation of that bitmap would be `0x00000061`. In order to make this usable and maintainable, each bit would need to be documented so that anyone who modifies or works with this stored procedure would know exactly how it works.

While this stored procedure has many parameters, most will not be needed at any one time, unless the end user truly wants to filter on and display everything. Note that the additional bit columns are not included in the parameters for `sp_executesql`. These bit columns are used in building the command string only, but are not required within the Dynamic SQL. As a result, adding additional bits does not cause the `sp_executesql` statement to grow, although it will add more parameters to the `search_products` stored procedure. As a result, the `sp_executesql` statement is the same in this example as it was in the previous one.

The column list has been broken into a series of parameter checks as well. Any optional column is included only if its respective bit column is set. For example, if `@show_product_model` is set to 1, then the `ProductModel.Name` column will be included in the `SELECT` statement. The following `EXEC` statement illustrates a single filter on `ProductModel.Name` and the inclusion of that name, as well as the product color:

```
EXEC dbo.search_products @product_model = 'Mountain', @show_product_model = 1, @show_color = 1
```

The resulting command string for this search is shown in Listing 3-5.

Listing 3-5. Command String Generated from Stored Procedure in Listing 3-4

```
SELECT
       Product.Name AS product_name,
       Product.ProductNumber AS product_number,
       ProductModel.Name AS product_model_name,
       Product.Color AS product_color
FROM Production.Product
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID
WHERE 1 = 1
      AND ProductModel.Name LIKE @product_model
```

Note that the actual TSQL executed is only what is needed to service the user's request and nothing more. All sections of the query were customized in order to meet the exact search that was requested.

The example here only returns columns that are explicitly called out by the user. If desired, the TSQL can be written such that you return all columns in a table if any one of them is selected, or just the columns that could be selected by the end user. Using this methodology, if `@show_product_model = 1`, then `ProductModel.Name` and `ProductModel.CatalogDescription` would be selected. The application could then remove any unneeded columns. This alternative would be easier to maintain and update over time, but would sacrifice a small amount of performance, as more data would be returned than is needed, as shown in Listing 3-6.

Listing 3-6. Search Proc with a Simplified SELECT Statement Using Fewer Conditionals

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_products')
BEGIN
      DROP PROCEDURE dbo.search_products;
END
GO

-- Search with a check to avoid empty searches
CREATE PROCEDURE dbo.search_products
       @product_name NVARCHAR(50) = NULL, @product_number NVARCHAR(25) = NULL,
       @product_model NVARCHAR(50) = NULL,
       @product_subcategory NVARCHAR(50) = NULL, @product_sizemeasurecode NVARCHAR(50) = NULL,
       @product_weightunitmeasurecode NVARCHAR(50) = NULL,
       @show_color BIT = 0, @show_safetystocklevel BIT = 0, @show_reorderpoint BIT = 0,
       @show_standard_cost BIT = 0,
```

```
        @show_catalog_description BIT = 0, @show_subcategory_modified_date BIT = 0,
        @show_product_model BIT = 0,
        @show_product_subcategory BIT = 0, @show_product_sizemeasurecode BIT = 0,
        @show_product_weightunitmeasurecode BIT = 0
AS
BEGIN
      SET NOCOUNT ON;

      IF COALESCE(@product_name, @product_number, @product_model, @product_subcategory,
                    @product_sizemeasurecode, @product_weightunitmeasurecode) IS NULL
            RETURN;

      -- Add "%" delimiters to parameters that will be searched as wildcards.
      SET @product_name = '%' + @product_name + '%';
      SET @product_number = '%' + @product_number + '%';
      SET @product_model = '%' + @product_model + '%';

      DECLARE @sql_command NVARCHAR(MAX);
      -- Define the parameter list for filter criteria
      DECLARE @parameter_list NVARCHAR(MAX) = '@product_name NVARCHAR(50),
      @product_number NVARCHAR(25),
      @product_model NVARCHAR(50), @product_subcategory NVARCHAR(50),
      @product_sizemeasurecode NVARCHAR(50),
      @product_weightunitmeasurecode NVARCHAR(50)';

-- Generate the simplified command string section for the SELECT columns
SELECT @sql_command = '
      SELECT
             Product.Name AS product_name,
             Product.ProductNumber AS product_number,';
             IF @show_product_model = 1 OR @show_catalog_description = 1 SELECT
             @sql_command = @sql_command + '
                   ProductModel.Name AS product_model_name,
                   ProductModel.CatalogDescription AS productmodel_catalog_description,';
              IF @show_product_subcategory = 1 OR @show_subcategory_modified_date = 1 SELECT
              @sql_command = @sql_command + '
                   ProductSubcategory.Name AS product_subcategory_name,
                   ProductSubcategory.ModifiedDate AS product_subcategory_modified_date,';
              IF @show_product_sizemeasurecode = 1 SELECT @sql_command = @sql_command + '
                   SizeUnitMeasureCode.Name AS size_unit_measure_code,';
              IF @show_product_weightunitmeasurecode = 1 SELECT @sql_command = @sql_command + '
                   WeightUnitMeasureCode.Name AS weight_unit_measure_code,';
              IF @show_color = 1 OR @show_safetystocklevel = 1 OR @show_reorderpoint = 1 OR
              @show_standard_cost = 1
              SELECT @sql_command = @sql_command + '
                   Product.Color AS product_color,
                   Product.SafetyStockLevel AS product_safety_stock_level,
                   Product.ReorderPoint AS product_reorderpoint,
                   Product.StandardCost AS product_standard_cost';
```

```
-- In the event that there is a comma at the end of our command string, remove it
before continuing:
IF (SELECT SUBSTRING(@sql_command, LEN(@sql_command), 1)) = ','
        SELECT @sql_command = LEFT(@sql_command, LEN(@sql_command) - 1);
SELECT @sql_command = @sql_command + '
FROM Production.Product'
-- Put together the JOINs based on what tables are required by the search.
IF (@product_model IS NOT NULL OR @show_product_model = 1 OR @show_catalog_
description = 1)
        SELECT @sql_command = @sql_command + '
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID';
IF (@product_subcategory IS NOT NULL OR @show_subcategory_modified_date = 1 OR @show_
product_subcategory = 1)
        SELECT @sql_command = @sql_command + '
LEFT JOIN Production.ProductSubcategory
ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID';
IF (@product_sizemeasurecode IS NOT NULL OR @show_product_sizemeasurecode = 1)
        SELECT @sql_command = @sql_command + '
LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode';
IF (@product_weightunitmeasurecode IS NOT NULL OR @show_product_
weightunitmeasurecode = 1)
        SELECT @sql_command = @sql_command + '
LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
ON Product.WeightUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode'

SELECT @sql_command = @sql_command + '
WHERE 1 = 1'
-- Build the WHERE clause based on which tables are referenced and required by the
search.
IF @product_name IS NOT NULL
        SELECT @sql_command = @sql_command + '
        AND Product.Name LIKE @product_name'
IF @product_number IS NOT NULL
        SELECT @sql_command = @sql_command + '
        AND Product.ProductNumber LIKE @product_number'
IF @product_model IS NOT NULL
        SELECT @sql_command = @sql_command + '
        AND ProductModel.Name LIKE @product_model'
IF @product_subcategory IS NOT NULL
        SELECT @sql_command = @sql_command + '
        AND ProductSubcategory.Name = @product_subcategory'
IF @product_sizemeasurecode IS NOT NULL
        SELECT @sql_command = @sql_command + '
        AND SizeUnitMeasureCode.Name = @product_sizemeasurecode'
IF @product_weightunitmeasurecode IS NOT NULL
        SELECT @sql_command = @sql_command + '
        AND WeightUnitMeasureCode.Name = @product_weightunitmeasurecode'
```

```
    PRINT @sql_command;
    EXEC sp_executesql @sql_command, @parameter_list, @product_name, @product_number,
    @product_model, @product_subcategory, @product_sizemeasurecode,   @product_
    weightunitmeasurecode
END
GO
```

The TSQL in Listing 3-6 shows the difference that using fewer conditionals makes. The resulting command string will potentially contain some extra columns, but the stored procedure has become simpler, with five conditionals, instead of 10. Consider this an alternative for smaller searches, or those where the data sets are straightforward. If the number of columns required per table were to increase in the future, this might need to be redesigned to maintain efficient query execution. Alternatively, for very small tables, `SELECT TableName.*` could also be used to further reduce the size of the stored procedure. The following TSQL shows this change for the `ProductModel` table:

```
IF @show_product_model = 1 OR @show_catalog_description = 1 SELECT @sql_command =
@sql_command + '
              ProductModel.*,';
```

While simple, this would return an indeterminate number of columns, which could become a bottleneck in the future if tables continue to add new columns. In addition, with this syntax, you lose control over the column names, which could result in duplicates in a case where many tables use the same column names for different data elements. In `AdventureWorks`, you would have no way to differentiate between the product name and the product model name, as both columns are simply called `Name`. Please use caution whenever returning all columns from a table using *. This can be a useful tool for a small table with a very predictable and unchanging structure. On the other hand, if the table changes, this stored procedure could easily break or return additional unexpected data.

The joins in this dynamic search only happen when a column is required from a table. This occurs if a column is explicitly requested via an input parameter bit, or if it is filtered on.

The combination of dynamic joins, dynamic `SELECT` statement, and dynamic `WHERE` ensures that you do not access any table that isn't required for the search grid. While the stored procedure has become larger, the command strings generated by it are shrinking, which is the primary goal of this exercise.

Search Grid Considerations

The stored procedure presented in the previous section is a huge leap forward in terms of customization, but it is more complex than the previous searches. With any added complexity comes a variety of considerations that will help in making intelligent design decisions, as well as avoid pitfalls associated with this level of flexibility.

Disallowing Blank Searches

A common theme throughout all of the searches so far has been to provide the end users with as much control as possible over what they see and can filter on. This can potentially be dangerous, though, if the data set is large and users request a huge amount of that data. It's generally a good practice to not allow users to perform a blank search unless the data set is sufficiently small, or paged in such a way that it won't be a strain on the database server. That is, if they go to the search page and click Go without providing any additional details, the program should either do nothing or return an error:

```
IF COALESCE(@product_name, @product_number, @product_model, @product_subcategory,
@product_sizemeasurecode, @product_weightunitmeasurecode) IS NULL
      RETURN;
```

This additional COALESCE statement at the start of the stored procedure will immediately exit if none of the filter criteria is populated. Consider these EXEC statements:

```
EXEC dbo.search_products @show_product_model = 1;
EXEC dbo.search_products;
```

For both of these search attempts, the stored procedure will exit as soon as it reaches the COALESCE check. If preferred, RAISEERROR can be used to throw a specific error back to the application that the search originated from. Regardless, it's up the application to handle scenarios where no data set is returned or an error is thrown and to ensure that the end users receive a friendly and helpful message that explains why their search was invalid.

Data Paging

It is rare that you would want to blindly return all rows in a result set. Consider your favorite internet search engine: It's unlikely that any will return more than 25 results at a time by default. In a web search scenario, a single search could return millions of hits. For the sake of the search provider and your own computer, avoiding returning millions of rows is definitely beneficial!

Paging can be accomplished in a number of ways, depending on the version of SQL Server that you are using. The simplest method is for the application to request a specific set of IDs and then request additional sets of IDs whenever the user clicks Next. Since users typically won't click through hundreds of pages of search results, querying the database each time they click isn't likely to be a significant drain on resources. If a data set is such that the end user will want to eventually view everything, then selecting all of the data and allowing the application to page through it as necessary will likely be more efficient than selecting 25 rows over and over again. The following TSQL will return 25 products when the color is NULL:

```
SELECT  Name,
              ProductNumber,
              Color,
              Size,
              DaysToManufacture
FROM Production.Product
WHERE Product.Color IS NULL
AND ProductID BETWEEN 316 AND 359
```

Alternatively, a CTE can be used so that row numbers can be compared, instead of directly pulling IDs for a set of products:

```
WITH CTE_PRODUCTS AS (
       SELECT
              ROW_NUMBER() OVER (ORDER BY ProductID ASC) AS rownum,
              Name,
              ProductNumber,
```

```
              Color,
              Size,
              DaysToManufacture
       FROM Production.Product
       WHERE Product.Color IS NULL)
SELECT
       Name,
       ProductNumber,
       Color,
       Size,
       DaysToManufacture
FROM CTE_PRODUCTS
WHERE rownum BETWEEN 5 AND 29
```

The results returned by each of these queries are the same. While the second query is easier for the application to process (as it doesn't need to manage ProductIDs), it will be less efficient as it needs to reorder the data each time a search is performed. The ID search simply grabs 25 rows using a clustered index seek, rather than adding row numbers to the entire data set, prior to paging.

Starting in SQL Server 2012, the OFFSET functionality was added, which allows for paging without the need for window functions or explicit ID references. The following statement will return 25 products, starting at the 51st product, based on the ProductID:

```
SELECT  Name,
              ProductNumber,
              Color,
              Size,
              DaysToManufacture
FROM Production.Product
WHERE Product.Color IS NULL
ORDER BY ProductID ASC
OFFSET 50 ROWS
FETCH NEXT 25 ROWS ONLY
```

Using this syntax, an ORDER BY clause must be present as it is necessary to determine the column to page off of. The OFFSET determines how many rows to skip before selecting the data you are interested in. Lastly, FETCH NEXT tells SQL Server how many rows to retrieve from that starting point. FETCH NEXT is optional and if omitted, all data after the offset will be returned. This syntax is the simplest and easiest to use from an application perspective as the OFFSET and FETCH NEXT row counts can be provided by an application, TSQL, or user input, in order to quickly return exactly the result set desired.

You will investigate performance in further detail in a later chapter, but for now, it is worth mentioning that paging performance can vary greatly based on the TSQL syntax used. Different use cases will lend themselves to different approaches, though each option mentioned here is capable of effectively returning paged results based on whatever user input is provided.

Conditional Paging

If the size of a data set can vary greatly, then it may be beneficial to perform some initial intelligence on the data prior to gathering it. For example, if you know that a data set contains only 13 rows, then there is no need to page it. You can select all rows from the 13 row results in a single statement and have no further work to do. Similarly, if a result set is 30 rows, you know that it will fit on 1-2 pages, depending on how many results are displayed per page. For both of those scenarios, it is likely that the end user will view most, if not all, the results most of the time. If a search returns a huge set of results, then you know that paging is necessary. In addition, you know that the users will almost certainly not view all results in the set. If results are returned based on a relevance score, such as with a web search engine, then it's very likely the users will only view the first 10 or 20 before either moving on or adjusting their search criteria.

The page size can also be dynamic, if desired, as an additional way to make the result set as useful as possible. For example, if 26 results are returned, having to click to a new page for a single result would be somewhat wasteful. Instead, simply returning all 26 at once would be easier, more efficient, and convenient for the users. If results are verbose and include additional details that consume a large amount of space, then returning fewer results automatically (based on how verbose) could be advantageous.

Knowing how an application works can help in determining the optimal method of paging. The following is an example of a search that returns line item details for orders based on a tracking number wildcard search. As a common search, it's likely that `CarrierTrackingNumber` will be indexed and that most searches will be for a single tracking number only. However, the application may have different requirements with regards to how to execute the search, as shown in Listing 3-7.

Listing 3-7. Sales Order Detail Search with a Variety of Input Parameters

```
CREATE PROCEDURE dbo.search_sales_order_detail
@tracking_number NVARCHAR(25), @offset_by_this_many_rows INT = 0, @row_count_to_return INT =
25, @return_all_results BIT = 0
AS
BEGIN
      SET NOCOUNT ON;
      -- Add wildcard delimiters to the tracking number
      SELECT @tracking_number = '%' + @tracking_number + '%';

      -- If the result set is small, return all results to the application for display.
      IF @return_all_results = 1
      BEGIN
            SELECT
                   SalesOrderHeader.OrderDate,
                   SalesOrderHeader.ShipDate,
                   SalesOrderHeader.Status,
                   SalesOrderHeader.PurchaseOrderNumber,
                   SalesOrderDetail.CarrierTrackingNumber,
                   SalesOrderDetail.OrderQty,
                   SalesOrderDetail.UnitPrice,
                   SalesOrderDetail.UnitPriceDiscount,
                   SalesOrderDetail.LineTotal,
                   Product.Name,
                   Product.ProductNumber
            FROM Sales.SalesOrderHeader
            INNER JOIN Sales.SalesOrderDetail
            ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
            INNER JOIN Production.Product
            ON SalesOrderDetail.ProductID = Product.ProductID
            WHERE CarrierTrackingNumber LIKE @tracking_number
            ORDER BY SalesOrderDetail.SalesOrderDetailID;
      END
      ELSE
      BEGIN
```

```
            SELECT
                   SalesOrderHeader.OrderDate,
                   SalesOrderHeader.ShipDate,
                   SalesOrderHeader.Status,
                   SalesOrderHeader.PurchaseOrderNumber,
                   SalesOrderDetail.CarrierTrackingNumber,
                   SalesOrderDetail.OrderQty,
                   SalesOrderDetail.UnitPrice,
                   SalesOrderDetail.UnitPriceDiscount,
                   SalesOrderDetail.LineTotal,
                   Product.Name,
                   Product.ProductNumber
            FROM Sales.SalesOrderHeader
            INNER JOIN Sales.SalesOrderDetail
            ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
            INNER JOIN Production.Product
            ON SalesOrderDetail.ProductID = Product.ProductID
            WHERE CarrierTrackingNumber LIKE @tracking_number
            ORDER BY SalesOrderDetail.SalesOrderDetailID
            OFFSET @offset_by_this_many_rows ROWS
            FETCH NEXT @row_count_to_return ROWS ONLY;
      END
END
GO
```

This search provides four options. The tracking number input, which can be all or part of a tracking number, is the only required option. `@offset_by_this_many_rows` determines if you are skipping ahead in the search and `@row_count_to_return` indicates the number of rows to select. The `@return_all_results` parameter can be set to `1` in order to bypass all paging logic and return everything. This can be useful if the input is a complete tracking number, where returning all parts of the shipment would make logical sense and it's unlikely that the data returned would be unusually large. In this example, the application handles the check for the input format to verify this, but the stored procedure could do this as well, if it were universally constant that a full tracking number results in all data being returned.

Defaults are placed on the input parameters to simplify assumptions, but could be left off if the application wanted to always populate them. Let's consider some sample input to this new search:

```
EXEC dbo.search_sales_order_detail '4911-403C-98', NULL, NULL, 1;
```

This search is for a complete tracking number. As a result, the application indicated that all results should be returned, regardless of the data size. This is accomplished by setting `@return_all_results` to `1`. This execution returns 12 rows, which constitute every sales order detail that has a carrier tracking number of `4911-403C-98`.

```
EXEC dbo.search_sales_order_detail '491';
```

This search is much more generic, only searching for three characters of a tracking number. Without any additional input, the stored procedure defaults to selecting the first 25 rows only. If more are required, the application will need to provide additional parameter values to account for this:

```
EXEC dbo.search_sales_order_detail '491', 25, 50, 0;
```

By adding an offset of 25 rows and a row count of 50, this stored procedure call will return the next 50 rows of this tracking number search. If the user continues to click Next, then more results would be returned by increasing the offset. Alternatively, the users would refine their search, adding more characters to their tracking number input string in order to more effectively find what they are looking for.

This example did not involve any Dynamic SQL, but the techniques used can be applied to any searching mechanism to include some level of pagination in the result set. Paging is a common and often necessary way to add control over a data set, increase customization by the end user, and maintain good performance by not returning too much data at one time.

Search Limitations

If you've ever tried searching a folder on your computer using very generic search terms, you've experienced the latency associated with running a very generic search. When building a search procedure for any application, it's important to disallow or limit any user input that could cause strain on the search experience, as well as on server performance. A common approach is to not allow blank searches. That is, if users try to click Go with no text in any search box, the program either does nothing or returns a message requesting more information. Alternatively, the search could simply grab the first 50 results, display them, and wait for further user input as to the next steps to take. At no point in the process do you want to return excessive amounts of data from the database server, nor do you want to make the end users wait forever for that data to appear.

An additional way to limit data volume is to ensure that too many columns cannot be requested from a custom search grid. If a results grid could theoretically have 500 different columns, it would be in your best interest to limit them to a much smaller number. Depending on the application, ten columns may be enough, or 25, or maybe even 50. That limit would be based on average application usage as well as the size of the columns and the amount of resources needed to return the data. If the search begins to experience lag after the 30^{th} column, then capping the number of columns in the results grid to 25 would be sensible.

Input-Based Search

The previous example allowed parameters to be passed into a search stored procedure that allowed for quite a bit of customization. As an additional step, you can parse user input and determine from the format what sort of data is being searched for. This is useful for the corner search box found on many web pages. In these applications, there is sometimes an advanced search feature available, but the average user wants to enter text in a single place and receive immediate feedback. These searches can be a bit messy as they may need to search many types of data, and running a blanket search on many different columns at once will likely perform poorly and return false positives. If the search instructions indicate that the text can be entered in one of many forms before defaulting to a single text description, you can optimize the search to focus on a select few indexed columns, rather than every possible search criteria all at once. Listing 3-8 illustrates a sales order search that allows a variety of inputs to be entered.

Listing 3-8. Sales Order Detail Search that Detects Input Type Based on String Form

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_sales_order_detail')
BEGIN
      DROP PROCEDURE dbo.search_sales_order_detail;
END
GO
```

```
CREATE PROCEDURE dbo.search_sales_order_detail
      @input_search_data NVARCHAR(25), @offset_by_this_many_rows INT = 0,
      @row_count_to_return INT = 25, @return_all_results BIT = 0
AS
BEGIN
      SET NOCOUNT ON;
      -- For this search procedure, do not allow blank input. If blank is entered,
      return immediately with no result set.
      -- Input parameter does not allow NULLs
      IF LTRIM(RTRIM(@input_search_data)) = ''
            RETURN;

      -- Pad the input string with spaces, in case it isn't 25 characters long. This will
      avoid string truncation below.
      SET @input_search_data = @input_search_data + REPLICATE(' ', 25 - LEN(@input_search_data));

      -- Parse the @input_search_data to determine the data it references
      DECLARE @input_type NVARCHAR(25);

      -- Search by Sales Order Number: Starts with "SO" and at least 5 numbers
      IF (LEFT(@input_search_data, 2) = 'SO' AND ISNUMERIC(SUBSTRING(@input_search_data,
      3, 5)) = 1)
            SET @input_type = 'SalesOrderNumber';
      ELSE
      -- Search by Purchase Order Number: Starts with "PO" and at least 10 numbers
      IF (LEFT(@input_search_data, 2) = 'PO' AND ISNUMERIC(SUBSTRING(@input_search_data,
      3, 10)) = 1)
       SET @input_type = 'PurchaseOrderNumber';
      ELSE
      -- Search by Account Number: Starts with two number, a hyphen, 4 numbers, a hyphen,
      and at least 6 additional numbers
      IF (ISNUMERIC(LEFT(@input_search_data, 2)) = 1 AND SUBSTRING(@input_search_data, 3, 1)
      = '-' AND ISNUMERIC(SUBSTRING(@input_search_data, 4, 4)) = 1
            AND SUBSTRING(@input_search_data, 8, 1) = '-'
            AND ISNUMERIC(SUBSTRING(@input_search_data, 9, 6)) = 1)
            SET @input_type = 'AccountNumber';
      ELSE
      -- Search by Carrier Tracking Number: 4 Alphanumeric, 1 hyphen, 4 alphanumeric, one
      hyphen, and two alphanumeric
      IF (PATINDEX('%[^a-zA-Z0-9]%' , LEFT(@input_search_data, 4)) = 0 AND SUBSTRING
      (@input_search_data, 5, 1) = '-' AND PATINDEX('%[^a-zA-Z0-9]%' , SUBSTRING
      (@input_search_data, 6, 4)) = 0
            AND SUBSTRING(@input_search_data, 10, 1) = '-' AND PATINDEX('%[^a-zA-Z0-9]%' ,
            SUBSTRING(@input_search_data, 11, 2)) = 0)
            SET @input_type = 'CarrierTrackingNumber';
      ELSE
      -- Search by Product Number: Starts with two letters, a dash, and four alphanumeric
characters: AA-12YZ
```

```
IF (PATINDEX('%[^a-zA-Z]%' , LEFT(@input_search_data, 2)) = 0 AND SUBSTRING(@input_
search_data, 3, 1) = '-' AND PATINDEX('%[^a-zA-Z0-9]%' , SUBSTRING(@input_search_data,
4, 4)) = 0)
      SET @input_type = 'ProductNumber';
ELSE
-- Default our input to carrier tracking number, if no other format is identified.
      SET @input_type = 'CarrierTrackingNumber';

-- Remove additional padding to prevent bad string matches.
-- Add a wildcard delimiter to the end of the input, to account for additional
characters at the end.
SELECT @input_search_data = LTRIM(RTRIM(@input_search_data)) + '%';

DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

-- Create the parameter list and initial command string
SET @parameter_list = '@input_search_data NVARCHAR(25), @offset_by_this_many_rows INT,
@row_count_to_return INT';
SET @sql_command = '
      SELECT
             SalesOrderHeader.OrderDate,
             SalesOrderHeader.ShipDate,
             SalesOrderHeader.Status,
             SalesOrderHeader.PurchaseOrderNumber,
             SalesOrderHeader.AccountNumber,
             SalesOrderHeader.SalesOrderNumber,
             SalesOrderDetail.CarrierTrackingNumber,
             SalesOrderDetail.OrderQty,
             SalesOrderDetail.UnitPrice,
             SalesOrderDetail.UnitPriceDiscount,
             SalesOrderDetail.LineTotal,
             Product.Name,
             Product.ProductNumber
      FROM Sales.SalesOrderHeader
      INNER JOIN Sales.SalesOrderDetail
      ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
      INNER JOIN Production.Product
      ON SalesOrderDetail.ProductID = Product.ProductID';

-- Based on the value of @input_type, dynamically generate the WHERE clause.
IF @input_type = 'ProductNumber'
      SET @sql_command = @sql_command + '
      WHERE Product.ProductNumber LIKE @input_search_data';
ELSE IF @input_type = 'SalesOrderNumber'
      SET @sql_command = @sql_command + '
      WHERE SalesOrderHeader.SalesOrderNumber LIKE @input_search_data';
ELSE IF @input_type = 'PurchaseOrderNumber'
      SET @sql_command = @sql_command + '
      WHERE SalesOrderHeader.PurchaseOrderNumber LIKE @input_search_data';
```

```
	ELSE IF @input_type = 'AccountNumber'
		SET @sql_command = @sql_command + '
		WHERE SalesOrderHeader.AccountNumber LIKE @input_search_data';
	ELSE IF @input_type = 'CarrierTrackingNumber'
		SET @sql_command = @sql_command + '
		WHERE SalesOrderDetail.CarrierTrackingNumber LIKE @input_search_data';

	SET @sql_command = @sql_command + '
		ORDER BY SalesOrderDetail.SalesOrderDetailID';

	-- If there are any row limitations, append them here
	SET @sql_command = @sql_command + '
		 OFFSET @offset_by_this_many_rows ROWS';
	IF @return_all_results = 0
	SET @sql_command = @sql_command + '
		 FETCH NEXT @row_count_to_return ROWS ONLY;';

	PRINT @sql_command;
	EXEC sp_executesql @sql_command, @parameter_list, @input_search_data,
	@offset_by_this_many_rows, @row_count_to_return;
END
```

String comparisons early in the stored procedure check `@input_search_data` and determine the alphanumeric & symbol locations within the string. Based on parsing this parameter, the type of data stored in it is assessed, and the `@input_type` is assigned. When you build the Dynamic SQL statement, the `WHERE` clause is completely based on the type of input provided. `PATINDEX` is used to determine if any characters not in a specific range are present in a string. If you want to verify that a string of four characters is alphanumeric, then checking to see if any characters not in the ranges of a-z, A-Z, or 0-9 will accomplish that goal. The carat ^ is used to indicate a logical `NOT`, so the comparison string `'%[^a-zA-Z0-9]%'` will return a nonzero result if any non-alphanumeric characters are present in the input string.

Alternatively, a drop-down menu could appear along with the search box, indicating what the input type is. This is also effective, but the previous example was focused on the idea of a one-click solution, which is advantageous when the number of potential inputs (and their structure) is limited. It's also a simpler and faster interface for the end user to learn and utilize. The input parsing could be managed in the application as well, if that was preferable.

The main downside to the previous implementation is flexibility, but if the application controls what types of input can be provided, then there will be no need to check for every possible combination of letters and numbers. While not demonstrated here, it would also be possible to use more generic checks for different data types. For example, any string with `PO` in front is a purchase order number, or any that begins with `SO` is a sales order number. In this implementation, we defaulted to carrier tracking number in the event that the input string did not match up with any of the type checks. This is arbitrary and could default to any format, or return with no results (if that were preferable).

The following are a handful of example executions of the example stored procedure:

```
EXEC dbo.search_sales_order_detail @input_search_data = 'BK-M82B-42';
```

This represents a search for a specific product, based on the product number. The resulting WHERE clause in the command string will appear as a check only against this column:

```
WHERE Product.ProductNumber LIKE @input_search_data
ORDER BY SalesOrderDetail.SalesOrderDetailID
OFFSET @offset_by_this_many_rows ROWS
FETCH NEXT @row_count_to_return ROWS ONLY;
```

The remainder of the statement is constant for any executions where you do not explicitly want to return all results (using the @return_all_results parameter).

```
EXEC dbo.search_sales_order_detail @input_search_data = 'PO125', @offset_by_this_many_rows =
0, @row_count_to_return = 50, @return_all_results = 0;
```

This statement searches for a portion of a purchase order number while returning 50 rows at a time, instead of the default of 25:

```
WHERE SalesOrderHeader.PurchaseOrderNumber LIKE @input_search_data
ORDER BY SalesOrderDetail.SalesOrderDetailID
OFFSET @offset_by_this_many_rows ROWS
FETCH NEXT @row_count_to_return ROWS ONLY;
```

The only difference between this TSQL segment and the last is the filtering on PurchaseOrderNumber, rather than ProductNumber. The row offset and row count to return are specified by their respective parameters, regardless of the values passed in.

```
EXEC dbo.search_sales_order_detail @input_search_data = 'SO43662', @return_all_results = 1;
```

This is a search based on a specific sales order number. By setting @return_all_results to 1, the FETCH NEXT section is omitted, resulting in the following command string:

```
WHERE SalesOrderHeader.SalesOrderNumber LIKE @input_search_data
ORDER BY SalesOrderDetail.SalesOrderDetailID
OFFSET @offset_by_this_many_rows ROWS
```

The offset is still specified, but will default to zero as no value was provided.

Result Row Counts

It can be advantageous to return the total row count of a query, even if you are only returning a paged set of 25 (or 10 or 50) rows. You may want to know that a result set contains 118 rows and that only 25 are being displayed at the moment. Oftentimes the end users will need to know that, in addition to currently viewing rows 51-75, they are viewing those rows out of a total set of 118. This provides immediate feedback on the effectiveness of their search terms, as well as some validation that the result set is what they expected. If the total row count were too high, the response would be to refine the search to be more specific. If the row count was too low, then users would want to verify that they are entering valid data and that the data they are searching for is definitely in the system and available given the search criteria.

This count can be calculated ahead of time as a separate operation, which would result in an additional query using the same filters as the data retrieval itself. Listing 3-9 is an example that uses a simple purchase order search.

Listing 3-9. Retrieving a Count of Rows for a Specific Result Set

```
SELECT
      COUNT(*)
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
INNER JOIN Production.Product
ON SalesOrderDetail.ProductID = Product.ProductID
WHERE SalesOrderHeader.PurchaseOrderNumber LIKE 'PO125%';
```

This count can be executed as a separate query and cached for later use, in the event that the users continue to page through their current result set. This allows you to perform an expensive count only once, rather than each time the same data set is accessed. The query in Listing 3-10 returns `290` as the count of rows matching the criteria specified.

Listing 3-10. Retrieving Current and Total Row Counts Alongside the Result Set

```
SELECT
      COUNT(SalesOrderDetailID) OVER (ORDER BY SalesOrderDetailID ROWS BETWEEN UNBOUNDED
      PRECEDING AND CURRENT ROW) AS row_count_current,
      COUNT(SalesOrderDetailID) OVER (ORDER BY SalesOrderDetailID ROWS BETWEEN UNBOUNDED
      PRECEDING AND UNBOUNDED FOLLOWING) AS row_count_total,
      SalesOrderHeader.OrderDate,
      SalesOrderHeader.ShipDate,
      SalesOrderHeader.Status,
      SalesOrderHeader.PurchaseOrderNumber,
      SalesOrderHeader.AccountNumber,
      SalesOrderHeader.SalesOrderNumber,
      SalesOrderDetail.CarrierTrackingNumber,
      SalesOrderDetail.OrderQty,
      SalesOrderDetail.UnitPrice,
      SalesOrderDetail.UnitPriceDiscount,
      SalesOrderDetail.LineTotal,
      Product.Name,
      Product.ProductNumber
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
INNER JOIN Production.Product
ON SalesOrderDetail.ProductID = Product.ProductID
WHERE SalesOrderHeader.PurchaseOrderNumber LIKE 'PO125%'
ORDER BY SalesOrderDetail.SalesOrderDetailID;
```

This query returns the same result set, but includes a few counts alongside that data. The first count, `row_count_current`, is the row number of the current sales order detail record as ordered by the `SalesOrderDetailID. row_count_total`, on the other hand, will return the total row count for the result set, regardless of the current row number (which is `290`, as it was previously). The `ROWS` addition is syntax exclusive to SQL Server 2012 and later and allows you to determine the window over which the window function processes rows of data over more specifically. `ROWS UNBOUNDED PRECEEDING AND CURRENT ROW` will count from the start of the result set through the current row, hence returning an increasing row count based on the ORDER BY clause. ROWS UNBOUNDED PRECEEDING AND UNBOUNDED FOLLOWING, on the other hand, will return a count of all rows in the data set, regardless of the current row number. UNBOUNDED PRECEEDING references the start of the result set, whereas UNBOUNDED FOLLOWING references the end of the result set.

The last step is to combine these efforts so that you can retrieve row counts while also paging the data set, as shown in Listing 3-11.

Listing 3-11. Retrieving Current and Total Row Counts Alongside the Result Set with Data Paging

```
WITH CTE_SEARCH_DATA AS (
	SELECT
		COUNT(SalesOrderDetailID) OVER (ORDER BY SalesOrderDetailID ROWS BETWEEN
		UNBOUNDED PRECEDING AND CURRENT ROW) AS row_count_current,
		COUNT(SalesOrderDetailID) OVER (ORDER BY SalesOrderDetailID ROWS BETWEEN
		UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING) AS row_count_total,
		SalesOrderHeader.OrderDate,
		SalesOrderHeader.ShipDate,
		SalesOrderHeader.Status,
		SalesOrderHeader.PurchaseOrderNumber,
		SalesOrderHeader.AccountNumber,
		SalesOrderHeader.SalesOrderNumber,
		SalesOrderDetail.CarrierTrackingNumber,
		SalesOrderDetail.OrderQty,
		SalesOrderDetail.UnitPrice,
		SalesOrderDetail.UnitPriceDiscount,
		SalesOrderDetail.LineTotal,
		Product.Name,
		Product.ProductNumber
	FROM Sales.SalesOrderHeader
	INNER JOIN Sales.SalesOrderDetail
	ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
	INNER JOIN Production.Product
	ON SalesOrderDetail.ProductID = Product.ProductID
	WHERE SalesOrderHeader.PurchaseOrderNumber LIKE 'PO125%')
SELECT
	*
FROM CTE_SEARCH_DATA
ORDER BY CTE_SEARCH_DATA.row_count_current
OFFSET 25 ROWS
FETCH NEXT 50 ROWS ONLY;
```

This last example put the previous query into a common table expression and performed the paging operation using row_count_current to determine where to offset the result set from. The convenience of collecting data, row counts, and paging all in a single statement can be very useful, but must be weighed against performance. You will learn more about the performance of these statements in a later chapter, but in the meantime, as always, test all new TSQL thoroughly prior to release in order to avoid any inadvertent performance problems.

Dynamic SQL can be used in order to determine whether counts need to be included in the result set or not as well. This can help reduce the amount of work needed when the result set is small, or if you don't need the row count for any further operations. Listing 3-12 illustrates this use.

Listing 3-12. Dynamic SQL Is Used to Make Row Counts into Optional Components of the Result Set

```
DECLARE @include_row_counts BIT = 0;
DECLARE @sql_command NVARCHAR(MAX);

SELECT @sql_command = '
WITH CTE_SEARCH_DATA AS (
      SELECT';
IF @include_row_counts = 1
      SELECT @sql_command = @sql_command + '
             COUNT(SalesOrderDetailID) OVER (ORDER BY SalesOrderDetailID ROWS BETWEEN
             UNBOUNDED PRECEDING AND CURRENT ROW) AS row_count_current,
             COUNT(SalesOrderDetailID) OVER (ORDER BY SalesOrderDetailID ROWS BETWEEN
             UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING) AS row_count_total,';
SELECT @sql_command = @sql_command + '
             SalesOrderHeader.OrderDate,
             SalesOrderHeader.ShipDate,
             SalesOrderHeader.Status,
             SalesOrderHeader.PurchaseOrderNumber,
             SalesOrderHeader.AccountNumber,
             SalesOrderHeader.SalesOrderNumber,
             SalesOrderDetail.CarrierTrackingNumber,
             SalesOrderDetail.OrderQty,
             SalesOrderDetail.UnitPrice,
             SalesOrderDetail.UnitPriceDiscount,
             SalesOrderDetail.LineTotal,
             Product.Name,
             Product.ProductNumber
      FROM Sales.SalesOrderHeader
      INNER JOIN Sales.SalesOrderDetail
      ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
      INNER JOIN Production.Product
      ON SalesOrderDetail.ProductID = Product.ProductID
      WHERE SalesOrderHeader.PurchaseOrderNumber LIKE ''PO125%'')
SELECT
      *
FROM CTE_SEARCH_DATA';
IF @include_row_counts = 1
      SELECT @sql_command = @sql_command + '
ORDER BY CTE_SEARCH_DATA.row_count_current';
ELSE
SELECT @sql_command = @sql_command + '
ORDER BY CTE_SEARCH_DATA.OrderDate';
SELECT @sql_command = @sql_command + '
OFFSET 25 ROWS
FETCH NEXT 50 ROWS ONLY;';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The parameter `@include_row_counts` determines if the window functions are included in the command string or not and updates the `ORDER BY` accordingly. In this specific example, it is set to zero and the resulting command string is shown in Listing 3-13.

Listing 3-13. The Command String Generated in Listing 3-12, Which Omits Row Counts

```
WITH CTE_SEARCH_DATA AS (
      SELECT
            SalesOrderHeader.OrderDate,
            SalesOrderHeader.ShipDate,
            SalesOrderHeader.Status,
            SalesOrderHeader.PurchaseOrderNumber,
            SalesOrderHeader.AccountNumber,
            SalesOrderHeader.SalesOrderNumber,
            SalesOrderDetail.CarrierTrackingNumber,
            SalesOrderDetail.OrderQty,
            SalesOrderDetail.UnitPrice,
            SalesOrderDetail.UnitPriceDiscount,
            SalesOrderDetail.LineTotal,
            Product.Name,
            Product.ProductNumber
      FROM Sales.SalesOrderHeader
      INNER JOIN Sales.SalesOrderDetail
      ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
      INNER JOIN Production.Product
      ON SalesOrderDetail.ProductID = Product.ProductID
      WHERE SalesOrderHeader.PurchaseOrderNumber LIKE 'PO125%')
SELECT
      *
FROM CTE_SEARCH_DATA
ORDER BY CTE_SEARCH_DATA.OrderDate
OFFSET 25 ROWS
FETCH NEXT 50 ROWS ONLY;
```

Additional Filtering Considerations

There are an infinite number of modifications that can be applied to any of these searching methods in order to achieve a specific functionality. For example, Dynamic SQL can be used to control the grouping used in reporting queries to quickly retrieve specific sums or counts, while omitting others. Listing 3-14 is a simple example of a TSQL statement that will include one of two different summations (or both, or neither), depending on an input parameter.

Listing 3-14. Sums/Counts Returned Based on Input Parameters Using Dynamic SQL

```
DECLARE @start_date DATE = '2014-06-01';
DECLARE @end_date DATE = '2014-06-30';
DECLARE @include_order_count BIT = 1;
DECLARE @include_order_total BIT = 1;
IF @include_order_count = 0 AND @include_order_total = 0
      RETURN;
```

```
DECLARE @parameter_list NVARCHAR(MAX);
DECLARE @sql_command NVARCHAR(MAX);

SELECT @parameter_list = '@start_date DATE, @end_date DATE'

SELECT @sql_command = '
      SELECT';
IF @include_order_count = 1
SELECT @sql_command = @sql_command + '
      COUNT(DISTINCT SalesOrderDetail.SalesOrderDetailID) AS sales_order_count,';
IF @include_order_total = 1
SELECT @sql_command = @sql_command + '
      SUM(SalesOrderDetail.LineTotal) AS total_revenue,';
SELECT @sql_command = @sql_command + '
      1 AS place_holder
      FROM Sales.SalesOrderHeader
      INNER JOIN Sales.SalesOrderDetail
      ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
      WHERE OrderDate BETWEEN @start_date AND @end_date';

PRINT @sql_command;
EXEC sp_executesql @sql_command, @parameter_list, @start_date, @end_date;
```

Two input bits determine if you should include a count of all sales order detail lines, or a sum of all line charges, both, or neither. This can be extended greatly in order to reduce the number of complex operations necessary in a stored procedure. Alternatively, `IF…THEN` statements could be used to separately check whether each metric should be evaluated or not. This would work well for a small number of variables, but for a complex data set where there could be many different queries against many tables, gathering them all in a single efficient step may be a quicker and more efficient alternative to grabbing each, one at a time.

Conclusion

Using Dynamic SQL to create flexible, efficient search routines creates a limitless number of ways in which you can access data quickly, while customizing the TSQL solution to match whatever challenges an application may send your way. We could easily have filled hundreds of pages with examples of how different combinations of parameters and TSQL techniques could create a new or innovative search methodology.

Needless to say, the flexibility is, in of itself, the source of innovation. When you run into challenges and are unsure how to get every possible result set that you are looking for, experiment and try turning hard-coded conventions into parameters. While a Dynamic SQL stored procedure may appear at first glance to be more complex, the added lines of control logic can easily be formatted and documented to ensure that the resulting code is both easy to read and maintainable.

CHAPTER 4

Permissions and Security

Chapter 2 covered SQL injection and the multitude of ways in which poorly written TSQL can become a target for malicious attacks. This chapter steps back and reviews best practices for SQL Server security, with a focus on Dynamic SQL and its typical use cases. Security is an immense topic, one that could easily consume thousands of pages given the opportunity. It also evolves with each day that passes, as new products are released and vulnerabilities are found in older ones. The goal here is to cover the most important and common places in which you need to take care while developing database solutions using Dynamic SQL, without veering too far into one-offs or edge cases.

The Principle of Least Privilege

The most important consideration in security comes from the "Principle of Least Privilege". This says that for any application, the permissions available to it are exactly what are needed to perform its functions and nothing more. At the database level, this principle is critically important as database security is the last barrier against data theft. Once a hacker has gained unfettered access to your data, there is little left to protect against. The most important considerations are to determine what users an application should run under and what permissions that user should be assigned.

The most significant mistake that companies often make is to use a sysadmin user for their applications. This is convenient as it will always work, regardless of the TSQL that is executed. No matter what the application does, this user will provide total access to everything. While convenient, it poses a security nightmare in that the application using this account could perform actions that shouldn't be allowed. Worse, if the application were somehow compromised and malicious users gained access to execute TSQL commands, they would have access to everything.

Consider the following list of hypothetical applications and functions:

- Order processing system
- File transfer application
- Report generation
- Software installer
- Backup software

Each of these applications performs very different functions and will have to access a database server very differently. What types of permissions should the SQL Server login and user be given in order to satisfy these functions? Does the application need read access? Write access? Will it need to alter any server configurations or settings? Does the application only access a single database or a set of databases? Can the application be limited to permissions on a small set of objects? Obviously, creating a manual policy with

E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_4

granular access to everything may be more work than it is worth, and would constitute the most in-depth solution. Without going into that much detail, what would these applications generally need to operate?

- **Order processing system**: Read and write access to a specific database or set of databases (select, insert, update, and delete) would provide the ability to create, update, delete, and report on order statuses. If data were read/written via stored procedures, the ability to execute those routines would be necessary. It is unlikely that the application would have any reason to adjust server settings, alter database schema, access file data, or access unrelated data in other databases or servers.
- **File transfer application**: Read and write access to tables that document file transfers. The user will likely also need direct access to read and write to a file system. If possible, do not perform file access using `xp_cmdshell`. This system-stored procedure, when enabled on a database server, provides a huge amount of access to the operating system. A database login with unfettered access to data and the operating system is very powerful, and makes for a very tempting target for any hacker looking to compromise this application.
- **Report generation**: Read-only access ideally to only a separate reporting database. Reports generally run best when separated from the transactional data that is their overall data source. The ability to limit reports to read-only access greatly reduces the ways in which these applications can be hacked or broken. If desired, read access can be further broken down into the tables or stored procedures required for these reports. This ensures that protected or sensitive data is accessed only if needed.
- **Software installer**: When installing software, the application will often request as much in the way of permissions as possible, often looking for a sysadmin user. It's important that if this level of permissions is given, it be temporary. Typically, installing or upgrading software is an infrequent and irregular event. As such, if a separate user with high levels of permissions is needed, that user should never used for other applications, users, or functions. Do not use `sa` or piggyback on other service accounts where different uses may get mixed up. A DBA installing under his own account is acceptable so long as he has the permissions required for the installation.
- **Backup software**: The primary permissions required will be to take backups of your databases. This software may also need to access some metadata in order to read data about the databases or write log data, but this access will likely be minimal. It's possible that this software could run solely under a backup operator account with no need for any further permissions.

These were some typical examples based on common software applications that you'll see in development or IT, but with each environment comes its own suite of applications and security needs. As long as permissions are reduced to the minimum level required by an application, you can be assured that any security holes that could be exposed via extra permissions will never be realized.

The "Principle of Least Privilege" does not only apply to a database server, though. Security is best organized in layers, with the database being the lowest layer and is the last one to be accessed by the end user. Ensure that any applications that ultimately can access the database server also run with only the permissions they need. Each layer of security provides an additional lock on the vault that is your data.

Granular Permissions vs. Role Permissions

The most common permissions mistakes involve the server-level role of sysadmin or the database-level role of db_owner. Sysadmin provides a login with complete access to all SQL Server functions and is the most all-encompassing permission available to any login. The db_owner user role provides access to all maintenance and configuration functionality for a single database, as well as access to all objects within it. Both of these roles will generally provide far more access than is required by an application. They often are used for convenience, but can leave gaping security holes if a system were ever compromised.

In general, avoid giving any application login the sysadmin role, especially when an application is accessible to the Internet and/or the general public. Db_owner is often given to an application that accesses a database unique to its function, but rarely are the permissions provided by that role necessary for the application to work as intended. Does the application need to alter database configuration settings, access system views, or have the ability to drop the database? Odds are good that those functions are not needed, and discretion should be taken when configuring the application user.

While assigning more granular roles may take more time, effort, and planning, doing so ensures that you don't leave a gaping hole where malicious actions could be taken against the database server. If an application only requires read and write access to a set of 20 tables, then consider assigning db_reader and db_writer, instead of db_owner. If the database contains other sensitive data, consider assigning permissions exclusively to those 20 tables, and no others. While people tend to trust the applications they use, vulnerabilities are found every day in software, regardless of whether it is open source or proprietary. If any vulnerability could be exploited in an application you rely on, then ensuring it has minimal access to the database server will greatly reduce the damage caused by an attack and ensure the data is as safe as possible.

To review all server and database roles in this space would be a lengthy and somewhat off-topic digression. Microsoft provides extensive documentation on all built-in roles, as well as how to create your own, if they are inadequate. The following MSDN links provide the current documentation on server and database roles, as well as links to many useful, related topics:

Server roles: https://msdn.microsoft.com/en-us/library/ms188659.aspx

Database roles: https://msdn.microsoft.com/en-us/library/ms189121.aspx

Dynamic SQL and Ownership Chaining

When writing, testing, and executing Dynamic SQL, permissions run differently than what you may typically experience. Any string that is executed with EXEC or EXECUTE will be run under its own scope, although security context will not be changed. This can be confusing at first and can lead to security errors while running Dynamic SQL. Listing 4-1 shows an example that illustrates this behavior.

Listing 4-1. Simple Stored Procedure to Demonstrate Ownership Chaining

```
CREATE PROCEDURE dbo.ownership_chaining_example
AS
BEGIN
        SET NOCOUNT ON;
        -- Select the current security context for reference
        SELECT SUSER_SNAME();
        SELECT COUNT(*) FROM Person.Person;
```

```
        DECLARE @sql_command NVARCHAR(MAX);
        SELECT @sql_command = 'SELECT SUSER_SNAME();

        SELECT COUNT(*) FROM Person.Person';

        EXEC sp_executesql @sql_command;
END
GO
```

When you execute this stored procedure, the results are exactly what you expect: The user (me) for the current security context is returned and then the count of rows in Person.Person is returned using standard TSQL. After this, the same operations are performed using Dynamic SQL. The results appear in Figure 4-1.

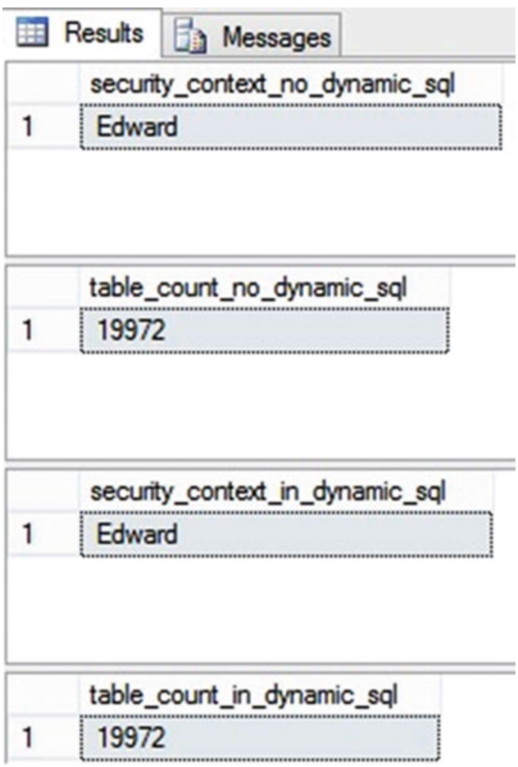


Figure 4-1. *Ownership chaining in inline TSQL vs. Dynamic SQL*

The user Edward is a sysadmin, which provides him with complete access to everything on this SQL Server. The results so far are not surprising. The security context and count from Person.Person are returned, both outside and inside the Dynamic SQL sections. What happens if a different user executes the stored procedure, one with significantly fewer permissions than this user possesses? To illustrate this, we will create a user called VeryLimitedUser with no permissions by default.

```
CREATE USER VeryLimitedUser WITHOUT LOGIN;
GO
```

```
CREATE ROLE VeryLimitedRole;
GO
EXEC sys.sp_addrolemember 'VeryLimitedRole', 'VeryLimitedUser';
GO
```

Next, we'll assign that user to execute permissions only on the stored procedure from above:

```
GRANT EXECUTE ON dbo.ownership_chaining_example TO VeryLimitedRole;
GO
```

With permissions assigned, we'll switch security contexts temporarily and execute the stored procedure using this new user:

```
EXECUTE AS USER = 'VeryLimitedUser';
GO
EXEC dbo.ownership_chaining_example;
GO
REVERT;
GO
```

The results from the execution are not the same as the previous ones. As shown in Figure 4-2, they require some additional explanation to make sense of them.

***Figure 4-2.** Results prior to a permissions error resulting from a lack of ownership chaining*

Upon trying to select the count from `Person.Person` with the `dynamic` command, an error is returned by SQL Server:

```
Msg 229, Level 14, State 5, Line 40
The SELECT permission was denied on the object 'Person', database 'AdventureWorks2014',
schema 'Person'.
```

Typically, when a user has `execute` permissions on a stored procedure, then any TSQL contained within the stored procedure will be run normally, regardless of what other objects the user has (or doesn't have) permissions to. In the previous example, `VeryLimitedUser` does not have read access to `Person.Person`. Despite this limitation, being granted execute permissions on the stored procedure allowed it to access the table. This was not the case for the select within the Dynamic SQL statement. What happened here!?

The phenomenon demonstrated here is called ownership chaining. In order to facilitate efficient and meaningful security within a database with many objects, the permissions of the initial caller of TSQL are passed along through any additional TSQL within it. For example, when you execute a stored procedure (and have the permissions to do so), any additional TSQL called from within will also execute successfully. Similarly, a user with permissions to a view does not require permissions to all of the underlying objects as well. Once access to the view is granted, all of the subsequent permissions to tables, views, and functions beneath it are implicitly granted as well.

Ownership chaining greatly simplifies security within SQL Server and allows you to quickly and safely delegate permissions to a stored procedure or view without also having to grant access to every single object referenced within it. For security administrators, this is a huge time-saver, and allows them to provide permissions based on logical or business need, without having to assign granular security for every referenced object.

There is one big exception to the rules of ownership chaining, though, and that is Dynamic SQL. As soon as a Dynamic SQL string is executed, the chain is broken, and execution resets to the permissions of the initial caller. In the previous example, `VeryLimitedUser` was able to access `Person.Person` without having explicit permissions to it, thanks to ownership chaining. The moment the Dynamic SQL was executed, permissions were reverted back to `VeryLimitedUser`, outside of the context of the stored procedure itself. As a result, the user, with no explicit permissions to `Person.Person`, was unable to access it and an error was thrown.

Note that security contexts do not change when ownership chaining is broken. The same result was returned for the current user security context above, regardless of the state of the ownership chain. Since the user has no login, the security context is returned as a system-generated numeric string instead.

Be aware of ownership chaining and ensure that the user who executes a stored procedure has adequate permissions for the proc itself, as well as any objects or Dynamic SQL called from within.

Typically, this break of the ownership chain will not pose a problem, assuming the permissions that are assigned to the user are similar to those that are required for any TSQL (dynamic or otherwise) executed by it. Careful testing of stored procedures and TSQL statements that utilize Dynamic SQL can ensure that the results are desired and that permission errors are not thrown unexpectedly. Always take the opportunity to test a newly written stored procedure using the login or user who will ultimately run it in production. Also test in an environment that is similar enough to production that you would catch any ownership chaining problems ahead of time. Oftentimes, developers work in sandbox environments with extensive permissions on their personal logins. As a result, everything runs successfully as a sysadmin or `db_owner`, but might not run well when the code is moved to production and permissions are more limited.

Changing Security Context On-the-Fly

Typically, these scenarios presented with ownership chaining will not pose problems in database development. It is possible, though, that in an isolated scenario, you'll want to allow a specific TSQL statement or stored procedure to run under a different user's security context. One of two situations may arise in which the default permissions are not adequate. A user could have too few permissions and is triggering a variety of security errors due to the breaking of ownership chaining, or inadequate permissions for a specific object. Alternatively, you may have a user with far more permissions than are needed and want to reduce them when executing a sensitive stored procedure.

There are a variety of ways to change security for a given object or execution, each of which we will demonstrate with examples. Please note that these assignments should be the rare exception, not the rule. If you find that more and more stored procedures are being given special permissions on-the-fly, it may be a sign that your overall security methodology is flawed. Consider reassigning the application user to a better set of database roles, or if necessary, create a new role that provides everything needed. Manually adjusting permissions in TSQL is difficult to document and track, and as a result will greatly increase complexity over time. Minimizing these exceptions will greatly increase maintainability and make understanding your code easier, especially when troubleshooting bugs or investigating unusual behavior.

One example of changing permissions was presented previously, and that is to change the security context of a user by using EXECUTE AS. This requires that the user executing the context change to have the permissions necessary to impersonate the user. This is important; otherwise, a user with minimal permissions could try to impersonate a sysadmin or other account with extensive server access. Consider the following TSQL:

```
SELECT SUSER_SNAME() AS SUSER_SNAME, USER_NAME() AS USER_NAME, ORIGINAL_LOGIN() AS ORIGINAL_LOGIN;
GO
EXECUTE AS USER = 'VeryLimitedUser';
SELECT SUSER_SNAME() AS SUSER_SNAME, USER_NAME() AS USER_NAME, ORIGINAL_LOGIN() AS ORIGINAL_LOGIN;
GO
```

Here, some basic information about the current user is selected, including the original login, which will return the initial login used for this connection, regardless of how permissions have changed since then. The initial permissions look like this:

```
Edward, dbo, Edward
```

After switching to the limited user, the current security info has changed to the following:

```
S-1-9-3-609289169-1216273702-1805054397-27368224, VeryLimitedUser, Edward
```

This shows that the login and user have changed to the limited access test user, but the original login is still Edward.

```
EXECUTE AS USER = 'Edward';
GO
```

Attempting to switch context back to Edward will fail and return the following error:

```
Msg 15517, Level 16, State 1, Line 48
Cannot execute as the database principal because the principal "Edward" does not exist, this
type of principal cannot be impersonated, or you do not have permission.
```

Now that you are executing as VeryLimitedUser, switching to Edward fails as this user does not have the necessary permissions to impersonate a system administrator. The only way to return to executing as Edward on this connection is to use the REVERT command:

```
REVERT;
GO
SELECT SUSER_SNAME() AS SUSER_SNAME, USER_NAME() AS USER_NAME, ORIGINAL_LOGIN() AS
ORIGINAL_LOGIN;
GO
```

Now the security context is back where it started:

```
Edward, dbo, Edward
```

If you want to change security context and not be able to change again, the WITH NO REVERT option allows for this:

```
EXECUTE AS USER = 'VeryLimitedUser' WITH NO REVERT;
```

As soon as this additional option is added, permissions are locked into VeryLimitedUser for the remainder of this stored procedure or connection. Any attempt to EXECUTE AS another user or revert will fail:

```
REVERT;
GO
EXECUTE AS USER = 'Edward';
```

Running either of these statements will return the following errors:

```
Msg 15196, Level 16, State 1, Line 55
The current security context is non-revertible. The "Revert" statement failed.
Msg 15517, Level 16, State 1, Line 56
Cannot execute as the database principal because the principal "Edward" does not exist,
this type of principal cannot be impersonated, or you do not have permission.
```

The errors remind you that REVERT will not work and you can't switch users. WITH NO REVERT is an excellent way to ensure that an entire stored procedure or connection is made with a single user and that there is no way for anyone to try to acquire more permissions than this. The only way to end an EXECUTE AS statement with this option is for the stored procedure to complete or the connection to end or be terminated.

The next way to alter permissions is to assign a specific security context to a stored procedure. When this is done, that stored proc will always execute as this user when it executes, regardless of the user who calls it, as shown in Listing 4-2.

Listing 4-2. Stored Procedure Demonstrating EXECUTE AS OWNER

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'ownership_chaining_example')
BEGIN
	DROP PROCEDURE dbo.ownership_chaining_example;
END
GO
```

```
CREATE PROCEDURE dbo.ownership_chaining_example
WITH EXECUTE AS OWNER
AS
BEGIN
	SET NOCOUNT ON;
	-- Select the current security context, for reference
	SELECT SUSER_SNAME() AS security_context_no_dynamic_sql;
	SELECT COUNT(*) AS table_count_no_dynamic_sql FROM Person.Person;

	DECLARE @sql_command NVARCHAR(MAX);
	SELECT @sql_command = 'SELECT SUSER_SNAME() AS security_context_in_dynamic_sql;

	SELECT COUNT(*) AS table_count_in_dynamic_sql FROM Person.Person';

	EXEC sp_executesql @sql_command;
END
GO
```

The EXECUTE AS OWNER option will cause the stored procedure to always execute with the permissions of its owner, regardless of which user runs it. This allows a user who normally would not have permission to access the objects internal to the stored procedure to run it. Alternatively, a user with more permissions than the owner will still execute it with the owner's permissions. The owner of an object is typically its creator, unless changed at a future time.

A potentially more restrictive and useful permissions change is to force a stored procedure to execute within the context of its caller. This is similar to breaking the ownership chain, as was shown in the Dynamic SQL in Listing 4-2. EXECUTE AS CALLER accomplishes this, as shown in Listing 4-3.

Listing 4-3. Stored Procedure Demonstrating EXECUTE AS CALLER

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'ownership_chaining_example')
BEGIN
	DROP PROCEDURE dbo.ownership_chaining_example;
END
GO

CREATE PROCEDURE dbo.ownership_chaining_example
WITH EXECUTE AS CALLER
AS
BEGIN
	SET NOCOUNT ON;
	-- Select the current security context, for reference
	SELECT SUSER_SNAME() AS security_context_no_dynamic_sql;
	SELECT COUNT(*) AS table_count_no_dynamic_sql FROM Person.Person;

	DECLARE @sql_command NVARCHAR(MAX);
	SELECT @sql_command = 'SELECT SUSER_SNAME() AS security_context_in_dynamic_sql;

	SELECT COUNT(*) AS table_count_in_dynamic_sql FROM Person.Person';

	EXEC sp_executesql @sql_command;
END
GO
```

When executed, the stored procedure will run under the permissions of whichever user calls it. As a result, all objects accessed within it will also check that user's permissions. This ensures that the user who calls a stored procedure has permissions on all of the objects referenced from within.

It is important to remember that, regardless of any of these security adjustments, Dynamic SQL will still break the ownership chain. The only way to ensure that Dynamic SQL executes successfully is to run the calling TSQL with a user who has adequate permissions or to grant more granular permissions over the specific execution, which can be accomplished as shown in Listing 4-4.

Listing 4-4. Stored Procedure Embedding a Security Context Change in Dynamic SQL

```
CREATE LOGIN EdwardJr WITH PASSWORD = 'AntiSemiJoin17', DEFAULT_DATABASE =
AdventureWorks2014;
GO
USE AdventureWorks2014
GO
CREATE USER EdwardJr FROM LOGIN EdwardJr;
EXEC sp_addrolemember 'db_owner', 'EdwardJr';
GO

IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'ownership_chaining_example')
BEGIN
        DROP PROCEDURE dbo.ownership_chaining_example;
END
GO

CREATE PROCEDURE dbo.ownership_chaining_example
AS
BEGIN
        SET NOCOUNT ON;
        -- Select the current security context, for reference
        SELECT SUSER_SNAME() AS security_context_no_dynamic_sql;
        SELECT COUNT(*) AS table_count_no_dynamic_sql FROM Person.Person;

        DECLARE @sql_command NVARCHAR(MAX);
        SELECT @sql_command = 'EXECUTE AS LOGIN = ''EdwardJr'';
        SELECT SUSER_SNAME() AS security_context_in_dynamic_sql;

        SELECT COUNT(*) AS table_count_in_dynamic_sql FROM Person.Person';

        EXEC sp_executesql @sql_command;
END
GO
```

This code explicitly changes the security context within the Dynamic SQL. This is another way to ensure a specific set of permissions once the ownership chain has been broken. In this case, `EdwardJr` is a new user with read, write, and execute permissions on all objects within this `AdventureWorks` database. This user has no other server permissions. You could execute this stored procedure as the sysadmin Edward:

```
EXEC dbo.ownership_chaining_example;
```

The results are shown in Figure 4-3.

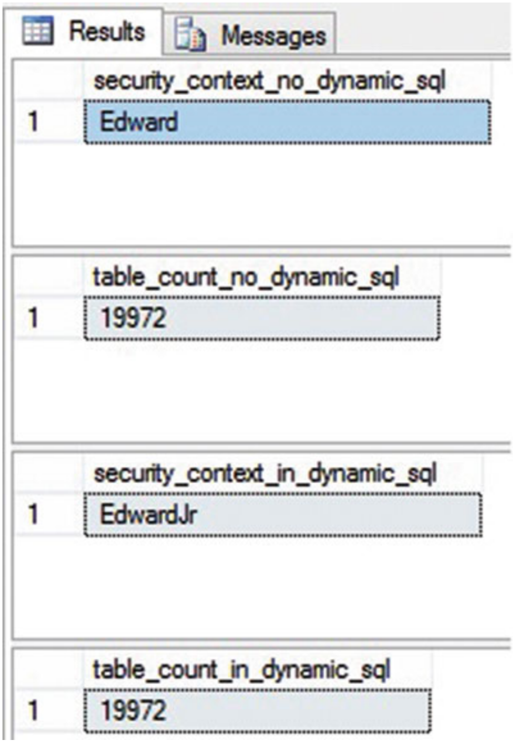


***Figure 4-3.** Changing security context when executing Dynamic SQL*

Note that the security context within the Dynamic SQL is no longer the same as the stored procedure caller (Edward), but has been changed to the new user EdwardJr, which has far fewer permissions than a sysadmin. This is a great way to set a predictable level of permissions for Dynamic SQL, when the breaking of the ownership chain is a frequent problem. If users with limited permissions attempt to run this stored procedure, they will run into trouble:

```
GRANT EXECUTE ON dbo.ownership_chaining_example TO VeryLimitedRole;
EXECUTE AS USER = 'VeryLimitedUser';
EXEC dbo.ownership_chaining_example;
REVERT;
GO
```

This code grants execute permissions to `VeryLimitedUser`, switches security context, and runs the stored procedure. The initial `SELECT` succeeds as this user has adequate permissions via the `GRANT EXECUTE`, but the moment you attempt to switch to EdwardJr, an error is thrown:

```
Msg 15406, Level 16, State 1, Line 142
Cannot execute as the server principal because the principal "EdwardJr" does not exist,
this type of principal cannot be impersonated, or you do not have permission.
```

The limited user does not have the necessary permissions to impersonate EdwardJr, or any other user for that matter, and is stopped as soon as the permissions change is attempted. This behavior may be desirable if you want to limit who can execute a specific block of Dynamic SQL. As always, let the business needs for your code dictate the minimal level of permissions required for your data access and adjust as needed along the way, if necessary.

Where Do Security Disasters Come From?

There are many answers to this question, some obvious, others more unexpected. Let's consider one possible definition of a security disaster: Any action that is taken but not desired by the organization and its security personnel. This is intentionally generic as we want to consider all of the ways in which "bad things" can happen. Everyone who has worked with databases long enough has experienced one of these situations:

- A hacking attempt (or suspected hacking attempt) is made against your organization.
- A disgruntled employee alters data without the appropriate authority to do so.
- A developer forgets the `WHERE` clause in her ad-hoc TSQL.
- A planned software release goes awry, resulting in lost data.
- Hardware or software failures result in infrastructure entering an undesirable state.
- Undesired changes are made via a legitimate use of the application.
- A software or hardware upgrade has unintended consequences.

You could likely name many more disasters that would easily keep you awake at night, but the key to all of them can be boiled down to two basic categories: Lack of planning and human error. How do you manage each risk in a way that is meaningful and non-obtrusive? With the intention of keeping this from straying too far from Dynamic SQL, let's briefly review these risks and provide starting points for managing them.

Keep in mind from earlier discussions that SQL injection, when exploited in the worst possible ways, can quickly hand complete control of a server over to the wrong person at the wrong time. Chapter 2 provided a solution to this specific security threat and stated that the best way to defend an application is to provide adequate security on multiple levels so that the sum of these efforts becomes extremely expensive to circumvent. There is no fool-proof way to secure a system against all threats. In the same way that a sufficiently motivated robber could probably break into anyone's house, a hacker (or group) who is ambitious enough can find ways to make your life difficult. Discouraging an attack can be achieved by avoiding any glaring security holes that would make your application a tempting target. The robber who sees solid locks, strong windows, and distinct signs of a security system is likely to move on to an easier target.

Lack of planning is rarely obvious until it's too late. Companies often put off high availability and disaster recovery solutions until after their first disaster scare. The penetration test is performed for the first time after a high-profile hacking attempt is identified. More rigorous testing of upgrades is planned and conducted after an upgrade goes awry one day. Confirmations are added to the application after the first time a customer accidentally deletes a significant portion of the data. Proper planning can be achieved with a concerted effort by employees who, as part of their job responsibilities, review application, software, and hardware features for common security threats. Ideally, a team of individuals from different departments and backgrounds would be involved. While a database professional would likely catch bad TSQL within the server, a developer would find bad code in the application, and a customer service representative might know the top ways in which customers get in trouble with data.

Do not assign database roles to users unless they absolutely need them. Avoid the sysadmin server role at all costs. Minimize use of the `db_owner` database role, unless truly required by an application or user.

As discussed earlier, providing applications and utilities with the minimum needed permissions (but no more) is the key to avoiding disasters. Consider that there are a plethora of functions in SQL Server that are included in sysadmin and `db_owner` by default. With each new version of SQL Server, new functionality is added and those features are often included in those roles as well. As a result, if an application is assigned a user with one of these roles, it may gain new permissions after an upgrade. Features, even those not currently used—such as replication, in-memory OLTP, AlwaysOn, and others—may become configurable inadvertently under these roles. Always consider carefully when providing any application or employee with a login. Consider the access it has and the worst things they could possibly do and decide if those scenarios are acceptable. It cannot be overstated that users cannot cause trouble if their permissions don't allow it. This is especially true if permissions are implicitly granted via database or server roles.

Not all dangerous actions are technical in nature. Many, many terrible things happen as a result of human error, human nature, or some combination of the two. Consider this scenario that plays out daily at companies around the world: A support rep answers the phone. On the other end is a manager from another division. This person sounds knowledgeable and is requesting access to restricted data about one of your largest customers. The representative, fearful of questioning this person, provides the data, hangs up, and forgets this ever happened. Trouble is, the person who called didn't work for the company at all and has gained access to important information. He only had to spend a few minutes to acquire it! This technique is known as social engineering and it poses a great threat. No amount of technology can stop people from using software as it is meant to be used, especially if they are motivated to do so.

Some of the other earlier examples had a similar theme of accidental misfortune. The developer who forgets the `WHERE` clause or the disgruntled employee did not hack to cause trouble; they simply misused the tools they had at their disposal. There are two tactics to defend against these types of incidents. The first is utilizing the "Principle of Least Privilege". It's worth overstating what has already been discussed: Only provide users with the access they need to perform the daily functions of their job. An employee without production write-access cannot truncate or delete from a table. The new DBA cannot accidentally run a schema-altering script in production if he has no ability to make DDL changes. If an employee is to be fired, be sure to revoke her access immediately, in order to prevent any opportunity for retribution. Review security roles and user access annually (or more often if possible) to ensure that changes in your organization or software don't necessitate permissions changes.

The second defense against human nature is education. Make *all* employees aware of your company's data and security policies. If these policies don't exist, then work with the appropriate managers to create them. It is important to educate all employees, as anyone with access to data, whether via SQL Server Management Studio or terminal software at their desk, can potentially make mistakes that can cost a great deal in the long run. For developers, QA specialists, IT, and other technical folks, encourage accessing data safely. Many utilities exist that will highlight and color-code connection strings or warn against any TSQL statements that have no `WHERE` clause or affect an entire table. Knowing that you are connected to a production server can prevent the dreaded situation when a script was intended for the development database, but accidentally runs in production.

Writing well-structured, documented, and maintainable code is a critical first step toward maintaining data security. To take all of those efforts and have data compromised as a result of human error would be an example of the ultimate irony for any IT department. Take care to exercise diligence on all fronts so that any angle that your application could be attacked is well defended against. Whether a compromised database is due to a SQL injection hack, a fearful customer service representative, or a database administrator with a fat finger is irrelevant to the organization as a whole. The end results are similar and should provide all of the necessary motivation to secure the application environment as much as possible from the human factor.

Users, Passwords, and Inconvenience

The chapter has discussed security roles, ownership chaining, and all of the ways in which human error can lead to disaster. What do all of these situations involve? Users. In order for any of these situations to come to fruition, a user's account must somehow be used improperly. There are few actions that elicit more groans than having to change your password regularly, but a strong and consistent password policy is a good defense against password hacking or old accounts that get resurrected for nefarious purposes.

When using Windows authentication, be sure to have all Windows users configured with an acceptable password policy. Require passwords to meet some level of complexity, don't allow users to reuse passwords, and force users to reset their passwords every so often. Not only will this minimize the chances that an account could be compromised, it greatly reduces the chance that a lesser used (or forgotten) account could somehow be used without your knowing. Also ensure that Active Directory is kept up-to-date and that all employees' accounts are disabled when they leave the company. Microsoft is adamant that Windows authentication is the recommended form of security in SQL Server, but to be certain that your server is as secure as possible, those Windows accounts must also be secure. When using Windows authentication, your SQL Server is only as safe as the Windows users who are provided access to it. Work with your network or systems administrator as necessary to ensure that all Windows accounts are secure and then confirm that only necessary accounts have access to your SQL servers.

If SQL Server authentication is used, be sure to make the same smart decisions for each server, as shown in Figure 4-4.

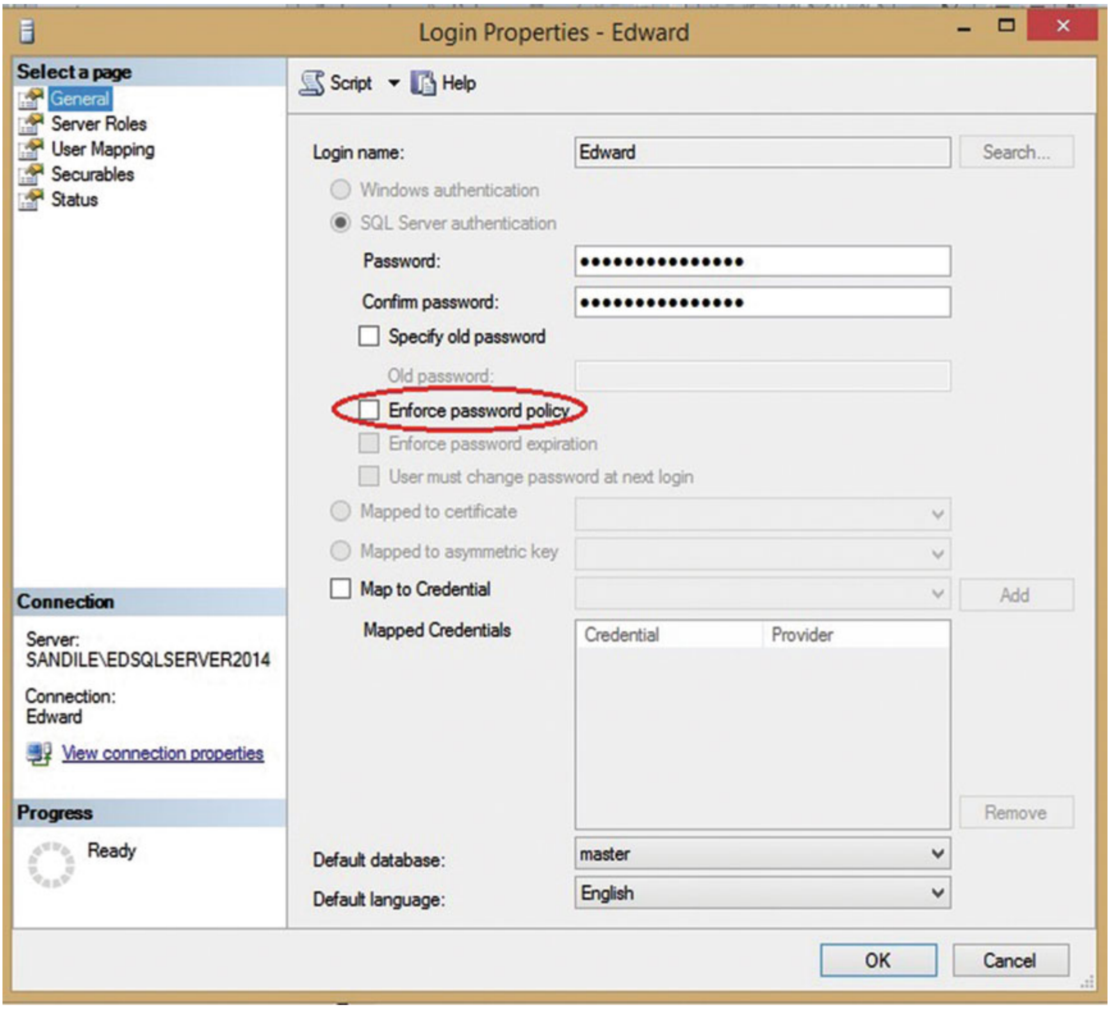


Figure 4-4. *Typical SQL Server user authentication options*

When users are created, you can configure their security settings. You can also adjust settings at any time by selecting the properties for a user. Be sure to enforce the password policy and expiration policy, as indicated by the checkbox in Figure 4-4. These policies are inherited from Windows, either from a server policy or from an Active Directory/group policy. This policy can include additional security features, such as locking out users who fail too many login attempts.

Users, including IT professionals, will gripe about the inconvenience of changing passwords and dealing with policies. However, the benefits of these rules far outweigh the inconvenience. If employees are used to the password rules and have had a long history of them being applied fairly, their complaints will generally be minimized. It is often the breaking of habit that is most responsible for confusion and mistakes when dealing with security rules. Planning ahead and configuring your database servers with strong, consistent user security will help to safeguard your data in the long run at little cost to you or your users.

Dynamic SQL Maintenance

Over time, all database objects will require some amount of maintenance. As applications evolve, tables grow, objects are added and removed, and software is upgraded, stored procedures, functions, views, jobs, maintenance plans, and more will require updating as well. This maintenance is a regular part of any software lifecycle, but is even more critical in the case of Dynamic SQL. Whenever an object such as stored procedure or function is created or altered, syntax and objects within it are checked for validity. If there are any syntax errors or if any objects are incorrect, errors will be thrown immediately and the `CREATE/ALTER` statement will fail. Since Dynamic SQL command strings are not subject to parsing or binding, they will always be created successfully, even if their contents are invalid.

This poses a significant maintenance challenge for both developers and database administrators. How are objects maintained when their references are not enforced by any SQL Server restrictions? There are several solutions that can make your life easier as application releases are being designed and planned. The first and most basic solution is to document stored procedures, jobs, functions, and other objects and their dependencies. There is no need to go into excessive detail, but this documentation should be easily searchable and allow anyone to quickly look up the basic functionality of an object and verify any major dependencies. Some organizations will implement this documentation in a database called a *data dictionary*. There are no codified rules for data dictionaries; they simply are a way to organize your database schema into a manageable reference guide. The details are left to each organization to manage as they see best for their own development and maintenance processes.

Whether implemented as a database, spreadsheet, Wiki, or text document, organizing your database objects in some fashion will provide an invaluable tool for the entire organization. They will easily be able to learn about database objects without having to track down a domain expert for help. In addition, when application changes are planned, determining the dependencies and areas that are affected by those changes will be significantly easier. The simplest data dictionary would be a list of tables, columns, indexes, stored procedures, and so on. Additional information can be added that describes the functionality of each object, the developers who worked most on them, and relationships to other objects or software modules.

If documentation is how you organize your application development environment, then cleanup is how you prevent an inevitable descent into an unmaintainable mess. Organizations greatly value the creation of new features in software and will generally show great interest in releasing new features rapidly, especially if those new features can earn money for the organization. A fine balance must be maintained between new features and technical debt. Technical debt is the accumulated to-do list that every developer knows all too well. The much-needed upgrade that no one has time for, cleaning up unused objects, performance optimization of old code, and so on, are all examples of technical debt. No matter how good your documentation is, it becomes difficult to keep track of all of these exceptions and relics. Developers slowly forget about them as newer projects take the forefront, and older developers retire or move on. Cleaning up old database objects and references to deprecated TSQL is critical to keeping code maintainable.

The objects that you put out of sight and mind about today can easily become security holes in the future. The Dynamic SQL that everyone forgot about quickly becomes the giant blob of string text that nobody wants to decipher. The application works and no one wants to mess with a poorly documented unknown object. Prevent this situation by making it a regular part of the release cycle to review all potential dependencies and take the appropriate actions to address them. Make sure that all objects that are no longer needed are removed. Those that require updating should be analyzed and the correct updates applied. These relics become security concerns as your software, security, and policies change. Old encryption algorithms that used to be considered solid and effective are eventually deprecated as modern technology renders them too weak to rely on anymore. The new coding standards that apply to all new stored procedures provide no defense against a poorly written proc from ten years ago. The TSQL written back when the company was a startup by developers putting in 16-hour days needs to be given the same treatment as the new objects that are created by a better equipped development team.

While documentation is extremely helpful in determining how to utilize, reference, and manage new and existing objects, how do you perform those initial searches to find out what those many references are? SQL Server provides a number of system views that provide extensive details on database objects, how they relate to each other, and the TSQL text that their CREATE statements contain. By leveraging these views, you can build a multi-purpose search stored procedure that uses a variety of system views and Dynamic SQL to return a list of objects that contain a given search term, as shown in Listing 4-5.

Listing 4-5. Schema Search Stored Procedure

```
CREATE PROCEDURE dbo.search_all_schema
        @searchString NVARCHAR(MAX)
AS
BEGIN
        SET NOCOUNT ON;

        -- This is the string you want to search databases and jobs for. MSDB, model and any
           databases named like tempDB will be ignored
        SET @searchString = '%' + @searchString + '%';
        DECLARE @sql NVARCHAR(MAX);
        DECLARE @database_name NVARCHAR(MAX);
        DECLARE @databases TABLE (database_name NVARCHAR(MAX));

        IF EXISTS (SELECT * FROM tempdb.sys.tables WHERE name = '##object_data')
        BEGIN
                DROP TABLE ##object_data;
        END

        CREATE TABLE ##object_data
        (
                database_name NVARCHAR(MAX),
                table_name SYSNAME,
                objectname SYSNAME,
                object_type NVARCHAR(MAX)
        );

        IF EXISTS (SELECT * FROM tempdb.sys.tables WHERE name = '##index_data')
        BEGIN
                DROP TABLE ##index_data;
        END

        CREATE TABLE ##index_data
        (
                database_name NVARCHAR(MAX),
                table_name SYSNAME,
                index_name SYSNAME,
                key_column_list NVARCHAR(MAX),
                include_column_list NVARCHAR(MAX)
        );
```

```
INSERT INTO @databases
        (database_name)
SELECT
        name
FROM sys.databases
WHERE name NOT IN ('msdb', 'model', 'tempdb')
AND state_desc <> 'OFFLINE';

DECLARE DBCURSOR CURSOR FOR SELECT database_name FROM @databases;
OPEN DBCURSOR;
FETCH NEXT FROM DBCURSOR INTO @database_name;

WHILE @@FETCH_STATUS = 0
BEGIN
        SET @sql = '
        USE ' + @database_name + ';

        WITH CTE_SCHEMA_METADATA AS (
              SELECT db_name() AS database_name, '''' AS table_name, o.Name AS
              objectname, CASE o.Type
                     WHEN ''P'' THEN ''Stored Procedure'' WHEN ''TR'' THEN
                     ''Trigger'' WHEN ''V'' THEN ''View'' WHEN ''C'' THEN ''Check
                     Constraint'' WHEN ''D'' THEN ''Default'' WHEN ''FN'' THEN
                     ''Scalar Function'' WHEN ''IF'' THEN ''Inline Function''
                     WHEN ''F'' THEN ''Foreign Key'' WHEN ''PK'' THEN ''Primary Key''
                     WHEN ''R'' THEN ''Rule'' WHEN ''TA'' THEN ''Assembly Trigger''
                     WHEN ''UQ'' THEN ''Unique Constraint'' WHEN ''TF'' THEN ''Table-
                     Valued Function'' ELSE o.Type END AS object_type
              -- Views, stored procedures, triggers, check constraints, default
              constraints, and rules.
              FROM
              (
              SELECT id,
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 1 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 2 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 3 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 4 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 5 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 6 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 7 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 8 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
              CAST(COALESCE(MIN(CASE WHEN sc.colId = 9 THEN sc.text END), '''') AS
              NVARCHAR(max)) +
```

```
CAST(COALESCE(MIN(CASE WHEN sc.colId = 10 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 11 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 12 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 13 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 14 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 15 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 16 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 17 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 18 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 19 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 20 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 21 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 22 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 23 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 24 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 25 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 26 THEN sc.text END), '''') AS
NVARCHAR(max)) +
CAST(COALESCE(MIN(CASE WHEN sc.colId = 27 THEN sc.text END), '''') AS
NVARCHAR(max)) [text]
FROM syscomments SC
WHERE SC.colId IS NOT NULL
GROUP BY id
) C
INNER JOIN sysobjects O
ON C.id = O.id
WHERE C.text LIKE ''' + @searchString + '''
  AND NAME NOT LIKE ''%syncobj%''
UNION ALL
SELECT db_name() AS database_name, ST.name AS table_name, '''' AS
objectname, ''Table'' AS object_type -- Tables (name only)
FROM sys.tables ST
WHERE ST.name LIKE ''' + @searchString + '''
UNION ALL
```

```
        SELECT db_name() AS database_name, ST.name AS table_name, SC.name AS
        column_name, ''Column'' AS object_type -- Columns
        FROM sys.tables ST
        INNER JOIN sys.columns SC
        ON ST.object_id = SC.object_id
        WHERE SC.name LIKE ''' + @searchString + '''
        UNION ALL
        SELECT
               db_name() AS database_name, ST.name AS table_name, SI.name AS
               column_name, ''Index'' AS object_type -- Indexes (name only)
        FROM sys.indexes SI
        INNER JOIN sys.tables ST
        ON ST.object_id = SI.object_id
        WHERE SI.name LIKE ''' + @searchString + ''')
INSERT INTO ##object_data
        (database_name, table_name, objectname, object_type)
SELECT
        *
FROM CTE_SCHEMA_METADATA
ORDER BY object_type ASC, objectname ASC;

WITH CTE_INDEX_COLUMNS AS (
        SELECT -- User indexes (with column name matching search string)
               db_name() AS database_name,
               TABLE_DATA.name AS table_name,
               INDEX_DATA.name AS index_name,
               STUFF(( SELECT '', '' + SC.name
                              FROM sys.tables AS ST
                              INNER JOIN sys.indexes SI
                              ON ST.object_id = SI.object_id
                              INNER JOIN sys.index_columns IC
                              ON SI.object_id = IC.object_id
                              AND SI.index_id = IC.index_id
                              INNER JOIN sys.all_columns SC
                              ON ST.object_id = SC.object_id
                              AND IC.column_id = SC.column_id
                              WHERE INDEX_DATA.object_id = SI.object_id
                              AND INDEX_DATA.index_id = SI.index_id
                              AND IC.is_included_column = 0
                              ORDER BY IC.key_ordinal
                       FOR XML PATH('''')), 1, 2, '''') AS key_column_list,
                       STUFF(( SELECT '', '' + SC.name
                              FROM sys.tables AS ST
                              INNER JOIN sys.indexes SI
                              ON ST.object_id = SI.object_id
                              INNER JOIN sys.index_columns IC
                              ON SI.object_id = IC.object_id
                              AND SI.index_id = IC.index_id
                              INNER JOIN sys.all_columns SC
                              ON ST.object_id = SC.object_id
                              AND IC.column_id = SC.column_id
```

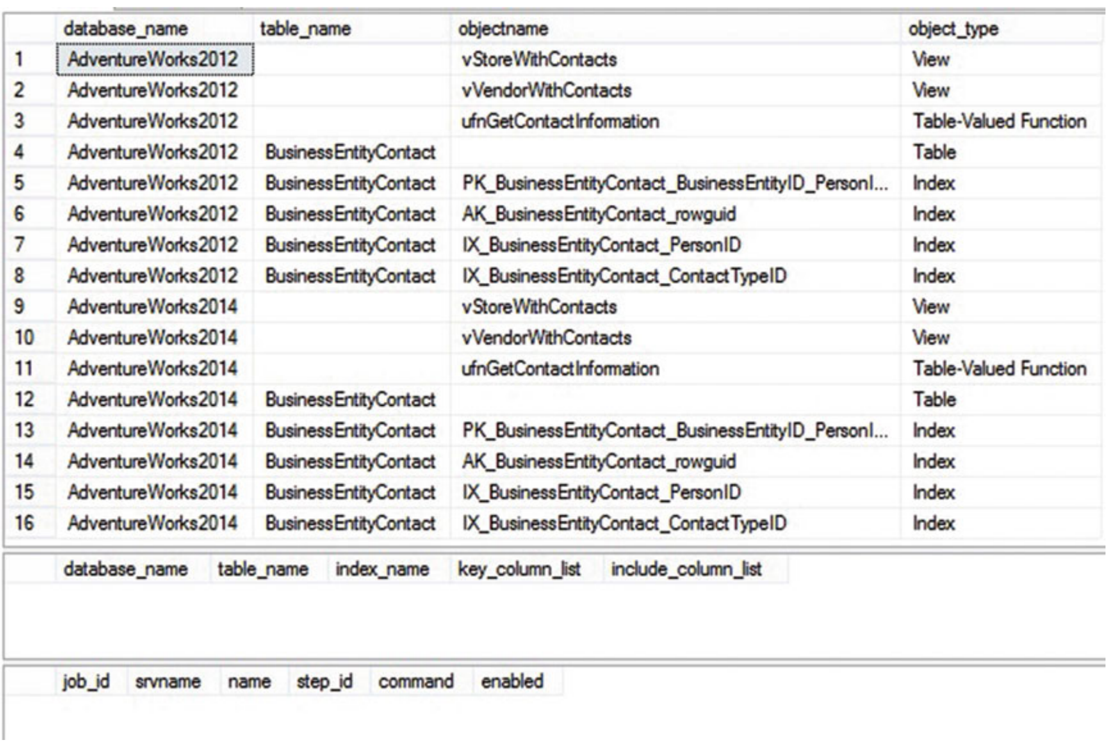
```
                                        WHERE INDEX_DATA.object_id = SI.object_id
                                        AND INDEX_DATA.index_id = SI.index_id
                                        AND IC.is_included_column = 1
                                        ORDER BY IC.key_ordinal
                                FOR XML PATH('''')), 1, 2, '''') AS include_column_list,
                                ''Index Column'' AS object_type
                FROM sys.indexes INDEX_DATA
                INNER JOIN sys.tables TABLE_DATA
                ON TABLE_DATA.object_id = INDEX_DATA.object_id
                WHERE TABLE_DATA.is_ms_shipped = 0       )
        INSERT INTO ##index_data
                (database_name, table_name, index_name, key_column_list, include_
                 column_list)
        SELECT
                database_name, table_name, index_name, key_column_list, ISNULL(include_
                column_list, '''') AS include_column_list
        FROM CTE_INDEX_COLUMNS
        WHERE CTE_INDEX_COLUMNS.key_column_list LIKE ''' + @searchString + '''
        OR CTE_INDEX_COLUMNS.include_column_list LIKE ''' + @searchString + ''';'
        EXEC sp_executesql @sql;

        FETCH NEXT FROM DBCURSOR INTO @database_name;
END

SELECT
        *
FROM ##object_data;

SELECT
        *
FROM ##index_data

-- Search to see if text exists in any job steps
SELECT
        j.job_id,
        s.srvname,
        j.name,
        js.step_id,
        js.command,
        j.enabled
FROM msdb.dbo.sysjobs j
INNER JOIN msdb.dbo.sysjobsteps js
ON js.job_id = j.job_id
INNER JOIN master.dbo.sysservers s
ON s.srvid = j.originating_server_id
WHERE js.command LIKE @searchString;

DROP TABLE ##object_data;
DROP TABLE ##index_data;
END
GO
```

This stored procedure is somewhat extensive, but provides an excellent research tool that will search all databases on a server, as well as SQL Server Agent jobs, for any text provided as the `@searchString`. Since database level system views differ within each database, it is necessary to query these views on a database-by-database basis. Dynamic SQL is used in order to quickly iterate through all databases (except `msdb`, `model`, `tempdb`, and any offline databases). Three result sets are returned: database objects, indexes, and jobs. If desired, these output tables can be combined into a single output table using `UNION ALL`, but for the purposes of this demonstration, we'll keep them separate, which makes each more readable.

If you had a generic search to perform, perhaps to determine if the `BusinessEntityContact` table is referenced anywhere on the server, you could run the stored procedure as follows:

```
EXEC dbo.search_all_schema N'BusinessEntityContact';
```

The resulting data set in Figure 4-5 includes four views, two table-valued functions, two tables, and eight indexes across two databases. No indexes or jobs were found with this name. If there was a desire to limit the database name so that you don't expend extra resources and return results from all databases, another parameter could easily be added to specify a database search term as well.



	database_name	table_name	objectname	object_type
1	AdventureWorks2012		vStoreWithContacts	View
2	AdventureWorks2012		vVendorWithContacts	View
3	AdventureWorks2012		ufnGetContactInformation	Table-Valued Function
4	AdventureWorks2012	BusinessEntityContact		Table
5	AdventureWorks2012	BusinessEntityContact	PK_BusinessEntityContact_BusinessEntityID_PersonI...	Index
6	AdventureWorks2012	BusinessEntityContact	AK_BusinessEntityContact_rowguid	Index
7	AdventureWorks2012	BusinessEntityContact	IX_BusinessEntityContact_PersonID	Index
8	AdventureWorks2012	BusinessEntityContact	IX_BusinessEntityContact_ContactTypeID	Index
9	AdventureWorks2014		vStoreWithContacts	View
10	AdventureWorks2014		vVendorWithContacts	View
11	AdventureWorks2014		ufnGetContactInformation	Table-Valued Function
12	AdventureWorks2014	BusinessEntityContact		Table
13	AdventureWorks2014	BusinessEntityContact	PK_BusinessEntityContact_BusinessEntityID_PersonI...	Index
14	AdventureWorks2014	BusinessEntityContact	AK_BusinessEntityContact_rowguid	Index
15	AdventureWorks2014	BusinessEntityContact	IX_BusinessEntityContact_PersonID	Index
16	AdventureWorks2014	BusinessEntityContact	IX_BusinessEntityContact_ContactTypeID	Index

	database_name	table_name	index_name	key_column_list	include_column_list

	job_id	srvname	name	step_id	command	enabled

Figure 4-5. *Example output from execution of a schema search using a table name*

This search capability can be extremely useful when researching software changes, existing objects, and dependencies. Finding all instances of a table name requires seconds, rather than hours, of research. This stored procedure can be used in order to search for more specific search terms, such as the name of a primary key:

```
EXEC dbo.search_all_schema N'PK_Sales';
```

The results in Figure 4-6 show a limited set of primary keys, all starting with the search term provided.

	database_name	table_name	objectname	object_type
6	AdventureWorks2012	SalesReason	PK_SalesReason_SalesReasonID	Index
7	AdventureWorks2012	SalesTaxRate	PK_SalesTaxRate_SalesTaxRateID	Index
8	AdventureWorks2012	SalesTerritory	PK_SalesTerritory_TerritoryID	Index
9	AdventureWorks2012	SalesTerritoryHistory	PK_SalesTerritoryHistory_BusinessEntityID_StartDate_Te...	Index
10	AdventureWorks2014	SalesOrderDetail	PK_SalesOrderDetail_SalesOrderID_SalesOrderDetailID	Index
11	AdventureWorks2014	SalesOrderHeader	PK_SalesOrderHeader_SalesOrderID	Index
12	AdventureWorks2014	SalesOrderHeaderSalesReason	PK_SalesOrderHeaderSalesReason_SalesOrderID_Sales...	Index
13	AdventureWorks2014	SalesPerson	PK_SalesPerson_BusinessEntityID	Index
14	AdventureWorks2014	SalesPersonQuotaHistory	PK_SalesPersonQuotaHistory_BusinessEntityID_QuotaD...	Index
15	AdventureWorks2014	SalesReason	PK_SalesReason_SalesReasonID	Index
16	AdventureWorks2014	SalesTaxRate	PK_SalesTaxRate_SalesTaxRateID	Index
17	AdventureWorks2014	SalesTerritory	PK_SalesTerritory_TerritoryID	Index
18	AdventureWorks2014	SalesTerritoryHistory	PK_SalesTerritoryHistory_BusinessEntityID_StartDate_Te...	Index
19	AdventureWorks2008	SalesOrderDetail	PK_SalesOrderDetail_SalesOrderID_SalesOrderDetailID	Index
20	AdventureWorks2008	SalesOrderHeader	PK_SalesOrderHeader_SalesOrderID	Index

***Figure 4-6.** Example output from execution of a schema search using a primary key name*

This illustrates some noise as a number of primary keys happen to contain the specific name you were looking for. Removing the noise from the result set is a trivial task, although the additional results can be useful when looking for schema similar to the target search object. A final example in Figure 4-7 shows the results for a more specific search using the full schema and table name for an object.

```
EXEC dbo.search_all_schema N'Production.Product';
```

	database_name	table_name	objectname	object_type
1	AdventureWorks2014		search_products	Stored Procedure
2	AdventureWorks2014		search_sales_order_detail	Stored Procedure

	database_name	table_name	index_name	key_column_list	include_column_list

	job_id	srvname	name	step_id	command	enabled
1	BC7C6186-26B7-4A1E-9154-955D9C541B15	SANDILE\EDSQLSERVER2014	Product Test	1	SELECT COUNT(*) FROM Production.Product	1

***Figure 4-7.** Example output from execution of a schema search using a full table name*

This execution shows very specific results, as only two stored procedures and a lone job reference the full text of `Production.Product`.

Tools such as this can be invaluable ways in which to keep up with database schema maintenance effectively. If there are capabilities specific to your database environment that are not addressed by this stored procedure, consider modifying it to add further filters, search capabilities, or specific hard-coded needs for one application. There are many other objects in SQL Server that are not addressed here, but could be, such as replication publication names, linked server names, logins, users, or SSIS package details. Adding these (or others) would be a task in appending additional TSQL to the Dynamic SQL section to include whatever additional objects are needed. Use search capabilities to assist in removing deprecated functionality, updating dependencies, and ensuring that your team has the necessary knowledge to ensure that technical debt is addressed as effectively and efficiently as possible, before it becomes unmanageable.

These regular searches can help ensure maximum security within your application as potential security holes can be quickly found and patched. A search for `sp_executesql` and `EXEC` could help uncover all uses of Dynamic SQL, which could be valuable in verifying that SQL injection is not possible from TSQL within the database server.

Cleaning House

A task that is often overlooked in favor of pushing forward with new features is removing old columns, tables, stored procedures, or other TSQL. A typical development cycle involves deprecating unused features and essentially flagging them for future removal. What are often left out are the details as to how and when those objects are removed. Until such a time arrives, it is unlikely that they will be fully updated or maintained. For all intents and purposes, they are technical debt that will remain indefinitely unless special efforts are made to deal with them.

Once you charge forward to work on upgrades, new features, and other research and development, cleanup becomes a distant memory. Even SQL Server itself is filled with a long list of deprecated features. A *deprecated* feature is one that is flagged for future removal, but remains in the interim for backward compatibility purposes. To provide context, at the time of this writing, SQL Server 2016 CTP contains a total of 254 deprecated features. In contrast, the number of discontinued features is 30. *Discontinued* features are those that are removed from the product and no longer usable. Clearly it is much easier to end support for a feature and cease upgrading it than to go through the trouble of removing it altogether. If this is a slow transition for Microsoft, then clearly it is a challenge for anyone!

An excellent way to manage the deprecation and removal of software features is to build the discontinuation process into the standard development lifecycle. When a feature is flagged as no longer needed, include a timeline by which it will be removed. Beyond just creating a schedule, be sure to include enough details that the discontinuation can be acted upon. Consider these questions:

- What components need to be addressed in order for this feature to be completely removed?
- How much effort is required to remove each component?
- Who needs to be involved in each component's removal?
- Where in the development schedule for new features will this work fit?
- What upkeep is required of these features in the interim, until they are removed?

As technical debt, this work will often fall lower in priority than new features. Asking and answering these questions can help ensure that important maintenance work is not forgotten. The last point is critically important when advocating for this work: What constant work and upkeep is required to properly maintain old components? This can incorporate software licensing costs, extra hardware usage, cloud storage and processing power, documentation, and anything else that could conceivably cost time and money.

In the same way that the tonsils or appendix might act as liabilities to your health, old features slowly impede progress over time. More importantly, they provide areas that are more likely to suffer from security vulnerabilities, as they are no longer in the forefront of your development efforts. Oftentimes deprecated features are maintained quickly and with minimal QA as they are no longer as critical to the application and may not even be used in the frontend anymore. These are facts that must be wrestled as part of the regular development of an application, but are of particular interest to DBAs when Dynamic SQL is involved, as it can provide additional access that may become undesirable over time.

If features are deprecated that use Dynamic SQL, `xp_cmdshell`, or any other features of SQL Server that can potentially provide extra access to database objects, consider additional steps to secure them as part of the process. If the feature is no longer used by the application, consider removing the Dynamic SQL portion and replacing it with a token placeholder. This ensures that it cannot be abused in any way by any party, internal or external to your organization. This tactic can be employed for any TSQL that is no longer used, but must be maintained so that software builds can complete successfully. If a feature is no longer used, but cannot be dropped, consider reducing it to the smallest footprint allowed by your development process. Not only will this reduce security risks, but it will make the removal process easier when the time comes, as more of the functionality would already be gone.

Removing unused and outdated code can be one of the most effective ways to prevent unexpected security breaches in the future.

A common error made when removing features is to accidentally leave it partially in use or have some component of it still running in the application. Maybe a search procedure still runs when software is loaded, even if the results are not captured by the application. Another possibility is that there is a web page that is no longer linked by any active pages, but can still be accessed by entering a URL manually or following a favorite to the same page. Removing core functionality as part of deprecation will highlight these missed opportunities and provide easy QA feedback so that these holes can be quickly closed. This can simplify the discontinuation process and remove the potential for future development errors or security breaches via unexpected/hidden code paths.

Login and User Usage

The "Principle of Least Privilege" tells you to provide logins and users with only what they need to do their jobs and nothing more. An additional implied step in order to be effective is to not share logins across multiple applications or users. Each individual SQL Server login, whether it uses Windows authentication or SQL Server authentication, should serve a distinct and singular purpose. This greatly improves security by:

- Making it easier to disable and later drop unused logins related to old applications or terminated employees.
- Providing more granular control over permissions for each individual application.
- Discouraging the sharing of users by different employees, especially if they are from different departments or in different roles.
- Encouraging responsible development habits by maintaining a subtle focus on security.
- Allowing for easier migration of applications to new servers or platforms.
- Improving the response time to security threats, breaches, or attacks.

Consider a scenario in which an application has `db_owner` privileges on three databases. A new employee starts and will be maintaining this application for your organization. She is provided with a standard login, access, and associated accounts. As a convenience, this user is also given the credentials for the login that is used by the application. This allows the new employee to immediately begin work on her application development without any additional security requests. A year later, the application expands and requires additional privileges to access some system views and manage some server settings.

Several years later, the employee leaves the company, and IT has forgotten that she had access to an application login, so they fail to change passwords or consider the repercussions of these facts. The employee discovers that her access is still intact via the application login and decides to quietly steal some organizational data. From this point on, this organization is compromised and it is highly unlikely that her access will be caught until some action is taken that gets their attention. In addition to stealing data, she could also alter database settings, change data, or even drop the application databases.

The solution to this problem is to never let this employee share logins in the first place. This may have taken some additional time to create a new login or alter their standard-issue credentials to incorporate these added permissions. Documentation would also be key to ensuring that this user's additional access is available by anyone who may need to audit, alter, or disable their access. The longer a login is shared, the easier it is to forget the nature of this duality and become complacent in its "just working".

An equally frustrating situation is when an individual's login is used as the logins credentials for an application. This setup works as long as the employee is working for the organization, but as soon as he leaves, things get tricky. In the event that IT notices the shared user, they will be forced to quickly plan an ad-hoc change of permissions. This may involve changing application passwords or creating a new application user. Either of these could require downtime in order to facilitate the change. If the shared user is not documented and is disabled as per standard procedures when this employee departs, the application will immediately stop working. The result will be unplanned downtime and likely a late night for those in charge of the application.

Auditing Users and Logins

An additional safeguard against any undesired security situations is to schedule and implement regular audits of all SQL Server logins and users. Verify that permissions are adequate and relevant given current security policies and application needs. Ensure that all logins and users are required and that permissions that map logins to users are needed. This process may seem daunting, both from an organizational and technical standpoint, but can be made easier with the right scripts and effective communication with all stakeholders. Generally, managers and fellow employees will be happy to help you ensure that their data is secure and that compliance with any related standards is maintained.

In the realm of TSQL scripts, there are many possibilities that can be useful. The chapter provides a few to get you started, but feel free to modify these or search the web for more in-depth versions. The goal is to identify all logins and users, customized securables, and mappings between logins and users. To begin, let's take a brief look at all logins and roles on the server using the script in Listing 4-6.

Listing 4-6. Script to Retrieve a List of Server Logins and Roles

```
SELECT
       server_principals.name AS Login_Name,
       server_principals.type_desc AS Account_Type
FROM sys.server_principals
WHERE server_principals.name NOT LIKE '%##%'
ORDER BY server_principals.name, server_principals.type_desc;
```

This query will return results that look similar to Figure 4-8.

	Login_Name	Account_Type
1	bulkadmin	SERVER_ROLE
2	dbcreator	SERVER_ROLE
3	diskadmin	SERVER_ROLE
4	EdPollack	SQL_LOGIN
5	Edward	SQL_LOGIN
6	EdwardJr	SQL_LOGIN
7	NT AUTHORITY\SYSTEM	WINDOWS_LOGIN
8	NT Service\MSSQL$EDSQLSERVER2014	WINDOWS_LOGIN
9	NT SERVICE\SQLAgent$EDSQLSERVER2014	WINDOWS_LOGIN
10	NT SERVICE\SQLWriter	WINDOWS_LOGIN
11	NT SERVICE\Winmgmt	WINDOWS_LOGIN
12	processadmin	SERVER_ROLE
13	public	SERVER_ROLE
14	sa	SQL_LOGIN
15	SANDILE\Edward	WINDOWS_LOGIN
16	securityadmin	SERVER_ROLE
17	serveradmin	SERVER_ROLE
18	setupadmin	SERVER_ROLE

Figure 4-8. *List of server logins and roles from TSQL in Listing 4-6*

The results include all SQL logins, such as my own login, Edward, and my test logins, EdPollack and EdwardJr. The Windows authentication user `SANDILE\Edward` also exists on this server. In addition are a variety of system logins used by SQL Server services and server level roles. Type can be filtered in order to limit the result set to non-system logins only. `U` indicates a Windows login, `S` indicates a SQL login, and `G` indicates a Windows group. Filtering to these types only will reduce the result set to what you are likely most interested in auditing, as shown in Figure 4-9.

	Login_Name	Account_Type
1	EdPollack	SQL_LOGIN
2	Edward	SQL_LOGIN
3	EdwardJr	SQL_LOGIN
4	NT AUTHORITY\SYSTEM	WINDOWS_LOGIN
5	NT Service\MSSQL$EDSQLSERVER2014	WINDOWS_LOGIN
6	NT SERVICE\SQLAgent$EDSQLSERVER2014	WINDOWS_LOGIN
7	NT SERVICE\SQLWriter	WINDOWS_LOGIN
8	NT SERVICE\Winmgmt	WINDOWS_LOGIN
9	sa	SQL_LOGIN
10	SANDILE\Edward	WINDOWS_LOGIN

Figure 4-9. *Login list with server roles removed*

This query can easily be executed on all production servers and the results can be aggregated to provide a quick peek into which logins exist on which server. This can quickly provide insight into logins that shouldn't exist, or that might be missing on a given server.

The next research will involve exposing customized securables. If specific permissions were granted on an object, you definitely want to know what they are and who they have been given to, and verify that they are indeed necessary. This is an area that is particularly vulnerable to carelessness or oversight, as it can be slow and cumbersome to verify these details from the SQL Server Management Studio GUI.

The query in Listing 4-7 returns a list of any object-level permissions that were explicitly assigned, as shown in Figure 4-10. Any system securables were omitted to remove a large amount of noise from the list.

Listing 4-7. Script that Lists Any User-Created Securables

```
SELECT
    OBJECT_NAME(database_permissions.major_id) AS object_name,
       USER_NAME(database_permissions.grantee_principal_id) AS role_name,
       database_permissions.permission_name
FROM sys.database_permissions
WHERE database_permissions.class = 1
AND OBJECTPROPERTY(database_permissions.major_id, 'IsMSSHipped') = 0
ORDER BY OBJECT_NAME(database_permissions.major_id);
```

	object_name	role_name	permission_name
1	ownership_chaining_example	VeryLimitedRole	EXECUTE
2	ownership_chaining_example	EdwardJr	EXECUTE
3	search_all_schema	Edward	EXECUTE
4	search_products	EdwardJr	EXECUTE

Figure 4-10. *Object-level permissions with system securables removed*

On my local server, there are a handful of permissions granted to some stored procedures. It may seem odd that my sysadmin user, Edward, is included, but in the event that my user account ever has its permissions reduced, knowledge of any additional securables I possess would be critical to completing that task in its entirety. This query can be run across production servers to let you know what special permissions were assigned over time to different users and roles. This can ensure that any security changes that are implemented take into account any and all exceptions that exist.

One additional task that you will often want to complete is to collect the associations between server logins and users within each database. These relationships determine additional permissions that a login may have within a given database. For example, a login may have no explicit permissions assigned at the server level, but could be given a variety of permissions at the database level that would coincide with job or application responsibilities.

The script in Listing 4-8 collects a list of login mappings using a SQL Server system-stored procedure, inserting the results directly into a temp table. The results are then returned from the temp table. The output of `sp_msloginmappings` is formatted as a single output set per login name, and as a result would be very difficult to use in reporting or analysis. By returning results directly into a temp table, you can get all of the mapping data into a single result set, which you can filter, sort, or read at your leisure. The result set on my local machine is shown in Figure 4-11.

Listing 4-8. TSQL to Return Relationships Between Server Logins and Database Users

```
CREATE TABLE #login_user_mapping (
    login_name NVARCHAR(MAX),
    database_name NVARCHAR(MAX),
    user_name NVARCHAR(MAX),
    alias_name NVARCHAR(MAX));

INSERT INTO #login_user_mapping
EXEC master.dbo.sp_msloginmappings;

SELECT
       *
FROM #login_user_mapping
ORDER BY database_name,
         user_name;

DROP TABLE #login_user_mapping;
```

	login_name	database_name	user_name	alias_name
12	Edward	AdventureWorks2008	Edward	NULL
13	EdPollack	AdventureWorks2012	EdPollack	NULL
14	Edward	AdventureWorks2012	Edward	NULL
15	Edward	AdventureWorks2014	Edward	NULL
16	EdwardJr	AdventureWorks2014	EdwardJr	NULL
17	##MS_AgentSigningCertificate##	master	##MS_AgentSigningCertificate##	NULL
18	##MS_PolicyEventProcessingLogin##	master	##MS_PolicyEventProcessingLogin##	NULL
19	sa	master	dbo	NULL
20	EdPollack	master	EdPollack	NULL
21	sa	model	dbo	NULL
22	EdPollack	model	EdPollack	NULL
23	##MS_PolicyEventProcessingLogin##	msdb	##MS_PolicyEventProcessingLogin##	NULL
24	##MS_PolicyTsqlExecutionLogin##	msdb	##MS_PolicyTsqlExecutionLogin##	NULL
25	sa	msdb	dbo	NULL
26	EdPollack	msdb	EdPollack	NULL
27	sa	tempdb	dbo	NULL
28	EdPollack	tempdb	EdPollack	NULL

Figure 4-11. *Full list of all login/user mappings on this SQL Server*

Each login is associated with a database and user. If any aliases existed, they would also be returned. This lets you keep track of which databases a given login has permissions to. Typically, when a login is deleted, any users associated with that login will remain in their respective databases until acted upon by an administrator. The results returned by this query can ensure that you properly clean up all database users when you disable or drop a server login.

There are many other system views and stored procedures that can be used to analyze SQL Server security, but the handful discussed in this chapter should provide a solid starting point with which to take stock of your database environment and identify any significant security flaws that could be easily addressed once this information is known.

Memory Consumption

Earlier, the chapter briefly discussed the effects of string truncation on Dynamic SQL and how it can cause command strings to be executed incorrectly or throw errors. Most of the Dynamic SQL examples thus far have had relatively short command strings whose lengths were predetermined, based on the parameters that were passed in. In a scenario where the length of the command string is controlled by a specific number of objects or amount of data, the resulting string can potentially be very large. Like other scalar parameters you define in SQL server, the command string is stored in memory. Consider the Dynamic SQL in Listing 4-9.

Listing 4-9. Dynamic SQL to Check Database Integrity on All Databases on this Instance

```
DECLARE @databases TABLE
        (database_name NVARCHAR(MAX));

INSERT INTO @databases
        (database_name)
SELECT
        databases.name
FROM sys.databases;

DECLARE @sql_command NVARCHAR(MAX) = '';

SELECT @sql_command = @sql_command + '
DBCC CHECKDB (' + database_name + ');'
FROM @databases;

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

This Dynamic SQL will create a command string that will run `DBCC CHECKDB` on all databases on this SQL Server instance. The command string will consist of one line per database, regardless of how many databases exist on the server. Since this particular command is short, the command string on my server will appear like this:

```
DBCC CHECKDB (master);
DBCC CHECKDB (tempdb);
DBCC CHECKDB (model);
DBCC CHECKDB (msdb);
DBCC CHECKDB (AdventureWorks2012);
DBCC CHECKDB (AdventureWorks2014);
DBCC CHECKDB (AdventureWorks2008);
```

While this example is short, consider what might happen if there were 500 databases on my server. In that scenario, the command string would be 500 lines long. This would still not be terribly large, but introduces a potential memory issue if the object count or text involved became too long. For example, what if you were to assemble a row count report for all tables in all databases on the server? In that scenario, on a server with 500 databases and 500 tables per database, you would have a command string that was 250,000 lines long. If the text of each command were similar to `SELECT COUNT(*) FROM schema_name.table_name`, each line of text would be about 300 bytes. The total command string size would be approximately 75MB, which is well below the amount of memory that a server is likely to have, but illustrates a potential performance and security threat that unbounded statements can pose.

When writing Dynamic SQL, be conscious of the length of a command string. In the event that it can grow unbounded, consider adding a cutoff to prevent it from getting excessively large. Alternatively, batch the statements so that sets of rows are processed, rather than all of them at one time. While it is rare that a command string would grow to be gigabytes in size, it is not out of the realm of possibilities, nor should it be ignored. Excessive growth could also occur due to developer error, such as if you forget to increment a counter or advance a cursor. If you allow the string to grow indefinitely, server memory would eventually run out. The result would likely be some variety of SQL Server crash that could influence other applications whose databases are hosted on this server.

Listing 4-10. Dynamic SQL to Gather Row Counts of All Tables on this SQL Server Instance

```
SET NOCOUNT ON;

DECLARE @databases TABLE
       (database_name NVARCHAR(MAX));

CREATE TABLE ##tables
       (database_name NVARCHAR(MAX),
        schema_name NVARCHAR(MAX),
        table_name NVARCHAR(MAX),
        row_count BIGINT);

DECLARE @sql_command NVARCHAR(MAX) = '';

INSERT INTO @databases
       (database_name)
SELECT
       databases.name
FROM sys.databases
WHERE databases.name <> 'tempdb';

DECLARE @current_database NVARCHAR(MAX);
WHILE EXISTS (SELECT * FROM @databases)
BEGIN
       SELECT TOP 1 @current_database = database_name FROM @databases;

       SELECT @sql_command = @sql_command + '
              USE [' + @current_database + ']
              INSERT INTO ##tables
                     (database_name, schema_name, table_name, row_count)
              SELECT
                     ''' + @current_database + ''',
                     schemas.name,
                     tables.name,
                     0
              FROM sys.tables
              INNER JOIN sys.schemas
              ON tables.schema_id = schemas.schema_id';
       EXEC sp_executesql @sql_command;
       DELETE FROM @databases WHERE database_name = @current_database;
END
```

```
SELECT @sql_command = '';
SELECT @sql_command = @sql_command + '
       UPDATE ##tables
              SET row_count = (SELECT COUNT(*)
       FROM [' + database_name + '].[' + schema_name + '].[' + table_name + '])
       WHERE database_name = ''' + database_name + '''
       AND schema_name = ''' + schema_name + '''
       AND table_name = ''' + table_name + ''';'
FROM ##tables;

SELECT (LEN(@sql_command) * 16) AS length_of_large_sql_command
EXEC sp_executesql @sql_command;

SELECT
       *
FROM ##tables;

DROP TABLE ##tables;
```

The TSQL in Listing 4-10 uses Dynamic SQL to construct a long command string that will gather row counts for all tables in all databases on the server (with the exception of TempDB). The more databases and the more tables on the server, the larger the string will be. Before executing the command string, you return the length in bytes, which is calculated as two times the number of characters in the string. The characters are multiplied by two in order to account for the fact that the command string is the NVARCHAR data type, which consists of double-byte UNICODE characters. On my local server with six databases, the length of this command string is 3.04MB. On a server with many more databases and tables, the length could become prohibitively long. Listing 4-11 shows an example of batching that limits the number of rows that are processed at one time, ensuring that the command string cannot grow too large. This specific example processes row counts for each database separately, which would generally be adequate in limiting the overall size of the command strings. The TSQL for this can be found in Listing 4-11.

Listing 4-11. Dynamic SQL to Gather Row Counts of All Tables on this SQL Server Instance Using Batched Command String Creation

```
SET NOCOUNT ON;

DECLARE @databases TABLE
        (database_name NVARCHAR(MAX));

CREATE TABLE ##tables
        (database_name NVARCHAR(MAX),
        schema_name NVARCHAR(MAX),
        table_name NVARCHAR(MAX),
        row_count BIGINT);

DECLARE @sql_command NVARCHAR(MAX) = '';

INSERT INTO @databases
        (database_name)
```

```
SELECT
	databases.name
FROM sys.databases
WHERE databases.name <> 'tempdb';

DECLARE @current_database NVARCHAR(MAX);
WHILE EXISTS (SELECT * FROM @databases)
BEGIN
	SELECT TOP 1 @current_database = database_name FROM @databases;

	SELECT @sql_command = '';

	SELECT @sql_command = @sql_command + '
		USE [' + @current_database + ']
		INSERT INTO ##tables
			(database_name, schema_name, table_name, row_count)
		SELECT
			''' + @current_database + ''',
			schemas.name,
			tables.name,
			0
		FROM sys.tables
		INNER JOIN sys.schemas
		ON tables.schema_id = schemas.schema_id';
	EXEC sp_executesql @sql_command;

	SELECT @sql_command = '';
	SELECT @sql_command = @sql_command + '
		UPDATE ##tables
			SET row_count = (SELECT COUNT(*)
		FROM [' + database_name + '].[' + schema_name + '].[' + table_name + '])
		WHERE database_name = ''' + database_name + '''
		AND schema_name = ''' + schema_name + '''
		AND table_name = ''' + table_name + ''';'
	FROM ##tables
	WHERE database_name = @current_database;

	SELECT (LEN(@sql_command) * 16) + 2 AS length_of_large_sql_command
	EXEC sp_executesql @sql_command;

	DELETE FROM @databases WHERE database_name = @current_database;
END

SELECT
	*
FROM ##tables;

DROP TABLE ##tables;
```

The only difference in the rewrite of the row count TSQL is that the collection of row counts happens in the main loop, after each database's tables are enumerated. This breaks up the command string generation into one per database. Instead of creating a 3MB command string, it creates and executes six different ones, none of which are more than 475KB. In a scenario where the length of a command string could become very long due to a large number of objects being analyzed, batching can ensure that memory pressure never becomes a security or stability concern, even when executed on extremely large data sets.

Conclusion

All of this security advice may seem distant to the topic of Dynamic SQL, but it's important in ensuring that the development you do is both effective and secure. Taking any or all of these best practices and suggestions and implementing them greatly reduces the risk of SQL injection, as well as other exploits that could inadvertently create vulnerabilities in your system. If this topic interests you, there are many books and courses out there that will dive into security in much greater detail. This chapter is intended to provide an introduction and overview of SQL Server security, with a focus on Dynamic SQL and the greatest security threats to it.

As you charge forward with further examples of how Dynamic SQL can perform powerful searches, maintenance, or data transformations, keep in mind how security related considerations can have lasting repercussions for the integrity of not only your queries, but your SQL Server as a whole. It is far easier to make the correct decisions now than to return at a later date and clean up the mistakes of previous development efforts.

CHAPTER 5

Managing Scope

The chapters covering security have alluded to the fact that Dynamic SQL does not run in the same scope as the remainder of TSQL in the same stored procedure. In addition to breaking the ownership chain, variables declared locally and globally will not have easy access to each other. When writing application code or stored procedures, passing variables into and out requires a bit of planning, ensuring that the inputs and outputs are correct. Working with Dynamic SQL is very similar, and luckily there are a variety of ways in which to manage variables effectively without any level of inconvenience.

What Is Scope?

To make understanding scope as easy as possible, you need to understand the terms and will also look at a few examples of why this is an important topic. *Scope* can be defined as where and how long a variable or object is available for within any SQL Server object. Consider the following simple TSQL statement:

```
DECLARE @FirstName NVARCHAR(50) = 'Edward';

SELECT
       *
FROM Person.Person
WHERE FirstName = @FirstName;
```

This is about as simple as TSQL gets, but what is the scope of the variable defined above? Without any interruptions or changes in control within these statements, `@FirstName` is in scope throughout the example and can be used (as you expect it could be) by the `SELECT` statement immediately after it. What happens if you end the batch prior to returning the results?

```
DECLARE @FirstName NVARCHAR(50) = 'Edward';
GO

SELECT
       *
FROM Person.Person
WHERE FirstName = @FirstName;
```

This simple change, adding a `GO` before the `SELECT`, will result in an error:

```
Msg 137, Level 15, State 2, Line 20
Must declare the scalar variable "@FirstName".
```


E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_5

When the batch ends, all locally defined variables are no longer available and in scope for the remainder of this TSQL. GO, by definition, will end a batch and trigger this behavior whenever used. Any TSQL that is encapsulated in its own object—such as a trigger, function, or stored procedure—will also execute within their own scope. Any attempt to access variables defined within these objects from outside of them will result in errors similar to this:

```
CREATE PROCEDURE dbo.get_people
AS
BEGIN
	DECLARE @FirstName NVARCHAR(50) = 'Edward';

	SELECT
		*
	FROM Person.Person
	WHERE FirstName = @FirstName;
END
GO

EXEC dbo.get_people;
SELECT @FirstName;
```

This stored procedure will perform the same search as the previous one. Executing it as shown yields the exact same results, but if you try to return the value of `@FirstName`, the same error is returned. By default, variables declared within a stored procedure are not available from anywhere outside of it. The same convention also applies to Dynamic SQL. It's therefore important to understand this when determining where variables are to be declared, modified, and returned.

Parameters can be added to stored procedures in order to facilitate the easy movement of data in and out of them so that their values can remain in scope and be used elsewhere in your work. The example in Listing 5-1 shows how variables can be passed into a stored procedure, and how values can be explicitly returned as well.

Listing 5-1. Stored Procedure Illustrating Input and Output Parameters

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'get_people')
BEGIN
	DROP PROCEDURE dbo.get_people;
END
GO
CREATE PROCEDURE dbo.get_people
	@first_name NVARCHAR(50), @person_with_most_entries NVARCHAR(50) OUTPUT
AS
BEGIN
	DECLARE @person_count INT;

	SELECT TOP 1
		@person_with_most_entries = Person.FirstName
	FROM Person.Person
	GROUP BY Person.FirstName
	ORDER BY COUNT(*) DESC;
```

```
    SELECT
        *
    FROM Person.Person
    WHERE FirstName = @first_name;

    RETURN @@ROWCOUNT;
END
GO
```

This example passes in a first name that will be used in the search. You also pass in an additional string that will be overwritten with the most common first name in Person.Person. Within the stored procedure, all rows in Person.Person will be returned that have the first name passed in. Lastly, the count of rows with that first name will be used as the return value from the stored proc. An example execution would look like this:

```
DECLARE @person_with_most_entries NVARCHAR(50);
DECLARE @person_count INT;

EXEC @person_count = dbo.get_people 'Edward', @person_with_most_entries OUTPUT;

SELECT @person_with_most_entries AS person_with_most_entries;
SELECT @person_count AS person_count
```

Note the use of the OUTPUT keyword. This TSQL reserved word can be used in a number of ways, but when working with a stored procedure, it signifies that the parameter that is being passed in will retain changes to its value as the stored procedure executes. In order for this to work properly, OUTPUT must also be specified in the parameter list for the stored procedure.

When executed, a search will be performed and all people with the name "Edward" will be returned. In addition, the @person_with_most_entries variable will be updated as an output variable. Lastly, the count of people with the first name provided will be returned from the stored procedure and stored in @person_count. When those variables are selected at the end, the expected values are returned, as shown in Figure 5-1.

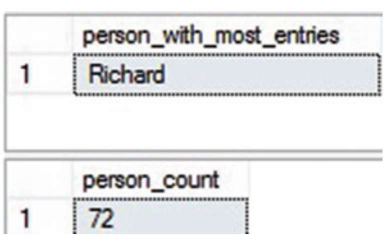


Figure 5-1. *Results from the dbo.get_people stored procedure*

Managing Scope in Dynamic SQL

Dealing with scope in Dynamic SQL isn't terribly different than when working with a stored procedure. Imagine everything within the Dynamic SQL statement as being separate from the remainder of your TSQL and act accordingly. To illustrate the similarities, consider the following TSQL, which is similar to the previous search examples:

```
DECLARE @sql_command NVARCHAR(MAX);

SELECT @sql_command = '
DECLARE @FirstName NVARCHAR(50) = ''Edward'';
SELECT
       *
FROM Person.Person
WHERE FirstName = @FirstName;'
EXEC sp_executesql @sql_command;
SELECT @FirstName
```

In this case, the variable `@FirstName` is declared within the command string, and as such is not available outside of the scope of the Dynamic SQL statement. The `SELECT` at the end will fail as `@FirstName` no longer exists:

```
Msg 137, Level 15, State 2, Line 84
Must declare the scalar variable "@FirstName".
```

Similarly, a variable declared outside of a command string will be unavailable for use on the inside. Lastly, multiple command strings each execute in their own scope. A variable declared in one command string will not be available in another Dynamic SQL statement.

Scope exists as a convenience and a security feature. If variables that were declared in one place within code were available everywhere, then you would need to keep track of each and every one very carefully to ensure you never accidentally reused an existing one when you intended to use a new one. Separating segments of TSQL from each other and breaking the ownership chain serve to compartmentalize distinct SQL statements and prevent any one application or function from over-reaching its bounds. While it may seem inconvenient at first to need to manage all of these variables more carefully, SQL Server provides many effective tools to do so under any circumstances.

Using OUTPUT in Dynamic SQL

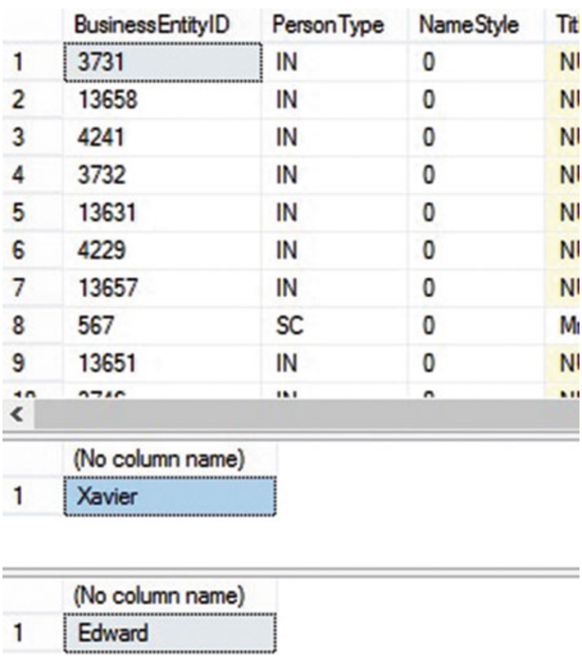
By default, any variables that are passed into `sp_executesql` are read-only. That is, they can be used in the scope of the Dynamic SQL whenever needed, but when the Dynamic SQL is complete and execution returns to the calling TSQL, any changes to parameters are not saved. Consider the TSQL in Listing 5-2, focusing on the `UPDATE` of the `@FirstName` parameter.

Listing 5-2. Dynamic SQL: Updating Parameters Within the Command String

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);
DECLARE @first_name NVARCHAR(50) = 'Edward';
```

```
SELECT @sql_command = '
SELECT
       *
FROM Person.Person
WHERE FirstName = @first_name;
SELECT @first_name = ''Xavier'';
SELECT @first_name;
'

SELECT @parameter_list = '@first_name NVARCHAR(50)'
EXEC sp_executesql @sql_command, @parameter_list, @first_name;

SELECT @first_name;
GO
```

In this example, the last action taken within the command string is to reassign the name "`Xavier`" to the parameter `@first_name`. Even though the parameter is read-only, you are allowed to change the value of it within the Dynamic SQL. The new value will remain relevant and in scope until the end of the Dynamic SQL. It is important to note that, despite the fact that you used the same variable name for the first name both within and outside of Dynamic SQL, they are still treated as completely separate variables. Depending on your applications, there may be value in using different variable names, which would help differentiate between separate variables, or in using the same variable names, which would make it more obvious when a distinct value is being used across TSQL statements, each with a different scope. The output is shown in Figure 5-2.



	BusinessEntityID	PersonType	NameStyle	Tit
1	3731	IN	0	NI
2	13658	IN	0	NI
3	4241	IN	0	NI
4	3732	IN	0	NI
5	13631	IN	0	NI
6	4229	IN	0	NI
7	13657	IN	0	NI
8	567	SC	0	Mi
9	13651	IN	0	NI

	(No column name)
1	Xavier

	(No column name)
1	Edward

Figure 5-2. *Reassigning a variable within Dynamic SQL without the OUTPUT operator*

The results of the search are retuned as you would expected them to be. The SELECT of the first name from within the Dynamic SQL shows that reassigning the parameter is allowed and succeeded. When you check the variable again after the Dynamic SQL execution is complete, you can see that @first_name is set to "Edward" instead of "Xavier". As a slight adjustment, you can go ahead and change the variable names, as shown in Listing 5-3, which helps emphasize that they are distinct and separate from each other.

Listing 5-3. Rewriting the TSQL from Listing 5-2, which Returns the Same Results

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);
DECLARE @first_name_calling_sql NVARCHAR(50) = 'Edward';

SELECT @sql_command = '
SELECT
       *
FROM Person.Person
WHERE FirstName = @first_name_within_dynamic_sql;
SELECT @first_name_within_dynamic_sql = ''Xavier'';
SELECT @first_name_within_dynamic_sql;
'

SELECT @parameter_list = '@first_name_within_dynamic_sql NVARCHAR(50)'
EXEC sp_executesql @sql_command, @parameter_list, @first_name_calling_sql;

SELECT @first_name_calling_sql;
```

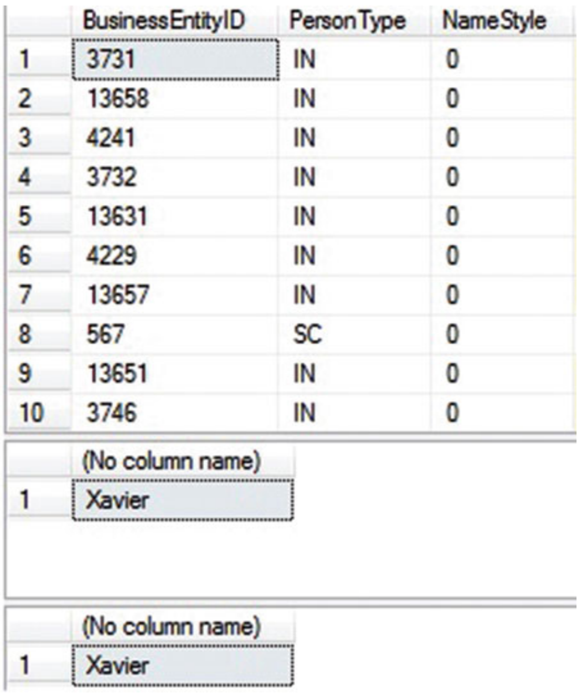
The results from this slightly different version are exactly the same as above. The only difference was that the name of the variable in the calling TSQL changed to @first_name_calling_sql and the parameter for the Dynamic SQL statement changed to @first_name_within_dynamic_sql.

What if you intentionally wanted changes to the parameters made within the Dynamic SQL to be saved and passed back to the original parameters that were passed in initially? The solution is nearly the same as with a stored procedure. Simply add OUTPUT to any parameter that is to pass its value back to the calling TSQL and it will work very similarly to the earlier examples, as shown in Listing 5-4.

Listing 5-4. Using OUTPUT to Permanently Modify a Parameter

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);
DECLARE @first_name_calling_sql NVARCHAR(50) = 'Edward';

SELECT @sql_command = '
SELECT
       *
FROM Person.Person
WHERE FirstName = @first_name_within_dynamic_sql;
SELECT @first_name_within_dynamic_sql = ''Xavier'';
SELECT @first_name_within_dynamic_sql;
'

SELECT @parameter_list = '@first_name_within_dynamic_sql NVARCHAR(50) OUTPUT'
EXEC sp_executesql @sql_command, @parameter_list, @first_name_calling_sql OUTPUT;

SELECT @first_name_calling_sql;
```

This example explicitly flags the first name parameter as an OUTPUT parameter. This indicates that if the value is changes within the Dynamic SQL, that change will be persisted after the command string has been executed and you switch back to the scope of the calling TSQL. The output is shown in Figure 5-3.



	BusinessEntityID	PersonType	NameStyle
1	3731	IN	0
2	13658	IN	0
3	4241	IN	0
4	3732	IN	0
5	13631	IN	0
6	4229	IN	0
7	13657	IN	0
8	567	SC	0
9	13651	IN	0
10	3746	IN	0

	(No column name)
1	Xavier

	(No column name)
1	Xavier

Figure 5-3. *Results when OUTPUT was used to persist @first_name_within_dynamic_sql*

This time when you change the value of `@first_name_within_dynamic_sql` to `"Xavier"`, that value is passed from the Dynamic SQL back to `sp_executesql` and remains until you act on it again. This is immensely useful when you want a parameter to change within Dynamic SQL or would like to pass variables in and out seamlessly.

Note that in this TSQL, the OUTPUT keyword is appended to both the parameter list and the parameter name in the `sp_executesql` statement. The keyword must be applied in both places or the parameter value will not be updated as expected. If OUTPUT is omitted from the parameter list, SQL Server does not know that it is intended to be persisted from the Dynamic SQL statement. The result is an explicit error message calling this out:

```
Msg 8162, Level 16, State 2, Line 152
The formal parameter "@first_name_within_dynamic_sql" was not declared as an OUTPUT
parameter, but the actual parameter passed in requested output.
```

Luckily the message is very easy to understand and makes it clear how to fix the error. SQL Server does not allow an OUTPUT parameter to be passed into a variable that is not declared in the same fashion.

What happens if you declare the parameter within the parameter list as an OUTPUT variable, but do not declare it as such in the `sp_executesql` command? In this scenario, no error is thrown. It is perfectly legal to declare a parameter with the OUTPUT keyword within the parameter list and not include the same keyword when executing the command string. The result will be that the TSQL executes successfully and the value of the first name parameter will not be persisted from Dynamic SQL back to the calling TSQL. Table 5-1 sums up the results of each use of the OUTPUT variable.

Table 5-1. *Results of Different Uses of OUTPUT: Green Is Good, Red Is Bad*

Parameter List	Input Variable	Result
		Parameter value is not persisted.
	OUTPUT	**Error is thrown by SQL Server.**
OUTPUT		**Parameter value is still not persisted.**
OUTPUT	OUTPUT	**Parameter value persisted from Dynamic SQL.**

The only way to successfully alter the value of a parameter and return it to the calling TSQL is to use OUTPUT on both the parameter list and the variable being passed in. In order to avoid confusion when writing Dynamic SQL, avoid the mixed scenarios where one variable is declared as OUTPUT but not the other. The results of one case will be an error message, which is certainly not desirable. The other ambiguous case will make for a difficult-to-understand piece of code whose purpose will not be clear to any other developer and could lead to coding mistakes in the future.

Any parameter may be passed into Dynamic SQL that is allowed to be passed into a stored procedure, including tables and even cursors. Table variables, discussed in the next section, are read-only, though, and may not be set as OUTPUT parameters.

Table Variables and Temporary Tables

An additional way of persisting data in SQL Server is to create table variables or temporary tables and store data in them. The behavior of each of these is somewhat unique and offers an alternative way to manage data within Dynamic SQL. This section discusses each in a bit more detail and illustrates each behavior and how it can impact your TSQL.

Table Variables

Consider the TSQL in Listing 5-5.

Listing 5-5. Results of Using a Table Variable Within Dynamic SQL that Is Declared Outside of It

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

DECLARE @last_names TABLE (
        last_name NVARCHAR(50));

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM @last_names)'

EXEC sp_executesql @sql_command;
```

Running this TSQL results immediately in an error:

```
Msg 1087, Level 15, State 2, Line 197
Must declare the table variable "@last_names".
```

The @last_names table variable may be created at the start of this example, but does not exist within the scope of the Dynamic SQL. It tries to return a set of first names using that data, but it cannot be found. As a result, any attempt to access it will fail. You can pass a table variable into Dynamic SQL. It just requires the additional step of declaring a custom type and using it as the data type, as shown in Listing 5-6.

Listing 5-6. Passing a Table Variable into Dynamic SQL

```
CREATE TYPE last_name_table AS TABLE
       (last_name NVARCHAR(50));
GO

DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);
DECLARE @first_name_calling_sql NVARCHAR(50) = 'Edward';

DECLARE @last_names AS last_name_table;

INSERT INTO @last_names
       (last_name)
SELECT
       LastName
FROM Person.Person WHERE FirstName = @first_name_calling_sql;

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM @last_name_table)
'

SELECT @parameter_list = '@first_name_within_dynamic_sql NVARCHAR(50), @last_name_table
last_name_table READONLY'
EXEC sp_executesql @sql_command, @parameter_list, @first_name_calling_sql, @last_names;
```

The first step is to create a table type once that will be used for the remainder of this example. It's passed as a parameter into sp_executesql just like any other parameter, but must be declared as READONLY within the parameter list. Table variables are always read-only and cannot be modified within the Dynamic SQL that they are passed into. If you were to try to delete from the table variable, or make any change to it at all, you would receive an error:

```
Msg 10700, Level 16, State 1, Line 255
The table-valued parameter "@last_name_table" is READONLY and cannot be modified.
```

SQL Server provides a very direct error message, reminding you that attempting to alter the table variable will fail.

Temporary Tables

How about temporary tables? Let's retry the initial example using a temp table instead of a table variable, as shown in Listing 5-7.

Listing 5-7. Results of Using a Temp Table Within Dynamic SQL that Is Declared Outside of It

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

CREATE TABLE #last_names (
       last_name NVARCHAR(50));

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM #last_names)'

EXEC sp_executesql @sql_command;

DROP TABLE #last_names
```

The result is not an error message but a result set (albeit an empty one). What if you modify the temporary table within the Dynamic SQL? Listing 5-8 shows the resulting TSQL.

Listing 5-8. Results of Modifying a Temp Table Within Dynamic SQL

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

CREATE TABLE #last_names (
       last_name NVARCHAR(50));

INSERT INTO #last_names
       (last_name)
SELECT 'Thomas'

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM #last_names);

INSERT INTO #last_names
       (last_name)
SELECT ''Smith'';
'
```

```
EXEC sp_executesql @sql_command;

SELECT * FROM #last_names;

DROP TABLE #last_names;
```

The results indicate that the temp table was not only accessible within the Dynamic SQL, but was written successfully, as shown in Figure 5-4.

	FirstName
1	Alexandra
2	Alexis
3	Alyssa
4	Andrew
5	Anna
6	Ashley
7	Benjamin
8	Blake
9	Brandon
10	Brianna

	last_name
1	Thomas
2	Smith

Figure 5-4. *Temporary tables created outside of Dynamic SQL are also accessible within*

The first result set shows that the temporary table is accessible within Dynamic SQL. The second result set shows that it can be modified within the Dynamic SQL and those results persisted later on in the example. This is very useful and provides a simple way to manage data that needs to pass between Dynamic SQL and other TSQL seamlessly. Since you are on a roll, what happens when you declare a temp table within Dynamic SQL and attempt to access it later in the code? Listing 5-9 shows the TSQL to accomplish this.

Listing 5-9. Results of Creating a Temp Table Within Dynamic SQL and Accessing It Later

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

SELECT @sql_command = '
CREATE TABLE #last_names (
       last_name NVARCHAR(50));

INSERT INTO #last_names
       (last_name)
SELECT ''Thomas'';
'

EXEC sp_executesql @sql_command;

SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM #last_names);
```

Your luck has run out; this example results in an error:

```
Msg 208, Level 16, State 0, Line 316
Invalid object name '#last_names'.
```

While a temporary table declared in the calling TSQL is accessible within Dynamic SQL, the reverse is not true. The table `#last_names` exists only within the scope of the Dynamic SQL and will not be available elsewhere. Similarly, referencing the temp table in another block of Dynamic SQL later in the code will result in the same error. In other words, the following example will also fail with the same error message, as shown in Listing 5-10.

Listing 5-10. Reusing a Temp Table in Subsequent Dynamic SQL Is Also Not Valid

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

SELECT @sql_command = '
CREATE TABLE #last_names (
       last_name NVARCHAR(50));

INSERT INTO #last_names
       (last_name)
SELECT ''Thomas'';
'

EXEC sp_executesql @sql_command;

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
```

```
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM #last_names);'

EXEC sp_executesql @sql_command;
```

Be mindful when creating and accessing temp tables to ensure that they are available where needed and not out of scope when required later in your code. Also keep in mind that these temp tables are only available within your current SQL Server connection. If you attempt to access a temp table created in this connection from a separate application or connection, it will also be unavailable.

Lastly, a temporary table will be automatically dropped when its connection is ended. It is a good practice to drop temp tables when your work with them is complete, but if you don't, SQL Server will remove them for you. This automatic removal only occurs when the connection under which the temp table was created ends. If that connection is maintained indefinitely, then the temp table will also remain indefinitely. If a table with the same name were later declared within the same session, an error would result as the table already exists.

Global Temporary Tables

One final option that is available is the global temporary table. These tables are declared just like standard temp tables, but with the ## prefix instead of #. Global temp tables are available server-wide for any TSQL accessing the same SQL Server instance they are created on. This access is not restricted based on connection or by database access.

Once created, a global temp table will persist until all connections to it end. The table may be created within the scope of Dynamic SQL or the calling TSQL, and will still be available within any other scope on the server.

Consider the example in Listing 5-11, similar to the previous one.

Listing 5-11. Example of Global Temporary Table Usage

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

SELECT @sql_command = '
CREATE TABLE ##last_names (
       last_name NVARCHAR(50));

INSERT INTO ##last_names
       (last_name)
SELECT ''Thomas'';'

EXEC sp_executesql @sql_command;

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM ##last_names);'

EXEC sp_executesql @sql_command;

SELECT * FROM ##last_names;
```

This TSQL declares a global temp table within Dynamic SQL. It then selects some first names from Person.Person using the global temp table, and later accesses it again in the calling TSQL. Everything works exactly as intended (this does happen sometimes)! Note that at the end of the example, the global temp table is not dropped. As a result, it will remain available until either all connections using it are ended or you explicitly drop it. This can be beneficial if you want to access it again or from another location. It can also be problematic if you forget about it and try to declare a temp table with the same name in the future:

```
CREATE TABLE ##last_names (
       last_name NVARCHAR(50));
```

When you run this table creation, an error is generated:

```
Msg 2714, Level 16, State 6, Line 351
There is already an object named '##last_names' in the database.
```

It is critically important to manage global temp tables in any code that creates or uses them. Forgetting to drop a temp table may turn out okay if you happen to end the connection and it is automatically removed by SQL Server. In the event that another connection is made to the table, it will not be dropped by SQL Server as it will still be in use. The best practice for dealing with temporary tables is to drop them when they are no longer needed. This removes any possibility of the table persisting and being accessed inadvertently later on or of being created when it already exists.

Always drop a temporary table when it is no longer needed. This ensures that it does not interfere with future table creation and is not somehow accessed when it's no longer needed.

Since there are the table ##last_names available, take a look at another feature of global temporary tables—their availability anywhere on the server:

```
CREATE DATABASE temp_table_test;
GO
USE temp_table_test;
GO
SELECT
       *
FROM ##last_names;
```

Even in this brand new database, the global temp table was still available. Since you've yet to drop this SQL Server connection, it will remain available indefinitely to any other connection on the server. This leads into a discussion of global temp table security, for which there happens to be none. Once created, a global temporary table is available everywhere to any login or user in any database, without restrictions.

In the last chapter, you created a user called VeryLimitedUser that only had access to a single stored procedure and no explicit access to any other database, tables, or SQL Server functionality. What happens when this user tries to access the global temp table?

```
EXECUTE AS USER = 'VeryLimitedUser';
GO
SELECT
       *
FROM ##last_names;
```

```
REVERT;
GO
DROP TABLE ##last_names;
GO
```

Despite having nearly no permissions on the server, this user can select data from the global temp table without issue. This raises a potential security concern with global temporary tables because they are, by design, accessible by anyone else on the server, regardless of their specific permissions. In addition, it is not possible to place permissions on a global temp table to restrict this behavior. Be mindful of any global temp tables that you create. Be sure that, if another user were to somehow access it, this access would not be problematic. If your global temp table contains any sensitive data, consider storing it in another format such as a table variable, a standard temporary table, or a permanent table that is used for staging or temporary data. Hashing or encrypting the data can also be a good way to limit its access, because it will reduce usability from other connections.

Another issue that can occur is when two global temp tables are created from two different connections that have the same name. Since these tables are global and in scope for the entire SQL Server instance, no two such tables may share the same name. If this occurs, an error will be thrown and the second person to attempt to declare the new table will be unable to continue without renaming it.

Using Permanent Tables for Temporary Storage

When you need to store temporary data often for a specific functionality, creating a permanent table is an efficient and secure approach. For the previous example, you could alternatively manage the list of last names in the manner shown in Listing 5-12.

Listing 5-12. Using a Permanent Table for Temporary Storage

```
CREATE TABLE last_names_staging (
       last_name NVARCHAR(50) NOT NULL CONSTRAINT PK_last_names_staging
       PRIMARY KEY CLUSTERED);
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

SELECT @sql_command = '

INSERT INTO last_names_staging
       (last_name)
SELECT ''Thomas'';'

EXEC sp_executesql @sql_command;

SELECT @sql_command = '
SELECT DISTINCT
       FirstName
FROM Person.Person
WHERE LastName IN (SELECT last_name FROM last_names_staging);'

EXEC sp_executesql @sql_command;

SELECT * FROM last_names_staging;
```

In this example, everything works as it did in the previous examples, except that the "temporary storage" is rather permanent. It may seem counter-intuitive to create a permanent object in order to store temporary data, but there are many benefits in doing so:

- Data is persisted permanently, regardless of connection.
- Tables can be accessed from anywhere on the server, regardless of the database.
- Security can be applied to the table, ensuring only authorized access.
- Indexes, statistics, constraints, and so on, may be added to the table.
- There is no need to access TempDB.

The drawbacks of using a permanent table are few, but significant:

- It becomes a permanent object that requires maintenance and documentation.
- Usage must be managed so that data is always relevant.

To summarize all of the points above: Use permanent tables when data needs to be stored on a more long-term basis, or when optimization becomes important. While indexes can be placed on temporary tables and table variables (with limitations), having a permanent place to stage temporary data can be extremely convenient and remove the need to constantly manage temporary objects.

Equally importantly, limit the use of tables for this purpose to only when it is sensible and efficient. Creating permanent tables for all temporary data creation/access could quickly result in a plethora of objects that require care and maintenance. One option to assist with organization is to create the table in its own schema, thus separating it from the rest of the objects in the database. Alternatively, for smaller use-cases, appending a prefix to these tables may be enough to organize and find them easily.

When a "permanent temporary table" is no longer needed, it can easily be dropped. This cleanup step is important, as you don't want to clutter a server with unneeded, temporary, or unused objects. Creating any permanent database object carries with it the implicit responsibility to document and manage it effectively. When the day comes that it is no longer needed, take the added time to deprecate and ultimately remove it.

Output Data Directly to a Table from Dynamic SQL

One final way to collect data from any stored procedure, including Dynamic SQL, is to insert it directly into a table as a part of the EXEC statement. This example, as shown in Listing 5-13, is a new twist on the temporary storage and eliminates the need to explicitly manage it within Dynamic SQL.

Listing 5-13. Inserting Dynamic SQL Output Directly into Another Table

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX);

CREATE TABLE #last_names (
       last_name NVARCHAR(50));

SELECT @sql_command = '
SELECT
       LastName
FROM Person.Person
WHERE FirstName = ''Edward'';
'
```

```
INSERT INTO #last_names
       (last_name)
EXEC sp_executesql @sql_command;

SELECT
       *
FROM #last_names

DROP TABLE #last_names;
```

In this example, you declare the temporary table `#last_names` at the start of the TSQL. Note that when you execute the command string, the output is directly placed into the temp table, without the need for passing parameters or managing additional objects. This is a very convenient way to save the output from Dynamic SQL or any other stored procedure and to do so quickly and efficiently. This is also an excellent way to save the output from a system stored procedure, as shown in Listing 5-14.

Listing 5-14. Using the INSERT...EXEC Syntax to Collect Output from sp_who

```
CREATE TABLE #sp_who_data
(
       spid SMALLINT,
       ecid SMALLINT,
       status NCHAR(30),
       loginame NCHAR(128),
       hostname NCHAR(128),
       blk CHAR(5),
       dbname NCHAR(128),
       cmd NCHAR(16),
       request_id INT
)

INSERT INTO #sp_who_data
       (spid, ecid, status, loginame, hostname, blk, dbname, cmd, request_id)
EXEC sp_who;

SELECT * FROM #sp_who_data
WHERE dbname = 'AdventureWorks2012'

DROP TABLE #sp_who_data;
```

A very common administrative need is to view the current SQL Server connections and gather details about who is connected to what database and what they are up to. While executing `sp_who` gathers that data, it only outputs it to the results window. On a busy server with many connections, you will want to filter that data by database, user, or some other criteria. You may also want to log that data permanently for auditing or other security purposes. The ability to insert that data directly into a table allows you to efficiently filter it down to a single database and get only the connections there, rather than on the entire server. Note that the data types in the `#sp_who_data` table were taken from MSDN and are not a byproduct of my active imagination:

`https://msdn.microsoft.com/en-us/library/ms174313.aspx`

This same syntax can be applied to any stored procedure, system-stored procedure, or Dynamic SQL output. While it is convenient, it is also somewhat inflexible. The table that the data is to be inserted into must be defined ahead of time and must be exactly the same structure as the output data. While it would be convenient to execute the command string while also creating a temporary table, SQL Server does not allow that syntax:

```
SELECT
       EXEC sp_who
INTO #sp_who_data;

SELECT INTO #sp_who_data
EXEC sp_who;

SELECT INTO #sp_who_data
(EXEC sp_who);
```

No matter how creative you get, there is no way to force SQL Server to create the temporary table on-the-fly for you. `SELECT INTO` is not allowed in conjunction with stored procedure execution, and no rearrangement of the TSQL will make this magically work. As a result, you must always define the target table for the output ahead of time.

Conclusion

While scope prevents you from effortlessly moving data among the Dynamic SQL, the other TSQL, and additional stored procedure executions, a number of tools exist that provide many ways in which to accomplish this anyway. As with any toolbox, always choose the correct tool for each job. Typically, the more temporary the data, the less need there is for creating elaborate structures or methodologies in order to manage it. If data is needed once, or only for the duration of a specific stored procedure, consider using the `INSERT..EXEC` syntax or a temporary table. If data may be needed in the future from other connections, then global temporary tables can be helpful in ensuring that it is available when needed. Use caution with global temp tables, as they lack the security and limitations in scope that other data structures have. Only use them when you are certain that they are needed. Lastly, for data that will be needed throughout the future, a permanent table can be a great way to save that data and manage it efficiently and securely for a long time to come.

Cleanup

The following TSQL will clean up any objects created in this chapter, if they exist:

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'get_people')
BEGIN
       DROP PROCEDURE dbo.get_people;
END
GO
IF EXISTS (SELECT * FROM sys.databases WHERE databases.name =
'temp_table_test')
BEGIN
       DROP DATABASE temp_table_test;
END
GO
```

CHAPTER 6

Performance Optimization

No discussion of Dynamic SQL would be complete without diving into its performance. Dynamic SQL can greatly improve performance, but can also increase complexity if not used effectively. As was the case with security, optimization is a topic that could easily occupy significantly larger books than this one. As such, this chapter focuses on Dynamic SQL and any performance concerns that relate to it.

Query Execution

Before jumping into the performance of Dynamic SQL and a variety of ways to monitor and tune performance, it is necessary to quickly review the process of query execution. What happens when you execute a TSQL statement through the moment that the results are returned and it is complete? Query execution is typically broken into four steps, discussed in the following sections.

Parsing

A query is checked for syntax and if there are any unidentified or invalid TSQL commands, an error will be thrown. In addition, the query is broken into a list of very high-level steps that will be followed by SQL Server throughout the remainder of this process. These steps are simple operations, such as selecting data from a table, joining another table, or executing some Dynamic SQL or stored procedure.

Binding

This step is primarily concerned with validating objects and ensuring that they are valid and used in the correct context. Tables, columns, functions, stored procedures, and any other named objects are checked against SQL Server's system catalogs to verify that the names are correct and that they are being used correctly. At this point, if no error has been received, then you know that syntax and object names are all correct. The list generated in the parsing step is used with this new information to generate what is known as an algebrized tree. This tree is a listing of steps that must be performed in order for the query to execute correctly.

Optimization

This is the most complex part of the execution process and involves SQL Server needing to take the tree from the binding step and find a good execution plan for it very, very quickly. This work proceeds similarly to the way a chess program attempts to find the best move in a game of chess. Basically, the query optimizer comes up with a possible execution plan and assigns a cost to it, then evaluates more execution plans until it decides that it has found a plan that is good enough.

E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_6

Query optimization is a race against time as the query itself will take time to process, but the optimization process also takes time. The optimizer needs to weigh this in order to not waste too much time optimizing a simple query, but also take enough time that it finds a plan that performs well. For example, if you had a query that took two seconds to execute, and the optimizer could spend one more second in order to save half a second during execution, then it would have wasted that time in doing so. If it could save 1.5 seconds using only 0.1 seconds of effort, then it would be a great deal. In addition to time, server resources such as CPU are taken into account. This process happens very quickly and is one of the most complex components of SQL Server.

The result of optimization is a list of detailed steps that SQL Server can execute in order to return the results desired in the original query.

Execution

The steps from the optimization process are executed and any required actions are taken in order to complete them.

Optimization Tools

In order to review performance and make intelligent decisions based on it, you need to define a set of tools that you will use going forward that will assist in this process. It is impossible to make consistently good decisions regarding performance without multiple metrics that you are comfortable using. If a query is slow, you need to know which part of it is the bottleneck and identify why this is the case.

Query Execution Plan

Query execution plans are the first and most visual of the tools available. Execution plans are the steps that the optimizer came up with during the optimization step and are executed by SQL Server.

The actual execution plan from a query can be viewed in SQL Server by clicking on the Include Actual Execution Plan icon in SQL Server Management Studio or by using the keyboard shortcut Ctrl+M, as shown in Figure 6-1.

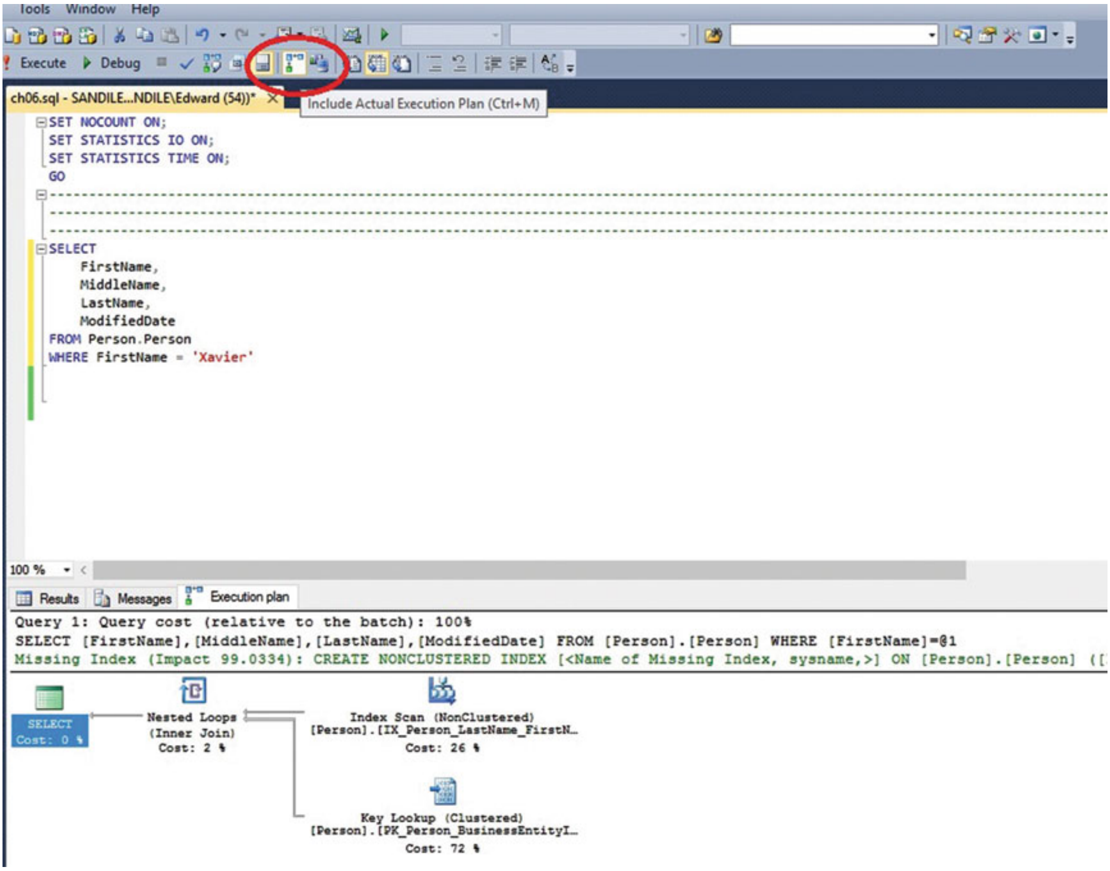


***Figure 6-1.** Turning on and using query execution plans in SQL Server Management Studio*

The icon to turn on the actual execution plan is circled in Figure 6-1. When you click this icon, you'll see an additional tab in the results window labeled Execution Plan. Included in this tab is a section for every query executed, including the query text. The graphical portion is read from right to left and is made of icons that represent operations performed by SQL Server, such as reading a table, joining data sets, sorting, and so on. If SQL Server thinks that a new index could help query performance, it will suggest it in green between the query text and the graphical plan. Hovering over an icon will produce details on the step, including rows processed, estimated IO, CPU, and subtree cost, as shown in Figure 6-2.

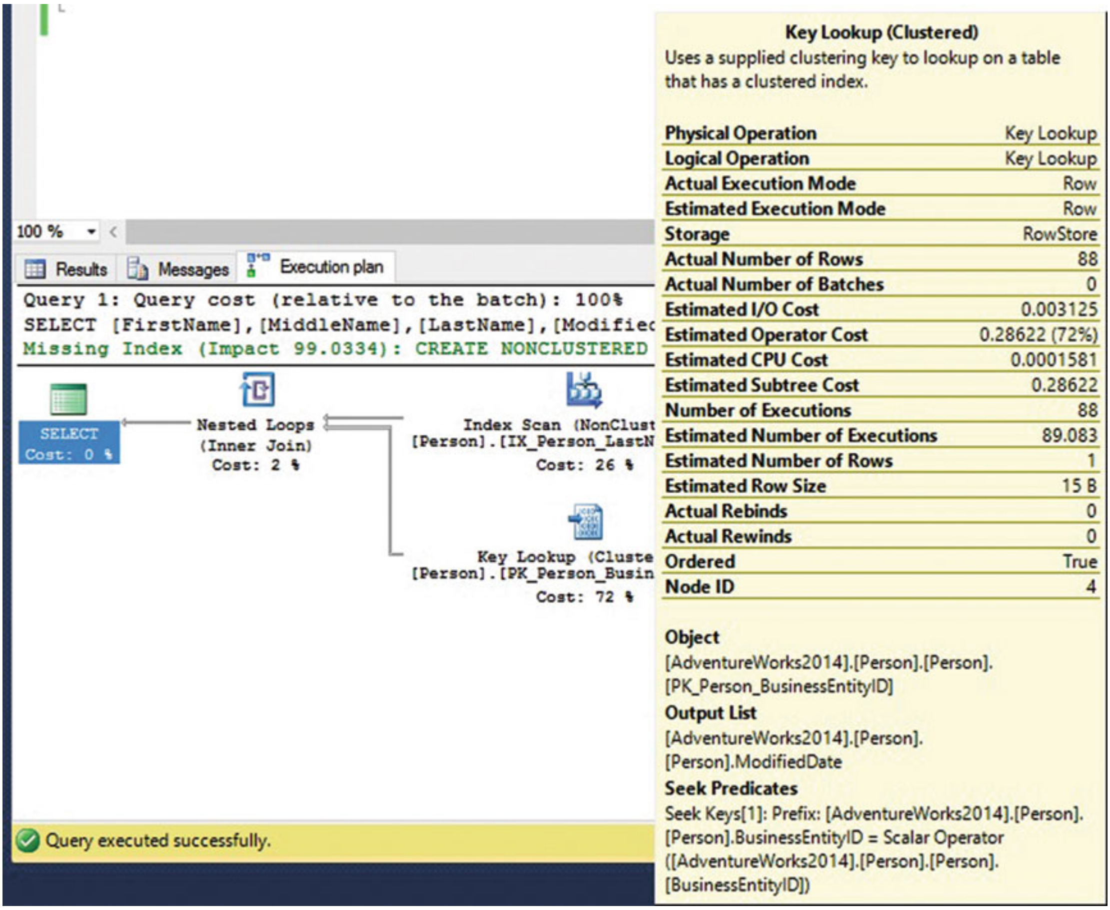


Figure 6-2. *Viewing detailed properties for any step within an execution plan*

Subtree cost is an indication of the cost determined during the optimization step and provides an idea of which parts of the query are most expensive to execute.

The width of the lines in between steps will indicate the relative number of rows processed by that step. Hovering over one of these lines will provide some basic information about the data transfer represented by the line. Figure 6-3 shows an example of these details.

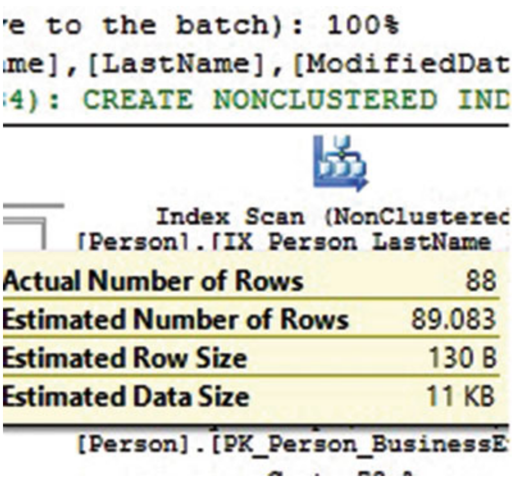


Figure 6-3. *Viewing details of the output from one step of the execution plan*

Execution plans may also include warnings, errors, or other issues that SQL Server ran into while executing a query. When in doubt, take a closer look at any troublesome steps, which could reveal useful information about why a query is performing poorly. Hovering over any part of an execution plan will provide additional details on the step. Opening the properties for a step will return an additional array of information regarding how the step performed.

STATISTICS IO

SQL Server can provide information about which tables were read and how many reads occurred against them. This can be turned on with the following TSQL:

```
SET STATISTICS IO ON;
```

This is very important information, as it indicates overall IO use. If a query is running slow, it could be the result of excessive reads against a table. The execution plan may not always convey the enormity of an IO bottleneck, but the knowledge that a query that returns two rows is taking a million reads to do so is an indication of a possible problem. Often, the two will correlate with each other, providing a solid foundation on which to understand why a query is slow. Once enabled, `STATISTICS IO` will add details to the text output screen, as shown in Figure 6-4.

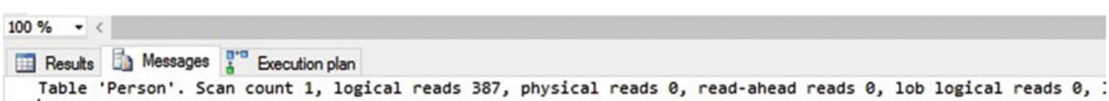


Figure 6-4. *Example output from STATISTICS IO*

While there are a number of operations detailed here, the discussion here is limited to the first four.

Objects

The name of the table or view that is being accessed.

Scan Count

This indicates if an object was read multiple times. A high number here can indicate that SQL Server is reading the same data over and over again, which can be a potential sign of an inefficient query.

Logical Reads

This is the number of reads made on the object indicated, regardless of whether the data is cached in memory or not. This will be the metric referred to throughout this chapter whenever you are concerned with IO read activity, as it will remain static for a given query even if the physical reads change.

Physical Reads

This is the number of reads where the data was not yet in the buffer cache. Whenever data is read for a query, it is placed into memory and remains there until it ages out or is replaced at a later time. The initial read of data into memory from your storage system can be very expensive. If queries are constantly making physical reads, that could be a sign that queries are reading too much data or that there is memory pressure on the server.

When you execute a query and access data for the first time, this number will be the same as the logical reads, but all subsequent executions will show zero for this metric as the data will now be in memory from the first execution.

STATISTICS TIME

What is likely the most important metric to any consumer of data is the time it takes for the server to return the data they are looking for. As database professionals, the most common complaint we will hear is, “It’s slow!” This metric breaks out the execution time for each step, which can be useful in determining which query in a stored procedure took the most time to execute. The following is the output for `STATISTICS TIME` for the same query used in the previous execution plan:

```
SQL Server parse and compile time:
CPU time = 0 ms, elapsed time = 0 ms.
SQL Server Execution Times:
CPU time = 0 ms, elapsed time = 64 ms.
```

Parse and compile time is the time spent by SQL Server to perform the parsing, binding, and optimization steps discussed earlier. Execution time is the actual time spent on running the query itself.

These times are very useful, but must be taken with a grain of salt. Execution times are affected by many different variables. If an execution plan is cached and reused, the parse and compile time will be zero. If data is cached in memory, the execution time will be much faster. External factors, such as network latency, IO latency, or contention from other processes can all affect execution time. As a result, it’s important to base your optimization decisions on many trial executions of the query to ensure that you are not making decisions based on exceptions or edge-cases.

As a rule of thumb, when timing a query's execution, I will try to run it at least 10-20 times to get a good idea of how it would perform in a production environment where it may be run over and over. How often you personally test a query will be based on its importance and complexity and on your organization's QA policies. When in doubt, take the time to run enough trials so that you are comfortable with the results and confident in using those results when justifying your decisions to others, if necessary.

Use All of These Tools!

It is important to use as many performance metrics as possible when analyzing a query's performance. An execution plan by itself may not tell the entire story, nor would execution times give you all of the information needed to tune a query. While more tools exist, the three discussed here (when used in concert) provide a very solid understanding of how a query performs, where a bottleneck exists, and some hints as to where to begin tuning in order to improve performance.

Dynamic vs. Standard SQL

While the TSQL that executes within a command string will be handled by SQL Server like any other standard SQL statement, there are some potential differences that are important to point out regarding performance.

Query Parsing and Binding

A big piece of the first two stages of query execution are checking syntax and object names and verifying that you didn't make any mistakes when writing your query that would prevent it from being executed. The contents of strings are evaluated at runtime and are not subject to these processes when you initially write and test a query. Since a Dynamic SQL command string is a string, it will not be checked for the validity of its contents until you've executed it. You can parse a query and verify its syntax by clicking the icon shown in Figure 6-5.

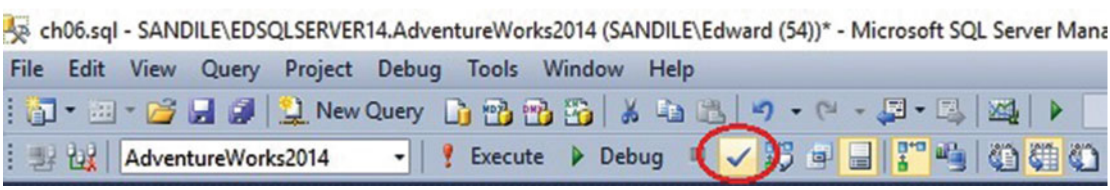


Figure 6-5. *Manually parsing a query in SQL Server Management Studio*

This feature allows you to verify syntax and check for any obvious mistakes before trying to execute your TSQL. The following query will generate a syntax error when parsing:

```
SELECT & FROM Person.Person;
```

My typo replaced the asterisk (*) with an ampersand (&). When I clicked the parse icon to validate my syntax, the result was an error:

```
Msg 102, Level 15, State 1, Line 18
Incorrect syntax near '&'.
```

Alternatively, if this were written as Dynamic SQL, no such error would be thrown:

```
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = 'SELECT & FROM Person.Person;';
EXEC (@sql_command);
```

The parser doesn't check the contents of `@sql_command` until it is executed, and is then treated as a new query that needs to be parsed, bound, optimized, and executed. It parses without an error, but will throw a similar error when executed:

```
Msg 102, Level 15, State 1, Line 19
Incorrect syntax near '&'.
```

As a result, it is important to carefully print and test command strings prior to executing them.

Execution Plan Caching

A query execution plan is generated for every unique query that executes in SQL Server. What makes a query unique? This is determined by its exact text. Optimizing a query in order to generate an execution plan takes time and server resources and is a relatively expensive process, especially for more complex queries. Consider the query in Listing 6-1, which hypothetically runs frequently on a server, 500 times per minute.

Listing 6-1. Example TSQL that Will Generate a New Execution Plan for Each First Name

```
DECLARE @FirstName NVARCHAR(MAX) = 'Edward';
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
               *
FROM Person.Person
WHERE FirstName = '' + @FirstName + '';
';
PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

When this is executed for the first time, an execution plan is created for its exact text, which will print out as follows:

```
SELECT
             *
FROM Person.Person
WHERE FirstName = 'Edward';
```

Note that the name `Edward` is included in the SQL text. Let's say that the query runs again, but for a different name:

```
DECLARE @FirstName NVARCHAR(MAX) = 'Xavier';
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
             *
```

```
FROM Person.Person
WHERE FirstName = "" + @FirstName + "";
'
PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The resulting SQL text will be different than the previous run of the query:

```
SELECT
            *
FROM Person.Person
WHERE FirstName = 'Xavier';
```

As a result, each will receive a different execution plan. Checking the data from the time statistics, you can see that some finite amount of time was spent on handling the query prior to execution:

```
SQL Server parse and compile time:
CPU time = 0 ms, elapsed time = 1 ms.
```

One microsecond may not seem like much, but if it executed 500 times per minute, you would end up with 720,000ms of extra execution time every day! For a more complex query, this could add up to a huge amount of latency. When an execution plan is reused, the time indicated for the parse and compile time will be zero, which is much more desirable for a query that is executed often.

The fix for this dilemma is the same as the fix for many of the security and SQL injection concerns you saw in earlier chapters: parameterize the query! Rewriting the query changes `FirstName` into a parameter that can be used over and over with the same execution plan:

```
DECLARE @FirstName NVARCHAR(MAX) = 'Edward';
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX) = '@first_name NVARCHAR(MAX)';
SELECT @sql_command = '
SELECT
            *
FROM Person.Person
WHERE FirstName = @first_name;'
PRINT @sql_command;
EXEC sp_executesql @sql_command, @parameter_list, @FIrstName;
```

When `@sql_command` is printed out for this version of the simple query, the resulting text is as follows:

```
SELECT
            *
FROM Person.Person
WHERE FirstName = @first_name;
```

In fact, the query text will be the same, no matter what value of `@FirstName` is passed in to the Dynamic SQL command string. As a result, you will only pay the price of optimizing the query once, and then the execution plan will be reused over and over from that point on. That's 12 minutes of latency shaved off of this query per day. If it were a more complex query that required 20ms to parse and compile, then the savings would be four hours of latency!

Let's quickly prove this and show that the behavior I am describing is true and not just theoretical. First, you'd clear out the procedure cache, which will provide you with a clean slate to work on with no distractions:

```
DBCC FREEPROCCACHE;
```

Executing this DBCC command will clear all execution plan data out of cache. This is an excellent way to create a clean environment to test in, but should only be used in isolated environments where important workloads cannot be affected! For the test purposes on local test servers here, this is a fine way to aid your work.

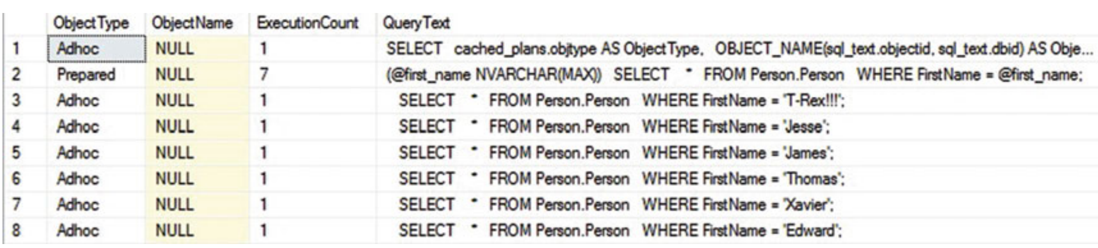
Never clear out the procedure cache in production unless you absolutely mean it! This removes all query execution plan data from cache, and on a busy server could cause immense latency as queries will need to be re-optimized!

Now, let's run the previous queries on Person.Person a few times, each one with a variety of different names. This is solely to add execution data to the cache for the upcoming demo, and therefore any queries that run on this table will end up in cache and visible below. Once it's done, you can build a TSQL statement that will read query data from the cache, as shown in Listing 6-2.

Listing 6-2. TSQL that Can Retrieve SQL Text from the Query Plan Cache

```
SELECT
cached_plans.objtype AS ObjectType,
OBJECT_NAME(sql_text.objectid, sql_text.dbid) AS ObjectName,
cached_plans.usecounts AS ExecutionCount,
sql_text.TEXT AS QueryText
FROM sys.dm_exec_cached_plans AS cached_plans
CROSS APPLY sys.dm_exec_sql_text(cached_plans.plan_handle) AS sql_text
WHERE sql_text.TEXT LIKE '%Person.Person%';
```

This returns only a handful of relevant columns from the plan cache for your viewing pleasure, but could be altered to return quite a bit more data, if you wanted. The results of this query are shown in Figure 6-6.



	ObjectType	ObjectName	ExecutionCount	QueryText
1	Adhoc	NULL	1	SELECT cached_plans.objtype AS ObjectType, OBJECT_NAME(sql_text.objectid, sql_text.dbid) AS Obje...
2	Prepared	NULL	7	(@first_name NVARCHAR(MAX)) SELECT * FROM Person.Person WHERE FirstName = @first_name;
3	Adhoc	NULL	1	SELECT * FROM Person.Person WHERE FirstName = 'T-Rex!!!';
4	Adhoc	NULL	1	SELECT * FROM Person.Person WHERE FirstName = 'Jesse';
5	Adhoc	NULL	1	SELECT * FROM Person.Person WHERE FirstName = 'James';
6	Adhoc	NULL	1	SELECT * FROM Person.Person WHERE FirstName = 'Thomas';
7	Adhoc	NULL	1	SELECT * FROM Person.Person WHERE FirstName = 'Xavier';
8	Adhoc	NULL	1	SELECT * FROM Person.Person WHERE FirstName = 'Edward';

Figure 6-6. *Sample data from the query plan cache*

The results are every query that is currently in the plan cache with TSQL text that includes the string "Person.Person". The first query is the one I just ran to collect this data. The second is the parameterized query, which I ran for a variety of different first names. Notice that the execution count indicates that it has been reused a number of times. The remaining six queries are the non-parameterized queries from earlier, executed for the names Edward, Xavier, Thomas, Jesse, James, and T-Rex!!!. Regardless of the results (or lack thereof) returned, a separate entry is in the plan cache for all of these, even though the queries are essentially the same.

Note that under the object type, the parameterized query is listed as Prepared rather than Adhoc, which indicates that the TSQL that was executed had no variables that could alter the TSQL text within it. By being completely parameterized, the query plan also becomes deterministic. Changing the first name you are searching for doesn't alter the SQL text, and therefore does not alter the execution plan. In the event that this query were executed very often for a large variety of first names, the non-parameterized query would quickly fill up the plan cache with a pile of entries for the same search. This would be very wasteful over time, not only consuming resources in constantly compiling query execution plans, but eventually bumping more important queries out of cache. As a result, whenever you're working with any query that is to be executed often, make sure that it can execute over and over but only needs a single execution plan.

Simplifying Queries

In the earlier discussion of dynamic searches, you were able to use Dynamic SQL as a way to remove excessive joins or WHERE clauses from TSQL statements. While the Dynamic SQL was more complex, the resulting TSQL that was executed was simpler. Now that you have some performance evaluation tools at your disposal, you can put that claim to the test! See Listing 6-3 for this stored procedure.

Listing 6-3. Dynamic Search Procedure that Selectively Queries Objects when Needed

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_products')
BEGIN
DROP PROCEDURE dbo.search_products;
END
GO
•      Search with a check to avoid empty searches
CREATE PROCEDURE dbo.search_products
@product_name NVARCHAR(50) = NULL, @product_number NVARCHAR(25) = NULL,
@product_model NVARCHAR(50) = NULL,
@product_subcategory NVARCHAR(50) = NULL, @product_sizemeasurecode NVARCHAR(50) = NULL,
@product_weightunitmeasurecode NVARCHAR(50) = NULL,
@show_color BIT = 0, @show_safetystocklevel BIT = 0, @show_reorderpoint BIT = 0,
@show_standard_cost BIT = 0,
@show_catalog_description BIT = 0, @show_subcategory_modified_date BIT = 0,
@show_product_model BIT = 0,
@show_product_subcategory BIT = 0, @show_product_sizemeasurecode BIT = 0,
@show_product_weightunitmeasurecode BIT = 0
AS
BEGIN
SET NOCOUNT ON;
IF COALESCE(@product_name, @product_number, @product_model, @product_subcategory,
@product_sizemeasurecode, @product_weightunitmeasurecode) IS NULL
RETURN;
•     Add "%" delimiters to parameters that will be searched as wildcards.
SET @product_name = '%' + @product_name + '%';
SET @product_number = '%' + @product_number + '%';
SET @product_model = '%' + @product_model + '%';
DECLARE @sql_command NVARCHAR(MAX);
•     Define the parameter list for filter criteria
```

```
DECLARE @parameter_list NVARCHAR(MAX) = '@product_name NVARCHAR(50),
@product_number NVARCHAR(25),
@product_model NVARCHAR(50), @product_subcategory NVARCHAR(50),
@product_sizemeasurecode NVARCHAR(50),
@product_weightunitmeasurecode NVARCHAR(50)';
•     Generate the simplified command string section for the SELECT columns
SELECT @sql_command = '
SELECT
Product.Name AS product_name,
Product.ProductNumber AS product_number,';
IF @show_product_model = 1 OR @show_catalog_description =
1 SELECT @sql_command = @sql_command + '
ProductModel.Name AS product_model_name,
ProductModel.CatalogDescription AS productmodel_catalog_description,';
IF @show_product_subcategory = 1 OR @show_subcategory_modified_date = 1 SELECT
@sql_command = @sql_command + '
ProductSubcategory.Name AS product_subcategory_name,
ProductSubcategory.ModifiedDate AS product_subcategory_modified_date,';
IF @show_product_sizemeasurecode = 1 SELECT @sql_command = @sql_command + '
SizeUnitMeasureCode.Name AS size_unit_measure_code,';
IF @show_product_weightunitmeasurecode = 1 SELECT @sql_command = @sql_command + '
WeightUnitMeasureCode.Name AS weight_unit_measure_code,';
IF @show_color = 1 OR @show_safetystocklevel = 1 OR @show_reorderpoint = 1 OR
@show_standard_cost = 1
SELECT @sql_command = @sql_command + '
Product.Color AS product_color,
Product.SafetyStockLevel AS product_safety_stock_level,
Product.ReorderPoint AS product_reorderpoint,
Product.StandardCost AS product_standard_cost';
•     In the event that there is a comma at the end of our command string, remove it before
continuing:
IF (SELECT SUBSTRING(@sql_command, LEN(@sql_command), 1)) = ','
SELECT @sql_command = LEFT(@sql_command, LEN(@sql_command) - 1);
SELECT @sql_command = @sql_command + '
FROM Production.Product'
•     Put together the JOINs based on what tables are required by the search.
IF (@product_model IS NOT NULL OR @show_product_model = 1 OR @show_catalog_description = 1)
SELECT @sql_command = @sql_command + '
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID';
IF (@product_subcategory IS NOT NULL OR @show_subcategory_modified_date = 1 OR
@show_product_subcategory = 1)
SELECT @sql_command = @sql_command + '
LEFT JOIN Production.ProductSubcategory
ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID';
IF (@product_sizemeasurecode IS NOT NULL OR @show_product_sizemeasurecode = 1)
SELECT @sql_command = @sql_command + '
LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode';
IF (@product_weightunitmeasurecode IS NOT NULL OR @show_product_weightunitmeasurecode = 1)
SELECT @sql_command = @sql_command + '
```

```
LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
ON Product.WeightUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode';
SELECT @sql_command = @sql_command + '
WHERE 1 = 1';
•    Build the WHERE clause based on which tables are referenced and required by the search.
IF @product_name IS NOT NULL
SELECT @sql_command = @sql_command + '
AND Product.Name LIKE @product_name';
IF @product_number IS NOT NULL
SELECT @sql_command = @sql_command + '
AND Product.ProductNumber LIKE @product_number';
IF @product_model IS NOT NULL
SELECT @sql_command = @sql_command + '
AND ProductModel.Name LIKE @product_model';
IF @product_subcategory IS NOT NULL
SELECT @sql_command = @sql_command + '
AND ProductSubcategory.Name = @product_subcategory';
IF @product_sizemeasurecode IS NOT NULL
SELECT @sql_command = @sql_command + '
AND SizeUnitMeasureCode.Name = @product_sizemeasurecode';
IF @product_weightunitmeasurecode IS NOT NULL
SELECT @sql_command = @sql_command + '
AND WeightUnitMeasureCode.Name = @product_weightunitmeasurecode';
PRINT @sql_command;
EXEC sp_executesql @sql_command, @parameter_list, @product_name, @product_number,
@product_model, @product_subcategory, @product_sizemeasurecode,
     @product_weightunitmeasurecode;
END
```

The following is a dynamic search you saw in Chapter 4. This stored procedure may seem long, but its length ensures that no table is queried and no column returned unless needed for the search that is being performed.

This stored procedure is written such that a table is queried only if data from it is needed for a WHERE clause or join. In addition, columns are returned by the query only if they are required by the calling application. Now that this is created, let's run it for a possible user search, as shown in Listing 6-4.

Listing 6-4. Execution Example for the Stored Procedure in Listing 6-3

```
EXEC dbo.search_products @product_name = 'Mountain Frame', @product_number = 'FR-M21B',
@product_model = 'LL Mountain Frame',
@product_subcategory = 'Mountain Frames', @show_color = 0, @show_safetystocklevel = 0,
@show_reorderpoint = 0, @show_standard_cost = 1, @show_catalog_description = 1,
@show_subcategory_modified_date = 0,
@show_product_model = 1, @show_product_subcategory = 1
```

This search has a variety of parameters passed in, as well as a few that were omitted. The user has no interest in the measurements of the bike frames, and therefore left out parameters for those variables. The result set is for the five mountain bike frames shown in Figure 6-7.

	product_name	product_number	product_model_name	productmodel_catalog_description	product_subcategory_name	product_subcategory_modified_date	product_colo
1	LL Mountain Frame - Black, 40	FR-M21B-40	LL Mountain Frame	NULL	Mountain Frames	2008-04-30 00:00:00.000	Black
2	LL Mountain Frame - Black, 42	FR-M21B-42	LL Mountain Frame	NULL	Mountain Frames	2008-04-30 00:00:00.000	Black
3	LL Mountain Frame - Black, 44	FR-M21B-44	LL Mountain Frame	NULL	Mountain Frames	2008-04-30 00:00:00.000	Black
4	LL Mountain Frame - Black, 48	FR-M21B-48	LL Mountain Frame	NULL	Mountain Frames	2008-04-30 00:00:00.000	Black
5	LL Mountain Frame - Black, 52	FR-M21B-52	LL Mountain Frame	NULL	Mountain Frames	2008-04-30 00:00:00.000	Black

Figure 6-7. *Results from the search proc, as executed from the TSQL in Listing 6-4*

The command string that was executed is shown in Listing 6-5.

Listing 6-5. The Command String Generated by the Execution of the Search Proc in Listing 6-4

```
SELECT
Product.Name AS product_name,
Product.ProductNumber AS product_number,
ProductModel.Name AS product_model_name,
ProductModel.CatalogDescription AS productmodel_catalog_description,
ProductSubcategory.Name AS product_subcategory_name,
ProductSubcategory.ModifiedDate AS product_subcategory_modified_date,
Product.Color AS product_color,
Product.SafetyStockLevel AS product_safety_stock_level,
Product.ReorderPoint AS product_reorderpoint,
Product.StandardCost AS product_standard_cost
FROM Production.Product
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID
LEFT JOIN Production.ProductSubcategory
ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID
HERE 1 = 1
AND Product.Name LIKE @product_name
AND Product.ProductNumber LIKE @product_number
AND ProductModel.Name LIKE @product_model
AND ProductSubcategory.Name = @product_subcategory
```

Some joins and `WHERE` clauses were omitted from this TSQL, as they were not required by the parameters passed in. How did this affect performance? Here are the IO statistics for this execution:

```
Table 'ProductModel'. Scan count 0, logical reads 10, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductSubcategory'. Scan count 0, logical reads 10, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Product'. Scan count 1, logical reads 14, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

The overall IO was 34 reads: 10 on `ProductModel`, 10 on `ProductSubcategory`, and 14 on `Product`. The execution plan for the same execution is shown in Figure 6-8.

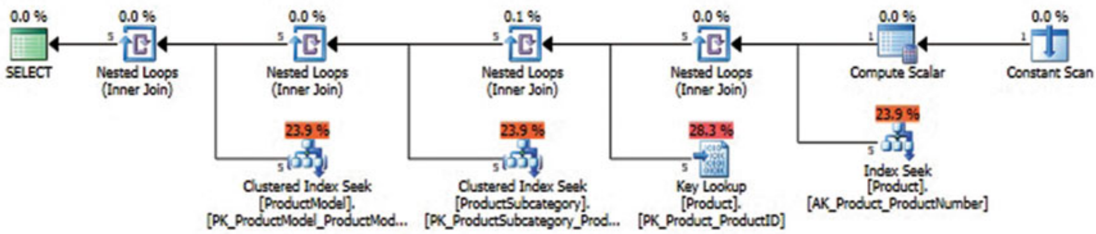


Figure 6-8. *Execution plan for the execution of the stored procedure in Listing 6-4*

The plan shows access to the three tables referenced in the IO stats and the various steps required to put all of that data together. For comparison's sake, the estimated subtree cost for the entire query is 0.014.

The alternative to a dynamic search would be a static search, where all tables are automatically joined and all columns returned in case you need them. This is shown in the stored procedure in Listing 6-6.

Listing 6-6. Search Procedure that Checks and Returns All Data Regardless of Parameters

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_products')
BEGIN
DROP PROCEDURE dbo.search_products;
END
GO
CREATE PROCEDURE dbo.search_products
@product_name NVARCHAR(50) = NULL, @product_number NVARCHAR(25) = NULL,
@product_model NVARCHAR(50) = NULL,
@product_subcategory NVARCHAR(50) = NULL, @product_sizemeasurecode NVARCHAR(50) = NULL,
@product_weightunitmeasurecode NVARCHAR(50) = NULL
AS
BEGIN
SELECT @product_name = '%' + @product_name + '%';
SELECT @product_number = '%' + @product_number + '%';
SELECT @product_model = '%' + @product_model + '%';
SELECT
Product.Name AS product_name,
Product.ProductNumber AS product_number,
ProductModel.Name AS product_model_name,
ProductModel.CatalogDescription AS productmodel_catalog_description,
ProductSubcategory.Name AS product_subcategory_name,
ProductSubcategory.ModifiedDate AS product_subcategory_modified_date,
SizeUnitMeasureCode.Name AS size_unit_measure_code,
WeightUnitMeasureCode.Name AS weight_unit_measure_code,
Product.Color AS product_color,
Product.SafetyStockLevel AS product_safety_stock_level,
Product.ReorderPoint AS product_reorderpoint,
Product.StandardCost AS product_standard_cost
FROM Production.Product
LEFT JOIN Production.ProductModel
ON Product.ProductModelID = ProductModel.ProductModelID
LEFT JOIN Production.ProductSubcategory
ON Product.ProductSubcategoryID = ProductSubcategory.ProductSubcategoryID
```

```
LEFT JOIN Production.UnitMeasure SizeUnitMeasureCode
ON Product.SizeUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
LEFT JOIN Production.UnitMeasure WeightUnitMeasureCode
ON Product.WeightUnitMeasureCode = SizeUnitMeasureCode.UnitMeasureCode
WHERE (Product.Name LIKE @product_name OR @product_name IS NULL)
AND (Product.ProductNumber LIKE @product_number OR @product_number IS NULL)
AND (ProductModel.Name LIKE @product_model OR @product_model IS NULL)
AND (ProductSubcategory.Name = @product_subcategory OR @product_subcategory IS NULL)
AND (SizeUnitMeasureCode.Name = @product_sizemeasurecode OR @product_sizemeasurecode IS
NULL)
AND (WeightUnitMeasureCode.Name = @product_weightunitmeasurecode OR
@product_weightunitmeasurecode IS NULL);
END
```

This TSQL is much easier to read and understand. The search is straight-forward, returning all possible columns that you may want, joining all tables, and checking all search parameters in the WHERE clause, even if they are not specified in the stored procedure parameters. The only differences in output are any extra columns that you explicitly left out in the previous version. You can run the same execution statement as before in order to evaluate performance:

```
EXEC dbo.search_products @product_name = 'Mountain Frame', @product_number = 'FR-M21B',
@product_model = 'LL Mountain Frame',
@product_subcategory = 'Mountain Frames'
```

The execution plan and IO statistics for this new version are shown in Figure 6-9.

```
Table 'UnitMeasure'. Scan count 1, logical reads 21, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductSubcategory'. Scan count 0, logical reads 10, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductModel'. Scan count 0, logical reads 10, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Product'. Scan count 1, logical reads 14, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

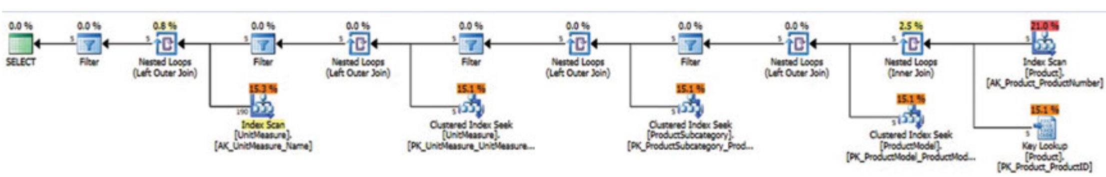


Figure 6-9. *Execution plan for the more inclusive search proc*

The primary difference in performance was that you had to access the UnitMeasure table twice in order to gather data on the size and weight measurements for the product. While those columns weren't required for the search that was run, the simplified TSQL does not discern between what you do and don't need. It trades simplicity in design for complexity in performance.

The result is that the same search required an additional 21 reads, and the subtree cost was 0.022. How did execution time compare? In a trial of 20 executions on my local server, the Dynamic SQL approach took an average of 40ms to run. The "simplified" version took 50ms. These decreases in performance may not seem immense as they are querying tables that are relatively small. If the UnitMeasure table had been larger, then the extra work would have also become more significant. Additionally, what if instead of four tables, you had to query 100? What if the possible columns that were options for the user to select from numbered in the thousands? If you were forced to read from 100 tables frequently when not needed, the results would be very noticeable on a production server.

Also keep in mind that each search that accesses different tables will result in a unique execution plan. In this case, that behavior is encouraged, as you would prefer a smaller and leaner execution when fewer objects need to be queried. Extra plans will not be created for different parameter values, though, but only in scenarios where the text of the query itself is changed. This would happen whenever joins are added, when the WHERE clause is given additional parameters, or when columns are added to the result set.

When a very large number of tables, columns, filters, or other variables are involved, the resulting search needs to be intelligent enough to not query objects that are unneeded. The necessary logic to accomplish this can be executed in application code or in SQL Server, but must be dealt with in some manner that eliminates the extra resource overhead needed for querying those unneeded objects. Dynamic SQL is an excellent tool to accomplish this in SQL Server, although thorough documentation and clean coding are required so that the increased performance is not gained at the expense of maintainability.

Paging Performance

Paging can be an expensive process, especially when used frequently. Interactive searches often require additional aggregate data that may not exist at the row level, such as:

- Total row count
- Current row number
- Sum, average, min, or max values for a column
- Page size
- Related or correlated results

Returning this data in-line with a result set presents many questions, such as whether to calculate the aggregates separately or with window functions. This is an area where there are no singular answers. The size, distribution, and indexing of the overall data sources matter. In addition, knowing what percentage of the result set is returned can influence the decision making process. To begin this analysis, let's review a handful of different ways in which you can page data and dig into the performance of each method.

The query in Listing 6-7 returns 25 search results as the user is paging through.

Listing 6-7. Basic Data Paging Using Row Numbers Based on Order Date

```
WITH CTE_PRODUCTS AS (
SELECT
ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
SalesOrderHeader.SalesOrderID,
SalesOrderHeader.Status,
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
```

```
WHERE SalesOrderHeader.SalesPersonID = 277
    )
SELECT
    *
FROM CTE_PRODUCTS
WHERE rownum BETWEEN 51 AND 75
```

The performance of this query is relatively straight-forward, as shown in Figure 6-10.

```
Table 'SalesOrderDetail'. Scan count 9, logical reads 42, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

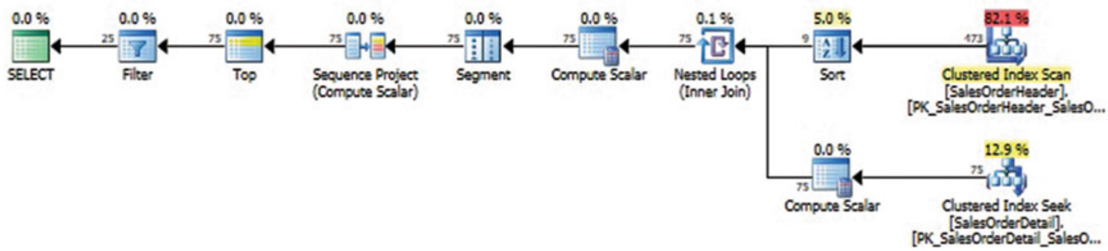


Figure 6-10. *Execution plan for the basic paging TSQL in Listing 6-7*

The resulting execution plan is composed of a seek on `SalesOrderDetail` and a scan on `SalesOrderHeader` as you collect data on a specific sales person's orders. Note that the reads on `SalesOrderDetail` are relatively low. Paging can improve read performance on your storage system, as it ultimately returns much less data than the total amount at one time.

This leads to an important consideration: Do you return all data at once, saving it for when the user clicks Next, or do you only return 25 rows and wait for the user to ask for more before returning it? This question can be addressed by adjusting the number of rows returned in the outermost `SELECT` statement. The following is the `STATISTICS` IO output for scenarios that return rows 51-200, 51-500, and 51-1000 rows, respectively:

```
Table 'SalesOrderDetail'. Scan count 19, logical reads 79, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 41, logical reads 157, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 77, logical reads 277, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

These reads increase as you commit to returning more data from SalesOrderDetail. In order to make a smart decision about performance, you must decide how many times users will click Next on average. If they typically only view a page or two and move on to other work, then returning a small data set each time is optimal. If the users will eventually page through most or all the data set, simply returning everything to a temporary table or to the application makes more sense.

Let's add some complexity to this query. What if you want to include the total result count along with the search results? There are many ways you could do this. Listing 6-8 shows a few examples along with performance metrics and notes.

Listing 6-8. Data Paging, Including Total Result Count as a Subquery in the Outermost SELECT

```
WITH CTE_PRODUCTS AS (
SELECT
ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
SalesOrderHeader.SalesOrderID,
SalesOrderHeader.Status,
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277
       )
SELECT
       *,
(SELECT COUNT(*) FROM CTE_PRODUCTS) AS total_result_count
FROM CTE_PRODUCTS
WHERE rownum BETWEEN 51 AND 75;
```

This first example creates a subquery in the final SELECT that returns the total count of rows in the common table expression. In this case, the entire result set is returned and the row count is recalculated every time the user requests more results. The performance for this method is shown in Figure 6-11.

```
Table 'SalesOrderDetail'. Scan count 10, logical reads 318, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 2, logical reads 692, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Workfile'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

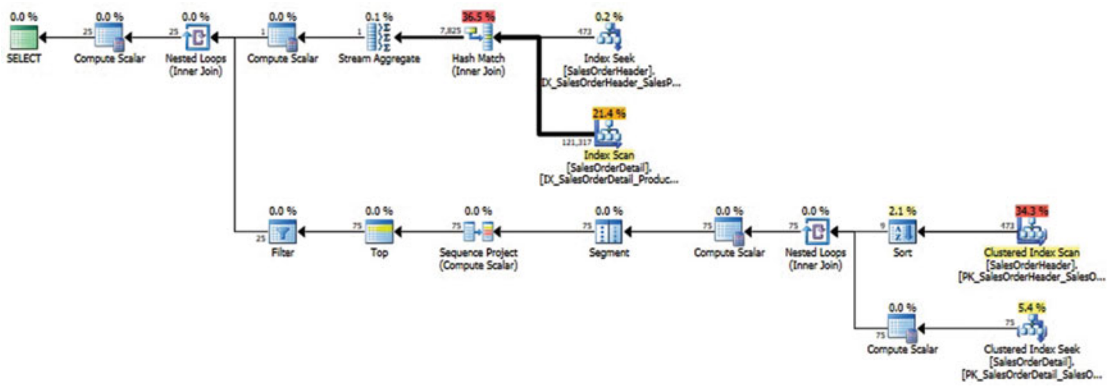


Figure 6-11. *Search query performance when the row count is returned with each execution*

In order to calculate the count, additional access to each table was required, and now the query must scan each table once and seek each table once. The overall reads increased by 279, or 38%. This isn't a very efficient method, but it is convenient and could be controlled easily with Dynamic SQL. Once the count has been acquired once, it could be stored and reused by the application, with Dynamic SQL filtering out the additional sub-select from the final query. This leads one to ask if you shouldn't just calculate the row count separately and reuse it for as long as necessary, as shown in Listing 6-9.

Listing 6-9. Data Paging by Calculating the Row Count as a Separate Operation

```
SELECT COUNT(*) AS total_result_count
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277;

WITH CTE_PRODUCTS AS (
SELECT
ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
SalesOrderHeader.SalesOrderID,
SalesOrderHeader.Status,
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277
       )
SELECT
       *
FROM CTE_PRODUCTS
WHERE rownum BETWEEN 51 AND 75;
```

This alternative calculates the total row count prior to fetching the actual data. This can be returned to the application once and used over and over again, until the user discards this particular search. This could be done via a RETURN value in a stored procedure, as a result set to a waiting application, saving it into a temporary table for repeated use later, or using other similar methods.

```
Table 'Workfile'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 1, logical reads 276, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 3, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 9, logical reads 42, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

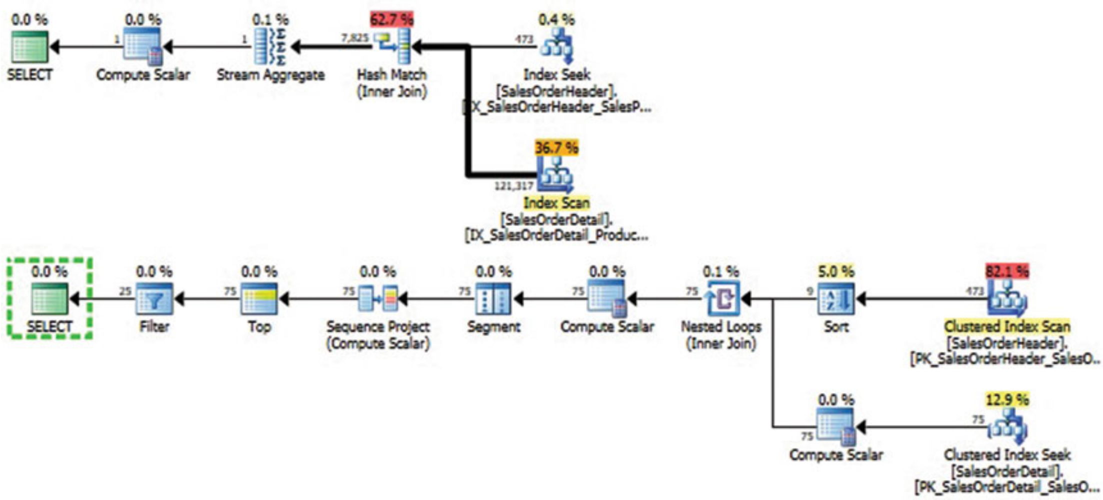


Figure 6-12. *Performance of the search when you cache the row count prior to execution*

The IO data shows that the cost to calculate the row count this way is identical to the previous example. The two execution plans shown cover the count (the first plan) and the data select (the second plan). Overall, the effort is similar to before in terms of operations required and the resources consumed by each.

The next example moves the count in with the common table expression, as shown in Listing 6-10.

Listing 6-10. Data Paging by Using a Window Function to Calculate the Total Row Count

```
WITH CTE_PRODUCTS AS (
SELECT
ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
COUNT(SalesOrderDetail.SalesOrderDetailID) OVER (ORDER BY
SalesOrderDetail.SalesOrderDetailID ROWS BETWEEN UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING)
AS total_result_count,
SalesOrderHeader.SalesOrderID,
```

```
SalesOrderHeader.Status,
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277
    )
SELECT
    *
FROM CTE_PRODUCTS
WHERE rownum BETWEEN 51 AND 75;
```

The syntax following the ORDER BY signifies that the row count should be for the entire data set (UNBOUNDED PRECEEDING AND UNBOUNDED FOLLOWING). Once again, the count calculation is within the data retrieval, but how does it perform?

```
Table 'Worktable'. Scan count 3, logical reads 16130, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 473, logical reads 1626, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

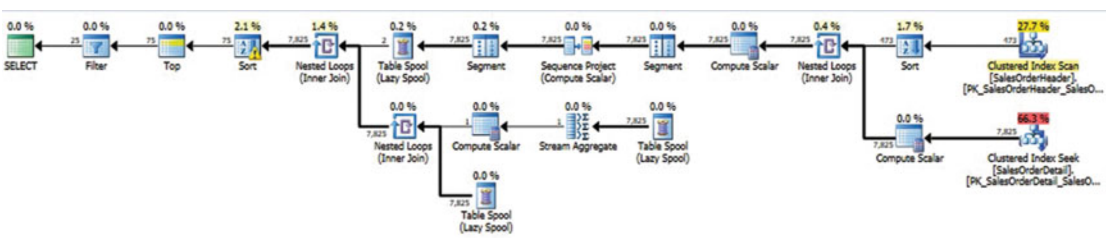


Figure 6-13. *Performance when determining row counts using a window function*

What happened!? The execution plan seems simple enough, with the two tables being accessed once. The IO statistics, though, tell a very different story! In order to calculate the count within the CTE, SQL Server recalculates it for every single row that is processed in the result set! The reads are many orders of magnitude higher than all of the previous examples and show that syntax that looks good doesn't always perform well. You can simplify the TSQL in an attempt to improve performance, as shown in Listing 6-11.

Listing 6-11. Data Paging with a Simplified Window Function

```
WITH CTE_PRODUCTS AS (
SELECT
ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
COUNT(*) OVER () AS total_result_count,
SalesOrderHeader.SalesOrderID,
SalesOrderHeader.Status,
```

```
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277
       )
SELECT
       *
FROM CTE_PRODUCTS
WHERE rownum BETWEEN 51 AND 75;
```

The performance is almost exactly the same as before. Despite removing the additional syntax, this method preforms extremely inefficiently. In a larger data set, this method would result in significantly more reads and latency as SQL Server attempts to calculate the count on each row throughout the data.

One final option is to persist the entire data set from the start. If the search results are not excessively large, or if you can limit them to a relatively compact segment, then you can optimize for this specific scenario, as shown in Listing 6-12.

Listing 6-12. Data Paging Using a Row Count Calculation After the Data Is Selected

```
SELECT
ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
SalesOrderHeader.SalesOrderID,
SalesOrderHeader.Status,
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
INTO #orders
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277;
SELECT @@ROWCOUNT AS total_result_count;
CREATE CLUSTERED INDEX IX_temp_orders_rownum ON #orders (rownum);
SELECT * FROM #orders WHERE rownum BETWEEN 1 AND 25;
SELECT * FROM #orders WHERE rownum BETWEEN 26 AND 50;
SELECT * FROM #orders WHERE rownum BETWEEN 51 AND 75;
SELECT * FROM #orders WHERE rownum BETWEEN 76 AND 100;

DROP TABLE #orders;
```

This example selects the entire data set into a temp table. It then grabs the total row count using @@ROWCOUNT, which does not require any data access to be returned. Since you are assuming a need to access much of the data returned, the next action is to create a clustered index on the temp table on rownum. This ensures that every query that filters on rownum will be very efficient. Here are the IO statistics for this version of the search:

```
Table 'SalesOrderDetail'. Scan count 473, logical reads 1626, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table '#orders'. Scan count 1, logical reads 62, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table '#orders'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table '#orders'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table '#orders'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table '#orders'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

You pay a hefty price up front for gathering all of the data in the search, racking up 2,315 reads! Adding the index costs another 62 reads on the temp table, but from this point on, all of the paged results come very inexpensively, as you can use that index effectively. Based on IO, is all of this effort worth it? The original search required 731 reads. Based on that number, you would come out ahead with this new approach after the fourth time paging through the result set. As stated previously, retrieving all of the data at once is effective when the data set is not prohibitively large and you know that you will want to page through a number of times, on average.

The query execution plans tell a similar story, as shown in Figure 6-14.

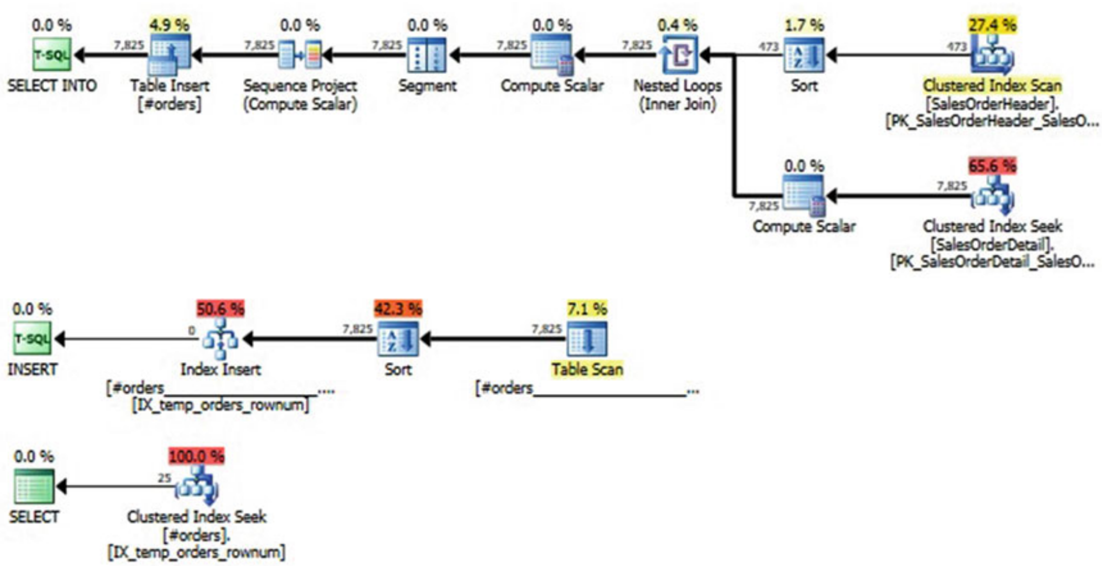


Figure 6-14. *Performance when you gather all data up front for repeated querying later*

The third execution plan is repeated for each subsequent paging search result executed against the existing data set. The subtree cost for the data collection query is 1.99, 0.8 for the index creation, and 0.003 to return paged search results. The results correlate well with the IO statistics. Quite a bit of effort is expended up front in order to retrieve the 7,825 rows in the entire result set, but from that point on, access is comparatively inexpensive.

Note that by saving and reusing the count, it won't update in the event that the underlying data changes. This can be tolerated in some search scenarios, where the result set must stay the same until the search is run again, but may not be acceptable in all use-cases. If a data set needs to be refreshed with each click through the results, then storing results and counts for later may not be good enough to meet that business need. In scenarios such as this, consider the structure of the data. If new data is appended to the end of the data set, it could be retrieved as an additional operation on top of the existing search. For example, in the previous example, you could check the maximum `SalesOrderDetailID` in the temp table and then add to the data set any additional new data in `SalesOrderHeader` and `SalesOrderDetail` that is newer. Alternatively, if the data has a last modified date and/or last create date, you could use those dates to quickly gather data that changed since the initial search was completed.

One final paging option that you've not yet seen is the `OFFSET` functionality. It allows you to order a result set, offset to any row number in that ordering, and select any number of rows starting at that point. This TSQL is shown in Listing 6-13.

Listing 6-13. Data Paging Using OFFSET

```
SELECT
SalesOrderHeader.SalesOrderID,
SalesOrderHeader.Status,
SalesOrderHeader.OrderDate,
SalesOrderHeader.ShipDate,
SalesOrderDetail.UnitPrice,
SalesOrderDetail.LineTotal
FROM Sales.SalesOrderHeader
INNER JOIN Sales.SalesOrderDetail
ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
WHERE SalesOrderHeader.SalesPersonID = 277
ORDER BY SalesOrderDetailID ASC
OFFSET 50 ROWS
FETCH NEXT 25 ROWS ONLY
```

The syntax for `OFFSET` is straightforward and allows you to page a data set without calculating row numbers yourself. The IO statistics and execution plan for this example are shown in Figure 6-15.

```
Table 'SalesOrderDetail'. Scan count 9, logical reads 45, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

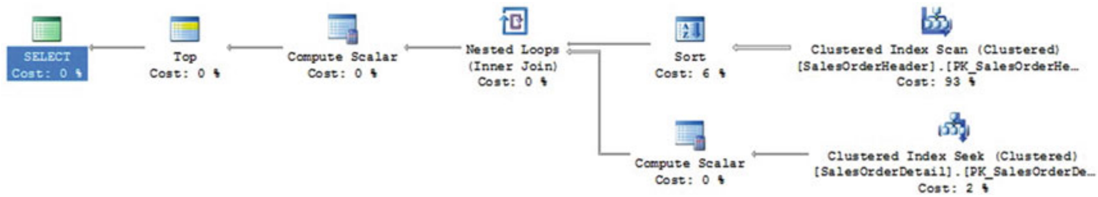


Figure 6-15. *Performance of paging using the OFFSET operator*

The execution plan is similar to what you have seen already, and the reads are similar to what you got in the first example using `ROW_NUMBER`. The key to using `OFFSET` is to make sure that the `ORDER BY` is on the column that you would like to page by. In these preceding examples, `OrderDate` was used to determine the order of the result set, but others could have been used, depending on business needs.

Filtered Indexes

By default, an index will apply to all rows in a given table. On large tables, indexes can become expensive to read as well as time-consuming and resource-intensive to maintain. If you have a common query or a set of queries that all rely on the same filters, you can create an index that only applies to those filter conditions. This filtered index will only apply when those exact filters are used, so it is important to get it right the first time!

A common use of filtered indexes is when you have a table for which a particular status or flag signifies data that you are interested in, whereas the remainder of the data will consistently be ignored. Consider the stored procedure in Listing 6-14, which executes a search of purchase orders.

Listing 6-14. Simple Dynamic Search with a Common Status Filter

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_in_process_purchasing_data')
BEGIN
DROP PROCEDURE dbo.get_in_process_purchasing_data;
END
GO
CREATE PROCEDURE dbo.get_in_process_purchasing_data
@return_detail_data BIT
AS
BEGIN
SET NOCOUNT ON;
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
PurchaseOrderHeader.PurchaseOrderID,
PurchaseOrderHeader.OrderDate,
PurchaseOrderHeader.ShipDate,
PurchaseOrderHeader.SubTotal,
PurchaseOrderHeader.Freight';
IF @return_detail_data = 1
SELECT @sql_command = @sql_command + ',
PurchaseOrderDetail.PurchaseOrderDetailID,
PurchaseOrderDetail.OrderQTY,
```

```
PurchaseOrderDetail.UnitPrice,
Product.Name,
Product.ProductNumber';
SELECT @sql_command = @sql_command + '
FROM purchasing.PurchaseOrderHeader
INNER JOIN purchasing.PurchaseOrderDetail
ON PurchaseOrderHeader.PurchaseOrderID = PurchaseOrderDetail.PurchaseOrderID';
IF @return_detail_data = 1
SELECT @sql_command = @sql_command + '
INNER JOIN Production.Product
ON Product.ProductID = PurchaseOrderDetail.ProductID';
SELECT @sql_command = @sql_command + '
WHERE PurchaseOrderHeader.Status = 2';

EXEC sp_executesql @sql_command;
END
GO
```

This stored procedure performs a search using a parameter that determines if detailed data can be returned or not. More importantly, a common filter exists in all executions:

```
WHERE PurchaseOrderHeader.Status = 2
```

To illustrate a baseline for performance, you could add a standard covering index that will help reduce reads on `PurchaseOrderHeader`:

```
CREATE NONCLUSTERED INDEX IX_PurchaseOrderHeader_status_INC
ON Purchasing.PurchaseOrderHeader (OrderDate, status)
INCLUDE (PurchaseOrderID, ShipDate, SubTotal, Freight);
GO
```

Now you can execute this for a detailed run:

```
EXEC dbo.get_in_process_purchasing_data @return_detail_data = 1;
```

The result set is comprised of 57 rows, containing all columns that could be returned by the Dynamic SQL within the stored procedure. The performance for this execution is as follows:

```
Table 'Product'. Scan count 0, logical reads 114, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'PurchaseOrderDetail'. Scan count 12, logical reads 24, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'PurchaseOrderHeader'. Scan count 1, logical reads 24, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

Note that even with the covering index, there are still 24 reads on `PurchaseOrderHeader`. The execution plan is shown in Figure 6-16.

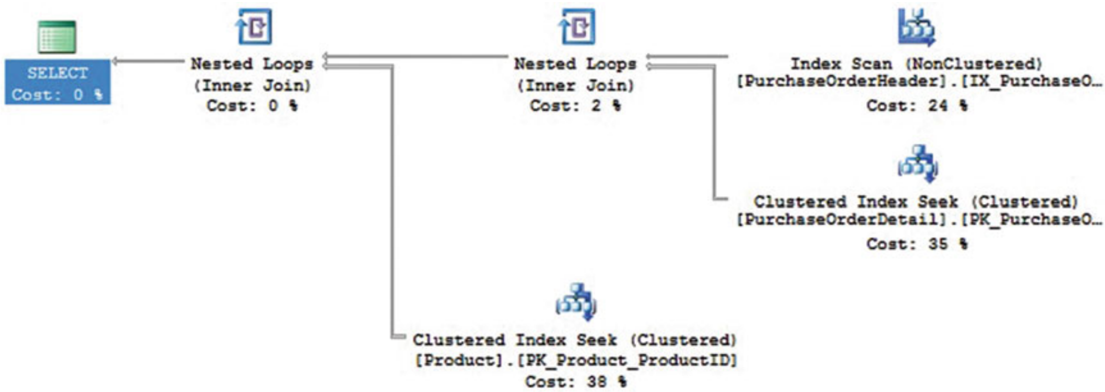


Figure 6-16. *Execution plan when a covering index is used for the search query*

The subtree cost for the entire query is 0.095894. Since there is an automatic filter on `status = 2` for this stored procedure, you can improve the index by adding the filter to the index itself:

```
IF EXISTS (SELECT * FROM sys.indexes WHERE indexes.name =
'IX_PurchaseOrderHeader_status_INC')
BEGIN
DROP INDEX IX_PurchaseOrderHeader_status_INC ON Purchasing.PurchaseOrderHeader
END
GO
CREATE NONCLUSTERED INDEX IX_PurchaseOrderHeader_status_INC
ON Purchasing.PurchaseOrderHeader (OrderDate, status)
INCLUDE (PurchaseOrderID, ShipDate, SubTotal, Freight)
WHERE status = 2;
```

Note the filter underneath the `INCLUDE` portion of the index. Adding a filter to the index will alter its structure to only include data pertaining to rows that match the filter. When you are interested in consistently querying a very small portion of a table, a filtered index can greatly improve performance. A smaller index:

- Is faster for SQL Server to read, which means it returns data faster with fewer logical reads
- Reduces the time it takes to perform index maintenance on it
- Requires less disk space to store

The performance metrics returned by executing the stored procedure with the new filtered index are as follows:

```
Table 'Product'. Scan count 0, logical reads 114, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'PurchaseOrderDetail'. Scan count 12, logical reads 24, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'PurchaseOrderHeader'. Scan count 1, logical reads 2, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

There are only two logical reads on PurchaseOrderHeader, a fraction of what you saw before! This improved execution plan is shown in Figure 6-17.

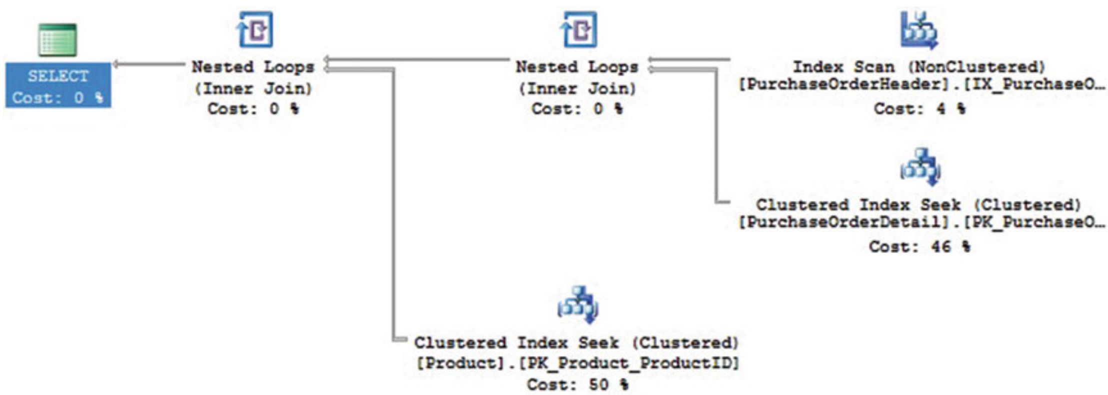


Figure 6-17. *Performance when a filtered covering index is utilized*

Note that even though the execution plan looks similar to before, the cost of the index scan on PurchaseOrderHeader has decreased, and the overall subtree cost has decreased by 25%.

Filtered indexes are excellent ways to manage queries on tables when only a small subset is regularly needed. On very large tables, the performance difference can be dramatic! Use caution though, as filtered indexes come with two caveats:

- WHERE clauses must be precise. While the query optimizer will try its best to use a filtered index, it can only make use of it when the query's WHERE clause overlaps the index. If the query changes enough so that the filters don't match, SQL Server will ignore the filtered index and try to use another instead.
- When data is written to a table with a filtered index, SQL Server must check to see whether the changed data matches the filter. This means that small numbers of extra reads may be required when altering data in order to properly maintain the filtered index. While this cost is generally low, it is important to recognize it when working on large data sets. For the example, any UPDATE that modifies status will need to verify if those changes will result in data being added or removed from the filtered index. In filtered indexes with a compound WHERE clause, modifications to any column of it will result in similar checks.

The benefits will typically outweigh the costs when considering a filter on an index. If a table contains 100 million rows, of which 10,000 contain current or relevant data, then you could expect reads on the index, as well as storage to be reduced to about 0.01% of the original amount. This is a significant improvement!

Cardinality

When discussing performance concerns, it is important to discuss cardinality and what it means for the queries you execute. *Cardinality* refers to the number of rows affected by an operation. When optimizing a query, SQL Server must determine how many rows will be affected by each part of the execution plan. That count will determine important decisions, such as whether to scan or seek a table, or whether to use a merge or hash join. An explanation of cardinality would be incomplete without a brief overview of statistics.

Statistics

By default, *statistics* are created on all indexes and columns in any given table. Statistics provide a simple yet powerful list of values within a table. For example, you can view the statistics on a given index with the following statement:

```
DBCC SHOW_STATISTICS ("Sales.SalesOrderheader", IX_SalesOrderHeader_CustomerID);
```

The output of this execution is comprised of three sets of data, as shown in Figure 6-18.

	Name	Updated	Rows	Rows Sampled	Steps	Density	Average key length	String Index	Filter Expression	Unfiltered Rows
1	IX_SalesOrderHeader_CustomerID	Jul 17 2014 4:11PM	31465	31465	153	0.6162394	8	NO	NULL	31465

	All density	Average Length	Columns
1	5.230399E-05	4	CustomerID
2	3.178134E-05	8	CustomerID, SalesOrderID

	RANGE_HI_KEY	RANGE_ROWS	EQ_ROWS	DISTINCT_RANGE_ROWS	AVG_RANGE_ROWS
1	11000	0	3	0	1
2	11019	47	17	18	2.611111
3	11091	186	28	71	2.619718
4	11142	132	17	50	2.64
5	11185	109	27	42	2.595238
6	11223	160	27	37	4.324324
7	11262	125	27	38	3.289474
8	11300	149	27	37	4.027027
9	11331	84	27	30	2.8
10	11417	173	7	85	2.035294

Figure 6-18. *Sample output of DBCC SHOW_STATISTICS*

The first row returned is an overview of the statistics, including the name, last update time, total rows in the table, and sampled rows. The rows sampled will equal the row count for smaller tables, but in larger tables will be smaller. Updating statistics isn't free, and scanning millions of rows to update may not be worth the effort if data is relatively uniform in nature. The steps are the number of ranges that the data was broken into, where 200 is the maximum SQL Server will use. For this example, a total of 31,465 rows were sampled (the entire table) and broken into 153 ranges in which values of `CustomerID` were counted.

The second result set shows the density for each column involved in the index, including the clustered index column(s), which this index refers back to. Density is equal to 1/(# of distinct values). For the previous values:

```
SELECT DISTINCT CustomerID FROM Sales.SalesOrderheader;
```

This returns 19,119 distinct values for `CustomerID`. 1/19119 = 5.230399E-05, which is the value provided. The combination of `CustomerID` and `SalesOrderID` (the clustered primary key column) is as unique as the primary key in this case:

```
SELECT DISTINCT CustomerID, SalesOrderID FROM Sales.SalesOrderheader;
```

This query returns 31,465 values: 1/31465 = 3.178134E-05, the second value above.

Density is an important metric for the query optimizer, as it provides quick insight into how unique a column is, and therefore how many potential values there will be on average for each individual value. To determine further details and to expand upon density, let's review the last data set from above, which is the statistics histogram. The histogram shows ranges of values for `CustomerID` and the number of rows of values that fall into that range.

For example, take a look at a single row of the histogram:

RANGE_HI_KEY	RANGE_ROWS	EQ_ROWS	DISTINCT_RANGE_ROWS	AVG_RANGE_ROWS
11331	84	27	30	2.8
11417	173	7	85	2.035294
11439	68	6	21	3.238095

173 values are found in the range 11331 < X < 11417. In addition to that range, there are seven values that are equal to the maximum value of the range (11417). There are 85 possible values within this range (11417 – 11331 - 1), and the average range rows per value is 2.035294.

This is all well and good, but what does it mean? This data is somewhat esoteric, but it provides great value to the query optimizer. It can cross-check filters, groupings, and joins with this data very quickly and determine how to process a query. If a filter is very inclusive and it turns out that it will return most rows in a table, a table scan will likely be used. In scenarios like this, it's faster to return everything than it is to selectively pick and choose a large volume of rows separately. If a filter is very exclusive, the optimizer will quickly realize that an index seek is the fastest way to return the results.

The query optimizer is only as good as the data that is provided to it by statistics. If this data becomes inaccurate for any reason, the result can be suboptimal execution plans, poor performance, and users calling you at absurdly late hours of the night looking for help.

There are three settings in SQL Server that guide how statistics are handled within a database. All are included in system views and can be reviewed for a given database like this:

```
SELECT
is_auto_update_stats_on,
is_auto_create_stats_on,
is_auto_update_stats_async_on
FROM sys.databases WHERE name = 'AdventureWorks2014';
```

Removing the filter will return info on all databases on this SQL Server. The results of this query are as follows:

is_auto_update_stats_on	is_auto_create_stats_on	is_auto_update_stats_async_on
1	1	0

What do these values mean?

`Auto_update_stats_on` tells you if SQL Server will automatically update stale statistics, which by default is on. This does not guarantee statistics that will give you accurate execution plans, but handles a few use-cases when statistics are deemed stale. More on this coming up!

`Auto_create_stats_on` indicates if statistics will be automatically created on columns and indexes as needed, which is on by default. This is useful and should only be turned off if you are very confident about maintaining statistics manually. This setting does not apply to views, for which you will need to manually create statistics when needed.

`Auto_update_stats_async_on` determines if statistics should be updated before or after a query's execution and is off by default. Turning this on speeds up query execution, but can lead to inaccurate execution plans. It's therefore recommended to keep this off.

For these settings, the defaults are generally best unless you have a very compelling reason to make changes. What does auto-updating statistics entail, and when does it happen?

By default, a database is set with AUTO_UPDATE_STATISTICS on. This will cause statistics to update whenever:

- An empty table has rows inserted into it.
- The row count in a table increases from less than 500 rows to more than 500 rows by a count of at least 500.
- The row count in a table increases from greater than 500 rows by 500 rows, plus 20%.

These scenarios update statistics when row counts change significantly, but are not necessarily comprehensive enough for a complex production environment. In order to ensure that statistics are completely up-to-date, even if this criteria is not met, you can consider updating statistics manually or on a maintenance schedule. All statistics can be updated on a database in one fell swoop as follows:

```
EXEC sys.sp_updatestats;
```

This will recalculate all statistics on every table in your database. This is generally unadvised, as the volume of data that needs to be scanned can be quite large, take a long time, and cause contention for important production loads. If you cannot update everything all at once, what alternatives are there?

Updating statistics can be a very IO intensive operation. Only perform this maintenance when necessary, and only on objects where it is needed.

Statistics can be updated on any single object with the following syntax:

```
UPDATE STATISTICS Production.Product;
```

This will update all statistics on the table Production.Product. Additionally, a single statistics can be updated:

```
UPDATE STATISTICS Production.Product PK_Product_ProductID;
```

This statement updates only the statistics on the primary key for Production.Product

The next logical question to ask is, "How do you know when you should update statistics manually?" Generally, you don't need to worry about this process unless there is a specific reason. SQL Server's default settings tend to be reliable for most common database designs. If you don't need to perform expensive maintenance, then you certainly shouldn't! What happens when statistics do become stale, though?

To help facilitate this example, we'll turn off the automatic updating of statistics. This should never be done in a production environment! For testing purposes, though, it's an excellent way to watch the effect of stale statistics on query optimization and execution:

```
ALTER DATABASE AdventureWorks2014
SET AUTO_UPDATE_STATISTICS OFF;
```

After executing this, you can verify the statistics settings on the database using the query from earlier:

```
SELECT
is_auto_update_stats_on,
is_auto_create_stats_on,
is_auto_update_stats_async_on
FROM sys.databases WHERE name = 'AdventureWorks2014';
```

is_auto_update_stats_on	is_auto_create_stats_on	is_auto_update_stats_async_on
0	1	0

Note that is_auto_update_stats_on is now disabled, and as a result, statistics will update only if you do it manually. This example uses a new index on Production.Product on the Weight column:

```
CREATE NONCLUSTERED INDEX IX_Product_Weight ON Production.Product (Weight);
```

Consider the following query:

```
SELECT
ProductID,
Weight,
Name
FROM Production.Product
WHERE Weight = 170
```

This returns a single row (out of 504) from the table. The performance metrics are shown in Figure 6-19.

```
Table 'Product'. Scan count 1, logical reads 4, physical reads 0, read-ahead reads 0, lob
logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

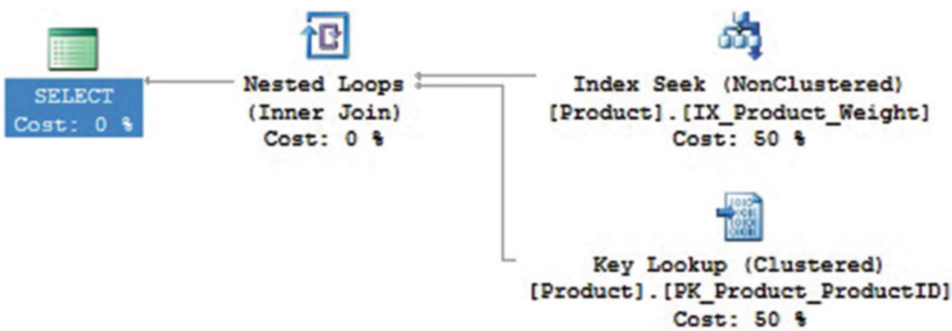


Figure 6-19. *Performance of a simple index seek operation*

This is a relatively straight-forward example! Four reads on Production.Product and an execution plan that performs a seek on the new index, as well as a key lookup to retrieve the Name column, which is not in the index you created above. Let's now insert a large number of new data into the table, as shown in Listing 6-15.

Listing 6-15. TSQL to Populate the Product Table with 1,999 New Products

```
-- Turn off execution plan here
SET STATISTICS IO OFF
SET STATISTICS TIME OFF

DECLARE @count INT = 1
WHILE @count < 2000
```

```
BEGIN
INSERT INTO Production.Product
( Name ,
ProductNumber ,
MakeFlag ,
FinishedGoodsFlag ,
Color ,
SafetyStockLevel ,
ReorderPoint ,
StandardCost ,
ListPrice ,
Size ,
SizeUnitMeasureCode ,
WeightUnitMeasureCode ,
Weight ,
DaysToManufacture ,
ProductLine ,
Class ,
Style ,
ProductSubcategoryID ,
ProductModelID ,
SellStartDate ,
SellEndDate ,
DiscontinuedDate ,
rowguid ,
ModifiedDate
                    )
SELECT
'Hoverboard' + CAST(@count AS VARCHAR(25)),
'HOV-' + CAST(@count AS VARCHAR(25)),
1 AS MakeFlag ,
1 AS FinishedGoodsFlag ,
NULL AS Color ,
500 AS SafetyStockLevel ,
375 AS ReorderPoint ,
55 AS StandardCost ,
100 AS ListPrice ,
NULL AS Size ,
NULL AS SizeUnitMeasureCode ,
'G' AS WeightUnitMeasureCode ,
170 AS Weight ,
5 AS DaysToManufacture ,
NULL AS ProductLine ,
'H' AS Class ,
NULL AS Style ,
5 AS ProductSubcategoryID ,
97 AS ProductModelID ,
'1/1/2015' AS SellStartDate ,
NULL AS SellEndDate ,
NULL AS DiscontinuedDate ,
```

```
NEWID() AS rowguid,
CURRENT_TIMESTAMP AS ModifiedDate

SET @count = @count + 1
END
```

This query will insert 1,999 rows into `Production.Product`, all with the same weight (170). Turning off the execution plan and the statistics metrics will greatly speed up the insert, since you are using a quick and dirty loop to complete the task. Once this is complete, you can rerun the query that previously ran very efficiently:

```
SET STATISTICS IO ON;
SET STATISTICS TIME ON;
SET NOCOUNT ON;
SELECT
ProductID,
Weight,
Name
FROM Production.Product
WHERE Weight = 170;
```

Execution completes quickly enough, but looking under the covers at performance reveals another story altogether. This can be shown in Figure 6-20.

```
Table 'Product'. Scan count 1, logical reads 4008, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

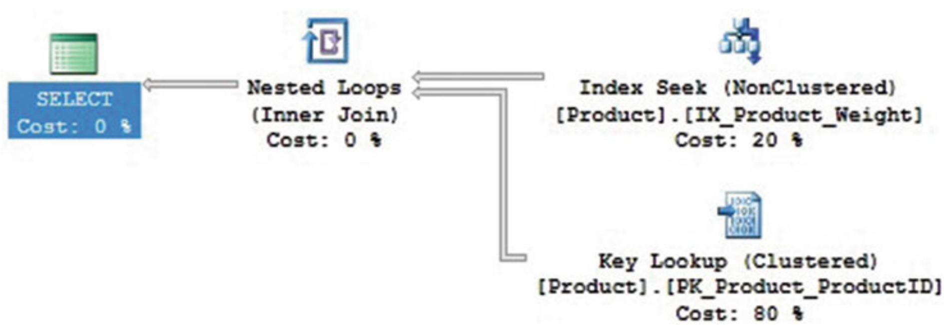


Figure 6-20. *Performance of the search query against a larger result set*

The execution plan is identical to what you got previously, but the reads on `Production.Product` are significantly higher! 4,004 reads on a table with about 2,500 rows seems very high for a query that only returns three columns. By turning off statistics auto-update, you removed the query optimizer's most important tool in order to find good execution plans: accurate statistics. Let's review the statistics for the index you used in Figure 6-21.

```
DBCC SHOW_STATISTICS ("Production.Product", IX_Product_Weight);
```

	RANGE_HI_KEY	RANGE_ROWS	EQ_ROWS	DISTINCT_RANGE_ROWS	AVG_RANGE_ROWS
89	29.90	1	1	1	1
90	30.00	0	2	0	1
91	149.00	1	1	1	1
92	168.00	0	2	0	1
93	170.00	0	1	0	1
94	185.00	0	1	0	1
95	189.00	0	1	0	1
96	215.00	0	2	0	1
97	218.00	0	1	0	1

Figure 6-21. *Stale statistics for the IX_Product_Weight index on Production.Product*

Note that for the range including 170, there is only a single equality row, despite the fact that you added 1,999 rows. The query optimizer cannot make a smart decision with data that is this inaccurate. To illustrate this, you can update the statistics on this index manually:

```
UPDATE STATISTICS Production.Product IX_Product_Weight;
```

Running the DBCC command to recheck the statistics on the `IX_Product_Weight` index reveals the changes you'd expect to see, as shown in Figure 6-22.

	RANGE_HI_KEY	RANGE_ROWS	EQ_ROWS	DISTINCT_RANGE_ROWS	AVG_RANGE_ROWS
89	29.90	1	1	1	1
90	30.00	0	2	0	1
91	149.00	1	1	1	1
92	168.00	0	2	0	1
93	170.00	0	2000	0	1
94	185.00	0	1	0	1
95	189.00	0	1	0	1
96	215.00	0	2	0	1
97	218.00	0	1	0	1

Figure 6-22. *Updated statistics for the IX_Product_Weight index on Production.Product*

Now there are 2,000 rows reported with a weight equal to 170, which matches expectations after the inserts. With statistics updated, you can run the test query one last time:

```
SELECT
ProductID,
Weight,
Name
FROM Production.Product
WHERE Weight = 170
```

This time, performance metrics look much less concerning, as shown in Figure 6-23.

```
Table 'Product'. Scan count 1, logical reads 58, physical reads 0, read-ahead reads 0, lob
logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

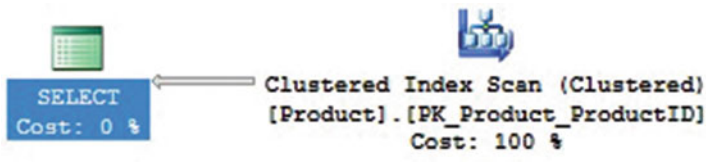


Figure 6-23. *Performance of the previous search query with updated statistics*

Only 58 reads were needed instead of 4004, and a clustered index scan was chosen as the most efficient data retrieval method. It turns out that when you are looking to return a very large portion of a table, it's faster to simply return everything and discard what you don't need, rather than traverse an index to find all of the necessary rows. As soon as the query optimizer had accurate data on the contents of the index, it was able to opt for a scan, knowing that this was the best course of action.

Trace Flag 2371

There is an additional way to manage auto-updating statistics in SQL Server, and that is a trace flag that became available in SQL Server 2008 R2 Service Pack 1. Trace Flag 2371 is intended to address the needs of very large tables, whereby the metrics used to auto-update statistics normally simply don't fit well. Wait for changes to 20% of a table with millions of rows, and you may be forced to wait for a very long time.

When you turn on this trace flag, the formula for when to update statistics becomes somewhat dynamic. When a table exceeds 25,000 rows, then the percentage of rows that need to be modified to trigger the update of statistics decreases. This addresses the needs of large tables while also not changing the functionality on smaller tables.

If you are responsible for a database that contains tables with millions or billions of rows, then this trace flag can be a significant boon to performance and a way to avoid having to manually manage statistics. This trace flag can be enabled as follows:

```
DBCC TRACEON (2371);
```

As always, do not make changes to SQL Server trace flags until you have performed a thorough assessment of your database environment and tested to ensure that this change is beneficial. While you might get very excited when new performance features or options are available, performing adequate QA on these changes is critical to ensuring that they are both necessary and helpful.

More documentation on this trace flag can be found on MSDN in a very well-written article:

```
http://blogs.msdn.com/b/saponsqlserver/archive/2011/09/07/changes-to-automatic-update-
statistics-in-sql-server-traceflag-2371.aspx
```

Back to Dynamic SQL

We've discussed statistics, how they are used, and how inaccurate statistics can affect performance. How does this relate to Dynamic SQL and your day-to-day tasks? Cardinality is a measure of quantity used in every step of query optimization. In each step, the query optimizer must use statistics in order to determine how many rows it expects to be returned in that step, whether it be a seek, join, or filter. If statistics are inaccurate, even in a single step, it could result in a suboptimal execution plan in which performance is worse than it need be or (worst case) unacceptably slow.

You can check cardinality by hovering over any step in an execution plan, as shown in Figure 6-24.

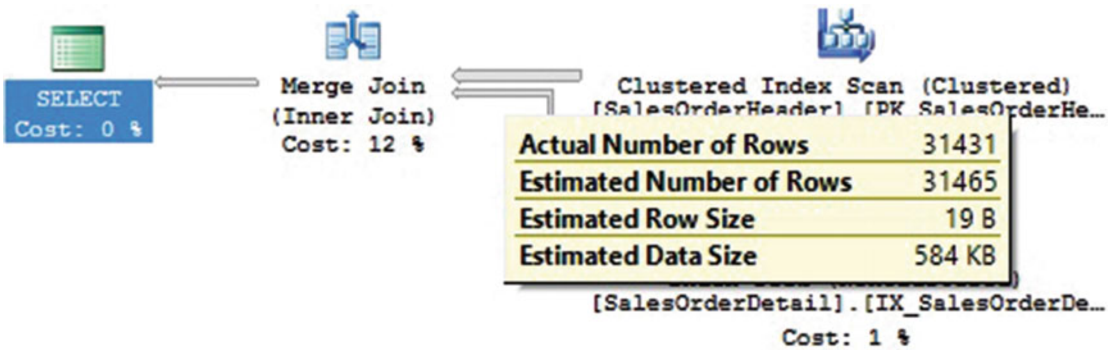


Figure 6-24. *Viewing row counts in SQL Server Management Studio*

Hovering over the arrow between the clustered index scan and merge join reveals that the optimizer estimated 31,465 rows to be output to the join. When executed, though, the actual number of rows was 31,431. A difference this small will rarely present a performance concern, but if you are reviewing a query execution plan and notice that the actual and estimated number of rows differ greatly, then definitely take a closer look at statistics and ensure they are accurate.

Dynamic SQL introduces scenarios where there can be queries that change all the time, or that shift between a handful of common use-cases. The potential for statistics to be wrong, or for execution plans to get used or reused in suboptimal ways, becomes higher. Chapter 8 discusses parameter sniffing and dives deeper into cardinality and the ways in which bad estimates can lead to performance headaches. Understanding these issues can greatly reduce the head-scratching when they arise.

Query Hints

There are many ways that you can nudge the query optimizer in order to get it to do exactly what you want. Consider one of the most common hints used in SQL Server, the NOLOCK hint, as shown in Listing 6-16.

Listing 6-16. Example of the NOLOCK Query Hint

```
SELECT
SalesOrderDetail.SalesOrderDetailID,
SalesOrderDetail.SalesOrderID,
SalesOrderDetail.ProductID
FROM Sales.SalesOrderDetail WITH (NOLOCK)
WHERE ProductID = 713;
```

NOLOCK is a commonly used hint that can be used on SELECT statements that will avoid contention by reading existing data (dirty pages) from memory, even if other transactions are operating on the data involved. At first glance, this sounds spectacular—no contention! It's a double-edged sword, though, as it is very possible to run a SELECT while an UPDATE is in progress and never return data that was changed or not committed in that UPDATE statement.

NOLOCK is an example of a query hint, and this is a somewhat poorly named feature as it is more a command than a hint. Hints are often used as ways to fix performance problems when they arise. For example, a DBA that sees frequent locking or deadlocking may use NOLOCK to stop that contention from occurring. This hint can be useful in a reporting-style environment where the timeliness of data is not critical and you simply need an idea of what data looked like at a given time. Even then, you would want to ask yourself why you are running reporting queries in a highly transactional environment. Only when that question is answered should you be comfortable in making this change.

The downside to using query hints is that you are telling the query optimizer exactly what to do, as though you are smarter than it. While there are times when you may know better, things can change in any busy production environment. The hint that works perfectly today may be useless tomorrow or even hinder performance.

Liberal use of join hints will often be a mistake, as shown in Listing 6-17.

Listing 6-17. Using Join Hints to Force a Particular Join by the Optimizer

```
DECLARE @ProductID INT = 713;
SELECT
SalesOrderDetail.SalesOrderDetailID,
SalesOrderDetail.SalesOrderID,
SalesOrderDetail.ProductID,
SalesOrderHeader.OrderDate
FROM Sales.SalesOrderDetail
INNER LOOP JOIN Sales.SalesOrderHeader
ON SalesOrderDetail.SalesOrderID = SalesOrderHeader.SalesOrderID
WHERE ProductID = @ProductID;
SELECT
SalesOrderDetail.SalesOrderDetailID,
SalesOrderDetail.SalesOrderID,
SalesOrderDetail.ProductID,
SalesOrderHeader.OrderDate
FROM Sales.SalesOrderDetail
INNER MERGE JOIN Sales.SalesOrderHeader
ON SalesOrderDetail.SalesOrderID = SalesOrderHeader.SalesOrderID
WHERE ProductID = @ProductID;
SELECT
SalesOrderDetail.SalesOrderDetailID,
SalesOrderDetail.SalesOrderID,
SalesOrderDetail.ProductID,
SalesOrderHeader.OrderDate
FROM Sales.SalesOrderDetail
INNER HASH JOIN Sales.SalesOrderHeader
ON SalesOrderDetail.SalesOrderID = SalesOrderHeader.SalesOrderID
WHERE ProductID = @ProductID;
```

The query optimizer will choose what it considers the best join type when you join two tables together in a query. Sometimes you may find that if you override the default and force a particular join, you can get better performance. This may not always work, though, and if you review the performance above, you'll see a variety of results:

```
Warning: The join order has been enforced because a local join hint is used.
Table 'SalesOrderHeader'. Scan count 0, logical reads 1322, physical reads 0, read-ahead
reads 19, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 1, logical reads 3, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Warning: The join order has been enforced because a local join hint is used.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 688, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 1, logical reads 3, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Warning: The join order has been enforced because a local join hint is used.
Table 'Workfile'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 1, logical reads 3, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

When you review the IO statistics, you can see that forcing a loop join resulted in much higher reads than a hash or merge join. Different values of `@ProductID` may result in different joins, thereby producing better or worse performance results. Note that SQL Server reminds you that the join order has been enforced by the query hint. This is its way of gently telling you that whatever happens next is your fault and you cannot call up Microsoft and complain if the results aren't what you expect.

Similarly, the execution plans for these queries look different and each reflects different subtree costs. You can see these by reviewing the three execution plans in Figure 6-25.

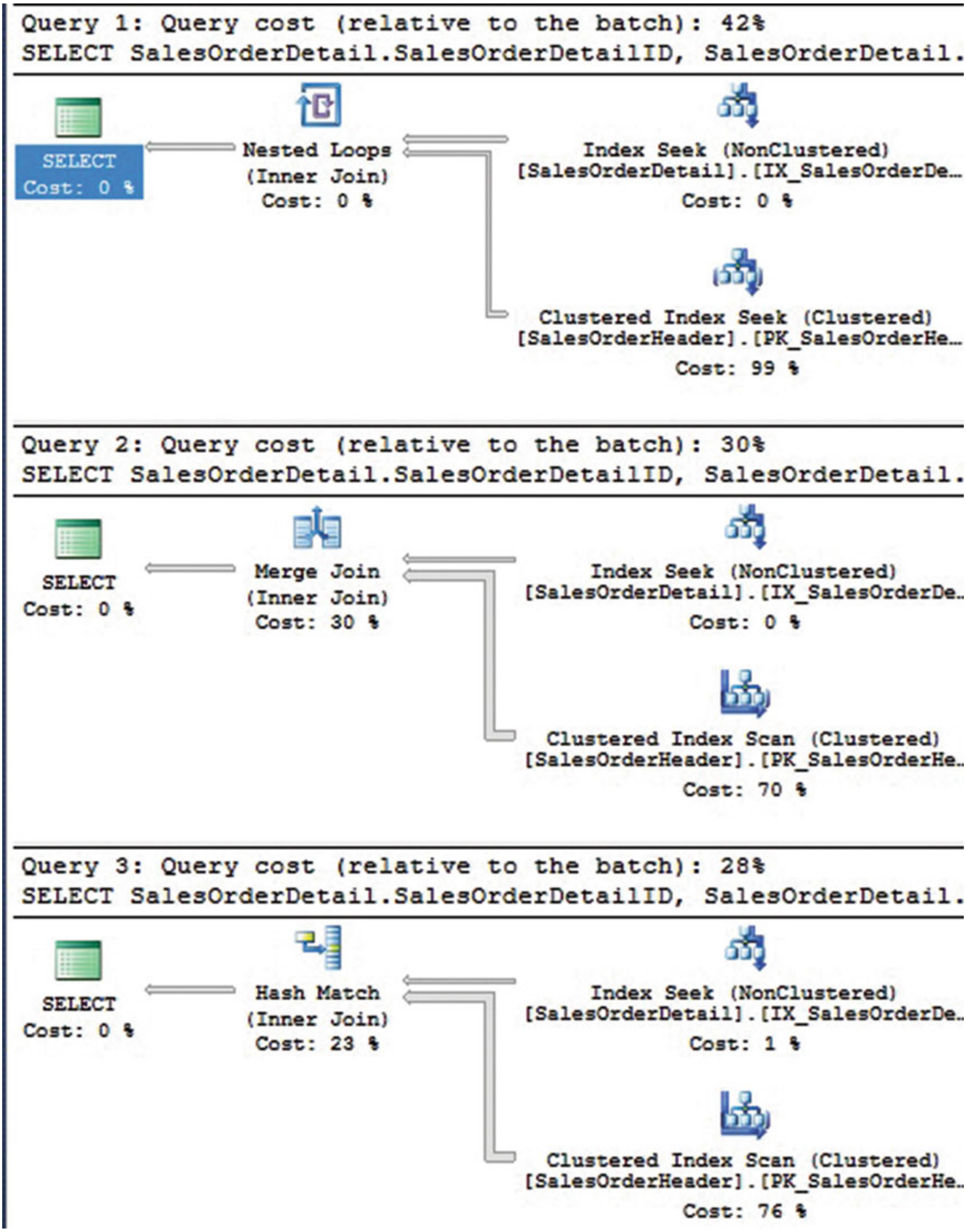


Figure 6-25. *Execution plans when different joins are forced with query hints*

Forcing specific joins is going to eventually backfire. Perhaps a hash join seems like the best choice right now, as you see a large table joining a small table, but data and application usage can change. When your tweaks eventually become irrelevant, you will not remember or notice the problem until it is too late and performance degrades as the use-case for the changes no longer applies. Change is a constant in database design and management and you must write scripts that are nimble enough to be relevant in months or even years from now. Query hints put constraints on your design, reducing the options that the optimizer has to choose from. If those options would be useful in the future, then your hints will prevent their usage.

Another frequently used query hint is `RECOMPILE`, which will force SQL Server to create a new execution plan for a query, even if an adequate one already exists in the query plan cache. This is often used as a way to sidestep bad execution plans or ensure that the best plan is found each time. The optimization process is expensive, though, and on a busy production server, the costs associated with frequently recompiling large volumes of queries could result in unusually high CPU utilization and query latency. Consider the last test query with a hint added to it, as shown in Listing 6-18.

Listing 6-18. Using a RECOMPILE Hint to Force a New Execution Plan to Be Created and Used

```
DECLARE @ProductID INT = 713;
SELECT
SalesOrderDetail.SalesOrderDetailID,
SalesOrderDetail.SalesOrderID,
SalesOrderDetail.ProductID,
SalesOrderHeader.OrderDate
FROM Sales.SalesOrderDetail
INNER JOIN Sales.SalesOrderHeader
ON SalesOrderDetail.SalesOrderID = SalesOrderHeader.SalesOrderID
WHERE ProductID = @ProductID
OPTION (RECOMPILE);
```

Running this query, you'll find that nearly everything appears normal in the execution plan and IO statistics. Where you'll find a seemingly minor, yet significant, difference is in the `STATISTICS TIME` results:

```
SQL Server parse and compile time:
CPU time = 0 ms, elapsed time = 1 ms.
```

Within the output, notice that no matter how many times you run the query, the parse and compile time is always non-zero. This is the price for forcing the execution plan to recompile. A millisecond may seem small, but for more complex queries with many tables and joins, the time can be much higher. Combine increased times with frequent execution and performance will be significantly impacted by the time and effort required to continuously create new execution plans.

Query hints should be used sparingly, only when necessary, and when all alternatives have been exhausted. Change over time can render hints destructive to database performance, rather than helpful.

You could easily review dozens of query hints, highlighting common usage, as well as potential pitfalls, but generally it is important to recognize that query hints are often ways to cheat your way past bigger problems. Very often, hints are used to cover up poorly designed tables, inefficiently written queries, bad indexing, or other mistakes that could be resolved to fix the performance problem.

Don't get me wrong, there are legitimate uses for query hints. However, it is important to view them as last resorts rather than tools that should be implemented frequently. Only implement them after extremely thorough testing and assurances that the likelihood of breaking changes is very low. A list of available query and table hints can be found on MSDN:

```
https://msdn.microsoft.com/en-us/library/ms181714.aspx
```

Note the warning provided near the top of the article:

```
If one or more query hints cause the query optimizer not to generate a valid plan,
error 8622 is raised.
```

Some hints can remove the only valid transforms available from the query optimizer. If this happens, then a query can fail to execute, generate an error, and likely wake you up at an uncomfortably late hour. Knowledge of these options is important, but use caution when implementing them. Use hints when deemed necessary and safe and utilize all alternatives first. If a query can be rewritten, an index added, or a view altered, consider those and similar changes first before bossing around the query optimizer.

Conclusion

Performance optimization is a huge topic, and this sprint through many important topics only scratches the surface. There is no shortage of ways in which you can dig deeper into query tuning, indexing, statistics, or other ways to improve performance.

Approach each problem with a plan in mind and research it thoroughly. SQL Server provides many tools that allow you to easily assess performance and resource consumption and find ways to get your most important queries to execute faster. Always test and confirm the expected results of any change and be certain that your predictions match the test results. While it can be humbling to have your performance hypothesis struck down by other metrics that you didn't consider, this is still much better than releasing suboptimal changes into a production environment.

The duration of this book will dig further into performance in many of its examples. This will allow you to apply what you have read thus far and learn a variety of ways in which to test some of these conclusions. Look forward to many more examples of execution plans, statistics, and query comparisons that will aid in your exploration of Dynamic SQL.

CLEANUP

The TSQL in Listing 6-19 will clean up any objects created in this chapter, if they exist.

Listing 6-19. Script to Clean Up Any Objects Created in this Chapter

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'search_products')
BEGIN
DROP PROCEDURE dbo.search_products;
END
GO
IF EXISTS (SELECT * FROM sys.indexes WHERE indexes.name =
'IX_PurchaseOrderHeader_status_INC')
BEGIN
DROP INDEX IX_PurchaseOrderHeader_status_INC ON Purchasing.PurchaseOrderHeader
END
GO
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_in_process_purchasing_data')
BEGIN
DROP PROCEDURE dbo.get_in_process_purchasing_data;
END
```

CHAPTER 7

Scalable Dynamic Lists

Generating lists of data is a common task with a wide variety of use-cases. Perhaps you want to output data to an application or file with a specific formatting or syntax. Maybe the best format to read a list of data is in a single line, rather than a tabular format. Maybe you want to store data in a table using a particular string format that needs to be quickly built prior to storing it.

While this is not an often-advertised feature of SQL Server, it is one that can be implemented in ways that perform quite well. Alternatively, it is very easy to concoct list generation in ways that are unbelievably inefficient. This chapter will serve as a discussion of many different ways in which lists can be generated. In addition to syntax, the chapter reviews performance and maintainability in order to ensure that there is no question as to which method is the best for the job.

Performance tuning will be referenced frequently in this chapter. Refer to Chapter 6 for details on reading execution plans, reviewing IO statistics, and other considerations with regards to Dynamic SQL and query tuning and optimization.

What Is a Dynamic List

The easiest way to introduce this topic is with an example. Say for example you want to output a comma-separated list of IDs for a list of people. One commonly used method is to build this string piece-by-piece using a CURSOR, as shown in Listing 7-1.

Listing 7-1. Example of a Cursor-Based Approach to Building a Comma-Delimited List of IDs

```
DECLARE @nextid INT;
DECLARE @myIDs NVARCHAR(MAX) = '';

DECLARE idcursor CURSOR FOR
SELECT TOP 100
       BusinessEntityID
FROM Person.Person
ORDER BY LastName;
OPEN idcursor;
FETCH NEXT FROM idcursor INTO @nextid;

WHILE @@FETCH_STATUS = 0
BEGIN
      SET @myIDs = @myIDs + CAST(@nextid AS NVARCHAR) + ',';
      FETCH NEXT FROM idcursor INTO @nextid;
END
```


E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_7

```
SET @myIDs = LEFT(@myIDs, LEN(@myIDs) - 1);
CLOSE idcursor;
DEALLOCATE idcursor;

SELECT @myIDs AS comma_separated_output;
```

In this TSQL, a `CURSOR` is declared for 100 IDs and is looped through, one-by-one, as the string `@myIDs` is slowly built up with IDs and commas. The last string modification uses the `LEFT` function to remove the trailing comma that is leftover from the loop. The result will be 100 `BusinessEntityIDs`, separated by commas. The text output will appear like this:

```
285,293,295,2170,38,211,2357,297,291,299,121,16867,16901,16724,10263,10312,...
```

We'll cut off the list here after 16 IDs, as there's no need to waste space with that... ☺

In general, iteration should be avoided when writing TSQL in any scenario where a set-based approach could be applied. SQL Server is built to efficiently process sets of data, and when you try to pull data a row at a time, you will often see poor performance as a result. This is an example of where TSQL that involves loops can be extremely inefficient. First look at the execution plan shown in Figure 7-1.

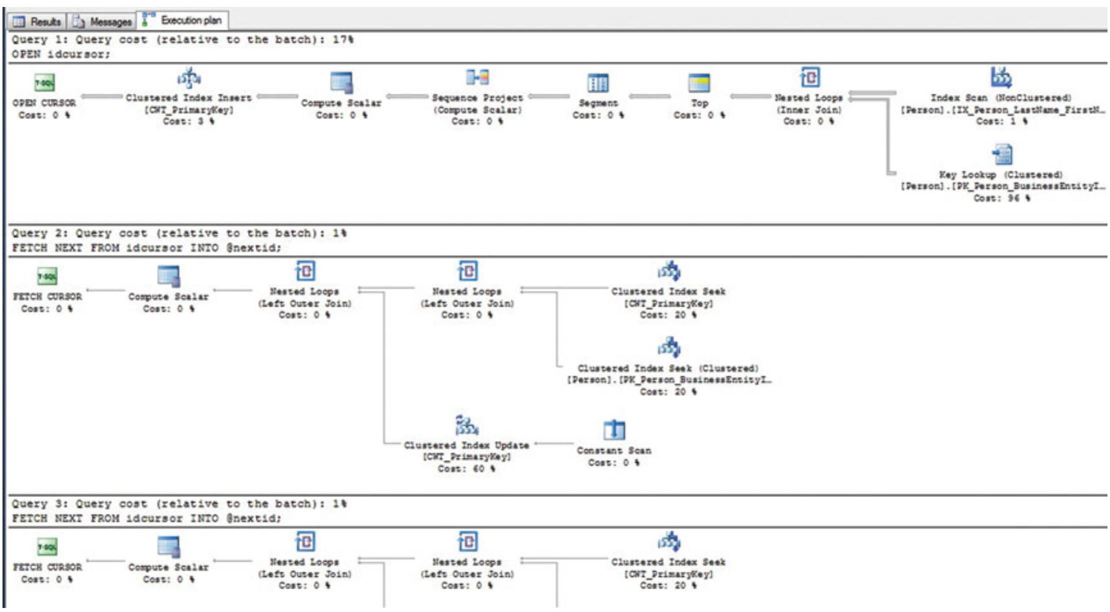


Figure 7-1. *Execution plan for a Simple SELECT Query that Iterates Through a Loop*

The execution plan is cut off after the first two queries, as the next 99 are exactly the same as the second one. It's immediately clear that you have to consider 101 execution plans in order to determine the overall effort expended by SQL Server when generating this list. As a result, it is necessary to read from `Person.Person` over 100 times, in addition to reading from the cursor itself, which is not a free operation. On my SQL Server, this took a total of 10 seconds to run. For a TSQL application whose purpose it is to read 100 IDs, this is quite slow! While much of this execution time results from generating 100 extra execution plans, it illustrates how any seemingly simple task performed often enough can become cumulatively painful.

To gain more insight into the inefficiency introduced here, let's review the IO statistics as well:

```
Table 'Worktable'. Scan count 0, logical reads 201, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Person'. Scan count 1, logical reads 318, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.

Table 'Worktable'. Scan count 0, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Person'. Scan count 0, logical reads 3, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

The first set of IO statistics covers the initial cursor declaration. The second represents a single iteration of the `WHILE` loop, which will be repeated another 99 times. If you add the total logical reads for all of the queries involved, you get 1019 reads, which is quite a lot given that it only intends to return 100 integer values.

While the output of this example was exactly what you were looking for, it took a relatively immense amount of computing resources to get there. Imagine if you wanted a list of a thousand or a million IDs. What if instead of IDs, you wanted a list of large strings? The result could easily be millions of reads and a query that grinds the server to a halt! Correct output is desirable, but with unscalable and unmaintainable performance, code like this will come back to haunt you in the future as software changes and your assumptions about data size or acceptable performance metrics become invalid.

Using XML to Create a Dynamic List

It's clear that generating a string using any form of loop is going to be inefficient for all but the tiniest data sets. An alternative that is widely used is to select the desired data from the underlying table and format it using XML. Consider the following example of this syntax, shown in Listing 7-2, that generates the same list as the loop introduced in the last example.

Listing 7-2. Generating a List of IDs Using XML

```
DECLARE @myIDs NVARCHAR(MAX) = '';

SET @myIDs = STUFF((SELECT TOP 100 ',' + CAST(BusinessEntityID AS NVARCHAR)
FROM Person.Person
ORDER BY LastName
FOR XML PATH(''), TYPE
).value('.', 'NVARCHAR(MAX)'), 1, 1, '');

SELECT @myIDs;
GO
```

The first thing you should notice is that the syntax is more complicated and somewhat less readable. The result set is the same, as intended:

```
285,293,295,2170,38,211,2357,297,291,299,121,16867,16901,16724,10263,10312,...
```

To understand how XML generates this list, you can break the query up, starting with the innermost TSQL and then building on it as you move forward:

```
SELECT TOP 100 ',' + CAST(BusinessEntityID AS NVARCHAR) AS ID_CSV
FROM Person.Person
ORDER BY LastName;
```

This SELECT statement returns a list of IDs with a comma preceding each, as shown in Figure 7-2.

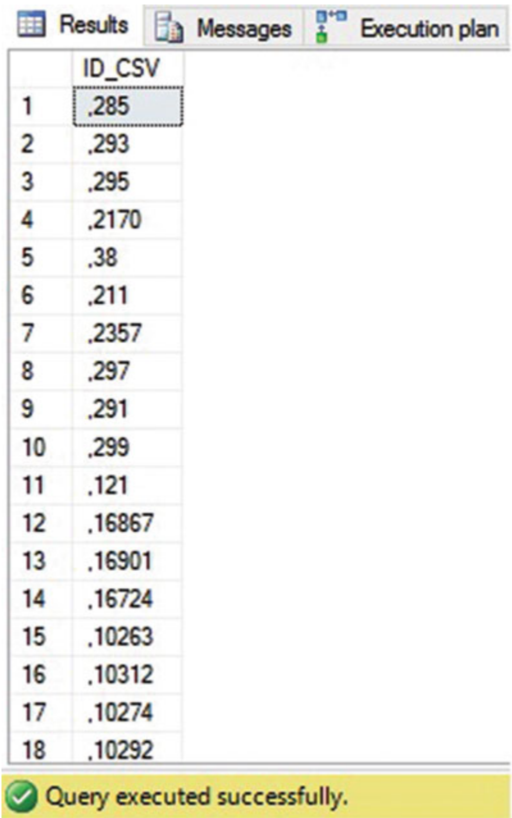


Figure 7-2. *ID List that Will Be Used in an XML-Generated List*

Nothing out of the ordinary here. The next step will concatenate all of the rows of data into an XML format, which in SQL Server will display as a comma-delimited list:

```
SELECT (SELECT TOP 100 ',' + CAST(BusinessEntityID AS NVARCHAR)
FROM Person.Person
ORDER BY LastName
FOR XML PATH(''));
```

The result of this SELECT will show a result that is on its way to being the finished product:

```
285,293,295,2170,38,211,2357,297,291,299,121,16867,16901,16724,10263,10312,...
```

There are two pieces of unfinished business that you need to deal with before you can consider this query fully dissected and correct. The first is to ensure that the XML output is the correct data type:

```
SELECT (SELECT TOP 100 ',' + CAST(BusinessEntityID AS NVARCHAR)
FROM Person.Person
ORDER BY LastName
FOR XML PATH(''), TYPE
).value('.', 'NVARCHAR(MAX)');
```

The XML `value` method converts the XML results to the data type provided prior to returning it. In the event that this is a very long list, the conversion makes sure that you don't suffer from string truncation along the way. It also lets you choose between `VARCHAR` and `NVARCHAR`, if the distinction is important. This example uses `NVARCHAR(MAX)` as the data type to return. The results of this query are identical to the output from the last step as the data type conversion is invisible to the SQL Server output you are viewing.

The last step is to remove that pesky comma from the left, which can be accomplished via a number of string-manipulation techniques. `STUFF` is used above to cram the contents of the comma-delimited list into the character at position 1, which happens to be the comma you are looking to remove anyway. This method is convenient as it can be accomplished in a single step, without having to store the results in a variable, if you don't need to. An alternative is to use `RIGHT` or `SUBSTRING` to remove the leading comma:

```
DECLARE @myIDs NVARCHAR(MAX) = '';

SET @myIDs = (SELECT TOP 100 ',' + CAST(BusinessEntityID AS NVARCHAR)
FROM Person.Person
ORDER BY LastName
FOR XML PATH(''), TYPE
).value('.', 'NVARCHAR(MAX)');

SELECT RIGHT(@myIDs, LEN(@myIDs) - 1);
SELECT SUBSTRING(@myIDs, 2, LEN(@myIDs) - 1);
```

The results of each `SELECT` are identical and they match what you were looking for in the output:

```
285,293,295,2170,38,211,2357,297,291,299,121,16867,16901,16724,10263,10312,...
```

Now that you see that XML can be used to generate a comma-delimited list, you should take the additional steps to performance test it and determine its level of efficiency. First, examine the IO statistics for the query:

```
Table 'Person'. Scan count 1, logical reads 3, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

This looks great! The reads are the equivalent of what you would expect if were to simply run the `SELECT` statement from `Person.Person` with no additional formatting applied to it. Using XML reduced the reads from 1019 to 3, which I consider an excellent deal any day of the week! Next, let's see how the execution plan looks, as in Figure 7-3.

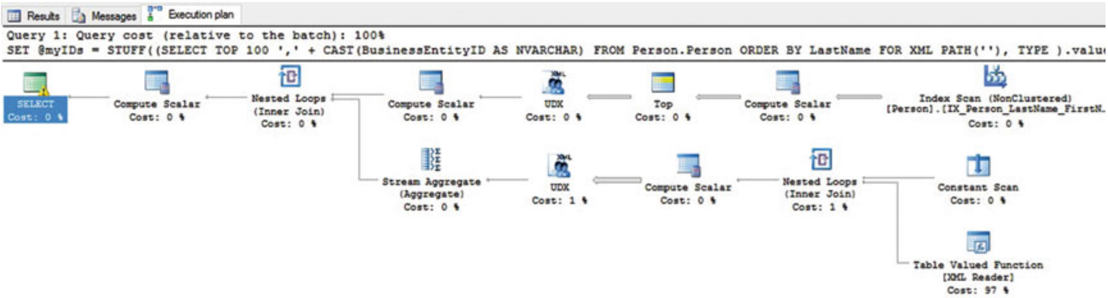


Figure 7-3. *Performance of List-Generation Using XML*

For a query that is grabbing a list of IDs, this is a bit complex. The magic that is performed behind-the-scenes by the XML reader isn't free, and that becomes clear here, as it consumes 97 percent of the resources of the query. Examining the subtree cost of the execution plan, you'll find that it is about 1.09, which is similar to the query cost of the `WHILE` loop method. In other words, the XML cost is similar to 100 queries in the loop from earlier. While it has reduced disk IO greatly, you risk consuming hefty amounts of CPU if you rely heavily on XML.

Set-Based String Building

While the XML solution was better, it was not perfect. The execution plan was somewhat confusing and illustrated that CPU consumption by XML can be high. Let's consider an additional option, as shown in Listing 7-3.

Listing 7-3. Generating a List of IDs by Building a String Directly into a Variable

```
DECLARE @myIDs NVARCHAR(MAX) = '';

SELECT TOP 100 @myIDs = @myIDs + CAST(BusinessEntityID AS NVARCHAR) + ','
FROM Person.Person
ORDER BY LastName;

SET @myIDs = LEFT(@myIDs, LEN(@myIDs) - 1);

SELECT @myIDs;
```

This TSQL is much more aesthetically pleasing. It is so simple that it might beg you to scratch your head and ask, "How does it work?" When you execute it, the results are the same as the previous examples:

```
285,293,295,2170,38,211,2357,297,291,299,121,16867,16901,16724,10263,10312,...
```

SQL Server allows you to `SELECT` string data directly into a scalar variable in a single step. The string building is reminiscent of Dynamic SQL, even if you are not executing a command string in order to generate it. The general structure of this statement is as follows:

1. Declare a string, typically `VARCHAR(MAX)` or `NVARCHAR(MAX)`.
2. Set the string variable equal to an empty string (or any leading characters that you'd like).

3. SELECT `@variable` = `@variable` plus a combination of columns and string data.
4. Remove the trailing comma from the end of the string.
5. Proceed with the comma-separated list as needed.

First, let's take a look at the IO statistics to determine how much data was read in order to generate this list:

```
Table 'Person'. Scan count 1, logical reads 3, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

As with the XML solution, the reads are the same as that the SELECT query on its own would have required. Three reads to generate that list is excellent. Figure 7-4 shows the execution plan.

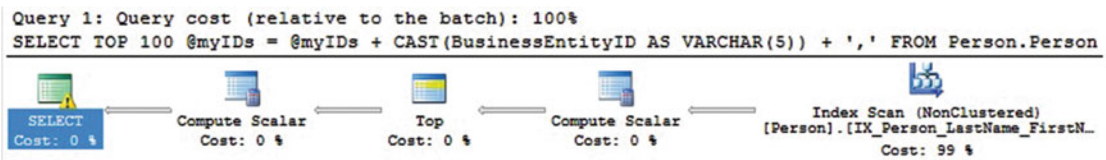


Figure 7-4. *Performance of List-Generation Using a String-Based SELECT*

This execution plan is about as simple as it gets: A single scan of the target table and some inexpensive operations to assemble the string. The subtree cost for this is 0.004, which is significantly lower than all other string-building techniques that you've seen so far. Removing the element of XML greatly reduces the overhead that the XML reader requires in order to crunch data into the desired output format. Additionally, SQL Server can build the string in a completely set-based operation with no need for iteration, temporary tables, or any other expensive mediums.

This method is exceptionally fast, efficient, and easy to code and maintain. The lack of loops or XML make the resulting TSQL easy enough for a beginner to experiment with and understand. Only minimal documentation would be required in order to explain what this does and why the method was chosen.

The dynamically-built list is not limited to a single column or scalar string value. You are free to build the string out of as many data elements as you wish, whether they be column data, scalar variables, string literals, or strings converted from other data types. Listing 7-4 shows how to generate a list with multiple variables.

Listing 7-4. Building a List with Multiple Columns and String Literals

```
DECLARE @myData NVARCHAR(MAX) = '';
SELECT @myData =
       @myData + 'ContactTypeID: ' + CAST(ContactTypeID AS NVARCHAR) + ',Name: ' + Name + ','
FROM person.ContactType
SET @myData = LEFT(@myData, LEN(@myData) - 1);

SELECT @myData;
```

This example is similar to the last, but includes the Name column and the column names preceding the values themselves. The syntax for this TSQL is nearly identical to the previous example, with the only difference being the columns and literals that are concatenated in the SELECT statement. The value of @myData ends up being:

```
ContactTypeID: 1,Name: Accounting Manager,ContactTypeID: 2,Name: Assistant Sales
Agent,ContactTypeID: 3,Name: Assistant Sales Representative,ContactTypeID: 4,Name:
Coordinator Foreign Markets,ContactTypeID: 5,Name: Export Administrator,...
```

In the event that you wanted headers for your data, additional columns, labels, or any other useful information embedded into the string, getting them there is relatively straightforward. There's no limit to what you can include in the string, although it is worth examining the length of the output to ensure that whatever application, report, or file is accepting the data can handle whatever the maximum expected size could be.

One final simplification that you can make is to eliminate the need to remove the trailing comma at the end with a clever use of ISNULL. Listing 7-5 shows this short example.

Listing 7-5. Using ISNULL to Eliminate the Leading Comma Within the SELECT Statement

```
DECLARE @myData NVARCHAR(MAX);

SELECT @myData =
       ISNULL(@myData + ',','') + 'ContactTypeID: ' + CAST(ContactTypeID AS NVARCHAR)
       + ',Name: ' + Name
FROM person.ContactType;

SELECT @myData;
```

ISNULL can accomplish this by checking the value of @myData to see if it is NULL:

1. Do not assign an initial empty string value to @myData.
2. If @myData is NULL, which occurs on the first value only, then insert a blank.
3. If @myData is not NULL, then insert a comma.

This logic will implicitly eliminate the leading comma that would have been introduced, thereby reducing the number of SQL statements by one. The results of this query are identical to the previous example. The performance of the TSQL is also the same. COALESCE can also be used instead of ISNULL with the same effect:

```
DECLARE @myData NVARCHAR(MAX);

SELECT @myData =
       COALESCE(@myData + ',','') + 'ContactTypeID: ' + CAST(ContactTypeID AS NVARCHAR)
       + ',Name: ' + Name
FROM person.ContactType;

SELECT @myData;
```

Whether you use an ISNULL, LEFT, or COALESCE statement is a matter of personal preference, but suffice it to say that these options are significantly better than a loop or XML, each of which carries additional complexity and performance concerns.

Revisiting Security

While the various string building methods presented here are not Dynamic SQL in the traditional sense, they share many of the strengths and weaknesses found when creating command strings for use in Dynamic SQL. The lengthy list of security concerns presented in previous chapters are as relevant here as they were before.

Anytime you are building strings using at least one parameter that is entered from an outside source, the threat of SQL injection becomes as real as it was when you performed an open-ended web search. The example in Listing 7-6 illustrates string building using a stored procedure that accepts parameters from an external source.

Listing 7-6. A Reminder of SQL Injection when Building a List with Dynamic SQL

```
CREATE PROCEDURE dbo.return_person_data
       @last_name NVARCHAR(MAX) = NULL, @first_name NVARCHAR(MAX) = NULL
AS
BEGIN
       SET NOCOUNT ON;
       DECLARE @return_data NVARCHAR(MAX) = '';
       DECLARE @sql_command NVARCHAR(MAX);
       DECLARE @parameter_list NVARCHAR(MAX);

       SELECT @parameter_list = '@output_data NVARCHAR(MAX) OUTPUT';

       SELECT @sql_command = '
       SELECT
           @output_data = @output_data + ''ID: '' + CAST(BusinessEntityID AS NVARCHAR) + '',
           Name: '' + FirstName + '' '' + LastName + '',''
       FROM Person.Person
       WHERE 1 = 1'
       IF @last_name IS NOT NULL
          SELECT @sql_command = @sql_command + '
          AND LastName LIKE ''%' + @last_name + '%''';
       IF @first_name IS NOT NULL
          SELECT @sql_command = @sql_command + '
          AND FirstName LIKE ''%' + @first_name + '%''';

       PRINT @sql_command;
       EXEC sp_executesql @sql_command, @parameter_list, @return_data OUTPUT;

       SELECT @return_data = LEFT(@return_data, LEN(@return_data) - 1);

       SELECT @return_data;
END
```

This stored procedure combines Dynamic SQL and list building to generate a comma-separated list of IDs and names. It also manages to create several glaring security risks. Let's consider some executions of this proc:

```
EXEC dbo.return_person_data @first_name = 'Edward';
```

The results of this execution are what you'd expect:

```
ID: 3731, Name: Edward Adams,ID: 13658, Name: Edward Alexander,ID: 4241, Name: Edward
Anderson,ID: 3732, Name: Edward Baker,ID: 13631, Name: Edward Barnes,ID: 4229, Name: Edward
Brown,ID: 13657, Name: Edward Bryant...
```

The list is truncated after the seventh value, as there's no need to list the extensive list of people from `AdventureWorks` with the first name of "Edward". The generated string contains an ID and a name, which is the combination of each person's first name, last name, and a space inserted in between. Commas separate each field, with the trailing comma removed from the final `LEFT` statement.

What happens when the user passes in a blank?

```
EXEC dbo.return_person_data @first_name = '';
```

In this scenario, my server churns for 2:58 before returning results. With 19,972 rows in `Person.Person`, it turns out that it takes a significant amount of time to render all of those IDs and names. While you often get used to memory being significantly faster than disk, it is not infinitely so. SQL Server needs to temporarily cache data to disk while the query completes. The results are the following IO statistics:

```
Table 'Person'. Scan count 1, logical reads 109, physical reads 0, read-ahead reads 0, lob
logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 758369, physical reads 0, read-ahead reads 0,
lob logical reads 244941773, lob physical reads 0, lob read-ahead reads 3909272.
```

Where did 244,941,773 reads come from? That unbelievable number comes from the volume of data being returned in conjunction with the blank search string. SQL Server cannot manage this operation on-the-fly in memory and is forced to use TempDB instead, which is significantly slower. Reads on `Person.Person` are not significant, but `Worktable` reads are very, very impressive!

This is an important call-out to quality assurance that testing is critically important in any application. If a search can theoretically return tens of thousands of rows, be sure to implement some method of paging or to limit the data set so that a lazy or careless user doesn't bring your server down with an empty search.

Let's return to the malicious example that caused you to lose sleep in an earlier chapter:

```
EXEC dbo.return_person_data @first_name = 'whatever''; SELECT * FROM Person.Password;
SELECT ''';
```

Here, you intentionally close the search string with arbitrary text (`whatever`) and begin a new SQL statement with a `SELECT` from `Person.Password`. This situation is as dangerous as it was earlier, as the intended query returns an empty set of people and instead the `Person.Password` table is returned. The resulting command string for this parameter value is as unfortunate as it appears to be:

```
SELECT
       @output_data = @output_data + 'ID: ' + CAST(BusinessEntityID AS NVARCHAR) + ',
       Name: ' + FirstName + ' ' + LastName + ','
FROM Person.Person
WHERE 1 = 1
AND FirstName LIKE '%whatever'; SELECT * FROM Person.Password; SELECT '%'
```

This TSQL throws an error as well, on top of this already messy result set:

```
Msg 537, Level 16, State 3, Procedure return_person_data, Line 204
Invalid length parameter passed to the LEFT or SUBSTRING function.
```

Since @output_data is NULL, its length is NULL, which is not a valid input for the LEFT function. Despite this, the password list was returned prior to the error message generating. Depending on application and error-handling settings, the hackers who entered this TSQL may have gotten the data they wanted.

Whenever inputs are provided by an outside source, be sure to parameterize your sp_executesql statement to ensure that there is no way for dangerous TSQL to be inserted into your command string. This is shown in Listing 7-7.

Listing 7-7. Dynamic SQL List Generation Using Parameters for Inputs

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'return_person_data')
BEGIN
       DROP PROCEDURE dbo.return_person_data;
END
GO

CREATE PROCEDURE dbo.return_person_data
       @last_name NVARCHAR(MAX) = NULL, @first_name NVARCHAR(MAX) = NULL
AS
BEGIN
       SET NOCOUNT ON;
       SELECT @last_name = '%' + @last_name + '%';
       SELECT @first_name = '%' + @first_name + '%';

       DECLARE @return_data NVARCHAR(MAX) = '';
       DECLARE @sql_command NVARCHAR(MAX);
       DECLARE @parameter_list NVARCHAR(MAX);

       SELECT @parameter_list = '@output_data NVARCHAR(MAX) OUTPUT, @first_name
       NVARCHAR(MAX), @last_name NVARCHAR(MAX)';

       SELECT @sql_command = '
       SELECT
           @output_data = @output_data + ''ID: '' + CAST(BusinessEntityID AS NVARCHAR) + '',
           Name: '' + FirstName + '' '' + LastName + '','' 
       FROM Person.Person
       WHERE 1 = 1'
       IF @last_name IS NOT NULL
            SELECT @sql_command = @sql_command + '
            AND LastName LIKE @last_name';
       IF @first_name IS NOT NULL
            SELECT @sql_command = @sql_command + '
            AND FirstName LIKE @first_name';

       PRINT @sql_command;
       EXEC sp_executesql @sql_command, @parameter_list, @return_data OUTPUT, @first_name,
       @last_name;

       SELECT @return_data = LEFT(@return_data, LEN(@return_data) - 1);

       SELECT @return_data;
END
```

This updated stored procedure contains parameters for `@first_name` and `@last_name`. When you execute the examples again, what happens?

```
EXEC dbo.return_person_data @first_name = 'Edward';
```

The results from this execution are the same as earlier. All data for people with the first name of “`Edward`” are returned as expected.

```
EXEC dbo.return_person_data @first_name = '';
```

The blank search still takes three minutes to run, but at least it does so securely!

```
EXEC dbo.return_person_data @first_name = 'Edward''; SELECT * FROM Person.Password;
SELECT ''';
```

The attempt to use SQL injection to retrieve passwords still generates an error with the zero being passed to the `LEFT` function as the input length. Luckily, parameterization removes the ability for the end users to inject their own TSQL into any of the parameters, so they do not gain access to `Person.Password` as they did previously.

It’s important to be diligent and fix the looming errors in this example. Letting SQL server grind away for minutes on a big query could be as destructive to the server as error messages or SQL injection attempts could be. Let’s patch the holes in Listing 7-8 and hope that QA doesn’t find any more.

Listing 7-8. List Generation Stored Procedure, with Fixes for Long Waits and Error Messages

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'return_person_data')
BEGIN
	DROP PROCEDURE dbo.return_person_data;
END
GO

CREATE PROCEDURE dbo.return_person_data
	@last_name NVARCHAR(MAX) = NULL, @first_name NVARCHAR(MAX) = NULL
AS
BEGIN
	SET NOCOUNT ON;
	SELECT @last_name = '%' + @last_name + '%';
	SELECT @first_name = '%' + @first_name + '%';

	DECLARE @return_data NVARCHAR(MAX) = '';
	DECLARE @sql_command NVARCHAR(MAX);
	DECLARE @parameter_list NVARCHAR(MAX);

	SELECT @parameter_list = '@output_data NVARCHAR(MAX) OUTPUT, @first_name
	NVARCHAR(MAX), @last_name NVARCHAR(MAX)';

	SELECT @sql_command = '
	SELECT TOP 25
	    @output_data = @output_data + ''ID: '' + CAST(BusinessEntityID AS NVARCHAR) + '',
	    Name: '' + FirstName + '' '' + LastName + '','''
	FROM Person.Person
	WHERE 1 = 1'
```

```
        IF @last_name IS NOT NULL
            SELECT @sql_command = @sql_command + '
            AND LastName LIKE @last_name';
        IF @first_name IS NOT NULL
            SELECT @sql_command = @sql_command + '
            AND FirstName LIKE @first_name';

        PRINT @sql_command;
        EXEC sp_executesql @sql_command, @parameter_list, @return_data OUTPUT, @first_name,
        @last_name;

        IF LEN(@return_data) > 0 AND @return_data IS NOT NULL
            SELECT @return_data = LEFT(@return_data, LEN(@return_data) - 1);

        SELECT @return_data;
END
```

This variation on the stored procedure introduces a Top 25 to the list building `SELECT` statement. This limits the result set to 25 people, preventing a runaway query that could consume immense server resources. In addition, a check was placed on the `LEFT` function near the end of the stored procedure that checks if the length of `@return_data` is `NULL` or `0`. This ensures that if there is no result set, it won't throw errors when trying to manipulate it.

The steps that you walked through here are an important reminder that security is an ever-present concern and that the situations that could bring a server to its knees may not always be the obvious ones. Quality assurance is extremely important! Ensure that any software that you are writing is thoroughly tested for all possible values, regardless of whether they are normal use-cases or oddball edge cases. Empty searches, empty result sets, and SQL injection attempts are all situations that can be easily dealt with, but you must identify these threats in order to effectively respond to them.

Conclusion

The dynamic list building presented here is not the same sort of Dynamic SQL discussed thus far in this book. While it is generally simpler and does not require a separate execution to get the result set, many commonalities exist between it and the command strings that you built earlier.

In any scenario where you are accepting user input in order to build a string, parallels can immediately be drawn between the SQL injection threats that you tackled earlier and the ones that can be similarly identified when you want to list names or ID numbers.

In addition to SQL injection, dynamic lists share similarities in syntax, string manipulation, formatting, security, and the ability to combine them with additional Dynamic SQL in order to create even greater flexibility. With added complexity is an added need for careful testing, both for unexpected input as well as SQL injection attempts. While dynamically generated lists may not always carry the threats associated with external user input, being consistently aware of best practices regarding parameterization and QA can ensure that your TSQL is the highest quality and most secure possible.

CHAPTER 8

Parameter Sniffing

Chapter 6 introduced a number of tools, methods, and tips for performance optimization. A critical component that was briefly discussed was the query plan cache. Whenever a query is executed for the first time, an execution plan is generated by the query optimizer. This process is expensive and therefore it is beneficial to minimize the work that is performed by it. Execution plans are placed into the query plan cache when optimization is complete, where they will remain until sufficient changes occur in execution, available memory, or the underlying data to push that plan out of cache.

This process by which execution plans are saved is critical to optimal SQL Server performance. Whenever a query is executed that matches a query in cache, the existing plan will be used. This allows SQL Server to bypass the optimizer and jump directly to execution, saving time and resources along the way! Without this feature, you would be forced to add significant resources to busy servers in order to account for the resources needed to constantly optimize every query that is executed.

What Is Parameter Sniffing?

Execution plans are placed in cache based on a query hash that is assigned to it when the plan is generated. This hash is based on the exact text of the query and will be different if any part of a query is different. As a result, parameterizing queries will allow you to reuse the same plan over and over, regardless of the value of the parameter. The execution plan will be created based on the parameter value that is passed into the query during its first execution. Each subsequent execution will reuse the same plan, regardless of the value.

This leads to a question of accuracy: Will the plan that was chosen during the first execution of a query be the best plan for all possible values going forward? If parameters that are passed into a stored procedure are somewhat consistent, odds are very good that the initially created plan will be good enough for all future executions. In this scenario, query plan caching is working perfectly, so there is no reason to consider performance concerns. What if parameter values are sporadic and lead to a wide variety of possible results? Given enough time, an execution plan will be generated that will not be the best plan for other parameter values.

Execution plan reuse for different parameters is the definition of parameter sniffing and is an inadvertent side-effect of SQL Server's use of the query plan cache. Suboptimal plan reuse is a potential way in which this behavior can cause performance troubles. Before getting started, let's introduce a stored procedure that will read some data from the query plan cache based on a string search of the query text. This will save you time later when researching the contents of the plan cache and how they relate to the performance of the following example queries. Listing 8-1 shows the stored procedure that's used throughout this chapter.

E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_8

Listing 8-1. Stored Procedure to Read Optimization and Execution Data from the Query Plan Cache

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'read_query_plan_cache')
BEGIN
       DROP PROCEDURE dbo.read_query_plan_cache;
END
GO

CREATE PROCEDURE dbo.read_query_plan_cache
       @text_string NVARCHAR(MAX) = NULL
AS
BEGIN
    SELECT @text_string = '%' + @text_string + '%';
       DECLARE @sql_command NVARCHAR(MAX);
       DECLARE @parameter_list NVARCHAR(MAX) = '@text_string NVARCHAR(MAX)';

       IF @text_string IS NULL
           SELECT @sql_command = '
               SELECT TOP 25
                   DB_NAME(execution_plan.dbid) AS database_name,
                   cached_plans.objtype AS ObjectType,
                   OBJECT_NAME(sql_text.objectid, sql_text.dbid) AS ObjectName,
                   query_stats.creation_time,
                   query_stats.last_execution_time,
                   query_stats.last_worker_time AS cpu_last_execution,
                   query_stats.last_logical_reads AS reads_last_execution,
                   query_stats.last_elapsed_time AS duration_last_execution,
                   query_stats.last_rows AS rows_last_execution,
                   cached_plans.size_in_bytes,
                   cached_plans.usecounts AS ExecutionCount,
                   sql_text.TEXT AS QueryText,
                   execution_plan.query_plan,
                   cached_plans.plan_handle
               FROM sys.dm_exec_cached_plans cached_plans
               INNER JOIN sys.dm_exec_query_stats query_stats
               ON cached_plans.plan_handle = query_stats.plan_handle
               CROSS APPLY sys.dm_exec_sql_text(cached_plans.plan_handle) AS sql_text
               CROSS APPLY sys.dm_exec_query_plan(cached_plans.plan_handle) AS
               execution_plan';
       ELSE
           SELECT @sql_command = '
               SELECT TOP 25
                   DB_NAME(execution_plan.dbid) AS database_name,
                   cached_plans.objtype AS ObjectType,
                   OBJECT_NAME(sql_text.objectid, sql_text.dbid) AS ObjectName,
                   query_stats.creation_time,
                   query_stats.last_execution_time,
                   query_stats.last_worker_time AS cpu_last_execution,
                   query_stats.last_logical_reads AS reads_last_execution,
                   query_stats.last_elapsed_time AS duration_last_execution,
                   query_stats.last_rows AS rows_last_execution,
                   cached_plans.size_in_bytes,
```

```
                cached_plans.usecounts AS ExecutionCount,
                sql_text.TEXT AS QueryText,
                execution_plan.query_plan,
                cached_plans.plan_handle
            FROM sys.dm_exec_cached_plans cached_plans
            INNER JOIN sys.dm_exec_query_stats query_stats
            ON cached_plans.plan_handle = query_stats.plan_handle
            CROSS APPLY sys.dm_exec_sql_text(cached_plans.plan_handle) AS sql_text
            CROSS APPLY sys.dm_exec_query_plan(cached_plans.plan_handle) AS
            execution_plan
        WHERE sql_text.TEXT LIKE @text_string';

        EXEC sp_executesql @sql_command, @parameter_list, @text_string
END
GO
```

This stored procedure will greatly simplify your research, as you can pass it any query text and it will return a variety of data about queries in cache, their execution plans, and performance metrics on the last execution. You will use this in order to collect information on queries as you test them here, but it can be reused in any circumstance where you want to search the query cache for specific information. TOP 25 is used on the SELECT statements in order to limit the result set. On a busy server, this could otherwise return a very large amount of data, which could adversely affect server or client performance.

Parameter Sniffing Examples

In order to be sure you are getting clean test results, you should clear the query plan cache. As advised earlier in this book, do not run this in a production environment or any place where consistent performance is expected. Clearing the query plan cache is an excellent way to debug queries by forcing them to create fresh new plans with each execution, but as the optimizer takes significant resources to do its job, you should only ever do this in isolated environments:

```
DBCC FREEPROCCACHE;
```

You may also provide a specific plan handle as a parameter to this DBCC command. This would allow you to clear only a single plan of choice from cache, rather than everything. For simplicity, we will clear the entire cache here, but the syntax to clear a single query would look like this:

```
DBCC FREEPROCCACHE (0x06000700E8C6530730F36E6B030000000100000000000000000000000
000000000000000000000000000000);
```

The plan handle is included in the query plan cache search query, in case it's needed for further research. Now, in order to illustrate parameter sniffing, you need to create a simple stored procedure that searches Production.Product based on the ProductModelID, as shown in Listing 8-2 .

Listing 8-2. Example Stored Procedure to Be Used to Test Parameter Sniffing

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'get_products_by_model')
BEGIN
       DROP PROCEDURE dbo.get_products_by_model;
END
GO

CREATE PROCEDURE dbo.get_products_by_model (@firstProductModelID INT, @lastProductModelID INT)
AS
BEGIN
       SELECT
           PRODUCT.Name,
           PRODUCT.ProductID,
           PRODUCT.ProductModelID,
           PRODUCT.ProductNumber,
           MODEL.Name
       FROM Production.Product PRODUCT
       INNER JOIN Production.ProductModel MODEL
       ON MODEL.ProductModelID = PRODUCT.ProductModelID
       WHERE PRODUCT.ProductModelID BETWEEN @firstProductModelID AND @lastProductModelID;
END
```

Note that there are two parameters that are being passed into the stored procedure: `@firstProductModelID` and `@lastProductModelID`. If you execute this for a small range of product IDs, as follows:

```
EXEC get_products_by_model 120, 12
```

It returns six rows of data, as shown in Figure 8-1.

	Name	ProductID	ProductModelID	ProductNumber	Name
1	LL Mountain Rear Wheel	823	123	RW-M423	LL Mountain Rear Wheel
2	ML Mountain Rear Wheel	824	124	RW-M762	ML Mountain Rear Wheel
3	HL Mountain Rear Wheel	825	125	RW-M928	HL Mountain Rear Wheel
4	Touring-Panniers, Large	842	120	PA-T100	Touring-Panniers
5	Fender Set - Mountain	878	121	FE-6654	Fender Set - Mountain
6	All-Purpose Bike Stand	879	122	ST-1401	All-Purpose Bike Stand

Figure 8-1. *Result set for a restrictive product search that returns only six rows*

The performance metrics for this execution are as follows:

```
Table 'ProductModel'. Scan count 0, logical reads 12, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Product'. Scan count 1, logical reads 15, physical reads 0, read-ahead reads 0, lob
logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

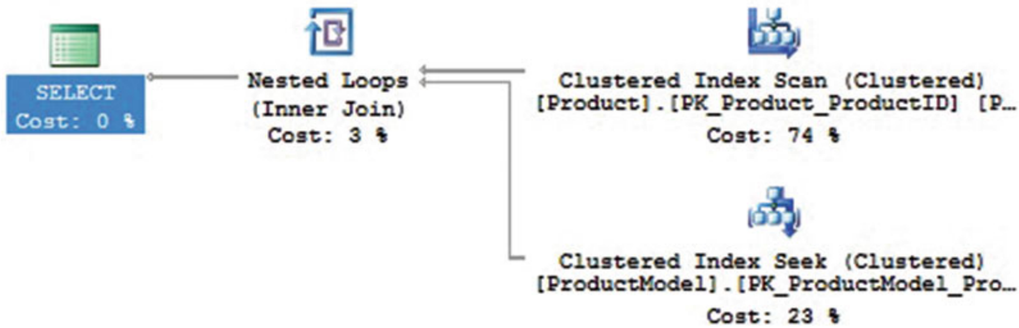
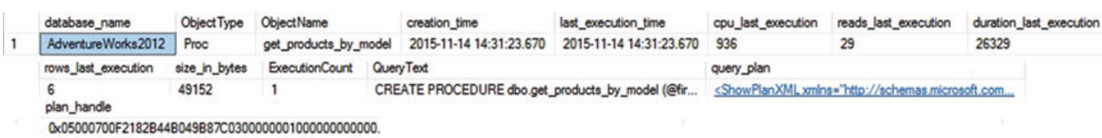


Figure 8-2. *Performance of a product search returning a small amount of data*

There were a total of 27 logical reads for this execution and SQL Server utilized a scan and seek to get the necessary data from `Product` and `ProductModel` in order to return the results. To confirm what you see here and add some additional metrics, you can use the query plan cache stored procedure from earlier to learn more about this execution:

```
EXEC dbo.read_query_plan_cache 'get_products_by_model';
```

This returns a variety of useful information about this single execution of the stored procedure, as shown in Figure 8-3.



	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks2012	Proc	get_products_by_model	2015-11-14 14:31:23.670	2015-11-14 14:31:23.670	936	29	26329

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
6	49152	1	CREATE PROCEDURE dbo.get_products_by_model (@fir...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x05000700F2182B44B049B87C030000000001000000000000.

Figure 8-3. *Metrics returned by dbo.read_query_plan_cache for a restrictive search query*

In an effort to keep Figure 8-3 easy to read, I've wrapped the image of the query results to multiple lines, rather than trying to squeeze it into a single query result row. This following information can be gleaned from these results:

CPU: 936 microseconds

Reads: 29

Duration: 26ms (26,329 microseconds)

Rows Returned: 6

The query text and execution plan are also available here if needed. Now, let's clear the plan cache and execute the same stored procedure, but for a different range of IDs:

```
DBCC FREEPROCCACHE;
EXEC get_products_by_model 0, 10000;
```

This execution returns 295 results rather than six, as shown in Figure 8-4.

	Name	ProductID	ProductModelID	ProductNumber	Name
1	HL Road Frame - Black, 58	680	6	FR-R92B-58	HL Road Frame
2	HL Road Frame - Red, 58	706	6	FR-R92R-58	HL Road Frame
3	Sport-100 Helmet, Red	707	33	HL-U509-R	Sport-100
4	Sport-100 Helmet, Black	708	33	HL-U509	Sport-100
5	Mountain Bike Socks, M	709	18	SO-B909-M	Mountain Bike Socks
6	Mountain Bike Socks, L	710	18	SO-B909-L	Mountain Bike Socks
7	Sport-100 Helmet, Blue	711	33	HL-U509-B	Sport-100
8	AWC Logo Cap	712	2	CA-1098	Cycling Cap
9	Long-Sleeve Logo Jersey, S	713	11	LJ-0192-S	Long-Sleeve Logo Jersey
10	Long-Sleeve Logo Jersey, M	714	11	LJ-0192-M	Long-Sleeve Logo Jersey
11	Long-Sleeve Logo Jersey, L	715	11	LJ-0192-L	Long-Sleeve Logo Jersey
12	Long-Sleeve Logo Jersey, XL	716	11	LJ-0192-X	Long-Sleeve Logo Jersey
13	HL Road Frame - Red, 62	717	6	FR-R92R-62	HL Road Frame
14	HL Road Frame - Red, 44	718	6	FR-R92R-44	HL Road Frame
15	HL Road Frame - Red, 48	719	6	FR-R92R-48	HL Road Frame
16	HL Road Frame - Red, 52	720	6	FR-R92R-52	HL Road Frame
17	HL Road Frame - Red, 56	721	6	FR-R92R-56	HL Road Frame
18	LL Road Frame - Black, 58	722	9	FR-R38B-58	LL Road Frame

Query executed successfully. | SANDILE\EDSQLSERVER14 (12.0... | SANDILE\Edward (54) | AdventureWorks2012 | 00:00:00 | 295 rows

***Figure 8-4.** Product results for a less restrictive search returning 295 rows*

The performance is not significantly different, but a different execution plan was chosen, as shown in Figure 8-5.

```
Table 'Workfile'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Product'. Scan count 1, logical reads 15, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductModel'. Scan count 1, logical reads 2, physical reads 1, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

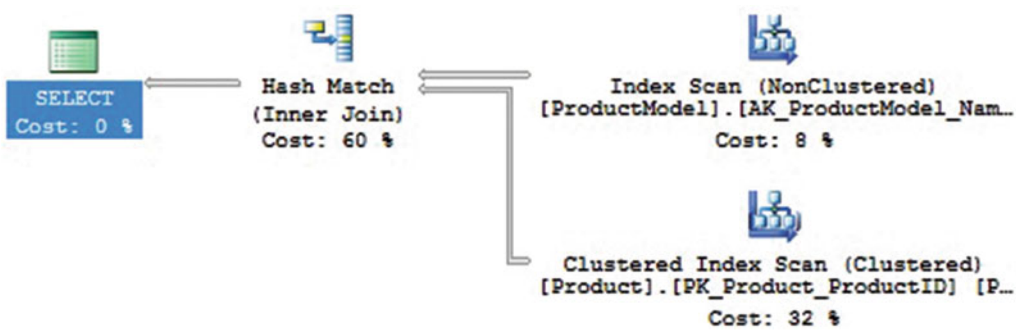


***Figure 8-5.** Performance when a less restrictive search query is executed*

Since you were selecting such a large number of rows from the table, the query optimizer decided that an index scan on `ProductModel` would be more efficient. This is often a good decision as it becomes expensive to seek through an index when the number of rows being returned approaches a large portion of the table. The exact turning point will typically depend on the data size, but this is an excellent example of a situation where an index scan offers superior performance to an index seek.

Before reading the plan cache, run `get_products_by_model` five more times, which will add data into the cache that will be useful to review:

```
EXEC get_products_by_model 0, 10000;
EXEC get_products_by_model 0, 10000;
EXEC get_products_by_model 0, 10000;
EXEC get_products_by_model 0, 10000;
EXEC get_products_by_model 0, 10000;
```

As you did before, you can run the stored procedure to read information from the plan cache for this new execution of the search proc. The resulting metrics can be found in Figure 8-6.

```
EXEC dbo.read_query_plan_cache 'get_products_by_model';
```

	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks2012	Proc	get_products_by_model	2015-11-14 14:41:00.997	2015-11-14 14:41:01.813	1858	19	80324

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
295	65536	6	CREATE PROCEDURE dbo.get_products_by_model (@fir...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x05000700F2182B44B049B87C0300000001000000000000.

Figure 8-6. *Metrics returned by dbo.read_query_plan_cache for a less restrictive search query*

The results are in line with what you saw previously:

CPU: 1858 microseconds

Reads: 19

Duration: 80ms (80,324 microseconds)

Rows Returned: 295

Note that the execution count is six here. By running the query a number of times, we can illustrate plan reuse when it is desired. Once a plan was found, it will be retained and reused until it is eventually released from the plan cache. Despite the execution count, the results are almost identical for each execution.

So far there have been no surprises. Each execution has returned the expected data and the optimizer did a great job of choosing the correct plan in order to minimize resource utilization. Let's clear the cache one last time and run the search proc twice in a row, first for a small range of product models and then with the large range:

```
DBCC FREEPROCCACHE;
EXEC get_products_by_model 120, 125;
EXEC get_products_by_model 0, 10000;
```

When you run this TSQL, the first execution performs exactly as it did earlier. A plan is chosen with an index scan on `Product` and an index seek on `ProductModel`. The resulting execution plan and IO statistics are also exactly the same. When you run the second execution of the stored procedure, something unusual happens: it performs very poorly! The performance metrics for the second product search are shown in Figure 8-7 for the scenario where a wide range of IDs was passed in:

```
Table 'ProductModel'. Scan count 0, logical reads 590, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Product'. Scan count 1, logical reads 15, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

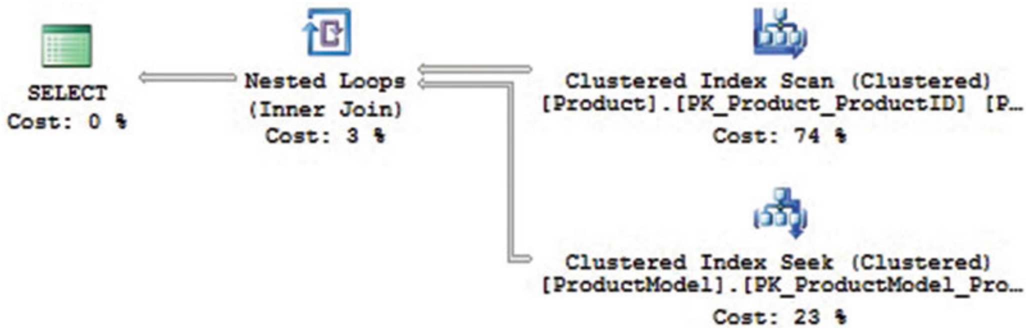
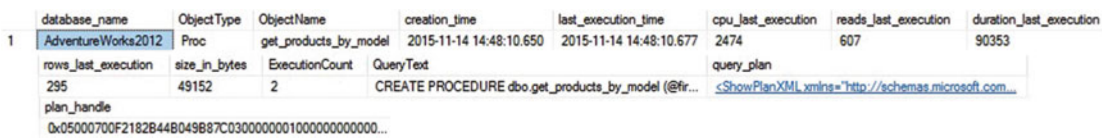


Figure 8-7. Search performance when a suboptimal plan is reused

This time, reads were significantly higher than you'd expect for this stored procedure. The execution plan chosen was reused from the previous one that was used for the narrow range of IDs (index seek on `ProductModel`), rather than one that is optimal for a large result set (index scan on `ProductModel`). Reading the plan cache helps to understand what happened:

```
EXEC dbo.read_query_plan_cache 'get_products_by_model';
```

The results in Figure 8-8 show that the execution plan that was created for the narrow range of IDs was reused for the second run, despite providing parameters that resulted in a very different cardinality.



	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks2012	Proc	get_products_by_model	2015-11-14 14:48:10.650	2015-11-14 14:48:10.677	2474	607	90353

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
295	49152	2	CREATE PROCEDURE dbo.get_products_by_model (@fir...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x05000700F2182B44B049B87C0300000001000000000000...

Figure 8-8. Metrics returned by dbo.read_query_plan_cache illustrate parameter sniffing

Note that `ExecutionCount` is 2. This is proof that the initial execution plan was reused for the second execution of the search proc. The rest of the metrics returned confirm the poor performance viewed previously:

CPU: 2474 microseconds

Reads: 607

Duration: 90ms (90,353 microseconds)

Rows Returned: 295

This is an example of parameter sniffing when it directly harms query execution performance. A suboptimal execution plan was chosen and the result was significantly higher reads, CPU utilization, and a longer query runtime.

Before discussing ways in which you can resolve performance problems with parameter sniffing, let's look at an additional example that shows how parameter sniffing can potentially interfere when working with Dynamic SQL. These examples will use sales orders and will take advantage of a new salesperson in order to illustrate the effects of poor cardinality estimates on execution plans:

```
INSERT INTO Sales.SalesPerson
       (BusinessEntityID, TerritoryID, SalesQuota, Bonus, CommissionPct, SalesYTD,
SalesLastYear, rowguid, ModifiedDate)
VALUES
       (1, 1, 1000000, 289, 0.17, 0, 0, NEWID(), CURRENT_TIMESTAMP);

UPDATE Sales.SalesOrderHeader
       SET SalesPersonID = 1
WHERE SalesPersonID IS NULL;

UPDATE STATISTICS Sales.SalesOrderHeader;
GO
```

These statements will create a new salesperson and assign her to all sales orders that currently have no one assigned to them. In addition, it updates statistics on the table to ensure that the optimizer is aware of the new data when making optimization decisions. This will provide you with a salesperson with 27,659 sales orders assigned to her. Let's introduce a new stored procedure that will search sales orders based on a `SalesPersonID` that is provided as a parameter. In addition, the number of rows returned and offset can be provided, if you want to page the results, as shown in Listing 8-3.

Listing 8-3. Search Procedure Demonstrating Parameter Sniffing

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_sales_orders_by_sales_person')
BEGIN
       DROP PROCEDURE dbo.get_sales_orders_by_sales_person;
END
GO

CREATE PROCEDURE dbo.get_sales_orders_by_sales_person
       @SalesPersonID INT, @RowCount INT, @Offset INT
AS
BEGIN
       DECLARE @sql_command NVARCHAR(MAX);
       DECLARE @parameter_list NVARCHAR(MAX) = '@SalesPersonID INT, @RowCount INT,
       @Offset INT';
       -- Add one to the offset to get the correct starting row
       SELECT @Offset = @Offset + 1;

       SELECT @sql_command = '
       WITH CTE_PRODUCTS AS (
           SELECT
               ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
               SalesOrderHeader.SalesOrderID,
               SalesOrderHeader.Status,
               SalesOrderHeader.OrderDate,
```

```
            SalesOrderHeader.ShipDate,
            SalesOrderDetail.UnitPrice,
            SalesOrderDetail.LineTotal
        FROM Sales.SalesOrderHeader
        INNER JOIN Sales.SalesOrderDetail
        ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
        WHERE SalesOrderHeader.SalesPersonID = @SalesPersonID
        )
    SELECT
        *
    FROM CTE_PRODUCTS
    WHERE rownum BETWEEN @Offset AND @Offset + @RowCount;';

    EXEC sp_executesql @sql_command, @parameter_list, @SalesPersonID, @RowCount, @Offset;
END
```

This stored procedure is completely parameterized, allowing you to change the inputs at execution time without having to adjust the Dynamic SQL. Let's start out by looking at the performance of a search involving the new salesperson:

```
DBCC FREEPROCCACHE;
EXEC dbo.get_sales_orders_by_sales_person 1, 1000, 0;
```

The query plan cache is cleared first to ensure that the results are unaffected by any other queries executed on this server. The additional parameters are set to return 1,000 rows from the result set (which contains 27,659 rows), starting from row 1. The performance metrics for this execution are found in Figure 8-9.

```
Table 'SalesOrderDetail'. Scan count 1000, logical reads 3231, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

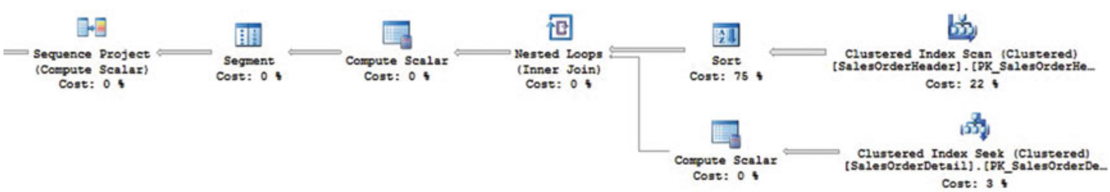


Figure 8-9. *Execution plan for a search that uses parameterized paging*

In addition, the execution metrics returned by the plan cache reading stored procedure can be seen in Figure 8-10:

```
EXEC dbo.read_query_plan_cache 'CTE_PRODUCTS';
```

	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks2012	Prepared	NULL	2015-11-16 16:20:08.147	2015-11-16 16:20:08.150	13726	4062	115309

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
1000	65536	1	(@SalesPersonID INT, @RowCount INT, @Offset IN...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x060007009CB74F1D90C9B87C030000000100000000000.

Figure 8-10. *Metrics returned by dbo.read_query_plan_cache for a parameterized search with paging*

Note that since some parameters were defined locally for the Dynamic SQL, the stored procedure itself was not entered into the plan cache—instead only the Dynamic SQL statement was. The contents of `QueryText` are shown in Listing 8-4.

Listing 8-4. Resulting Query Text as Executed in the Dynamic Search with Paging

```
(@SalesPersonID INT, @RowCount INT, @Offset INT)
       WITH CTE_PRODUCTS AS (
           SELECT
               ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
               SalesOrderHeader.SalesOrderID,
               SalesOrderHeader.Status,
               SalesOrderHeader.OrderDate,
               SalesOrderHeader.ShipDate,
               SalesOrderDetail.UnitPrice,
               SalesOrderDetail.LineTotal
           FROM Sales.SalesOrderHeader
           INNER JOIN Sales.SalesOrderDetail
           ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
           WHERE SalesOrderHeader.SalesPersonID = @SalesPersonID
           )
       SELECT
           *
       FROM CTE_PRODUCTS
       WHERE rownum BETWEEN @Offset AND @Offset + @RowCount;
```

The desired effect is still achieved in that the query that you intend to run is fully parameterized and an execution plan will be reused whenever the stored procedure is executed. Searching for it in cache, though, requires entering some text from the `SELECT` query, rather than the stored procedure name.

All of these results show that the optimizer chose a clustered index scan on `SalesOrderHeader` and a clustered index seek on `SalesOrderDetail`. 3,926 reads were needed in order to query this large data set and the results from the query metrics are as follows:

CPU: 14ms (13,726 microseconds)

Reads: 4062

Duration: 115ms (115,309 microseconds)

Rows Returned: 1000

You could clear the cache and repeat this exercise for a salesperson with far fewer sales records:

```
DBCC FREEPROCCACHE;
EXEC dbo.get_sales_orders_by_sales_person 285, 1000, 0;
```

The result set for this execution is 245 rows instead of 27,659. As such, limiting the result set to 1,000 rows will have no effect on what is returned by SQL Server. The performance metrics for this execution are shown in Figure 8-11.

```
Table 'SalesOrderDetail'. Scan count 16, logical reads 53, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 50, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

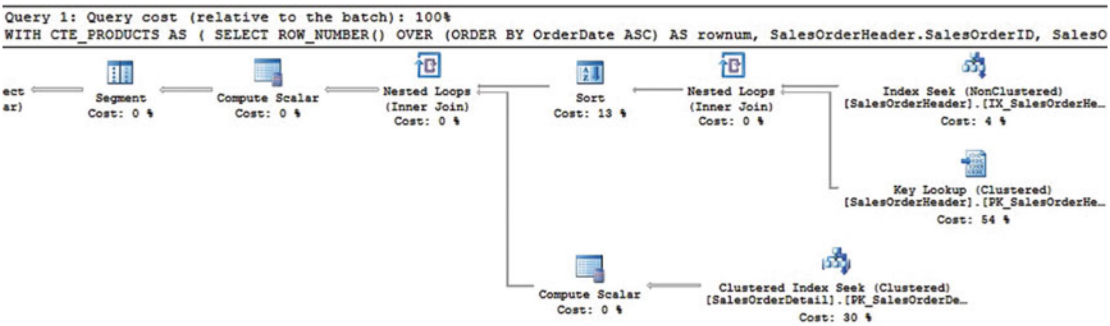


Figure 8-11. *Execution plan for a parameterized paged search with a small result set*

Only 103 reads were required to return this smaller data set, and the optimizer chose to use an index seek on SalesOrderHeader and a clustered index seek on SalesOrderDetail. Despite the fact that a key lookup is an expensive random IO operation, the optimizer still chose that over the alternative of scanning the entire table. Let's review the additional query stats for this execution, as shown in Figure 8-12.

```
EXEC dbo.read_query_plan_cache 'CTE_PRODUCTS';
```

	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks2012	Prepared	NULL	2015-11-16 16:25:31.670	2015-11-16 16:25:31.673	2127	103	94877

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
245	73728	1	(@SalesPersonID INT, @RowCount INT, @Offset IN...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x060007009CB74F1D90C9B87C0300000001000000000000...

Figure 8-12. *Metrics returned by dbo.read_query_plan_cache for a parameterized search with paging and a small result set*

This data agrees with everything reviewed so far. This execution requires significantly fewer reads to return fewer rows and does so a bit faster than before.

CPU: 2127 microseconds

Reads: 103

Duration: 95ms (94,877 microseconds)

Rows Returned: 245

Now that you have established a baseline for the performance of this stored procedure with regards to large vs. small result sets, you can compare parameter sniffing for a scenario that is the opposite of the one reviewed earlier. You would clear the query plan cache one last time and run the sales order search for the salesperson with the very large number of orders assigned to them:

```
DBCC FREEPROCCACHE;
EXEC dbo.get_sales_orders_by_sales_person 1, 1000, 0;
```

A quick review of the performance metrics for this execution confirms that it executes exactly the way it did earlier, as shown in Figure 8-13.

```
Table 'SalesOrderDetail'. Scan count 1000, logical reads 3231, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

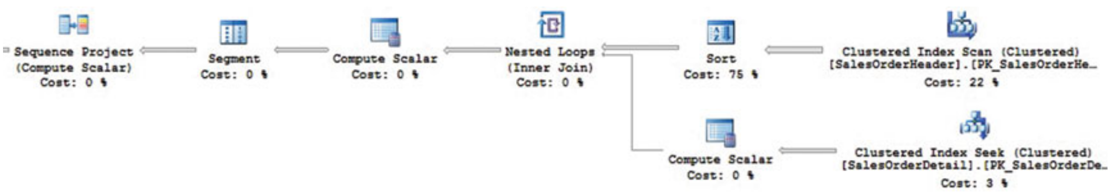


***Figure 8-13.** Performance of the search from earlier with a large result set*

Both the IO statistics and execution plan match the first execution from earlier. Now, let's execute the same stored procedure for the second use-case, where the salesperson has far fewer sales orders (without clearing the plan cache):

```
EXEC dbo.get_sales_orders_by_sales_person 285, 1000, 0;
```

While the results returned are the same as when you ran this same query earlier, the performance is significantly different. Figure 8-14 illustrates this with the IO statistics and the execution plan.

```
Table 'SalesOrderDetail'. Scan count 16, logical reads 74, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 689, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

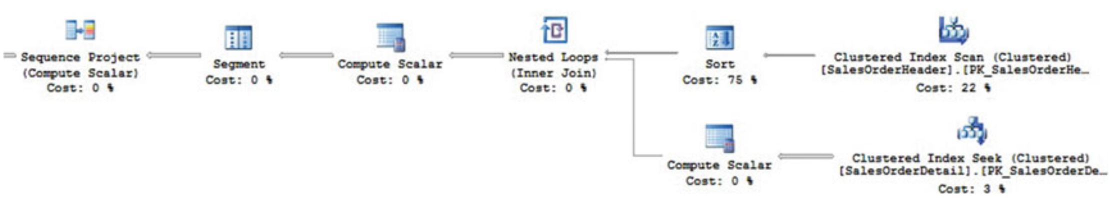


***Figure 8-14.** Performance when the execution plan for a large result set is reused with a significantly smaller one*

Since you did not clear the query plan cache, the execution plan from above was reused for this execution of the stored procedure. The execution plan is exactly the same as the previous execution. The optimizer uses a clustered index scan on `SalesOrderHeader`, even though this is not the optimal way to retrieve data from the table for the smaller cardinality illustrated in this example. As a result, the reads on `SalesOrderHeader` are significantly higher, and the reads on `SalesOrderDetail` are about 50% higher. To show that plan reuse occurred, run the `read_query_plan_cache` stored procedure one last time. You can review the results in Figure 8-15.

```
EXEC dbo.read_query_plan_cache 'CTE_PRODUCTS';
```

	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks2012	Prepared	NULL	2015-11-16 16:40:45.213	2015-11-16 16:43:54.407	3402	777	97993

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
245	65536	2	(@SalesPersonID INT, @RowCount INT, @Offset IN...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x060007009CB74F1D90C9B87C0300000001000000000000.

Figure 8-15. *Metrics returned by dbo.read_query_plan_cache for a parameterized search with paging when parameter sniffing results in undesired plan reuse*

Summarizing this data, let's can pull out the most relevant details for review:

Executions: 2

CPU: 3402 microseconds

Reads: 777

Duration: 98ms (97,993 microseconds)

Rows Returned: 245

The execution count is the proof that the execution plan was indeed reused. In this scenario, reuse was not beneficial and caused the query to take significantly greater resources to execute. On a larger, busier production database, performance could be seriously degraded by this sort of parameter sniffing.

The next logical question would be to ask how you deal with this phenomenon and how to correctly compensate for parameter sniffing. In order to provide the best answer possible, you'll learn about a few additional considerations before diving into a variety of solutions.

Design Considerations

Rule one for managing a phenomenon like parameter sniffing is to know your data! Since this is a SQL Server feature and not a bug, you need to carefully assess any scenario when it becomes problematic, before trying to implement a solution.

Consider both of the previous examples: What was the precise cause of undesired plan reuse? Ultimately, it was the fact that multiple executions of the stored procedure resulted in wildly different cardinality estimates for the result set. One parameter value returned 245 rows whereas the other returned over 100 times as much data.

When addressing parameter sniffing, you should ask a variety of questions in order to accurately gauge its severity, frequency, and effects of change:

- How often is the query executed?
- What is the most common order of magnitude for cardinality that will be returned by an execution? Was parameter sniffing helpful most of the time, or did it lead to poor execution plans more often than you would want?

- How will increasing data sizes over time affect these cardinality estimates?
- Are there other culprits involved, such as stale statistics, poorly written TSQL, or missing or fragmented indexes?
- What are the most frequent parameter values that are likely to be passed to the stored procedure?
- Do you already know the cardinality of the result set, regardless of inputs? For example, does a stored procedure always return one row?
- Can a complex query be broken up into multiple simpler queries?

More often than not, queries that satisfy a business need will fit a regular pattern of use. Determining that pattern and then finding situations that fall well outside of the norm can help in figuring out if your TSQL is accommodating common use-cases or if you are inadvertently setting yourself up for poor performance by writing for the exceptions, rather than common occurrences.

To properly answer these questions, let's briefly review each one in more detail.

Query Execution Details

How often does a query execute overall and how often does it execute in such a way that parameter sniffing is a discernable problem? If it is run constantly, then you need to ensure that it is efficient, as something that executes thousands of times a minute cannot afford to be inefficient. You would need to determine the most common use-case and write TSQL to accommodate it. If there are multiple common scenarios that run constantly, you could consider separate stored procedures for each one, multiple code paths within a single proc, or other ways to make the most out of each situation.

If a query executes infrequently, though, such as for a daily report or infrequent search, then recompiling the query plan each time would be a reasonable solution as it would ensure the best possible plan and not reuse an old plan. Since it is uncommonly run, the cost of recompilation would not be significant enough to cause the server any resource pressure due to the extra work the optimizer needs to perform each time. In these cases, you are at liberty to take a wider variety of actions to resolve the undesired plan reuse. Verify, though, that the query that is rarely executed today does not become more frequently used in the future. If the once-a-day query becomes popular and starts to be executed every five seconds throughout the day, then recompilation will become an expensive operation to perform so frequently.

A query hint may be used to force a recompile every time it executes by using `OPTION (RECOMPILE)`. The syntax is shown in Listing 8-5.

Listing 8-5. Example of the RECOMPILE Query Hint

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'get_sales_orders_by_sales_
person')
BEGIN
	DROP PROCEDURE dbo.get_sales_orders_by_sales_person;
END
GO

CREATE PROCEDURE dbo.get_sales_orders_by_sales_person
	@SalesPersonID INT, @RowCount INT, @Offset INT
```

```
AS
BEGIN
       DECLARE @sql_command NVARCHAR(MAX);
       DECLARE @parameter_list NVARCHAR(MAX) = '@SalesPersonID INT, @RowCount INT, @Offset INT';

       SELECT @sql_command = '
       WITH CTE_PRODUCTS AS (
           SELECT
               ROW_NUMBER() OVER (ORDER BY OrderDate ASC) AS rownum,
               SalesOrderHeader.SalesOrderID,
               SalesOrderHeader.Status,
               SalesOrderHeader.OrderDate,
               SalesOrderHeader.ShipDate,
               SalesOrderDetail.UnitPrice,
               SalesOrderDetail.LineTotal
           FROM Sales.SalesOrderHeader
           INNER JOIN Sales.SalesOrderDetail
           ON SalesOrderHeader.SalesOrderID = SalesOrderDetail.SalesOrderID
           WHERE SalesOrderHeader.SalesPersonID = @SalesPersonID
           )
       SELECT
               *
       FROM CTE_PRODUCTS
       WHERE rownum BETWEEN @Offset AND @Offset + @RowCount
       OPTION (RECOMPILE);';

       EXEC sp_executesql @sql_command, @parameter_list, @SalesPersonID, @RowCount, @Offset;
END
```

The only difference between this stored procedure and the one you worked ith earlier was the addition of the `RECOMPILE` hint at the end of the `SELECT` query. With this in place, you can run the last parameter sniffing example:

```
DBCC FREEPROCCACHE;
EXEC dbo.get_sales_orders_by_sales_person 1, 1000, 0;

EXEC dbo.get_sales_orders_by_sales_person 285, 1000, 0;

EXEC dbo.read_query_plan_cache 'CTE_PRODUCTS';
```

Last time you executed the stored procedure in this manner, the query execution plan was reused, resulting in poor performance. Let's review the performance for the second execution in Figure 8-16, which was for the small result set:

```
Table 'SalesOrderDetail'. Scan count 16, logical reads 53, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderHeader'. Scan count 1, logical reads 50, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

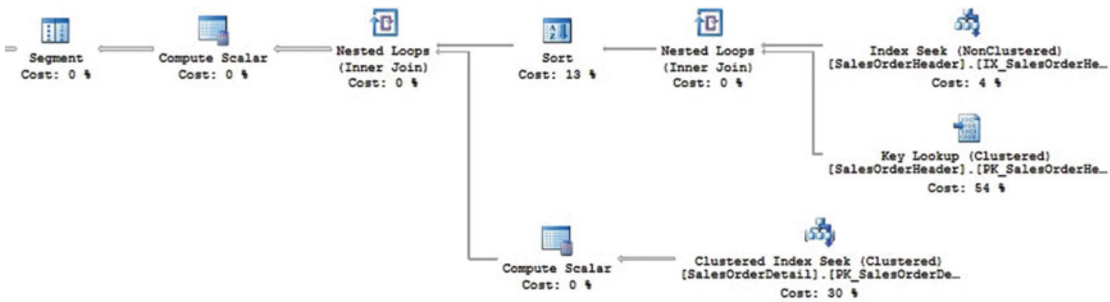


Figure 8-16. *Performance when the execution plan is recompiled at runtime, preventing reuse of a suboptimal plan*

This time around, SQL Server executed the query and recompiled the query plan at runtime to obtain the optimal plan for each set of parameters, rather than the one used for the large result set that preceded it.

As always, query hints should be used cautiously and only when deemed necessary. The resources required by the optimizer to generate an execution plan are not trivial, and recompiling plans too frequently can result in additional CPU consumption and increased query latency. This tool is best used when you are certain that a query executes infrequently, or its cardinality is so sporadic that plan reuse often results in poor performance.

An additional consideration is to determine if poor performance resulting from plan reuse is the rule or the exception. Adding recompilation to a query as a result of an occasional anomaly would not be beneficial. It may be best to tolerate undesired plan reuse if a query executes optimally for a majority of the time. Also worth investigating is if the anomaly is indicative of a bigger problem, such as a data validation error or illegitimate data being passed into your stored procedure.

The tradeoff for recompiling an execution plan is to (hopefully) improve query execution performance at the cost of optimization performance. When determining if this tradeoff is worth it, consider the future: Will this query execute similarly in the future? Could the application or query source change, resulting in new, unexpected behavior that could turn this good decision into a bad one? In addition, has your research been exhaustive enough to ensure that all use-cases have been covered? If you can confidently answer these questions, then making the correct decision with regard to recompiling query execution plans should be straight-forward.

The Red Herrings

Sometimes, bad execution plans may arise from other sources. If statistics are out of date, then suboptimal query execution plans could be chosen prior to parameter sniffing occurring. In other words, plan reuse was perfectly fine, but the optimizer initially created a bad plan due to the lack of accurate statistics, and that bad plan was later reused. In this scenario, a bad plan would have likely been generated even if plan reuse had not occurred. Verifying the estimated vs. actual row counts in an execution plan is a good way to spot potential statistics inaccuracies. See Chapter 6 for details on viewing, using, and updating statistics.

Realistically, any way in which TSQL can be poorly written could lead to accidentally blaming parameter sniffing for undesired plan reuse. The simple example in Listing 8-6 shows a query that was written in such a way that suboptimal performance was essentially guaranteed.

Listing 8-6. An AdventureWorks Query Guaranteed to Perform Poorly

```
SELECT DISTINCT
       PRODUCT.ProductID,
       PRODUCT.Name
FROM Production.Product PRODUCT
INNER JOIN Sales.SalesOrderDetail DETAIL
ON PRODUCT.ProductID = DETAIL.ProductID
OR PRODUCT.rowguid = DETAIL.rowguid
```

This query, which returns 266 rows, yields the performance metrics shown in Figure 8-17.

```
Table 'Product'. Scan count 5, logical reads 40, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 4, logical reads 4984, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 4, logical reads 1209220, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

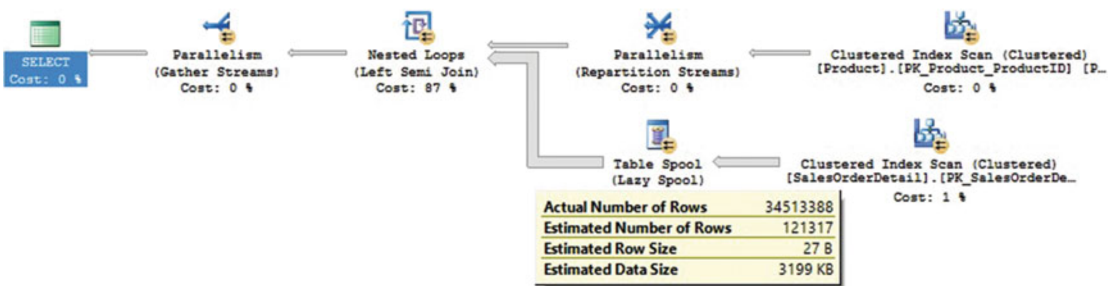


Figure 8-17. *Performance of an (intentionally) poorly written query*

Check out that row count heading into the nested loops! 34.5 million rows! Since `SalesOrderDetail` contains only 121,317 rows, you clearly have a problem that needs to be resolved. It turns out that using an `OR` operator in a join can cause catastrophically bad performance, as the query optimizer has a very difficult time determining the best way to intersect the data sets efficiently.

If this query plan were reused in the future, it would perform poorly, not because of parameter sniffing, but because the query itself is poorly designed. If you rewrote the query to remove the `OR`, such as by using two statements separated by a `UNION`, you could realize significantly better performance. Listing 8-7 shows this improved TSQL.

Listing 8-7. The Optimized Version of the Slow Query from Listing 8-6

```
SELECT
       PRODUCT.ProductID,
       PRODUCT.Name
FROM Production.Product PRODUCT
INNER JOIN Sales.SalesOrderDetail DETAIL
```

```
ON PRODUCT.ProductID = DETAIL.ProductID
UNION
SELECT
       PRODUCT.ProductID,
       PRODUCT.Name
FROM Production.Product PRODUCT
INNER JOIN Sales.SalesOrderDetail DETAIL
ON PRODUCT.rowguid = DETAIL.rowguid
```

While this TSQL may seem longer and more complex, the query optimizer will have a significantly easier time finding a good plan for it:

```
Table 'Product'. Scan count 2, logical reads 30, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'SalesOrderDetail'. Scan count 505, logical reads 1554, physical reads 0, read-ahead
reads 0, lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

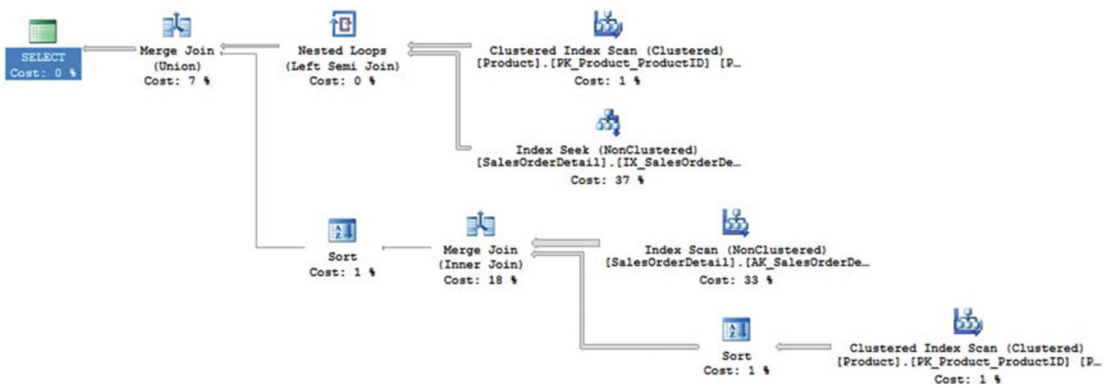


Figure 8-18. *Performance of the rewritten and optimized query in Listing 8-7*

While the execution plan may seem more complex, the TSQL syntax allowed the optimizer to break a complex problem into two simpler problems that could then be easily solved, combined, and the same result set returned. The reads were reduced by over 75x and the runtime went from 10 seconds down to 100ms.

Dividing and conquering a complex query is often an excellent way to prevent the query optimizer from being unable to find the best possible plan. This simple-looking query was a performance bomb for the optimizer to deal with. Separating it into two sections is one solution and using a temporary table or table variable to store the data in intermediary steps is also a valid solution to this performance problem.

If a query becomes large and unwieldy, consider breaking it into smaller, simpler queries. With each table that is joined into a query, the number of possible execution plans that the query optimizer must evaluate grows exponentially. Depending on the query style, the number of join orders that exist for n tables will either be n! (n factorial, for a query tree that is left-deep) or (2n-2)!/(n-1)! (an even larger number if the query tree is bushy). Consider for a moment the number of ways in which four tables in a left-deep join order can be ordered:

Table A JOIN Table B JOIN Table C JOIN Table D

```
ABCD ABDC ACBD ACDB ADBC ADCB BACD BADC BCAD BCDA BDAC BDCA
CABD CADB CBAD CBDA CDAB CDBA DABC DACB DBAC DBCA DCAB DCBA
```

The result is that there are 24 (4! = 4 * 3 * 2 * 1) possible ways to arrange the four tables involved in this example. Left-deep and bushy trees are ways to describe the query trees that are built by any query processor. Figure 8-19 shows how each type looks when illustrated as a tree.

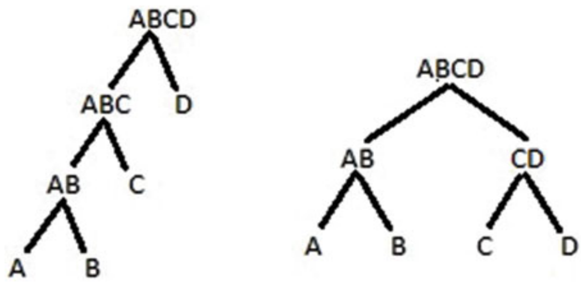


Figure 8-19. *Example of a left-deep query tree (left) and a bushy query tree (right)*

The left-deep tree consists of a sequence of tables that are joined one-at-a-time, while a bushy tree is composed of separately joined tables whose results are then joined together as each set of joins is completed. There are far more ways to express the ordering in a bushy tree, which is why the mathematical expression for the permutations of join orders is significantly larger than with a left-deep tree.

Without entering into an in-depth discussion of each type of query tree, it is safe to say that with each table added into a query, the number of ways the joins can be ordered will increase significantly. Removing even one table from a complex query and collecting the data from it separately can result in major performance gains.

Always test these changes and ensure that the refactored TSQL truly performs better. Equally important, be certain that the data returned is the same as it was earlier. Highly transactional data may change in between an initial data collection and the final query, resulting in inconsistent data. As a result, be comfortable with the data that is being queried and don't blindly optimize without being certain that the output of the resulting query will be the same as the original.

Investigating indexing is also worthwhile. Verify that correct indexes are being used and that they are not overly fragmented. Fragmentation will slow down all reads on an index and result in SQL Server needing to read more pages of data into memory before it has all of the index pages needed to execute the query. In addition, ensure that your query can take advantage of the correct index. Is the index that you expect the query to use enabled and if it is a filtered index, is that filter being correctly applied?

Before investigating parameter sniffing as the culprit to a performance problem, always verify that there are no other bigger problems that require tackling first. In addition to statistics, indexing, and TSQL mistakes, it is possible that SQL Server configuration settings may also affect query performance. Parallelism, trace flags, and memory/CPU pressure could all lead to unexpected performance degradation.

Despite all of these possibilities, always start with the simplest solutions first, and then explore more complex ones when they are disproven. It is significantly more likely that a performance problem related to undesired plan reuse is simply the result of classic parameter sniffing, and not of some other mysterious origin. If not, then consider the impact of statistics, indexing, and query structure. Only when all else fails is it necessary to investigate the guts of your SQL Server installation for further clues. This will be a rare scenario if it ever happens, but being prepared and knowing where to look to solve performance problems can save a lot of time in the future.

Parameter Values

A good way to investigate parameter sniffing is to inspect the parameters themselves and the typical values that are being passed into them. Is a certain value or set of values very common? Are the values always different and indicative of a process that never repeats? Does a parameter typically receive a value that seems random, or do they follow a distinct pattern?

This knowledge can help determine the best course of action. If a small set of values is always passed into a stored procedure, you may be able to make assumptions about them and design the TSQL to take into account those artificial limits. Some useful observations include:

- Is a parameter always `NOT NULL`?
- Will a parameter always be set to the current date or a current value for an important metric?
- Is there a very limited set of values for a parameter?
- Are parameter values seemingly random?
- Is a particular value extremely common, or is that value more important or relevant than other values?

As noted earlier, it's important to take into account the possibility of change. If application changes could impact parameter values, it is necessary to anticipate those changes and not write TSQL that will be harmed by those changes in the future. If this can be verified, then use simplifying assumptions to rewrite stored procedures to be shorter, simpler, and easier for the optimizer to make the correct decisions as often as possible.

Additionally, knowing the cardinality of a result set can greatly affect how you write a stored procedure. For example, if a single row is always returned from a given stored proc, you can ensure that each section of it is optimized for that small result set. Similarly, if you are paging data and will always return 25 or 50 rows, that information can be used to make sure the stored proc is written to return that row count and no more or less.

As was illustrated in Chapter 3, paging data sets can be optimized for a small result set when it is unlikely that you will request more data. If you know that a user will request page after page, you can write your queries to return more data, in anticipation of the next click. The application knowledge that allows you to draw these conclusions also provides the information you need to write TSQL that aligns with the business logic you are trying to satisfy.

Local Variables

In order to prepare for this example, add an index to `Production.Product`, which will help support the queries that you are about to run:

```
CREATE NONCLUSTERED INDEX NCI_production_product_ProductModelID ON Production.Product
(ProductModelID) INCLUDE (Name);
```

A tactic that is sometimes used to try to eliminate parameter sniffing is to redeclare all variables locally, rather than using the parameters passed into a stored procedure. The effect of this may seem similar to the use of the `RECOMPILE` hint, but there can be some subtle differences that can result in worse performance in the long run. To demonstrate this effect, let's create a new version of the stored procedure from the start of this chapter and redefine all stored procedure parameters as local variables within it, as shown in Listing 8-8.

Listing 8-8. Stored Procedure that Redeclares Parameters as Local Variables

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_products_by_model_local')
BEGIN
    DROP PROCEDURE dbo.get_products_by_model_local;
END
GO
CREATE PROCEDURE dbo.get_products_by_model_local (@firstProductModelID INT,
@lastProductModelID INT)
AS
BEGIN
    DECLARE @ProductModelID1 INT = @firstProductModelID;
    DECLARE @ProductModelID2 INT = @lastProductModelID;

    SELECT
        PRODUCT.Name,
        PRODUCT.ProductID,
        PRODUCT.ProductModelID,
        PRODUCT.ProductNumber,
        MODEL.Name
    FROM Production.Product PRODUCT
    INNER JOIN Production.ProductModel MODEL
    ON MODEL.ProductModelID = PRODUCT.ProductModelID
    WHERE PRODUCT.ProductModelID BETWEEN @ProductModelID1 AND @ProductModelID2;
END
```

Note that `@firstProductModelID` and `@secondProductModelID` have been assigned to `@ProductModelID1` and `@ProductModelID2`, respectively. These new variables are then used in the final `SELECT` statement at the end of the stored procedure. Using this new version of the proc, let's test performance using the example from earlier in this chapter:

```
DBCC FREEPROCCACHE;
EXEC dbo.get_products_by_model_local 120, 125;
EXEC dbo.get_products_by_model_local 0, 10000;
```

Here, you establish a baseline for what the optimizer believes to the best plan for the product search. For the first execution, which covers a small range of product models and therefore carries with it a small result set (only six rows), the performance is different from the original version of the stored proc. The new IO statistics and execution plans for both are found in Figure 8-20, with the new on top, and the old one below:

```
Table 'Product'. Scan count 6, logical reads 24, physical reads 0, read-ahead reads 0, lob
logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductModel'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

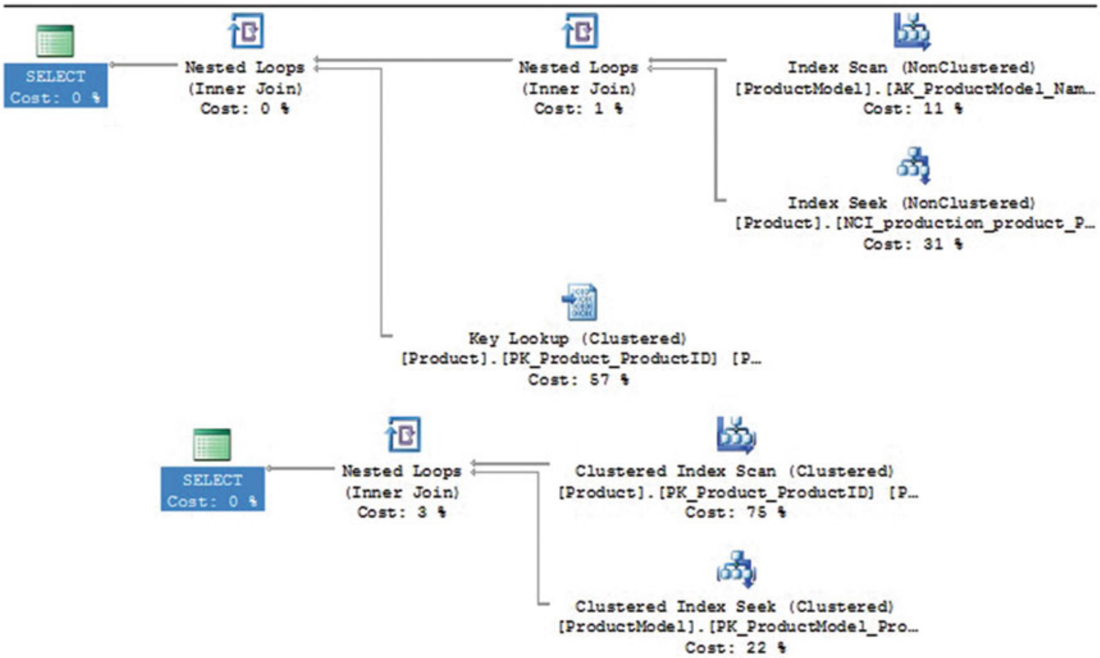


Figure 8-20. *Performance of a query with a small result set when variables are declared and the stored proc parameters are reassigned locally*

Declaring local variables and using them in the query resulted in a different execution plan, as well as different IO statistics. Now let's compare the new and old for the second scenario, where the result set is much larger. Figure 8-21 shows these performance metrics.

```
Table 'Product'. Scan count 128, logical reads 849, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductModel'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

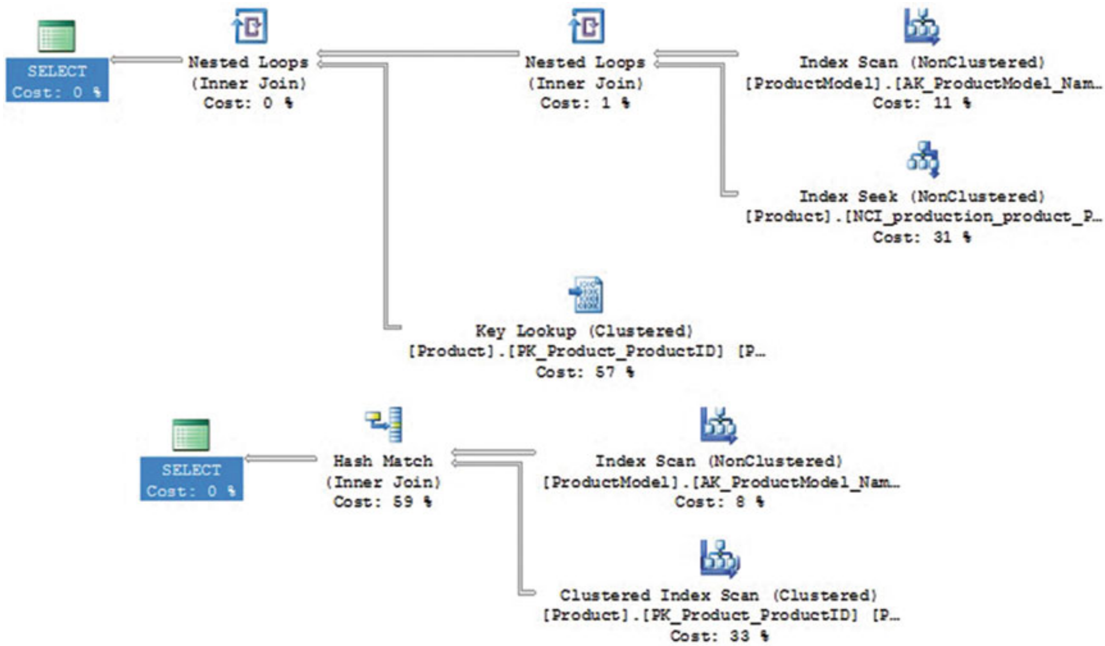


Figure 8-21. *Performance metrics for a large result set when variables are declared and the stored proc parameters are reassigned locally*

As above, a different (and more complex) execution plan was chosen for the new version of the stored procedure. This version also required far more IO in order to return the same data. In fact, the same execution plan was chosen by the query optimizer for both sets of parameters. This consistently leads to good performance when working with the small result set, but poor performance on the large result set. Parameter sniffing *appears* to no longer occur here, since the same plan is used for either set of parameter values, but if you execute your stored procedure a few times on a row, you can confirm that the plan is in fact being reused:

```
DBCC FREEPROCCACHE;
EXEC dbo.get_products_by_model_local 120, 125;
EXEC dbo.get_products_by_model_local 0, 10000;
EXEC dbo.get_products_by_model_local 120, 125;
EXEC dbo.get_products_by_model_local 0, 10000;
```

Let's review the data from the query plan cache for this stored procedure, as shown in Figure 8-22.

```
EXEC dbo.read_query_plan_cache 'get_products_by_model_local';
```

	database_name	ObjectType	ObjectName	creation_time	last_execution_time	cpu_last_execution	reads_last_execution	duration_last_execution
1	AdventureWorks	Proc	get_products_by_model_local	2015-11-17 08:24:08.727	2015-11-17 08:24:08.997	3751	853	162420

rows_last_execution	size_in_bytes	ExecutionCount	QueryText	query_plan
295	65536	4	CREATE PROCEDURE dbo.get_products_by_model_loca...	<ShowPlanXML xmlns="http://schemas.microsoft.com...

plan_handle
0x050005007BAB7C0BB0E937F904000000001000000000000...

***Figure 8-22.** Metrics returned by dbo.read_query_plan_cache for the product search where parameters are reassigned to local variables*

You can see that the only plan returned was executed four times, so there was plan reuse. Since the execution plan chosen for each set of parameters was the same, it did not matter that reuse occurred. The results would be the same, regardless of how many times you executed the stored procedure or the order of those executions. Despite redeclaring variables locally, parameter sniffing still occurred, and the resulting performance was still not optimal.

What happened here? Why was the same execution plan used for two very different sets of data? The answer lies in how the query optimizer uses statistics. The optimizer must make quick and intelligent decisions using whatever statistics are available to it when a query is executed. Any information that is unavailable until runtime will be also be unavailable to the optimizer. The three pieces of information provided by statistics as introduced earlier were:

- **Summary data**, which provides row count, average key length, and an overview of the statistics object
- **Density data**, which provides information on the uniqueness of each object bring tracked
- **Histogram data**, which gives row counts for different values over the sample range of the statistics object

For the query optimizer to make the most accurate decision possible, it requires all of this information. Unfortunately, some TSQL techniques will force parameter data to become unavailable or unusable until runtime. This results in suboptimal execution plans as the optimizer is forced to make decisions without the benefit of the histogram, density data, or both.

In the the example above, where you declared local variables and reassigned the parameters to them, you took away the optimizer's ability to use the histogram. Previously, you executed the stored procedure and the parameters were used to determine the execution plan the first time. Then the plan was reused each time thereafter. In this case, you executed the stored procedure the first time and the summary and density data were all that was available for the optimizer to create an execution plan. Since local variables have unknown values until runtime, there is no way to check the histogram for cardinality data and it is therefore omitted from the optimization process. As a result, the execution plan that was generated and reused had to be created based on assumptions. In addition, the execution plan chosen would be the same for any parameter values passed in, not just the two examples that you reviewed, since those values were unavailable until runtime.

In summary, this means that whenever you use local variables in a stored procedure, the query optimizer will need to make assumptions, and ultimately this can lead to poor cardinality estimates. Oftentimes in this situation, a DBA may find that the execution plan that is chosen happens to perform better, but this is largely due to luck and the optimizer stumbling upon a plan that works well for the use-cases that are being scrutinized.

To fully illustrate what is happening, take a closer look at the execution plans for a single execution of each version of the stored procedure, focusing on cardinality estimates versus the actual row counts from each IO step. First, the original stored procedure (running for the large result set) is shown in Figure 8-23.

```
DBCC FREEPROCCACHE;
EXEC dbo.get_products_by_model 0, 10000;
```

Index Scan (NonClustered)
Scan a nonclustered index, entirely or only a range.

Physical Operation	Index Scan
Logical Operation	Index Scan
Actual Execution Mode	Row
Estimated Execution Mode	Row
Storage	RowStore
Actual Number of Rows	128
Actual Number of Batches	0
Estimated I/O Cost	0.003125
Estimated Operator Cost	0.0034228 (8%)
Estimated Subtree Cost	0.0034228
Estimated CPU Cost	0.0002978
Estimated Number of Executions	1
Number of Executions	1
Estimated Number of Rows	128
Estimated Row Size	65 B
Actual Rebinds	0
Actual Rewinds	0
Ordered	False
Node ID	1

Clustered Index Scan (Clustered)
Scanning a clustered index, entirely or only a range.

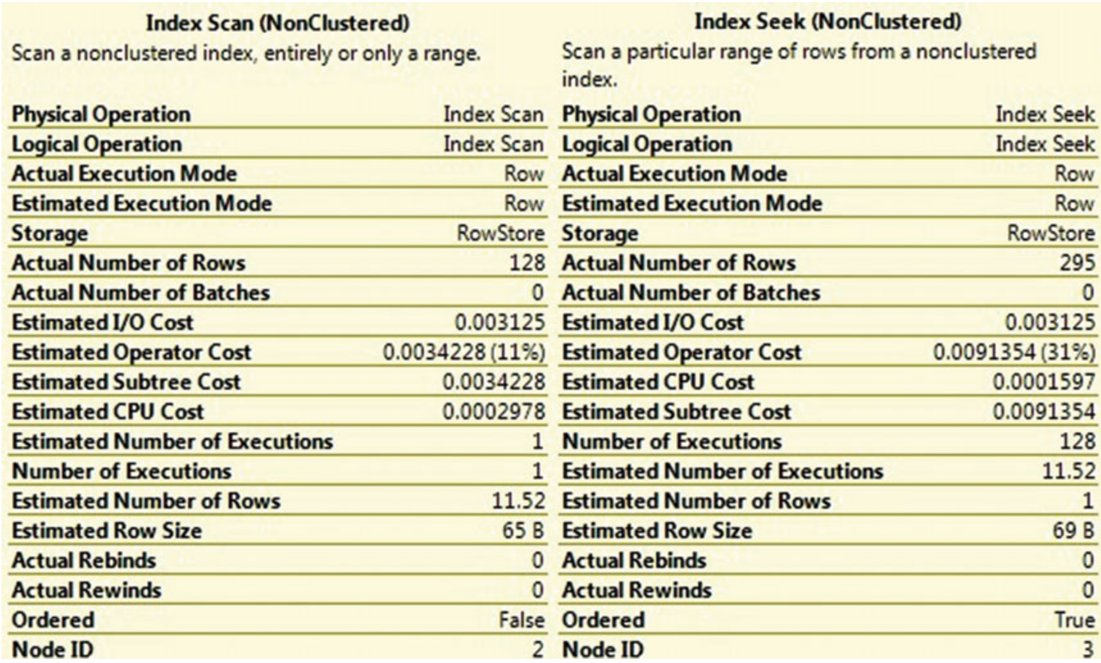
Physical Operation	Clustered Index Scan
Logical Operation	Clustered Index Scan
Actual Execution Mode	Row
Estimated Execution Mode	Row
Storage	RowStore
Actual Number of Rows	295
Actual Number of Batches	0
Estimated I/O Cost	0.0127546
Estimated Operator Cost	0.013466 (33%)
Estimated Subtree Cost	0.013466
Estimated CPU Cost	0.0007114
Estimated Number of Executions	1
Number of Executions	1
Estimated Number of Rows	295
Estimated Row Size	96 B
Actual Rebinds	0
Actual Rewinds	0
Ordered	False
Node ID	2

Figure 8-23. *Execution plan details for the parameterized stored procedure*

Note that the actual and estimated number of rows are identical for both IO operations. This indicates that the optimizer had sufficient statistics data to correctly estimate the row counts for each step and choose a suitable execution plan. Once executed, the results confirmed the optimizer's work. You can give it a pat on the back for a job well done.

Here are the execution plan details for the IO steps when you declare local variables and use them instead of the stored procedure parameters, as shown in Figure 8-24.

```
DBCC FREEPROCCACHE;
EXEC dbo.get_products_by_model_local 0, 10000;
```



Index Scan (NonClustered)
Scan a nonclustered index, entirely or only a range.

Physical Operation	Index Scan
Logical Operation	Index Scan
Actual Execution Mode	Row
Estimated Execution Mode	Row
Storage	RowStore
Actual Number of Rows	128
Actual Number of Batches	0
Estimated I/O Cost	0.003125
Estimated Operator Cost	0.0034228 (11%)
Estimated Subtree Cost	0.0034228
Estimated CPU Cost	0.0002978
Estimated Number of Executions	1
Number of Executions	1
Estimated Number of Rows	11.52
Estimated Row Size	65 B
Actual Rebinds	0
Actual Rewinds	0
Ordered	False
Node ID	2

Index Seek (NonClustered)
Scan a particular range of rows from a nonclustered index.

Physical Operation	Index Seek
Logical Operation	Index Seek
Actual Execution Mode	Row
Estimated Execution Mode	Row
Storage	RowStore
Actual Number of Rows	295
Actual Number of Batches	0
Estimated I/O Cost	0.003125
Estimated Operator Cost	0.0091354 (31%)
Estimated CPU Cost	0.0001597
Estimated Subtree Cost	0.0091354
Number of Executions	128
Estimated Number of Executions	11.52
Estimated Number of Rows	1
Estimated Row Size	69 B
Actual Rebinds	0
Actual Rewinds	0
Ordered	True
Node ID	3

Figure 8-24. *Execution plan details for the stored procedure using local variables*

In this example, while the actual number of rows was the same as previously shown, the estimates are way off! 11.52 rows were estimated for the IO operation on `ProductModel` and 1 row estimated on `Product`. This is the source of the suboptimal execution plan that you saw previously. On the `ProductModel` table, the optimizer has no information to go on as the operation is an inequality with no parameters. For the `Product` table, the optimizer can use the density data in order to try to get a good estimate, but without the histogram, will fall short.

There are many reasons why the query optimizer may make poor cardinality estimates when evaluating different parts of an execution plan. While some of those possibilities are normal and by-design, you certainly do not want to artificially limit the information available to it and cause even worse estimations to be made. Declaring local variables may appear to fix bad execution plans or eliminate parameter sniffing, but ultimately it will worsen the situation by limiting the optimizer's access to valuable information. Unless significant research has been done on the data and queries involved, localizing variables in a stored procedure will likely be a risky decision in the long run, even if it appears to solve a business need right now.

Forcing Cardinalities to the Optimizer

You have experimented with the query optimizer, recompiling plans or altering variable scope in order to try to improve query performance. An additional option is available when you have very complete knowledge of your data and want to instruct the query optimizer on cardinality directly. In a query, you can use the `OPTIMIZE FOR` hint in order to directly instruct the optimizer on what value to accept as the cardinality for a parameter.

Let's reconsider the product model search from earlier in which you declared local variables to try to manage cardinality. When you used local variables, you robbed the query optimizer of the ability to use the histogram data, thus forcing it to use less accurate estimates based on the remaining data. If you always returned a large data set and knew that as fact, you could consider telling the query optimizer to base cardinality on specific values, as shown in Listing 8-9.

Listing 8-9. Example of Using the OPTIMIZE FOR Query Hint

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_products_by_model_local')
BEGIN
    DROP PROCEDURE dbo.get_products_by_model;
END
GO
CREATE PROCEDURE dbo.get_products_by_model (@firstProductModelID INT, @lastProductModelID INT)
AS
BEGIN
    SELECT
        PRODUCT.Name,
        PRODUCT.ProductID,
        PRODUCT.ProductModelID,
        PRODUCT.ProductNumber,
        MODEL.Name
    FROM Production.Product PRODUCT
    INNER JOIN Production.ProductModel MODEL
    ON MODEL.ProductModelID = PRODUCT.ProductModelID
    WHERE PRODUCT.ProductModelID BETWEEN @firstProductModelID AND @lastProductModelID
    OPTION (OPTIMIZE FOR (@firstProductModelID = 0, @lastProductModelID = 10000));
END
```

In this example, you force the optimizer to base all analysis on the values that you provide, rather than turning to statistics to determine the best way to proceed. When you do this, the performance returns to what you saw earlier when it was using the optimal plan, as shown in Figure 8-25.

```
DBCC FREEPROCCACHE;
EXEC dbo.get_products_by_model 0, 10000;

Table 'Workfile'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'Product'. Scan count 1, logical reads 16, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductModel'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

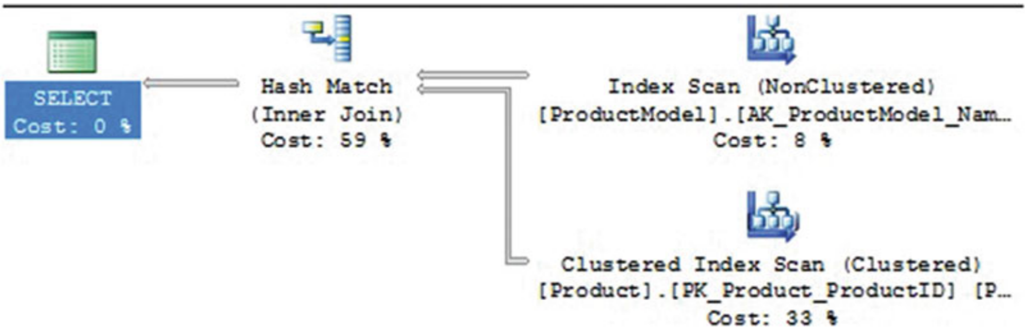


Figure 8-25. *Execution plan when you force the cardinality for each parameter in the query*

The result is the optimal execution plan and only 18 reads. When you use this hint, it will choose this plan regardless of what values are passed in. `OPTIMIZE FOR` is intended for a use-case in which you have extensive knowledge of the input parameters. This is an infrequent scenario, but one that can exist in stored procedures or code where the inputs and outputs are very predictable.

There is one additional way that you can use the `OPTIMIZE FOR` hint, and that is to take away parameter values altogether and instruct the optimizer to make its decisions using only statistics, with no insight into parameter values. Let's try this method with the same stored procedure, as shown in Listing 8-10.

Listing 8-10. Example of Using the OPTIMIZE FOR UNKNOWN Query Hint

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_products_by_model_local')
BEGIN
    DROP PROCEDURE dbo.get_products_by_model;
END
GO
CREATE PROCEDURE dbo.get_products_by_model (@firstProductModelID INT, @lastProductModelID INT)
AS
BEGIN
    SELECT
        PRODUCT.Name,
        PRODUCT.ProductID,
        PRODUCT.ProductModelID,
        PRODUCT.ProductNumber,
        MODEL.Name
    FROM Production.Product PRODUCT
    INNER JOIN Production.ProductModel MODEL
    ON MODEL.ProductModelID = PRODUCT.ProductModelID
    WHERE PRODUCT.ProductModelID BETWEEN @firstProductModelID AND @lastProductModelID
    OPTION (OPTIMIZE FOR (@firstProductModelID UNKNOWN, @lastProductModelID UNKNOWN));
END
```

In this example, instead of providing static values, you use UNKNOWN, which instructs the optimizer to not base its analysis on any particular parameter value and instead determine cardinality based solely on statistics. Let's check out the performance for this version of the stored procedure when you use this new hint, which is shown in Figure 8-26.

```
DBCC FREEPROCCACHE;
EXEC dbo.get_products_by_model 0, 10000;

Table 'Product'. Scan count 128, logical reads 849, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
Table 'ProductModel'. Scan count 1, logical reads 2, physical reads 0, read-ahead reads 0,
lob logical reads 0, lob physical reads 0, lob read-ahead reads 0.
```

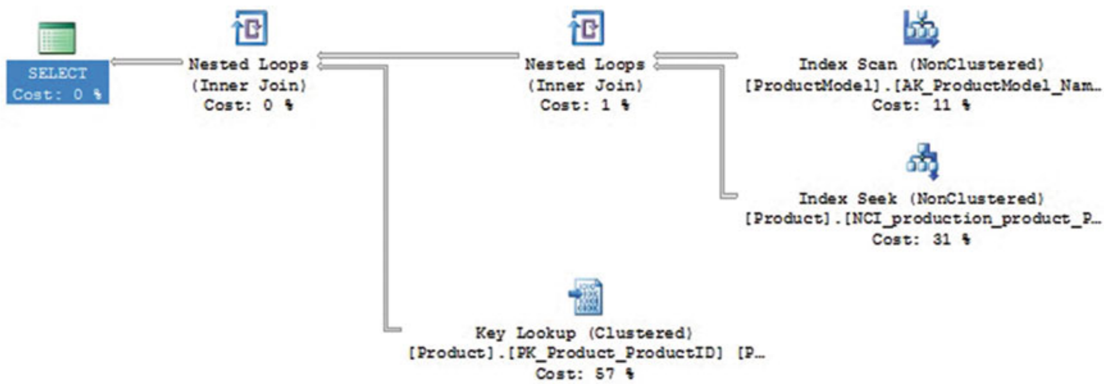


Figure 8-26. *Performance metrics when you use OPTIMIZE FOR UNKNOWN*

When you leave the optimizer to its own devices, it will resort to statistics in order to determine the best execution plan. In this case, the results are exactly what you got previously, when a poor plan was chosen. Typically, when the optimizer relies on statistics only with no parameter guidance, it will typically create an execution plan that is geared toward the most common parameter values that could be passed in. In this example, you are returning an unusually large amount of data, which the optimizer was not prepared for. The result was very similar to when you used local variables to bypass the optimizer's standard parameter analysis.

OPTIMIZE FOR, like all hints, can be very useful when applied to very specific or unusual circumstances. Use it with caution, as it may help performance for a select set of parameter values, but could also greatly harm performance if other unexpected values are passed in. Query hints should always be applied conservatively, and only when you are certain that you have full knowledge of the queries involved, the parameter values, and a good handle on cardinality.

Conclusion

Query execution plan reuse is an important feature in SQL Server that conserves memory and CPU while allowing common queries to execute quickly and efficiently. When parameter sniffing leads to poor performance, this side-effect should be diagnosed carefully to ensure that it is indeed the cause and not a symptom of another, bigger problem.

When suboptimal parameter sniffing is found, analyze the data to determine metrics that describe the parameters, data, and usage patterns. This research will greatly help in determining the best course of action (if any) that should be taken. Test potential solutions for all use-cases and ensure as much as possible that application or query changes in the future will not invalidate your changes.

Query tuning and refactoring can be a more useful tool than query hints. Consider different ways that a query can be written in order to execute more efficiently. In addition, look for simplifying assumptions that may allow for a query to be reduced or rewritten into something simpler and easier for the optimizer to digest. Sometimes that effort will completely remove parameter sniffing as a problem, thus eliminating the need for further research or the need to resort to query hints or hacks in order to achieve success.

Cleanup

The TSQL in Listing 8-11 will clean up any objects created in this chapter, if they exist, except for the stored procedure `read_query_plan_cache`, which may come in handy later.

Listing 8-11. Script that Cleans Up Any Objects Created in this Chapter

```
IF EXISTS (SELECT * FROM sys.indexes WHERE indexes.name =
'NCI_production_product_ProductModelID')
BEGIN
    DROP INDEX NCI_production_product_ProductModelID ON Production.Product;
END
GO
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_products_by_model_local')
BEGIN
    DROP PROCEDURE dbo.get_products_by_model;
END
GO
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'get_sales_orders_by_sales_person')
BEGIN
    DROP PROCEDURE dbo.get_sales_orders_by_sales_person;
END
GO
```

CHAPTER 9

Dynamic PIVOT and UNPIVOT

PIVOT is an extremely efficient way to alter the structure of a result set, expanding a single column of values into a set of separate columns. UNPIVOT does the exact opposite, taking a set of columns and resolving them into a single output column. Both of these operators can be very useful in reporting, analytics, or when trying to format existing data into a specific structure as required by an application.

A significant limitation of both operators is that the column or name list for each must be defined prior to runtime in your TSQL. This can be acceptable if the name list is static or predictable enough that you will not need to modify your code frequently in order for it to work. If this list changes, though, you are forced to create many different stored procedures or functions in order to handle the many list values, or force limitations into your code to prevent having to do this.

There is a fun alternative to either of these issues, and that is to use Dynamic SQL in order to generate name lists on-the-fly. Once you introduce the dynamic aspect to this operator, you can write TSQL that incorporates all values in a column, a variable list, or those provided by user input. Without Dynamic SQL, it is very difficult and inefficient to accomplish tasks such as this without writing significantly longer or more complex TSQL to reach a similar result set.

PIVOT

PIVOT is common in analytics when you are looking to resolve transactional data into a columnar structure for use in reporting or metrics. The easiest way to introduce the challenge presented above is with an example. Consider the TSQL in Listing 9-1, which returns some quantity of data, as well as a color for products that are in inventory.

Listing 9-1. Query to Return Select Product Data from AdventureWorks

```
SELECT
       PRODUCT.Name AS product_name,
       PRODUCT.Color AS product_color,
       PRODUCT_INVENTORY.LocationID,
       PRODUCT.ReorderPoint,
       PRODUCT_INVENTORY.Quantity AS product_quantity
FROM Production.Product PRODUCT
LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID;
```


E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_9

	product_name	product_color	LocationID	ReorderPoint	product_quantity
745	Road-250 Red, 44	Red	60	75	51
746	Road-250 Red, 48	Red	7	75	99
747	Road-250 Red, 48	Red	60	75	86
748	Road-250 Red, 52	Red	7	75	67
749	Road-250 Red, 52	Red	60	75	81
750	Road-250 Red, 58	Red	7	75	104
751	Road-250 Red, 58	Red	60	75	123
752	Road-250 Black, 44	Black	7	75	56
753	Road-250 Black, 44	Black	60	75	78
754	Road-250 Black, 48	Black	7	75	116
755	Road-250 Black, 48	Black	60	75	49
756	Road-250 Black, 52	Black	7	75	100
757	Road-250 Black, 52	Black	60	75	88
758	Road-250 Black, 58	Black	7	75	65
759	Road-250 Black, 58	Black	60	75	83
760	Road-550-W Yellow...	Yellow	7	75	67
761	Road-550-W Yellow...	Yellow	60	75	81
762	Road-550-W Yellow...	Yellow	7	75	73
763	Road-550-W Yellow	Yellow	60	75	60

Figure 9-1. *The query in Listing 9-1 is simple enough and will return these results*

Note that a single product may have quantities in multiple locations. What if management was looking to correlate popularity and inventory with the color of a variety of products across all of those locations? They request a report where, instead of a row per product that includes color, there is a row per product name, and additional columns for each specified color. This would allow easy analysis to take place per product per color. PIVOT is the simplest way to accomplish the task, as shown in Listing 9-2.

Listing 9-2. Common Use of PIVOT to Report on Products by Color

```
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
```

```
PIVOT
(     SUM(product_quantity)
      FOR product_color IN ([Black], [Blue], [Grey], [Multi], [Red], [Silver],
      [Silver/Black], [White], [Yellow])
) PIVOT_DATA;
```

In this example, you move the previous query into a FROM clause that will be used for pivoting. The correct syntax for PIVOT requires two new components:

- An aggregate function, which will aggregate if multiple values exist. In the initial SELECT statement that returns product data, there were many duplicate rows. This example uses SUM whenever this occurs, which will add up product quantities if there are multiple rows with the same product name.
- A value list for all values that will be changed from row data into column headers. In this case, the list is of colors from Product.Color.

The output of this statement in Figure 9-2 illustrates the creation of the new columns.

	product_name	ReorderPoint	Black	Blue	Grey	Multi	Red	Silver	Silver/Black	White	Yellow
89	Mountain-500 Silver, 44	75	NULL	NULL	NULL	NULL	NULL	153	NULL	NULL	NULL
90	Mountain-500 Silver, 48	75	NULL	NULL	NULL	NULL	NULL	155	NULL	NULL	NULL
91	Mountain-500 Silver, 52	75	NULL	NULL	NULL	NULL	NULL	194	NULL	NULL	NULL
92	Road-150 Red, 44	75	NULL	NULL	NULL	NULL	223	NULL	NULL	NULL	NULL
93	Road-150 Red, 48	75	NULL	NULL	NULL	NULL	140	NULL	NULL	NULL	NULL
94	Road-150 Red, 52	75	NULL	NULL	NULL	NULL	128	NULL	NULL	NULL	NULL
95	Road-150 Red, 56	75	NULL	NULL	NULL	NULL	163	NULL	NULL	NULL	NULL
96	Road-150 Red, 62	75	NULL	NULL	NULL	NULL	133	NULL	NULL	NULL	NULL
97	Road-250 Black, 44	75	134	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
98	Road-250 Black, 48	75	165	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
99	Road-250 Black, 52	75	188	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
100	Road-250 Black, 58	75	148	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
101	Road-250 Red, 44	75	NULL	NULL	NULL	NULL	163	NULL	NULL	NULL	NULL

Figure 9-2. *Output of the PIVOT query in Listing 9-2*

The results show nine new columns, which are the same ones defined in the original query. In a scenario where multiple rows from the original query shared the same product name, the quantities were added. For example, for the product Road-250 Black, 48, there were two rows returned by the original query, with quantities of 116 and 49 for the color black. In the output generated by the PIVOT output, you can see that the two rows were combined into one with a quantity of 165 for the same color. If multiple products existed with the same name, but in different colors, then multiple columns would be populated with quantity data for a single product after the PIVOT was applied.

There is a single weakness in this approach, and that is that the column list must be explicitly provided in the PIVOT statement prior to runtime. Any attempt to rewrite the PIVOT to use a dynamic list without Dynamic SQL will fail, as shown in Listings 9-3 and 9-4.

Listing 9-3. Attempt to Use a Sub-SELECT Within a PIVOT Statement (Unsuccessfully)

```
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN (SELECT Color FROM Production.Product)
) PIVOT_DATA;
```

Listing 9-4. Attempt to Use a Table Variable Within a PIVOT Statement (also Unsuccessfully)

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
VALUES ('Black'), ('Blue'), ('Grey'), ('Multi'), ('Red'), ('Silver'), ('Silver/Black'),
('White'), ('Yellow');

SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN (SELECT color_name FROM @colors)
) PIVOT_DATA;
```

Both examples are logical attempts to incorporate more customizable inputs into the query. The first example tries to feed in all colors from `Production.Product`. If this worked, you could always use `PIVOT` for all values in a column, without the need to hard-code them ahead of time. The second attempt uses a table variable to store a set of colors prior to executing the `PIVOT` statement. If this worked, you could then customize a color list prior to runtime using input from an application or person.

Unfortunately, neither syntax works and they generate similar error messages:

```
Msg 156, Level 15, State 1, Line 50
Incorrect syntax near the keyword 'SELECT'.
Msg 102, Level 15, State 1, Line 50
Incorrect syntax near ')'.
```

This message isn't terribly helpful, but does imply that the syntax is incorrect. This slick attempt at solving a problem didn't work, but there is another way to get past this limitation in the syntax of PIVOT: Dynamic SQL! The column name list must be present in the TSQL prior to runtime, and that can be accomplished by building a command string with the column list details added in when the string is built. This will allow you to have a dynamic column list available from any source you choose. Listing 9-5 shows a new version of the PIVOT that uses a table variable to store a list of colors and feeds it into Dynamic SQL in order to output to a column list that you specify at runtime.

Listing 9-5. Use of Dynamic SQL and a Table Variable to Create a Variable Column List at Runtime

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
VALUES ('Black'), ('Grey'), ('Silver/Black'), ('White');

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN (';

SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) PIVOT_DATA
';

EXEC sp_executesql @sql_command;
```

The PIVOT TSQL is exactly the same as it was before, but it includes several dynamic SQL methods from earlier in this book in order to accomplish its goal. First, it generates a dynamic list of colors and adds it to the command string:

```
SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);
```

For any number of colors in the table variable, this will append them to the command string, contained in brackets and delimited by commas. The additional SELECT statement removes the trailing comma that remains from the list generation.

Once the list of colors has been appended, you can complete the command string and execute it in order to get the result set, as shown in Figure 9-3.

	product_name	ReorderPoint	Black	Grey	Silver/Black	White
1	All-Purpose Bike Stand	3	NULL	NULL	NULL	NULL
2	AWC Logo Cap	3	NULL	NULL	NULL	NULL
3	Bike Wash - Dissolver	3	NULL	NULL	NULL	NULL
4	Cable Lock	3	NULL	NULL	NULL	NULL
5	Classic Vest, L	3	NULL	NULL	NULL	NULL
6	Classic Vest, M	3	NULL	NULL	NULL	NULL
7	Classic Vest, S	3	NULL	NULL	NULL	NULL
8	Fender Set - Mountain	3	NULL	NULL	NULL	NULL
9	Full-Finger Gloves, L	3	144	NULL	NULL	NULL
10	Full-Finger Gloves, M	3	108	NULL	NULL	NULL

Figure 9-3. *Results of the dynamic PIVOT in Listing 9-5*

Note that columns only exist for the colors that you included in the table variable. Any products for which the color is not given in a column header will have NULLs for all new columns added by the PIVOT operation.

With this framework in place, you can tackle scenarios that were previously impossible. First, let's rewrite this query so that it includes all colors, regardless of which are added or removed in the underlying data over time. In order to accomplish this, all you need to do is replace the INSERT into the table variable to use a query of Production.Product, rather than a static list of values, as shown in Listing 9-6.

Listing 9-6. Dynamic PIVOT that Uses All Color Values in Production.Product

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
SELECT DISTINCT
       Product.Color
FROM Production.Product
WHERE Product.Color IS NOT NULL;
```

```
DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN (';

SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) PIVOT_DATA
';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The text of the command string prior to execution shows that it looks identical to the original hard-coded PIVOT query:

```
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN ([Black], [Blue], [Grey], [Multi], [Red], [Silver], [Silver/
       Black], [White], [Yellow])) PIVOT_DATA
```

The ultimate test is to add a few colors to `Production.Product` and see what happens to the command string and output when you run the dynamic `PIVOT` again:

```
UPDATE Production.Product
SET Product.Color = 'Fuschia'
WHERE Product.ProductID = 325 -- Decal 1
UPDATE Production.Product
SET Product.Color = 'Aquamarine'
WHERE Product.ProductID = 326 -- Decal 2
```

This updates two products to use new colors that were not present in `AdventureWorks` originally: Fuschia and Aquamarine. With these colors added, let's run the dynamic `PIVOT` and review the new command string:

```
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN ([Aquamarine], [Black], [Blue], [Fuschia], [Grey], [Multi],
       [Red], [Silver], [Silver/Black], [White], [Yellow]   )) PIVOT_DATA
```

Note that the new colors are now present in the `PIVOT`. Reviewing the output in Figure 9-4, you can confirm that the columns are in the result set and are correctly populated based on the changes you made.

	product_name	ReorderPoint	Aquamarine	Black	Blue	Fuschia	Grey	Multi	Red	Silver	Silver/Black	White	Yellow
349	Adjustable Race	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
350	Bearing Ball	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
351	Chain Stays	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
352	Chainring	750	NULL	1684	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
353	Chainring Bolts	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	1136	NULL	NULL	NULL
354	Chainring Nut	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	1750	NULL	NULL	NULL
355	Cone-Shaped Race	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
356	Crown Race	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
357	Cup-Shaped Race	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
358	Decal 1	750	NULL	NULL	NULL	1750	NULL	NULL	NULL	NULL	NULL	NULL	NULL
359	Decal 2	750	1684	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
360	External Lock Washer 1	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

***Figure 9-4.** Dynamic PIVOT with the inclusion of two new colors*

With this syntax, you can make any PIVOT dynamic and supply a list of values from user input, a TSQL query, or anywhere that data can be queried from in SQL Server. This reduces the need to hard-code specific column headings into stored procedure, thereby reducing maintenance costs over time. The last thing you want to worry about is adjusting TSQL or application code whenever a new color bike is added to the product inventory!

The following TSQL will clean up the changes and remove the new colors, returning them to their orignal NULL:

```
UPDATE Production.Product
SET Product.Color = NULL
WHERE Product.ProductID = 325 -- Decal 1
UPDATE Production.Product
SET Product.Color = NULL
WHERE Product.ProductID = 326 -- Decal 2
```

UNPIVOT

PIVOT has its counterpart called UNPIVOT, which takes a query with a column list and reconstructs it into row data. In order to demonstrate this using familiar data, you will output the results of the previous example into a table for use in this section using the TSQL in Listing 9-7.

Listing 9-7. Query to Store Data for Use in a Dynamic UNPIVOT Demonstration

```
SELECT @sql_command = '
SELECT
       *
INTO dbo.Products_By_Color
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity
       FROM Production.Product PRODUCT
  LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
  ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN (';
```

By adding an INTO to the SELECT, the output reviewed above will be stored in the table dbo.Products_By_Color, which will be used in the UNPIVOT testing.

The syntax for UNPIVOT is similar to PIVOT and involves the use of a similar column list, with the exception that the data will be reverted to rows, removing all additional columns listed. This can be seen in Listing 9-8.

Listing 9-8. Using UNPIVOT to Revert Column Headers into Row Data

```
SELECT
       *
FROM
  (SELECT
          *
    FROM dbo.Products_By_Color) AS PRODUCTS_BY_COLOR
UNPIVOT
    (product_quantity FOR Color IN
       ([Black], [Blue], [Grey], [Multi], [Red], [Silver], [Silver/Black], [White], [Yellow])
    ) AS UNPIVOT_DATA;
```

Figure 9-5 shows a subset of the output from this statement.

	product_name	ReorderPoint	product_quantity	Color
1	AWC Logo Cap	3	288	Multi
2	Classic Vest, L	3	252	Blue
3	Classic Vest, M	3	216	Blue
4	Classic Vest, S	3	180	Blue
5	Full-Finger Gloves, L	3	144	Black
6	Full-Finger Gloves, M	3	108	Black
7	Full-Finger Gloves, S	3	72	Black
8	Half-Finger Gloves, L	3	36	Black
9	Half-Finger Gloves, M	3	0	Black
10	Half-Finger Gloves, S	3	324	Black
11	Hydration Pack - 70 oz.	3	108	Silver
12	Long-Sleeve Logo Jersey, L	3	216	Multi
13	Long-Sleeve Logo Jersey, M	3	180	Multi
14	Long-Sleeve Logo Jersey, S	3	144	Multi
15	Long-Sleeve Logo Jersey, XL	3	252	Multi
16	Men's Bib-Shorts, L	3	144	Multi
17	Men's Bib-Shorts, M	3	108	Multi
18	Men's Bib-Shorts, S	3	72	Multi

Figure 9-5. *Output from the UNPIVOT statement in Listing 9-8*

All of the new columns introduced in the last section have been removed and their corresponding names inserted into the new Color column. The syntax for `UNPIVOT` involves three additional bits of syntax that are worth describing in detail:

- A new column for the unpivoted quantity data. In this case, we called the new column `product_quantity`, though any name could be used. When using `UNPIVOT`, there is no need to provide an aggregation, as any duplicate values will become distinct rows in the result.
- The new column that will contain the column names must be provided. In this example, we name it "`Color`".
- A column list must be provided, similar to when you wrote a PIVOT statement. Each column in this list will be included in rows of the result set. Any omitted column names will not be represented in the result set.

The results from this query are not the same as the original data. It is important to emphasize that `UNPIVOT` is not simply the opposite of `PIVOT` and that applying one after the other will rarely result in identical sets of data. In the previous example, there are two important differences between this data and what you began with at the start of the chapter.

First, `NULL`s have been eliminated. Any product with no color defined was dropped out of the result set. The results show all product-color combinations for which a color in the list was present and had a quantity defined. The second difference involves the quantities themselves. When you apply `PIVOT` to a set of data, you supply an aggregate in order to process multiple rows with the same value. Once quantities have been summed, there is no way to "un-sum" them. The results of the `UNPIVOT` contain product quantity totals that represent multiple products from the original data in `production.Product`. Now that you understand the important differences between `PIVOT` and `UNPIVOT`, and get the ways in which data is handled by each, you can work on making `UNPIVOT` more flexible.

As before, you want to be able to apply `UNPIVOT` from a dynamic list of column names, and not be forced to supply values ahead of time in your code. This allows you to make data or schema changes at will without having to make changes here each and every time. The first challenge is to generate a list of colors given a group of columns in a table, rather than row data. To get all of the columns, there are a few options available. The first is to go back to `Production.Product` and use the colors from that table to fuel this query, as shown in Listing 9-9.

Listing 9-9. A Dynamic UNPIVOT Using Original Row Data to Supply Color Names

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
SELECT DISTINCT
       Product.Color
FROM Production.Product
WHERE Product.Color IS NOT NULL;

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
       *
```

```
FROM
     (SELECT
             *
     FROM dbo.Products_By_Color) AS PRODUCTS_BY_COLOR
UNPIVOT
     (product_quantity FOR Color IN
     (';

SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) AS UNPIVOT_DATA;
';

EXEC sp_executesql @sql_command;
```

This approach works and will provide the same output as earlier, but has a distinct limitation in that the color list from earlier may not apply here. If it doesn't, then you need to collect column name data from the table schema itself and use that to power the UNPIVOT. This can be accomplished by querying the sys.tables and sys.columns system views, which provide information about the structure and names of the tables and columns. There are other system objects available that can provide similar data, such as INFORMATION_SCHEMA.COLUMNS, but for the example here, we'll stick to the two aforementioned views, which reference data in sys.objects. This can be seen in Listing 9-10.

Listing 9-10. A Dynamic UNPIVOT Using Schema Metadata to Supply Color Names

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
SELECT
       columns.name
FROM sys.tables
INNER JOIN sys.columns
ON columns.object_id = tables.object_id
WHERE tables.name = 'Products_By_Color'
AND columns.name NOT IN ('product_name', 'ReorderPoint');

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
       *
FROM
   (SELECT
           *
       FROM dbo.Products_By_Color) AS PRODUCTS_BY_COLOR
UNPIVOT
   (product_quantity FOR Color IN
      (';
```

```
SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) AS UNPIVOT_DATA;
';

EXEC sp_executesql @sql_command;
```

Everything in this example is the same as the previous one, except for the collection of color data, which uses the column names for the table `dbo.Products_By_Color` as provided by `sys.columns`. Note that you need to provide an exceptions list here that includes any columns that you do not wish to `UNPIVOT`. In this example, there are two additional columns that are not colors and that you do not wish to convert into row data: `product_name` and `ReorderPoint`. If you forget these exceptions, you might get unexpected output or an error message such as this:

```
Msg 8167, Level 16, State 1, Line 329
The type of column "ReorderPoint" conflicts with the type of other columns specified
in the UNPIVOT list.
```

In this case, we included columns of different data types in the `UNPIVOT`. While the quantities listed under the color columns are all of type `INT`, `ReorderPoint` is a `SMALLINT` and `product_name` is `NVARCHAR(50)`. The exceptions can be hard-coded as you have done above, or passed in as variables into wherever the TSQL for the `UNPIVOT` runs from.

Additional Examples

The functionality demonstrated so far was perfect for teaching the basics of `PIVOT` and `UNPIVOT`, as well as integrating dynamic SQL into their usage. A very common real-world use of these operators is to produce accounting data that is distributed by month, quarter, or year in column headers. For example, what if you wanted to return sales data with column headings per quarter? You can integrate `PIVOT` into a common table expression, which allows you to set up financial data that you can then transform into columnar data for reporting or further analysis. This example can be seen in Listing 9-11.

Listing 9-11. Using PIVOT to Group Sales Data by Quarter

```
WITH CTE_SALES AS (
	SELECT
		DATEPART(QUARTER, OrderDate) AS order_quarter,
		DATEPART(YEAR, OrderDate) AS order_year,
		TotalDue
	FROM Sales.SalesOrderHeader)
SELECT
	*
FROM
(	SELECT
		*
	FROM CTE_SALES
) PRODUCT_DATA
```

```
PIVOT
(       SUM(TotalDue)
        FOR order_quarter IN ([1], [2], [3], [4])
) PIVOT_DATA
ORDER BY order_year ASC;
```

The result of the query in Listing 9-11 can be seen in the small result set in Figure 9-6.

	order_year	1	2	3	4
1	2011	NULL	1074117.4188	5647550.6633	7434031.4429
2	2012	9443736.8161	9935495.1729	10164406.8281	8132061.4949
3	2013	8771886.3577	12225061.383	14339319.1851	13629621.0374
4	2014	14373277.4766	8046220.8391	NULL	NULL

Figure 9-6. *Using PIVOT to obtain sales by quarter*

Each quarter is given its own column, with sales totals aggregated in each row below. Instances of NULL represent scenarios where there was no data for those specific time periods. You could also write the PIVOT to return all quarters, including year, as a column header, as shown in Listing 9-12.

Listing 9-12. Using PIVOT to Group Sales Data by Quarter and Year in a Single Result Row

```
WITH CTE_SALES AS (
        SELECT
                'Totals' AS Totals,
                'Q' + CAST(DATEPART(QUARTER, OrderDate) AS VARCHAR(1)) + '-' +
                        CAST(DATEPART(YEAR, OrderDate) AS VARCHAR(4)) AS quarter_and_year,
                TotalDue
        FROM Sales.SalesOrderHeader)
SELECT
        *
FROM
(       SELECT
                *
        FROM CTE_SALES
) PRODUCT_DATA
PIVOT
(       SUM(TotalDue)
        FOR quarter_and_year IN ([Q2-2011], [Q3-2011], [Q4-2011], [Q1-2012],[Q2-2012], [Q3-
        2012], [Q4-2012],
                                [Q1-2013],[Q2-2013], [Q3-2013], [Q4-2013], [Q1-2014], [Q2-
2014])
) PIVOT_DATA
```

By combining quarter and year into a single string, you can condense the data into a single row with one column per quarter, including the year. The column Totals is included so that you have some sort of row header, but it is not necessary in order to successfully retrieve the result set.

This syntax introduces the same problem you had earlier, in that you were forced to hard-code a list of quarters into the TSQL. If new data is added, then the query will no longer be valid. Dynamic SQL can rescue you again, by allowing you to declare a list of quarters ahead of time and then integrate it into a command string that will use PIVOT to crunch the source data appropriately, regardless of the dates. This is shown in Listing 9-13.

Listing 9-13. Dynamic PIVOT Used to Return Any Number of Quarters of Financial Data

```
DECLARE @quarters TABLE
       (quarter_and_year NVARCHAR(7));

INSERT INTO @quarters
       (quarter_and_year)
SELECT DISTINCT
       'Q' + CAST(DATEPART(QUARTER, OrderDate) AS VARCHAR(1)) + '-' +
                CAST(DATEPART(YEAR, OrderDate) AS VARCHAR(4))
FROM Sales.SalesOrderHeader

DECLARE @sql_command NVARCHAR(MAX);

SELECT @sql_command = '
WITH CTE_SALES AS (
       SELECT
              ''Totals'' AS Totals,
              ''Q'' + CAST(DATEPART(QUARTER, OrderDate) AS VARCHAR(1)) + ''-'' +
                        CAST(DATEPART(YEAR, OrderDate) AS VARCHAR(4)) AS quarter_and_year,
              TotalDue
       FROM Sales.SalesOrderHeader)
SELECT
       *
FROM
(      SELECT
              *
       FROM CTE_SALES
) PRODUCT_DATA
PIVOT
(      SUM(TotalDue)
       FOR quarter_and_year IN ('

SELECT @sql_command = @sql_command + '[' + quarter_and_year + '], '
FROM @quarters;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) PIVOT_DATA
';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

Multiple PIVOT Operators

This next example illustrates a more advanced use of PIVOT. Whereas previously you used PIVOT to operate on only a single column—product color or sales quarter—it is possible to apply this operator to multiple columns of distinct values. Let's say that you wanted to crunch your product data by color and also by safety stock level? This can be done using a single query, as shown in Listing 9-14.

Listing 9-14. Using Multiple PIVOT Operators in a Single TSQL Statement

```
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity,
              PRODUCT.SafetyStockLevel
       FROM Production.Product PRODUCT
    LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
    ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN ([Black], [Blue], [Grey], [Multi], [Red], [Silver],
       [Silver/Black], [White], [Yellow])
) PIVOT_DATA_COLOR
PIVOT
(      COUNT(SafetyStockLevel)
       FOR SafetyStockLevel IN ([4], [60], [100], [500], [800], [1000])
) PIVOT_DATA_LEVEL
```

The query in Listing 9-14 will return the results shown in Figure 9-7.

	product_name	ReorderPoint	Black	Blue	Grey	Multi	Red	Silver	Silver/Black	White	Yellow	4	60	100	500	800	1000
1	Adjustable Race	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0	0	0	0	1
2	All-Purpose Bike Stand	3	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	1	0	0	0	0	0
3	AWC Logo Cap	3	NULL	NULL	NULL	288	NULL	NULL	NULL	NULL	NULL	1	0	0	0	0	0
4	BB Ball Bearing	600	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0	0	0	1	0
5	Bearing Ball	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0	0	0	0	1
6	Bike Wash - Dissolver	3	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	1	0	0	0	0	0
7	Blade	600	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0	0	0	1	0
8	Cable Lock	3	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	1	0	0	0	0	0
9	Chain	375	NULL	NULL	NULL	NULL	NULL	589	NULL	NULL	NULL	0	0	0	1	0	0
10	Chain Stays	750	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0	0	0	0	1

Figure 9-7. *Results of a query that uses two PIVOT operators for data aggregation*

A new set of columns has been added to the result set, indicating the number of times a particular SafetyStockLevel value matches the ones provided in the list. This can be a very handy trick if you want to report on multiple metrics side-by-side in a single query, rather than having to join multiple result sets.

You can implement Dynamic SQL just as you did before in order to ensure that all list values for both metrics are correctly accounted for. When you do this, you will need to include a separate table variable for SafetyStockLevel values, in addition to those for Color, as shown in Listing 9-15.

Listing 9-15. Using Multiple PIVOT Operators with Dynamic SQL

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
SELECT DISTINCT
       Product.Color
FROM Production.Product
WHERE Product.Color IS NOT NULL;

DECLARE @stock_levels TABLE
       (safety_stock_level SMALLINT);

INSERT INTO @stock_levels
SELECT DISTINCT
       Product.SafetyStockLevel
FROM Production.Product;

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity,
              PRODUCT.SafetyStockLevel
       FROM Production.Product PRODUCT
    LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
    ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN (';

SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;
```

```
SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) PIVOT_DATA_COLOR
PIVOT
(      COUNT(SafetyStockLevel)
       FOR SafetyStockLevel IN (';

SELECT @sql_command = @sql_command + '[' + CAST(safety_stock_level AS NVARCHAR) + '], '
FROM @stock_levels;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) PIVOT_DATA_LEVEL
';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The result set is exactly the same as it was previously. You can verify that you didn't make any mistakes by reviewing the text of the command string:

```
SELECT
       *
FROM
(      SELECT
              PRODUCT.Name AS product_name,
              PRODUCT.Color AS product_color,
              PRODUCT.ReorderPoint,
              PRODUCT_INVENTORY.Quantity AS product_quantity,
              PRODUCT.SafetyStockLevel
       FROM Production.Product PRODUCT
    LEFT JOIN Production.ProductInventory PRODUCT_INVENTORY
    ON PRODUCT.ProductID = PRODUCT_INVENTORY.ProductID
) PRODUCT_DATA
PIVOT
(      SUM(product_quantity)
       FOR product_color IN ([Black], [Blue], [Grey], [Multi], [Red], [Silver], [Silver/
       Black], [White], [Yellow])) PIVOT_DATA_COLOR
PIVOT
(    COUNT(SafetyStockLevel)
     FOR SafetyStockLevel IN ([4], [60], [100], [500], [800], [1000] )) PIVOT_DATA_LEVEL
```

Combining multiple PIVOT operators with Dynamic SQL provides lots of flexibility when generating columnar data given the contents of multiple columns. By producing a result set in a single query, you ensure relational integrity and guarantee that you didn't make any mistakes when outputting data to intermediate locations. The syntax is exactly the same as it was for a single PIVOT and does not become much more complex as you add instances of it.

Multiple UNPIVOT Operators

For the final example of this chapter, you'll build on your work so far in order to UNPIVOT the result set. This will be accomplished using multiple UNPIVOT operators. Keep in mind that the result set for this operation will not be the same as the original input data from the start of the last example. While the results of the UNPIVOT will be meaningful, it is important to remember that applying PIVOT and UNPIVOT to a data set is unlikely to return equivalent results to that data. Granularity is often lost and cannot be reconstituted, regardless of how fancy you get with your TSQL skills!

The first step is to take the data from the last example and store it in a table in order to reuse it in the UNPIVOT:

```
SELECT @sql_command = '
SELECT
       *
INTO dbo.Products_By_Color_and_Stock_Level
FROM
(      SELECT
```

The table Products_By_Color_and_Stock_Level is created to store the pivoted output that you will work with for the duration of this chapter. The first attempt at an UNPIVOT is shown in Listing 9-16.

Listing 9-16. First Attempt at Using Two UNPIVOT Operators in a Single Statement

```
SELECT
       *
FROM
   (SELECT
          *
       FROM dbo.Products_By_Color_and_Stock_Level) AS PRODUCTS_BY_COLOR_AND_STOCK_LEVEL
UNPIVOT
   (product_quantity FOR Color IN
        ([Black], [Blue], [Grey], [Multi], [Red], [Silver], [Silver/Black], [White],
        [Yellow])
) AS UNPIVOT_DATA_COLOR
UNPIVOT
   (safety_stock_level FOR SafetyStockLevel IN
       ([4], [60], [100], [500], [800], [1000])
) AS UNPIVOT_DATA_STOCK_LEVEL;
```

The query in Listing 9-16 returns results, but they are a bit suspect, as shown in the result set in Figure 9-8.

	product_name	ReorderPoint	product_quantity	Color	safety_stock_level	SafetyStockLevel
1	AWC Logo Cap	3	288	Multi	1	4
2	AWC Logo Cap	3	288	Multi	0	60
3	AWC Logo Cap	3	288	Multi	0	100
4	AWC Logo Cap	3	288	Multi	0	500
5	AWC Logo Cap	3	288	Multi	0	800
6	AWC Logo Cap	3	288	Multi	0	1000
7	Chain	375	589	Silver	0	4
8	Chain	375	589	Silver	0	60
9	Chain	375	589	Silver	0	100
10	Chain	375	589	Silver	1	500
11	Chain	375	589	Silver	0	800
12	Chain	375	589	Silver	0	1000
13	Chainring	750	1684	Black	0	4

Figure 9-8. *Results from an improperly constructed query with two UNPIVOT opetators*

Note that you receive six rows back for each product. Since the safety stock levels were defined as non-NULL counts, the UNPIVOT operation sees all as valid values and returns rows for each. Ideally, you want the column names pivoted into row values for both colors and stock levels, but with the assumption that zero values are omitted for all stock levels. There are a variety of ways to fix this, and you will do so using an additional WHERE clause to remove the zeroes altogether, as shown in Listing 9-17.

Listing 9-17. UNPIVOT Example with Zero Values Removed

```
SELECT
       product_name,
       ReorderPoint,
       product_quantity,
       Color,
       SafetyStockLevel
FROM
   (SELECT
           *
       FROM dbo.Products_By_Color_and_Stock_Level) AS PRODUCTS_BY_COLOR_AND_STOCK_LEVEL
UNPIVOT
   (product_quantity FOR Color IN
       ([Black], [Blue], [Grey], [Multi], [Red], [Silver], [Silver/Black], [White],
       [Yellow])
) AS UNPIVOT_DATA_COLOR
UNPIVOT
   (safety_stock_level FOR SafetyStockLevel IN
       ([4], [60], [100], [500], [800], [1000])
) AS UNPIVOT_DATA_STOCK_LEVEL
WHERE safety_stock_level <> 0;
```

By filtering on `safety_stock_level <> 0`, you remove the zeroes. In addition, you explicitly choose the columns for the output set such that `safety_stock_level` is not included, as its contents are no longer important to the result set (they will only contain ones). The results now look cleaner and more like what you expected the first time, as shown in Figure 9-9.

	product_name	ReorderPoint	product_quantity	Color	SafetyStockLevel
1	AWC Logo Cap	3	288	Multi	4
2	Chain	375	589	Silver	500
3	Chainring	750	1684	Black	1000
4	Chainring Bolts	750	1136	Silver	1000
5	Chainring Nut	750	1750	Silver	1000
6	Classic Vest, L	3	252	Blue	4
7	Classic Vest, M	3	216	Blue	4
8	Classic Vest, S	3	180	Blue	4
9	Freewheel	375	844	Silver	500
10	Front Brakes	375	767	Silver	500
11	Front Derailleur	375	853	Silver	500

Figure 9-9. *Results from the corrected UNPIVOT query in Listing 9-17*

Each column is now populated with meaningful values, with zero values and the extra placeholder `safety_stock_level` column removed.

Now that you have a working query with multiple `UNPIVOT` operators, you can apply Dynamic SQL to it in order to return results for any values of `Color` or `SafetyStockLevel` found in the `Products_By_Color_and_Stock_Level` table. This fun query can be found in Listing 9-18.

Listing 9-18. Dynamic SQL Used in Conjunction with Multiple UNPIVOT Operators

```
DECLARE @colors TABLE
       (color_name VARCHAR(25));

INSERT INTO @colors
       (color_name)
SELECT
       columns.name
FROM sys.tables
INNER JOIN sys.columns
ON columns.object_id = tables.object_id
WHERE tables.name = 'Products_By_Color_and_Stock_Level'
AND columns.name NOT IN ('product_name', 'ReorderPoint')
AND ISNUMERIC(columns.name) = 0;

DECLARE @stock_levels TABLE
       (safety_stock_level SMALLINT);
```

```
INSERT INTO @stock_levels
SELECT
       columns.name
FROM sys.tables
INNER JOIN sys.columns
ON columns.object_id = tables.object_id
WHERE tables.name = 'Products_By_Color_and_Stock_Level'
AND columns.name NOT IN ('product_name', 'ReorderPoint')
AND ISNUMERIC(columns.name) = 1;

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
       product_name,
       ReorderPoint,
       product_quantity,
       Color,
       SafetyStockLevel
FROM
   (SELECT
          *
       FROM dbo.Products_By_Color_and_Stock_Level) AS PRODUCTS_BY_COLOR_AND_STOCK_LEVEL
UNPIVOT
   (product_quantity FOR Color IN
      (';

SELECT @sql_command = @sql_command + '[' + color_name + '], '
FROM @colors;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) AS UNPIVOT_DATA_COLOR
UNPIVOT
   (safety_stock_level FOR SafetyStockLevel IN
      ('

SELECT @sql_command = @sql_command + '[' + CAST(safety_stock_level AS NVARCHAR) + '], '
FROM @stock_levels;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) AS UNPIVOT_DATA_STOCK_LEVEL
WHERE safety_stock_level <> 0;';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The first challenge here is parsing the column names into each table variable for use later. In this case, you are fortunate in that the colors are all string data, whereas the stock levels are all numeric. By checking whether the column name is numeric, you can split the column names into two meaningful lists. In the event that the column names cannot easily be separated, you could separate the initial data into multiple holding tables, rather than putting it all into Products_By_Color_and_Stock_Level.

In an effort to avoid adding more complexity, a likely better way to divide the columns would be to tag each with a meaningful name. For the example, colors could be prefixed with `Color:` and stock levels prefixed with `StockLevel:`. When you filter column names for each table variable of possible values, the prefixes could be easily checked instead. Since you determine the structure of those prefixes, you can ensure they are unique, meaningful, and allow you to maintain the data in a single holding table.

The command string for such a `UNPIVOT` operation will look like this:

```
SELECT
       product_name,
       ReorderPoint,
       product_quantity,
       Color,
       SafetyStockLevel
FROM
   (SELECT
           *
       FROM dbo.Products_By_Color_and_Stock_Level) AS PRODUCTS_BY_COLOR_AND_STOCK_LEVEL
UNPIVOT
   (product_quantity FOR Color IN
       ([Black], [Blue], [Grey], [Multi], [Red], [Silver], [Silver/Black],
       [White], [Yellow])) AS UNPIVOT_DATA_COLOR
UNPIVOT
   (safety_stock_level FOR SafetyStockLevel IN
       ([4], [60], [100], [500], [800], [1000])) AS UNPIVOT_DATA_STOCK_LEVEL
WHERE safety_stock_level <> 0;
```

This TSQL, with minor formatting differences, is identical to the statement that you tested in which Dynamic SQL was not used. The result set is also identical to what was returned previously. Note the row count of the generated results, as shown in Figure 9-10.

Figure 9-10. *Row count from the UNPIVOT query in Listing 9-18*

There were a total of 184 rows returned, which is far smaller than the size of the original data set that you worked with. The original data set, taken from `Production.Product` and `Production.ProductInventory`, contained 1,141 rows. The results of the `PIVOT` operations reduced that count to 504 rows. With each operation, the granularity of the data set is reduced as you aggregate the results. As such, it is important to remember that `PIVOT` and `UNPIVOT`, even when used one after the other, will generally not restore a data set to its original form. Therefore, use these transformations as methods to acquire reporting data efficiently, but not to reconstruct or validate data. While it is possible to build sequences of `PIVOT` and `UNPIVOT` operations that can reverse data into its original structure and contents, it is unlikely to be a useful exercise.

Utilizing multiple `UNPIVOT` operations can allow a complex reporting data set to be reverted into summary data for use in further reports, or as a way to input columnar data into a transactional system instead of as row data. Utilizing Dynamic SQL allows for all possible column values to be efficiently accounted for, even if the set of columns can change over time!

Conclusion

`PIVOT` and `UNPIVOT` are often seen by DBAs and developers as advanced or finicky operators to be avoided whenever possible. For the use-cases presented, though, they can provide large amounts of data quickly in an atomic and set-based approach. As a performance bonus, there is no need to implement loops, cursors, or other iterative solutions that could run slowly or be resource-intensive on larger volumes of data.

The biggest challenge with these operators is that column lists must be explicitly provided prior to runtime. Hard-coding these values greatly increases related technical debt by forcing you to keep track of and update these values whenever related application or database changes occur. This maintenance cost is high and presents opportunities for software bugs to manifest themselves that would be difficult to avoid and frustrating to diagnose.

Implementing Dynamic SQL in conjunction with `PIVOT` or `UNPIVOT` allows you to generate column lists at runtime based on whatever criteria the developer chooses to apply. So long as this logic is relevant, there will be no need to adjust stored procedures or code when new values are added or old ones removed.

CHAPTER 10

Solving Common Problems

Dynamic SQL presents a unique opportunity to take common database problems or limitations and solve them quickly. Oftentimes, you'll run into frustrating situations where you are managing different databases, schemas, or settings, and there is no easy way to make changes to a mixed set of objects. This chapter attempt to show you how Dynamic SQL can resolve complex situations such as these. In addition, this chapter provides general guidelines and techniques that could apply to any similar database problem.

Collation Conflicts

The Problem

Database collations are often used as a way to manage multiple languages or character sets within SQL Server in a meaningful fashion. The order in which characters are sorted in Spanish is different than in English or Japanese, and using an English collation on either of the other languages may result in strings being ordered incorrectly. In fact, SQL Server will prevent direct assignments or comparisons between string data of different collations. If you are working with data in multiple collations, you must account for the differences to ensure that you act on it according to the correct business logic.

To test collations, you will create a new database and table, populated with data from `AdventureWorks`, as shown in Listing 10-1.

Listing 10-1. Building a Test Database for Collation Testing

```
IF EXISTS (SELECT * FROM sys.databases WHERE name = 'Collation_Test')
BEGIN
	DROP DATABASE Collation_Test;
END
GO

CREATE DATABASE Collation_Test COLLATE Traditional_Spanish_CI_AS;
GO
USE Collation_Test;
GO

CREATE TABLE dbo.Spanish_Employees
(	BusinessEntityID INT NOT NULL,
	NationalIDNumber NVARCHAR(15) NOT NULL,
```


E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_10

```
        LoginID NVARCHAR(256) NOT NULL,
        OrganizationNode HIERARCHYID NULL,
        OrganizationLevel SMALLINT NULL,
        JobTitle NVARCHAR(50) NOT NULL,
        BirthDate DATE NOT NULL,
        MaritalStatus NCHAR(1) NOT NULL,
        Gender NCHAR(1) NOT NULL,
        HireDate DATE NOT NULL,
        SalariedFlag BIT NOT NULL,
        VacationHours SMALLINT NOT NULL,
        SickLeaveHours SMALLINT NOT NULL,
        CurrentFlag BIT NOT NULL,
        rowguid UNIQUEIDENTIFIER ROWGUIDCOL  NOT NULL,
        ModifiedDate DATETIME NOT NULL,);
GO

INSERT INTO Collation_Test.dbo.Spanish_Employees
SELECT
        *
FROM AdventureWorks2014.HumanResources.Employee;
```

Note that when the database Collation_Test was created, it was explicitly given the collation Traditional_Spanish_CI_AS. All strings in this database will, by default, be stored and sorted in this new collation, rather than the instance default or the settings found on other databases. On my SQL Server, the default collation is SQL_Latin1_General_CP1_CI_AS. This can be verified in the server properties in the GUI, as shown in Figure 10-1.

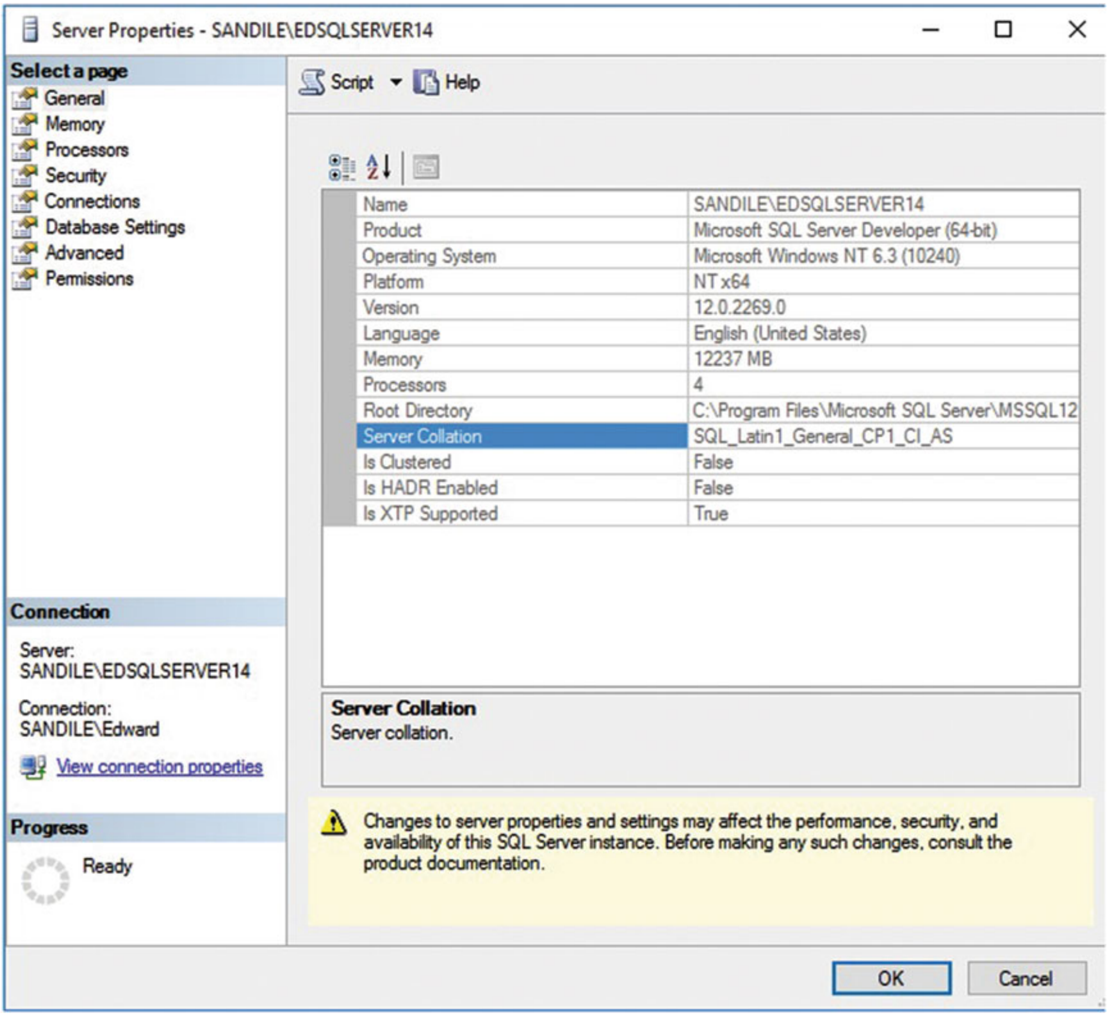


Figure 10-1. *Default server collation, as shown in the SQL Server Properties window*

Under the Server Collation option, you can find the default for your server. This is the collation that will be used on any new database that is created in which another collation is not supplied. This can also be verified with TSQL:

```
SELECT SERVERPROPERTY('Collation') AS ServerDefaultCollation;
```

The resulting collation is the same as shown in the GUI and can be verified in Figure 10-2.

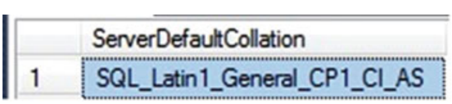


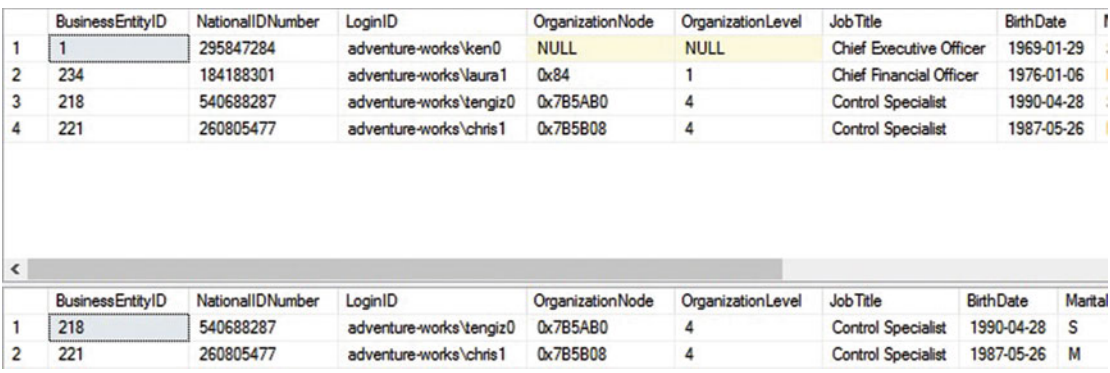
Figure 10-2. *The default collation on my test server*

In order to illustrate one of the differences between different collations, you will take a look at the HumanResources.Employee table, focusing on the JobTitle column within the original table and the newly created one that is collated using traditional Spanish. Listing 10-2 shows each of these queries.

Listing 10-2. Two Test Queries Illustrating the Differences in Two Distinct Collations

```
SELECT
        *
FROM AdventureWorks2014.HumanResources.Employee
WHERE JobTitle LIKE 'C%'
ORDER BY JobTitle;

SELECT
        *
FROM Collation_Test.dbo.Spanish_Employees
WHERE JobTitle LIKE 'C%'
ORDER BY JobTitle;
```

The results of the queries are a bit unusual and indicate that there are significant differences between each collation, as shown in Figure 10-3.



	BusinessEntityID	NationalIDNumber	LoginID	OrganizationNode	OrganizationLevel	JobTitle	BirthDate
1	1	295847284	adventure-works\ken0	NULL	NULL	Chief Executive Officer	1969-01-29
2	234	184188301	adventure-works\laura1	0x84	1	Chief Financial Officer	1976-01-06
3	218	540688287	adventure-works\tengiz0	0x7B5AB0	4	Control Specialist	1990-04-28
4	221	260805477	adventure-works\chris1	0x7B5B08	4	Control Specialist	1987-05-26

	BusinessEntityID	NationalIDNumber	LoginID	OrganizationNode	OrganizationLevel	JobTitle	BirthDate	Marital
1	218	540688287	adventure-works\tengiz0	0x7B5AB0	4	Control Specialist	1990-04-28	S
2	221	260805477	adventure-works\chris1	0x7B5B08	4	Control Specialist	1987-05-26	M

Figure 10-3. *Different collations result in the same query providing different results*

The second result set only returns two rows, whereas the original AdventureWorks table includes two additional executives. Why were the results different? It turns out that in traditional Spanish, the letters "*CH*" are considered a separate letter of the alphabet. You can view those rows of data for which the job title begins in those characters like this:

```
SELECT
        *
FROM Collation_Test.dbo.Spanish_Employees
WHERE JobTitle LIKE 'CH%'
ORDER BY JobTitle;
```

This query returns the results shown in Figure 10-4.

	BusinessEntityID	NationalIDNumber	LoginID	OrganizationNode	OrganizationLevel	JobTitle	BirthDate
1	1	295847284	adventure-works\ken0	NULL	NULL	Chief Executive Officer	1969-01-29
2	234	184188301	adventure-works\laura1	0x84	1	Chief Financial Officer	1976-01-06

Figure 10-4. *Illustration of the difference between "C" and "CH" in a Spanish collation*

Because of the language differences, the filter C% does not include the results that are returned by the filter CH%. In addition, these letters will not sort as they normally would in a Latin collation:

```
SELECT
       *
FROM Collation_Test.dbo.Spanish_Employees
WHERE JobTitle BETWEEN 'C' AND 'D'
ORDER BY JobTitle;
```

This query returns all four results, as shown in Figure 10-5.

	BusinessEntityID	NationalIDNumber	LoginID	OrganizationNode	OrganizationLevel	JobTitle	BirthDate
1	218	540688287	adventure-works\tengiz0	0x7B5AB0	4	Control Specialist	1990-04-28
2	221	260805477	adventure-works\chris1	0x7B5B08	4	Control Specialist	1987-05-26
3	1	295847284	adventure-works\ken0	NULL	NULL	Chief Executive Officer	1969-01-29
4	234	184188301	adventure-works\laura1	0x84	1	Chief Financial Officer	1976-01-06

Figure 10-5. *Sorting differences in the traditional Spanish collation*

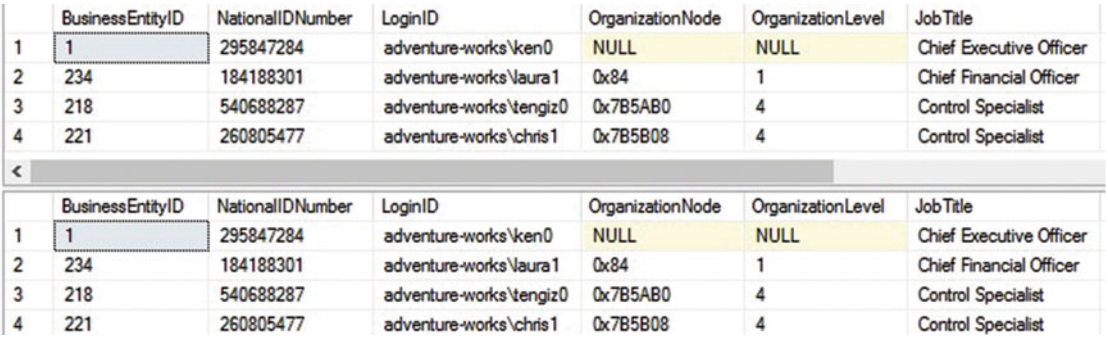
In this collation, "*C*" comes before "*CH*" in the alphabet. This may seem like a minor difference, but for a user running a web search, these results could easily lead to incorrect assumptions. For example, suppose the user searches as shown above, returns two results, and never realizes that there are two additional employees she may have been looking for in the table.

It is possible to force collations on any result set, as shown in Listing 10-3.

Listing 10-3. Forcing a Specific Collation on Filters and Sorts in a Result Set

```
SELECT
       *
FROM Collation_Test.dbo.Spanish_Employees
WHERE JobTitle COLLATE SQL_Latin1_General_CP1_CI_AS LIKE 'C%'
ORDER BY JobTitle COLLATE SQL_Latin1_General_CP1_CI_AS;

SELECT
       *
FROM Collation_Test.dbo.Spanish_Employees
WHERE JobTitle COLLATE SQL_Latin1_General_CP1_CI_AS BETWEEN 'C' AND 'D'
ORDER BY JobTitle COLLATE SQL_Latin1_General_CP1_CI_AS;
```

The results of these queries return the data you would typically expect, as shown in Figure 10-6.



	BusinessEntityID	NationalIDNumber	LoginID	OrganizationNode	OrganizationLevel	JobTitle
1	1	295847284	adventure-works\ken0	NULL	NULL	Chief Executive Officer
2	234	184188301	adventure-works\laura1	0x84	1	Chief Financial Officer
3	218	540688287	adventure-works\tengiz0	0x7B5AB0	4	Control Specialist
4	221	260805477	adventure-works\chris1	0x7B5B08	4	Control Specialist

	BusinessEntityID	NationalIDNumber	LoginID	OrganizationNode	OrganizationLevel	JobTitle
1	1	295847284	adventure-works\ken0	NULL	NULL	Chief Executive Officer
2	234	184188301	adventure-works\laura1	0x84	1	Chief Financial Officer
3	218	540688287	adventure-works\tengiz0	0x7B5AB0	4	Control Specialist
4	221	260805477	adventure-works\chris1	0x7B5B08	4	Control Specialist

Figure 10-6. *Forcing a collation in order to return desired results*

One final example of collation conflict occurs when you try to directly compare columns from any one collation to another:

```
SELECT
        *
FROM Collation_Test.dbo.Spanish_Employees
INNER JOIN AdventureWorks2014.HumanResources.Employee
ON Spanish_Employees.LoginID = Employee.LoginID;
```

This query will result in an error:

```
Msg 468, Level 16, State 9, Line 94
Cannot resolve the collation conflict between "SQL_Latin1_General_CP1_CI_AS" and
"Traditional_Spanish_CI_AS" in the equal to operation.
```

In order to make this query work, you must force the collation of one join column to match the other. Which collation you convert depends on the use-case, but without changing one of them, you will be unable to join, filter on, or compare results from either data set:

```
SELECT
        *
FROM Collation_Test.dbo.Spanish_Employees
INNER JOIN AdventureWorks2014.HumanResources.Employee
ON Spanish_Employees.LoginID = Employee.LoginID COLLATE Traditional_Spanish_CI_AS
```

By forcing a collation onto the join predicate, you can ensure that each column can be compared to the other and that the results are properly returned. This is a specific solution to a specific scenario, but we can do far better by using dynamic SQL in order to solve this for all variants on this problem!

The Solution

Forcing a specific collation works when you know exactly what collations to expect when running queries. What if you are working with many different collations and do not know until runtime exactly which you want to sort by? If you manage many servers and databases, each with a different default collation, then you cannot make assumptions when converting collations at runtime. In addition, forcing all columns to a specific collation may affect the output in ways that users or applications would be intolerant of.

Dynamic SQL can help you turn a six-page problem into a one-page solution! By returning the default collation of the server or database as above, you can always return or compare data in the correct collation. The script in Listing 10-4 will result in a collation conflict error.

Listing 10-4. Collation Conflict Example Using a Table Variable

```
USE AdventureWorks2014
GO

DECLARE @temp_employees TABLE
(       id INT NOT NULL IDENTITY(1,1),
        LoginID NVARCHAR(256) NOT NULL        );

INSERT INTO @temp_employees
        (LoginID)
SELECT TOP 50
        LoginID
FROM AdventureWorks2014.HumanResources.Employee
ORDER BY Employee.JobTitle;

SELECT
        Spanish_Employees.NationalIDNumber,
        Spanish_Employees.LoginID,
        Spanish_Employees.JobTitle,
        Spanish_Employees.BirthDate,
        Spanish_Employees.HireDate
FROM Collation_Test.dbo.Spanish_Employees
WHERE Spanish_Employees.LoginID IN
        (SELECT LoginID FROM @temp_employees);
```

Temporary tables and table variables are created using the collation of the `TempDB` database, which will typically match the server's default collation. In this case, the table variable is created in the Latin collation, whereas the `LoginID` you are checking is in the Spanish collation. This can be corrected permanently using the Dynamic SQL shown in Listing 10-5.

Listing 10-5. Resolving a Collation Conflict with Dynamic SQL

```
USE AdventureWorks2014
GO

DECLARE @sql_command NVARCHAR(MAX);
DECLARE @server_collation NVARCHAR(50);
SELECT @server_collation = CAST(SERVERPROPERTY('Collation') AS NVARCHAR(50));

SELECT @sql_command = '
```

```
DECLARE @temp_employees TABLE
(       id INT NOT NULL IDENTITY(1,1),
        LoginID NVARCHAR(256) NOT NULL        );

INSERT INTO @temp_employees
        (LoginID)
SELECT TOP 50
        LoginID
FROM AdventureWorks2014.HumanResources.Employee
ORDER BY Employee.JobTitle;

SELECT
        Spanish_Employees.NationalIDNumber,
        Spanish_Employees.LoginID,
        Spanish_Employees.JobTitle,
        Spanish_Employees.BirthDate,
        Spanish_Employees.HireDate
FROM Collation_Test.dbo.Spanish_Employees
WHERE Spanish_Employees.LoginID IN
        (SELECT LoginID COLLATE ' + @server_collation + ' FROM @temp_employees);'

EXEC sp_executesql @sql_command;
```

The method in Listing 10-5 can be reversed in order to work with data using the collation of a specific database. The script in Listing 10-6 will return data using the default collation of the test database, rather than the server collation.

Listing 10-6. Using Dynamic SQL to Collate Data into a Specific Database's Default Collation

```
USE master
GO
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @database_name NVARCHAR(128) = 'Collation_Test';

DECLARE @collation_name NVARCHAR(50);
SELECT @collation_name = collation_name
FROM sys.databases WHERE databases.name = @database_name;

SELECT @sql_command = '
SELECT
        Spanish_Employees.NationalIDNumber,
        Spanish_Employees.LoginID,
        Spanish_Employees.JobTitle,
        Spanish_Employees.BirthDate,
        Spanish_Employees.HireDate
FROM Collation_Test.dbo.Spanish_Employees
WHERE Spanish_Employees.LoginID IN
        (SELECT TOP 50 LoginID COLLATE ' + @collation_name + '
         FROM AdventureWorks2014.HumanResources.Employee ORDER BY LoginID COLLATE ' +
         @collation_name + ')';

EXEC sp_executesql @sql_command;
```

This example shows how to return a database's default collation from `sys.databases` and use that data to quickly resolve what would otherwise be a collation conflict.

Organizing and Archiving Data

The Problem

When working with the archival or movement of data, you may want to name objects such as tables, databases, or schemas with customized names based on the date, time, or application. Using standard TSQL, this would be difficult without some complex application code to manage the process.

What if you have a log table that grows very quickly, but you never need data older than a week? Partitioning the table such that the current week is isolated into a single partition is one solution, but is only available in Enterprise edition. In addition, you might want to move the old data to a different server or storage environment. If this, or any similar situations, are involved, then managing the process yourself may be an easier and more portable solution.

This example populates a table with a variety of data based on date and time, as shown in Listing 10-7.

Listing 10-7. Create Database Log Data for an Archiving Demonstration

```
CREATE TABLE dbo.Database_Log
        (log_id INT NOT NULL IDENTITY(1,1) CONSTRAINT PK_Database_Log PRIMARY KEY CLUSTERED,
         Log_Time DATETIME,
         Log_Data NVARCHAR(1000));

DECLARE @datetime DATETIME = CURRENT_TIMESTAMP;
DECLARE @datediff TABLE
        (previous_hour SMALLINT);
DECLARE @count SMALLINT = 0;
WHILE @count <= 360
BEGIN
        INSERT INTO @datediff
                (previous_hour)
        SELECT @count;

        SELECT @count = @count + 1
END

SELECT @count = 0;
WHILE @count <= 1000
BEGIN
        INSERT INTO Database_Log
                (Log_Time, Log_Data)
        SELECT
                DATEADD(HOUR, -1 * previous_hour, CURRENT_TIMESTAMP),
                CAST(DATEADD(HOUR, -1 * previous_hour, CURRENT_TIMESTAMP) AS NVARCHAR)
        FROM @datediff;

        SELECT @count = @count + 1;
END
```

This script creates a table called Database_Log and populates it with 361,361 rows of data containing a variety of log times, as well as the string conversion of those times. The data is shown in Figure 10-7.

log_id	Log_Time	Log_Data
67069	2015-11-15 13:30:10.707	Nov 15 2015 1:30PM
67070	2015-11-15 12:30:10.707	Nov 15 2015 12:30PM
67071	2015-11-15 11:30:10.707	Nov 15 2015 11:30AM
67072	2015-11-15 10:30:10.707	Nov 15 2015 10:30AM
67073	2015-11-15 09:30:10.707	Nov 15 2015 9:30AM
67074	2015-11-15 08:30:10.707	Nov 15 2015 8:30AM
67075	2015-11-15 07:30:10.707	Nov 15 2015 7:30AM
67076	2015-11-15 06:30:10.707	Nov 15 2015 6:30AM
67077	2015-11-15 05:30:10.707	Nov 15 2015 5:30AM
67078	2015-11-15 04:30:10.707	Nov 15 2015 4:30AM
67079	2015-11-15 03:30:10.707	Nov 15 2015 3:30AM
67080	2015-11-15 02:30:10.707	Nov 15 2015 2:30AM

Figure 10-7. *Sample of database log data created in Listing 10-7*

Say you want to archive data every week into a new table that contains a week's worth of data. This would normally require quite a bit of manual labor in order to manage table names correctly. What if you also wanted to separate data into databases by year, so that each calendar year had its own unique database? This may seem like an unusual use-case, but the need to move large volumes of data around a time slice is very common. Dynamic SQL techniques can be applied to any similar problem, regardless of the specific objects or business rules.

In order to provide some older data that will be archived into additional databases, let's run one more data population script to increase the data size even further, as shown in Listing 10-8.

Listing 10-8. Script to Increase the Size of the Data in the Database_Log Table

```
DECLARE @year_offset TINYINT = 5;

WHILE @year_offset > 0
BEGIN
        INSERT INTO dbo.Database_Log
                (Log_Time, Log_Data)
        SELECT TOP 10000
                DATEADD(YEAR, -1 * @year_offset, Log_Time),
                CAST(DATEADD(YEAR, -1 * @year_offset, Log_Time) AS NVARCHAR)
        FROM Database_Log

        SELECT @year_offset = @year_offset - 1;
END
```

Now you have an additional 50,000 rows of data from up to five years ago, which will easily demonstrate the problem. Using this data, we can better understand the ways in which we could archive data and customize targets based on specific business needs.

The Solution

In order to process this data correctly, you need to perform the following tasks:

1. Read data from the log table by time period.
2. Create new database or table objects (if they do not already exist).
3. Insert the data into those objects.
4. Delete the archived data from the log table.

The script in Listing 10-9 will accomplish the tasks outlined previously.

Listing 10-9. Using Dynamic SQL to Archive Data into Dynamically Named Tables

```
DECLARE @sql_command NVARCHAR(MAX);
DECLARE @parameter_list NVARCHAR(MAX) = '@start_of_week DATETIME, @end_of_week DATETIME';
DECLARE @min_datetime DATETIME;
SELECT @min_datetime = MIN(Log_Time) FROM Database_Log;
DECLARE @previous_min_time DATETIME = '1/1/1900';
DECLARE @start_of_week DATETIME = CAST(DATEADD(dd, -1 * (DATEPART(dw, @min_datetime) - 1),
@min_datetime) AS DATE);
DECLARE @end_of_week DATETIME = DATEADD(WEEK, 1, @start_of_week);
DECLARE @current_year SMALLINT;
DECLARE @current_week TINYINT;
DECLARE @database_name NVARCHAR(128);
DECLARE @table_name NVARCHAR(128);

WHILE (@previous_min_time <> @min_datetime)
BEGIN
        SELECT @current_year = DATEPART(YEAR, @start_of_week);
        SELECT @current_week = DATEPART(WEEK, @start_of_week);
        SELECT @database_name = 'Database_Log_' + CAST(@current_year AS NVARCHAR);
        SELECT @table_name = 'Database_Log_' + CAST(@current_year AS NVARCHAR) + '_' +
        CAST(@current_week AS NVARCHAR)

        -- Create the yearly database if it does not already exist
        IF NOT EXISTS (SELECT * FROM sys.databases WHERE databases.name = @database_name)
        BEGIN
                SELECT @sql_command = 'CREATE DATABASE [' + @database_name + ']';
                EXEC sp_executesql @sql_command;
        END
        -- Create the weekly table if it does not already exist
        SELECT @sql_command = '
        USE [' + @database_name + '];
        IF NOT EXISTS (SELECT * FROM sys.tables WHERE tables.name = ''' + @table_name + ''')
        BEGIN
                CREATE TABLE [dbo].[' + @table_name + ']
```

```
                (Log_Id INT NOT NULL CONSTRAINT PK_Database_Log_' + CAST(@current_year AS
                NVARCHAR) + '_' + CAST(@current_week AS NVARCHAR) + ' PRIMARY KEY CLUSTERED,
                 Log_Time DATETIME,
                 Log_Data NVARCHAR(1000));
        END'
        EXEC sp_executesql @sql_command;

        SELECT @sql_command = '
        INSERT INTO [' + @database_name + '].[dbo].[' + @table_name + ']
                (Log_Id, Log_Time, Log_Data)
        SELECT
                Log_Id,
                Log_Time,
                Log_Data
        FROM AdventureWorks2014.dbo.Database_Log
        WHERE Log_Time >= @start_of_week
        AND Log_Time <= @end_of_week
        AND Log_Time < DATEADD(WEEK, -1, CURRENT_TIMESTAMP);

        DELETE
        FROM AdventureWorks2014.dbo.Database_Log
        WHERE Log_Time >= @start_of_week
        AND Log_Time <= @end_of_week
        AND Log_Time < DATEADD(WEEK, -1, CURRENT_TIMESTAMP);'

        EXEC sp_executesql @sql_command, @parameter_list, @start_of_week, @end_of_week

        SELECT @previous_min_time = @min_datetime;
        SELECT @min_datetime = MIN(Log_Time) FROM Database_Log;
        SELECT @start_of_week = CAST(DATEADD(dd, -1 * (DATEPART(dw, @min_datetime) - 1),
        @min_datetime) AS DATE);
        SELECT @end_of_week = DATEADD(WEEK, 1, @start_of_week);
END
```

When the script completes running, you'll be able to view some new databases on the server, as shown in Figure 10-8.

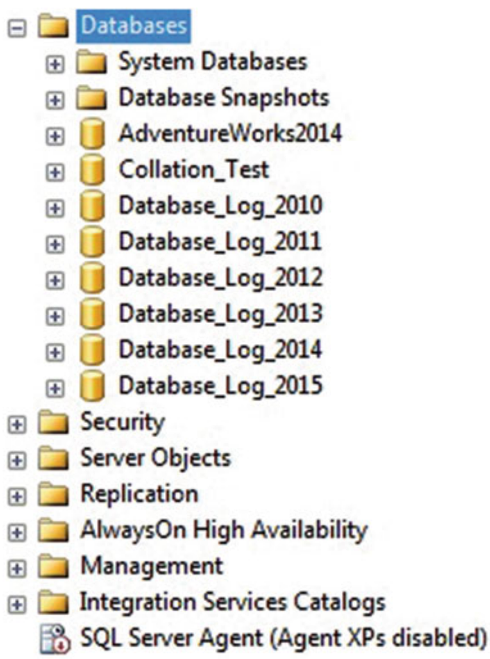


Figure 10-8. *New databases created when the script in Listing 10-9 is executed*

For each year represented by the `Log_Time` within `Database_Log`, a new database was created. In addition, tables were created in those databases for each week represented within that data, as shown in Figure 10-9.

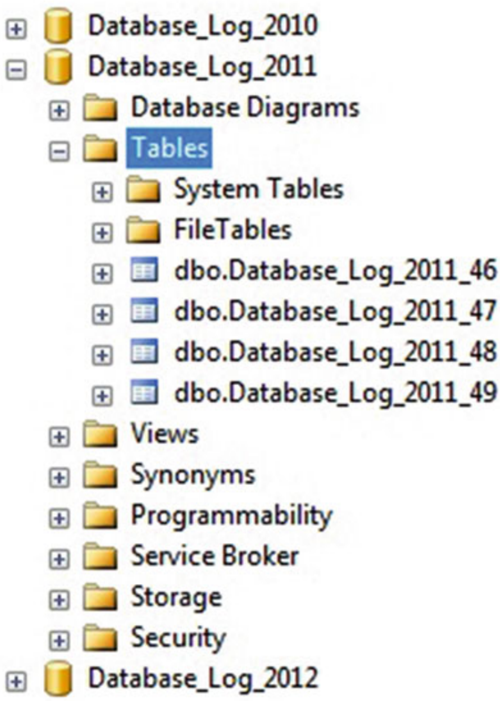


Figure 10-9. *New tables created when the script in Listing 10-9 is executed*

The guts of the logic employed above revolves around creating databases and tables dynamically based on the date and time provided by `Log_Time`. Once those objects are created, data is inserted into them and then deleted from the source table. You can review the data in a single table to verify that this script did exactly what you intended it to do, as shown in Figure 10-10.

```
SELECT
        *
FROM Database_Log_2011.dbo.Database_Log_2011_48
```

	Log_Id	Log_Time	Log_Data
1	371372	2011-11-26 23:41:40.400	Nov 26 2011 11:41PM
2	371373	2011-11-26 22:41:40.400	Nov 26 2011 10:41PM
3	371374	2011-11-26 21:41:40.400	Nov 26 2011 9:41PM
4	371375	2011-11-26 20:41:40.400	Nov 26 2011 8:41PM
5	371376	2011-11-26 19:41:40.400	Nov 26 2011 7:41PM
6	371377	2011-11-26 18:41:40.400	Nov 26 2011 6:41PM
7	371378	2011-11-26 17:41:40.400	Nov 26 2011 5:41PM
8	371379	2011-11-26 16:41:40.400	Nov 26 2011 4:41PM
9	371380	2011-11-26 15:41:40.400	Nov 26 2011 3:41PM
10	371381	2011-11-26 14:41:40.400	Nov 26 2011 2:41PM
11	371382	2011-11-26 13:41:40.400	Nov 26 2011 1:41PM
12	371383	2011-11-26 12:41:40.400	Nov 26 2011 12:41PM

Figure 10-10. *Sample data from a weekly log table*

All data within this new table is identical to how it appeared in the original `Database_Log` table, including the `Log_Id`. The only difference is the new database and table location of the data.

Reorganizing data when the reference points change over time can be a complex task. Dynamic SQL allows data to be organized and moved, and new objects are created with relatively simple logic. In under 100 lines of TSQL, you were able to take all old data from a log table and move it to any number of new database objects that were created at runtime based on the age of that data.

Every use-case for reorganizing, archiving, or moving data will be different, but this general technique can be extremely useful when you want to minimize the complexity and size of an important archiving process. Always consider how the archived data will be used prior to building a new process. Whether it is moved to separate databases, tables, or partitions, you now have the luxury of being able to index it uniquely based on its new purpose. By treating it as an archive repository and not transactional data, you gain the flexibility to optimize it based on its new purpose.

Dynamic SQL can be used to manage additional indexes, constraints, keys, views, and stored procedures that all can allow the new data to be accessed efficiently and conveniently. Creating those objects would be as easy as adding to the command string in the same way as the primary keys were created.

Customized Database Objects

The ability to create highly flexible custom objects is not a simple task unless some sort of dynamic code or TSQL is implemented. Your needs in this area can be very specific, but generalized techniques can be used to get exactly what you want every time.

The Problem

Sometimes you'll want to create objects with specific use-cases, but where the tables or columns involved may not always be the same. Generating a stored procedure, function, or view given those variables would normally be a manually intensive process. You can implement Dynamic SQL in order to create or modify existing objects in ways that are both scalable and reliable.

Chapter 9 introduced using Dynamic SQL in order to PIVOT or UNPIVOT data when the column lists were not known until runtime. What if you wanted to summarize the table data output by those processes into a view, which would provide a convenient data source for an application to access? Once a view is created, you can consider additional options, such as schemabinding in order to improve schema integrity.

Consider a scenario in which you want to provide insight into employee hire dates based on job titles. For a specific company, this is data that is requested so often that a request is made for a more permanent data structure based on it. There are a number of ways to approach this, including a custom table, view, or an ETL process to manage report data based on these needs. These processes could be managed via triggers, stored procedures, or a variety of other methods.

The Solution

For the scenario outlined previously, you'll provide an example solution using a schemabound view, although other methods could be used if the report or data requirements were different. The following TSQL in Listing 10-10 will return the raw data that you are looking for.

Listing 10-10. Dynamic PIVOT that Returns a Count of Hire Year by Job Title

```
DECLARE @hire_date_years TABLE
        (hire_date_year NVARCHAR(50));

INSERT INTO @hire_date_years
        (hire_date_year)
SELECT DISTINCT
        DATEPART(YEAR, Employee.HireDate)
FROM HumanResources.Employee;

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
SELECT
        *
FROM
(       SELECT
                Employee.BusinessEntityID,
                Employee.JobTitle,
                DATEPART(YEAR, Employee.HireDate) AS HireDate_Year
        FROM HumanResources.Employee
) EMPLOYEE_DATA
PIVOT
(       COUNT(BusinessEntityID)
        FOR HireDate_Year IN (';
```

```
SELECT @sql_command = @sql_command + '[' + hire_date_year + '], '
FROM @hire_date_years;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + ' )) PIVOT_DATA';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

The output of this query returns a data set similar to that in Figure 10-11.

	JobTitle	2006	2007	2008	2009	2010	2011	2012	2013
4	Accounts Receivable Specialist	0	0	1	2	0	0	0	0
5	Application Specialist	0	0	1	3	0	0	0	0
6	Assistant to the Chief Financial Officer	0	0	0	1	0	0	0	0
7	Benefits Specialist	0	0	1	0	0	0	0	0
8	Buyer	0	0	0	3	6	0	0	0
9	Chief Executive Officer	0	0	0	1	0	0	0	0
10	Chief Financial Officer	0	0	0	1	0	0	0	0
11	Control Specialist	0	0	1	1	0	0	0	0
12	Database Administrator	0	0	0	2	0	0	0	0
13	Design Engineer	0	0	2	0	0	1	0	0
14	Document Control Assistant	0	0	0	2	0	0	0	0
15	Document Control Manager	0	0	0	1	0	0	0	0
16	Engineering Manager	0	1	0	0	0	0	0	0
17	European Sales Manager	0	0	0	0	0	0	1	0
18	Facilities Administrative Assistant	0	0	0	1	0	0	0	0

***Figure 10-11.** Hire data returned by the dynamic PIVOT query in Listing 10-10*

Each job title is listed as the first column followed by a list of columns for each hire date year present in the Employee table. If employees are added or removed from the underlying table, columns may be added or removed from this data set as hire dates are added or removed.

Now that you have a query that returns the results you want in the columnar format that you are looking for, you can move this data into a customized view. One technicality that you need to overcome is that when you create a schemabound view, you cannot include * in the column list. If you take the TSQL and add a CREATE VIEW…WITH SCHEMABINDING to the query, you will get the following error:

```
Msg 1054, Level 15, State 6, Procedure v_job_title_year_summary, Line 6
Syntax '*' is not allowed in schema-bound objects.
Msg 102, Level 15, State 1, Procedure v_job_title_year_summary, Line 13
Incorrect syntax near 'EMPLOYEE_DATA'.
```

In order to make this syntax work, you need to make the column list dynamic, in addition to the PIVOT details. The TSQL in Listing 10-11 is the view creation script with that alteration included.

Listing 10-11. Dynamic SQL Used to Create a Customized View with a Variable Column List

```
IF EXISTS (SELECT * FROM sys.views WHERE views.name = 'v_job_title_year_summary')
BEGIN
        DROP VIEW v_job_title_year_summary
END
GO

DECLARE @hire_date_years TABLE
        (hire_date_year NVARCHAR(50));

INSERT INTO @hire_date_years
        (hire_date_year)
SELECT DISTINCT
        DATEPART(YEAR, Employee.HireDate)
FROM HumanResources.Employee;

DECLARE @sql_command NVARCHAR(MAX);
SELECT @sql_command = '
CREATE VIEW dbo.v_job_title_year_summary
WITH SCHEMABINDING
AS
SELECT
        JobTitle,'

SELECT @sql_command = @sql_command + '
[' + hire_date_year + '], '
FROM @hire_date_years;

SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + '
FROM
(       SELECT
                Employee.BusinessEntityID,
                Employee.JobTitle,
                DATEPART(YEAR, Employee.HireDate) AS HireDate_Year
        FROM HumanResources.Employee
) EMPLOYEE_DATA
PIVOT
(       COUNT(BusinessEntityID)
        FOR HireDate_Year IN (';

SELECT @sql_command = @sql_command + '[' + hire_date_year + '], '
FROM @hire_date_years;
```

```
SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

SELECT @sql_command = @sql_command + '          )) PIVOT_DATA';

PRINT @sql_command;
EXEC sp_executesql @sql_command;
```

Once this script is run, you can look in the views list to quickly verify that the new view was created and that it contains the correct columns, as shown in Figure 10-12.

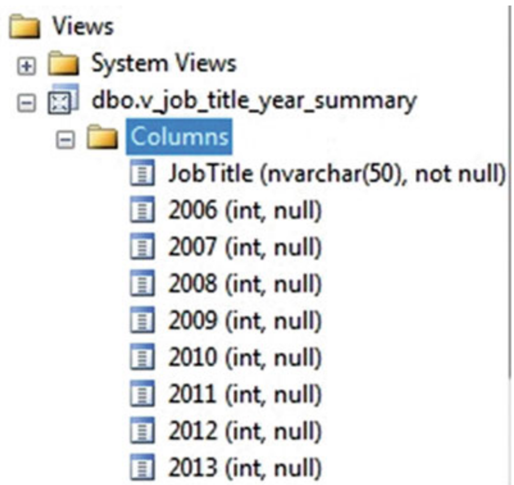


Figure 10-12. *Columns contained in the custom view created in Listing 10-11*

The view definition will not update automatically as data is updated, but since the underlying data is not likely to change constantly, you can manage this update daily (or at whatever interval is deemed necessary). Let's say that you update a few hire dates to years that are not included in the current underlying employee data:

```
UPDATE HumanResources.Employee
SET HireDate = '1/1/2015'
WHERE BusinessEntityID = 282

UPDATE HumanResources.Employee
SET HireDate = '1/1/2014'
WHERE BusinessEntityID IN (260, 285)
```

Now, if you select data from the view, you'll notice that 2014 and 2015 have not been added to it, as shown in Figure 10-13.

```
SELECT
        *
FROM dbo.v_job_title_year_summary
```

	JobTitle	2006	2007	2008	2009	2010	2011	2012	2013
1	Accountant	0	0	0	2	0	0	0	0
2	Accounts Manager	0	0	0	1	0	0	0	0
3	Accounts Payable Specialist	0	0	0	2	0	0	0	0
4	Accounts Receivable Specialist	0	0	1	2	0	0	0	0
5	Application Specialist	0	0	1	3	0	0	0	0
6	Assistant to the Chief Financial Officer	0	0	0	1	0	0	0	0
7	Benefits Specialist	0	0	1	0	0	0	0	0
8	Buyer	0	0	0	3	6	0	0	0
9	Chief Executive Officer	0	0	0	1	0	0	0	0
10	Chief Financial Officer	0	0	0	1	0	0	0	0

Figure 10-13. *Without refreshing the view, the 2014 and 2015 columns will not be returned*

In order for additional columns to be added to the view, it must be refreshed or recreated. In order to recreate it easily, you can encapsulate the TSQL view creation from earlier into a stored procedure, as shown in Listing 10-12.

Listing 10-12. Stored Procedure Used to Create a Dynamically Generated View

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'create_v_job_title_year_
summary')
BEGIN
        DROP PROCEDURE dbo.create_v_job_title_year_summary;
END
GO
CREATE PROCEDURE dbo.create_v_job_title_year_summary
AS
BEGIN
        IF EXISTS (SELECT * FROM sys.views WHERE views.name = 'v_job_title_year_summary')
        BEGIN
                DROP VIEW v_job_title_year_summary;
        END

        DECLARE @hire_date_years TABLE
                (hire_date_year NVARCHAR(50));

        INSERT INTO @hire_date_years
                (hire_date_year)
        SELECT DISTINCT
                DATEPART(YEAR, Employee.HireDate)
        FROM HumanResources.Employee;

        DECLARE @sql_command NVARCHAR(MAX);
        SELECT @sql_command = '
        CREATE VIEW dbo.v_job_title_year_summary
        WITH SCHEMABINDING
```

```
        AS
        SELECT
                JobTitle,'

        SELECT @sql_command = @sql_command + '
        [' + hire_date_year + '], '
        FROM @hire_date_years;

        SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

        SELECT @sql_command = @sql_command + '
        FROM
        (        SELECT
                        Employee.BusinessEntityID,
                        Employee.JobTitle,
                        DATEPART(YEAR, Employee.HireDate) AS HireDate_Year
                FROM HumanResources.Employee
        ) EMPLOYEE_DATA
        PIVOT
        (        COUNT(BusinessEntityID)
                FOR HireDate_Year IN (';

        SELECT @sql_command = @sql_command + '[' + hire_date_year + '], '
        FROM @hire_date_years;

        SELECT @sql_command = SUBSTRING(@sql_command, 1, LEN(@sql_command) - 1);

        SELECT @sql_command = @sql_command + '        )) PIVOT_DATA';

        PRINT @sql_command;
        EXEC sp_executesql @sql_command;
END
```

With this stored procedure, you can now recreate the dynamic view with ease:

```
EXEC dbo.create_v_job_title_year_summary;
```

When you check the contents of the view, you can verify that it has been appropriately updated, as shown in Figure 10-14.

```
SELECT
        *
FROM dbo.v_job_title_year_summary
```

	JobTitle	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
45	Production Technician - WC40	0	0	7	14	5	0	0	0	0	0
46	Production Technician - WC45	0	0	5	10	0	0	0	0	0	0
47	Production Technician - WC50	0	0	8	18	0	0	0	0	0	0
48	Production Technician - WC60	1	0	5	15	5	0	0	0	0	0
49	Purchasing Assistant	0	0	0	0	1	0	0	0	1	0
50	Purchasing Manager	0	0	0	0	0	1	0	0	0	0
51	Quality Assurance Manager	0	0	0	1	0	0	0	0	0	0
52	Quality Assurance Supervisor	0	0	1	0	0	0	0	0	0	0
53	Quality Assurance Technician	0	0	1	2	1	0	0	0	0	0
54	Recruiter	0	0	1	1	0	0	0	0	0	0
55	Research and Development Engineer	0	0	1	1	0	0	0	0	0	0
56	Research and Development Manager	0	0	0	2	0	0	0	0	0	0
57	Sales Representative	0	0	0	0	0	8	3	2	0	1

Figure 10-14. *New data for 2014 and 2015 has been included in the view, once refreshed*

Columns have been added for the 2014 and 2015 data and would have been added in order to encompass any other years that were added or removed since the last time the view was created. Note that a view that is based on a `PIVOT` cannot be indexed, but dynamically generated views can be indexed normally, so long as they do not include `PIVOT` or `UNPIVOT` and are schema-bound.

Generating schema using Dynamic SQL can be a very convenient way to create objects when schema knowledge may not be complete until runtime. It can also allow for complex business logic to be summarized into database objects using relatively simple TSQL syntax. The ability to greatly simplify application or report code can sometimes be more important than the burden of creating a new database object.

As with creating any new objects, always ensure that they are needed and that there is not a more efficient method available. Oftentimes, new SQL Server versions, application releases, or business changes can allow for new methods to be implemented for efficiently retrieving data.

Conclusion

This chapter reviewed a handful of Dynamic SQL applications that allow you to add flexibility to processes that are normally not tolerant of changes at runtime. Many more applications exist, with the only limitation being your imagination.

When creating any new schema, whether dynamically generated or not, always consider the impact and efficiency of doing so. All database objects must be maintained, and that cumulative upkeep must be considered when considering new objects. The goal of using Dynamic SQL is to either allow for processes that would otherwise not be easily possible or decrease complexity in processes that might require a manual or resource-intensive component.

The use of Dynamic SQL for these purposes will be dictated by your own business logic, database server version, and the rules and policies used by your development team. While some solutions will be useful to a wide audience, others may prove to be the savior of one specific development environment out of a million. Regardless of how universal the solution is, keeping this tool in mind will allow for difficult database challenges to be solved in creative ways that otherwise could be costly and time-consuming to resolve.

CHAPTER 11

Additional Applications

This final chapter takes a look at some more interesting applications of Dynamic SQL. The goal is to leave you with a variety of practical scripts that can be brought into any database environment and tailored to unique uses. There are many real-world challenges for which Dynamic SQL is an efficient solution and where you can accomplish a great deal of work in compact, reusable code.

Database Maintenance

One of the most challenging areas for DBAs and database developers is in providing regular care and maintenance to their servers, databases, and related software. Common tasks such as defragmenting indexes, maintaining statistics, and managing database backups are critically important to any application. Since every database environment is different, scripts to manage these tasks can and should vary in each. The following section outlines a handful of common maintenance tasks and how Dynamic SQL can be used to build a framework for each task. Once built, these scripts can be expanded upon and customized to meet the needs of your own database servers.

Index Defragmentation

Indexes are the key to optimal query performance. One of the most immediate questions that you should ask when reviewing a poorly performing query is if the correct indexes are in place and if they are adequate. An additional question that should not need to be asked is if those indexes are being properly maintained. Over time as an index is inserted to, updated, and deleted from, the B-tree that it is built on becomes fragmented. The more time that passes, the worse the situation gets and the more time it takes to traverse the B-tree effectively and return the data requested by your queries.

Running jobs regularly that check for index fragmentation and take action as necessary will ensure that this situation never becomes detrimental to application performance. The first task toward achieving this goal is to identify how fragmented your indexes are, and to do so on any set of databases on your server.

This information can be found in the `sys.dm_db_index_physical_stats` dynamic management view. The query in Listing 11-1 joins data from this view into a handful of system views in order to include the name of the database, table, and indexes involved.

E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2_11

Listing 11-1. Query to Determine Index Fragmentation for All Indexes in a Given Database

```
USE AdventureWorks2014
DECLARE @database_name VARCHAR(100) = 'AdventureWorks2014';

SELECT
        SD.name AS database_name,
        SO.name AS object_name,
        SI.name AS index_name,
        IPS.index_type_desc,
        IPS.page_count,
        IPS.avg_fragmentation_in_percent -- Be sure to filter as much as possible...this can
        return a lot of data if you don't filter by database and table.
FROM sys.dm_db_index_physical_stats(NULL, NULL, NULL, NULL , NULL) IPS
INNER JOIN sys.databases SD
ON SD.database_id = IPS.database_id
INNER JOIN sys.indexes SI
ON SI.index_id = IPS.index_id
INNER JOIN sys.objects SO
ON SO.object_id = SI.object_id
AND IPS.object_id = SO.object_id
WHERE alloc_unit_type_desc = 'IN_ROW_DATA'
AND index_level = 0
AND SD.name = @database_name
ORDER BY IPS.avg_fragmentation_in_percent DESC;
```

This query specifically targets one in the filter (based on the parameter declared at the top), but could be adjusted to check any or all user databases on a server. The results in Figure 11-1 show each index, ordered by fragmentation, along with some additional useful information.

	database_name	object_name	index_name	index_type_desc	page_count	avg_fragmentation_in_percent
1	AdventureWorks2014	DatabaseLog	PK_DatabaseLog_DatabaseLogID	NONCLUSTERED INDEX	4	75
2	AdventureWorks2014	BusinessEntityContact	AK_BusinessEntityContact_rowguid	NONCLUSTERED INDEX	4	75
3	AdventureWorks2014	BusinessEntityContact	IX_BusinessEntityContact_PersonID	NONCLUSTERED INDEX	3	66.6666666666667
4	AdventureWorks2014	BusinessEntityContact	IX_BusinessEntityContact_ContactTypeID	NONCLUSTERED INDEX	3	66.6666666666667
5	AdventureWorks2014	ProductReview	IX_ProductReview_ProductID_Name	NONCLUSTERED INDEX	3	66.6666666666667
6	AdventureWorks2014	ProductCostHistory	PK_ProductCostHistory_ProductID_StartDate	CLUSTERED INDEX	3	66.6666666666667
7	AdventureWorks2014	Store	AK_Store_rowguid	NONCLUSTERED INDEX	3	66.6666666666667
8	AdventureWorks2014	ProductDescription	AK_ProductDescription_rowguid	NONCLUSTERED INDEX	3	66.6666666666667
9	AdventureWorks2014	SpecialOfferProduct	PK_SpecialOfferProduct_SpecialOfferID_ProductID	CLUSTERED INDEX	3	66.6666666666667
10	AdventureWorks2014	ProductListPriceHistory	PK_ProductListPriceHistory_ProductID_StartDate	CLUSTERED INDEX	3	66.6666666666667
11	AdventureWorks2014	Employee	AK_Employee_LoginID	NONCLUSTERED INDEX	3	66.6666666666667

Figure 11-1. *Index fragmentation results from the query in Listing 11-1*

Now that you have identified the most fragmented tables, you need to figure out the best way to fix them. There are two options, discussed next.

Index Rebuild

When an index is rebuilt, it is completely replaced with a new copy of the index, built from scratch as though it were just newly created. In SQL Server Standard edition, this is an offline operation, meaning that it can cause contention while running. When rebuilding indexes in Standard Edition, use caution to schedule them at a time when that interruption is tolerable. In Enterprise Edition, rebuilds can be run online, allowing them to operate while other transactions occur at the same time. Regardless of edition, rebuilding indexes is a resource-intensive operation and should be done during off hours when the server has extra resources to spare.

If you cancel an index rebuild, the entire operation will need to roll back, which can also be time-consuming and resource-intensive.

Index Reorganization

Reorganizing an index results in cleanup at the leaf level, reordering pages and reapplying the fill factor as necessary. This operation is always online, regardless of the edition of SQL Server you are running and can be interrupted at any time with no ill effects.

Despite being a somewhat simpler process, an index reorg can potentially take as long as an index rebuild for a very wide index. Keeping track of these times can allow you to periodically review index maintenance tasks and ensure they are running acceptably fast.

Creating an Index Maintenance Solution

Since you now know what the problem is and what tools are available to solve it, you can step through an example solution. The need for Dynamic SQL is immediate: You have multiple databases, tables, indexes, and potential operations. This is a scenario where the Dynamic TSQL will be simpler and easier to implement than a long, procedural solution.

Let's start with a stored procedure that checks the fragmentation level and will choose whether to reorganize or rebuild based on user input. This example uses 10% for a reorg and 35% for a rebuild, as well as those numbers as default parameter values. It will have a `@print_only` flag that determines if you should print the results for review or execute them. The proc will include all databases on the instance, except for `model`, `master`, `msdb`, and `tempdb`. This can easily be customized to act on any set of databases, though. One last addition is the inclusion of the schema name, which is added so that you can support databases with multiple schemas aside from `dbo`. This new script can be viewed in its entirety in Listing 11-2.

Listing 11-2. Simple Index Maintenance Solution Using Dynamic SQL

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'index_maintenance_demo')
BEGIN
        DROP PROCEDURE dbo.index_maintenance_demo;
END
GO

CREATE PROCEDURE dbo.index_maintenance_demo
        @reorganization_percentage TINYINT = 10,
        @rebuild_percentage TINYINT = 35,
        @print_results_only BIT = 1
AS
BEGIN
        DECLARE @sql_command NVARCHAR(MAX) = '';
        DECLARE @parameter_list NVARCHAR(MAX) = '@reorganization_percentage TINYINT,
        @rebuild_percentage TINYINT'
        DECLARE @database_name NVARCHAR(MAX);
        DECLARE @database_list TABLE
                (database_name NVARCHAR(MAX) NOT NULL);
```

```
INSERT INTO @database_list
        (database_name)
SELECT
        name
FROM sys.databases
WHERE databases.name NOT IN ('msdb', 'master', 'TempDB', 'model');

CREATE TABLE #index_maintenance
(       database_name NVARCHAR(MAX),
        schema_name NVARCHAR(MAX),
        object_name NVARCHAR(MAX),
        index_name NVARCHAR(MAX),
        index_type_desc NVARCHAR(MAX),
        page_count BIGINT,
        avg_fragmentation_in_percent FLOAT,
        index_operation NVARCHAR(MAX));

SELECT @sql_command = @sql_command + '
USE [' + database_name + ']

INSERT INTO #index_maintenance
        (database_name, schema_name, object_name, index_name, index_type_desc,
        page_count, avg_fragmentation_in_percent, index_operation)
SELECT
        CAST(SD.name AS NVARCHAR(MAX)) AS database_name,
        CAST(SS.name AS NVARCHAR(MAX)) AS schema_name,
        CAST(SO.name AS NVARCHAR(MAX)) AS object_name,
        CAST(SI.name AS NVARCHAR(MAX)) AS index_name,
        IPS.index_type_desc,
        IPS.page_count,
        IPS.avg_fragmentation_in_percent, -- Be sure to filter as much as possible...
        this can return a lot of data if you dont filter by database and table.
        CAST(CASE
                WHEN IPS.avg_fragmentation_in_percent >= @rebuild_percentage THEN
                ''REBUILD''
                WHEN IPS.avg_fragmentation_in_percent >= @reorganization_percentage
                THEN ''REORGANIZE''
        END AS NVARCHAR(MAX)) AS index_operation
FROM sys.dm_db_index_physical_stats(NULL, NULL, NULL, NULL , NULL) IPS
INNER JOIN sys.databases SD
ON SD.database_id = IPS.database_id
INNER JOIN sys.indexes SI
ON SI.index_id = IPS.index_id
INNER JOIN sys.objects SO
ON SO.object_id = SI.object_id
AND IPS.object_id = SO.object_id
INNER JOIN sys.schemas SS
ON SS.schema_id = SO.schema_id
WHERE alloc_unit_type_desc = ''IN_ROW_DATA''
AND index_level = 0
```

```
        AND SD.name = ''' + database_name + '''
        AND IPS.avg_fragmentation_in_percent >= @reorganization_percentage
        AND SI.name IS NOT NULL -- Only review index, not heap data.
        AND SO.is_ms_shipped = 0 -- Do not perform maintenance on system objects
        ORDER BY SD.name ASC;'
        FROM @database_list
        WHERE database_name IN (SELECT name FROM sys.databases);

        EXEC sp_executesql @sql_command, @parameter_list, @reorganization_percentage,
        @rebuild_percentage;

        SELECT @sql_command = '';
        SELECT @sql_command = @sql_command +
        '        USE [' + database_name + ']
                ALTER INDEX [' + index_name + '] ON [' + schema_name + '].[' + object_name + ']
                ' + index_operation + ';
'
        FROM #index_maintenance;

        SELECT * FROM #index_maintenance
        ORDER BY avg_fragmentation_in_percent DESC;

        IF @print_results_only = 1
                PRINT @sql_command;
        ELSE
                EXEC sp_executesql @sql_command;

        DROP TABLE #index_maintenance;
END
GO
```

This script builds a long command string from a sequence of index rebuild or reorg operations. Note that each set of Dynamic SQL operations builds strings using a dynamically generated list prior to execution. This avoids the need for loops or cursors and accomplishes the tasks very quickly and efficiently. Let's execute this for the default parameters:

```
EXEC dbo.index_maintenance_demo @reorganization_percentage = 10, @rebuild_percentage = 35,
@print_results_only = 1;
```

Since `@print_results_only` is set to 1, no index actions will be taken. The command string will be printed out at the end of the stored procedure, prior to dropping the temporary table. Here is a subset of the results that printed on my server:

```
USE [AdventureWorks2014]
        ALTER INDEX [IX_vProductAndDescription] ON [Production].[vProductAndDescription]
        REORGANIZE;
USE [AdventureWorks2014]
        ALTER INDEX [IX_vStateProvinceCountryRegion] ON [Person].[vStateProvinceCountryRegion]
        REBUILD;
```

```
USE [AdventureWorks2012]
        ALTER INDEX [PK_ProductCostHistory_ProductID_StartDate] ON [Production].
        [ProductCostHistory]
        REBUILD;
USE [AdventureWorks2012]
        ALTER INDEX [AK_ProductDescription_rowguid] ON [Production].[ProductDescription]
        REBUILD;
USE [AdventureWorks2012]
        ALTER INDEX [PK_DatabaseLog_DatabaseLogID] ON [dbo].[DatabaseLog]
        REBUILD;
USE [AdventureWorks2012]
        ALTER INDEX [PK_ProductInventory_ProductID_LocationID] ON [Production].
        [ProductInventory]
        REORGANIZE;
```

When working with long command strings, beware of truncation, either in the string itself or by Management Studio's results pane when printing sample output. As a precaution against this, I've cast all strings in the temporary table as `NVARCHAR(MAX)` to ensure that the command string is not converted to any of the smaller string data types.

It is also important to note that Dynamic SQL was used to gather index fragmentation data, because some of the views, such as `sys.tables` and `dm_db_index_physical_stats`, are database-specific. In order to collect all data for each database, it was necessary to `USE` each database and then check the views within them independently of each other. Similarly, to perform index maintenance, it is necessary to `USE` the appropriate database first, before running a rebuild or reorganize statement.

The contents of the temporary table are also output so you can further review the data returned, as shown in Figure 11-2.

	database_name	schema_name	object_name	index_name	index_type_desc	page_count	avg_fragmentation_in_percent	index_operation
1	AdventureWorks2014	Production	ProductCostHistory	PK_ProductCostHistory_ProductID_StartDate	CLUSTERED INDEX	3	66.6666666666667	REBUILD
2	AdventureWorks2014	Production	ProductDescription	AK_ProductDescription_rowguid	NONCLUSTERED INDEX	3	66.6666666666667	REBUILD
3	AdventureWorks2014	dbo	DatabaseLog	PK_DatabaseLog_DatabaseLogID	NONCLUSTERED INDEX	4	75	REBUILD
4	AdventureWorks2014	Production	ProductInventory	PK_ProductInventory_ProductID_LocationID	CLUSTERED INDEX	7	57.1428571428571	REBUILD
5	AdventureWorks2014	Production	ProductListPriceHistory	PK_ProductListPriceHistory_ProductID_StartDate	CLUSTERED INDEX	3	66.6666666666667	REBUILD
6	AdventureWorks2014	Sales	SpecialOfferProduct	PK_SpecialOfferProduct_SpecialOfferID_ProductID	CLUSTERED INDEX	3	66.6666666666667	REBUILD
7	AdventureWorks2014	Sales	SpecialOfferProduct	AK_SpecialOfferProduct_rowguid	NONCLUSTERED INDEX	2	50	REBUILD
8	AdventureWorks2014	Person	StateProvince	PK_StateProvince_StateProvinceID	CLUSTERED INDEX	2	50	REBUILD
9	AdventureWorks2014	Production	ProductModelProduc...	PK_ProductModelProductDescriptionCulture_Prod...	CLUSTERED INDEX	4	50	REBUILD
10	AdventureWorks2014	Production	BillOfMaterials	AK_BillOfMaterials_ProductAssemblyID_Compone...	CLUSTERED INDEX	20	15	REORGANIZE
11	AdventureWorks2014	Production	BillOfMaterials	PK_BillOfMaterials_BillOfMaterialsID	NONCLUSTERED INDEX	9	33.3333333333333	REORGANIZE
12	AdventureWorks2014	Production	BillOfMaterials	IX_BillOfMaterials_UnitMeasureCode	NONCLUSTERED INDEX	10	30	REORGANIZE

Figure 11-2. *Full fragmentation results as returned from the query in Listing 11-2*

Here you can review each index, its fragmentation level, and the operation that was chosen based on the inputs. If you are confident that this stored procedure does exactly what you want it to, you can allow it to execute the entire command string and clean up all indexes in these databases:

```
EXEC dbo.index_maintenance_demo @reorganization_percentage = 10, @rebuild_percentage = 35,
@print_results_only = 0;
```

After about 30 seconds of waiting, the script completes successfully and your index maintenance is complete! You can add options and continue to customize this script to your heart's content. Some features to consider adding:

- Add `WITH (ONLINE = ON)` to rebuild operations so they can run online (Enterprise edition only).
- Add `WITH (SORT_IN_TEMP = ON)` to rebuild operations so they can sort intermediary rebuild results in TempDB, which can speed up operations. Keep in mind that enough space must be available in TempDB for this to work.
- Adjust the fill factor on an index if one besides the default is needed.
- Check the size of the index and take actions differently based on that information.
- Add logging so that you can review the commands executed, as well as the time needed to complete them.

Use this script as a starting point and tailor it to your environment's needs, regardless of how they may differ from what's presented here. There are an infinite number of ways to customize and improve on this concept, with your imagination being the only barrier between you and the perfect index maintenance solution!

Database Backups

Another necessary database maintenance task is to ensure that all important data is backed up on a regular basis. Maintenance plans are often used for this task, but they lack flexibility and can become very complex if you want to customize them for a variety of use-cases. If you are managing many database servers, all of which have different backup needs, the result can be dozens (or more) of different maintenance plans. Each of these will require the same level of care and maintenance, and hence the same level of technical debt to ensure normal operation over time.

What can often be preferable is to create a backup script tailored to an environment that is capable of being expanded, customized, and adjusted as needed over time. This section covers the three common needs of a backup plan: Full backups, differential backups, and transaction log backups. A common configuration is to run full backups once a week, differentials every other day, and transaction log backups intermittently throughout the day. As was the case with index defragmentation, the larger backups (full and differential) should be run off hours when the system is less used, as backup operations can require significant IO to process.

This stored procedure will execute as often as you want transaction log backups to run. When it is run at the time of day corresponding to `@differential_and_full_backup_time`, one of those will be run instead. `@full_backup_day` indicates which day of the week the full backup should be taken. `@backup_location` provides the location on disk where backups should be saved. Lastly, `@print_output_only` determines if backups should be taken or if the command string should be printed out instead. This stored procedure can be seen in Listing 11-3.

Listing 11-3. Database Backup Stored Procedure Using Dynamic SQL

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'backup_plan')
BEGIN
        DROP PROCEDURE dbo.backup_plan;
END
GO
```

```
CREATE PROCEDURE dbo.backup_plan
        @differential_and_full_backup_time TIME = '00:00:00', -- Default to midnight
        @full_backup_day TINYINT = 1, -- Default to Sunday
        @backup_location NVARCHAR(MAX) = 'E:\SQLBackups\', -- Default to my backup folder
        @print_output_only BIT = 1
AS
BEGIN
        SET NOCOUNT ON;
        DECLARE @current_time TIME = CAST(CURRENT_TIMESTAMP AS TIME);
        DECLARE @current_day TINYINT = DATEPART(DW, CURRENT_TIMESTAMP);
        DECLARE @datetime_string NVARCHAR(MAX) = FORMAT(CURRENT_TIMESTAMP , 'MMddyyyyHHmmss');
        DECLARE @sql_command NVARCHAR(MAX) = '';

        DECLARE @database_list TABLE
                (database_name NVARCHAR(MAX) NOT NULL, recovery_model_desc NVARCHAR(MAX));

        INSERT INTO @database_list
                (database_name, recovery_model_desc)
        SELECT
                name,
                recovery_model_desc
        FROM sys.databases
        WHERE databases.name NOT IN ('msdb', 'master', 'TempDB', 'model');

        -- Check if a full backup is to be taken now.
        IF (@current_day = @full_backup_day) AND (@current_time BETWEEN @differential_and_
        full_backup_time AND DATEADD(MINUTE, 10, @differential_and_full_backup_time))
        BEGIN
                SELECT @sql_command = @sql_command +
                '
                BACKUP DATABASE [' + database_name + ']
                TO DISK = ''' + @backup_location + database_name + '_' + @datetime_string +
                '.bak'';
                '
                FROM @database_list;

                IF @print_output_only = 1
                        PRINT @sql_command;
                ELSE
                        EXEC sp_executesql @sql_command;
        END
        ELSE -- Check if a differential backup is to be taken now.
        IF (@current_day <> @full_backup_day) AND (@current_time BETWEEN @differential_and_
        full_backup_time AND DATEADD(MINUTE, 10, @differential_and_full_backup_time))
        BEGIN
              SELECT @sql_command = '';
                SELECT @sql_command = @sql_command +
                '
                BACKUP DATABASE [' + database_name + ']
                TO DISK = ''' + @backup_location + database_name + '_' + @datetime_string +
                '.dif''
```

```
            WITH DIFFERENTIAL;
            '
            FROM @database_list;

            IF @print_output_only = 1
                    PRINT @sql_command;
            ELSE
                    EXEC sp_executesql @sql_command;
    END
    ELSE -- If neither full or differential, then take a transaction log backup
    BEGIN
          SELECT @sql_command = '';
            SELECT @sql_command = @sql_command +
            '
            BACKUP LOG [' + database_name + ']
            TO DISK = ''' + @backup_location + database_name + '_' + @datetime_string +
            '.trn''
            '
            FROM @database_list
            WHERE recovery_model_desc = 'FULL';

            IF @print_output_only = 1
                    PRINT @sql_command;
            ELSE
                    EXEC sp_executesql @sql_command;
    END
END
```

Note that as with the index maintenance script, this will perform backups on all databases except for `msdb`, `tempdb`, `master`, and `model`. As was the case in all previous scripts, the database list can easily be adjusted to cater to any custom needs. This script can be executed on any schedule and will perform transaction log backups of the database except when it is the allotted time and date for a differential backup or full backup. Assuming that the current time is 7:53pm on Tuesday, you can test the script for each backup use-case:

```
EXEC dbo.backup_plan @differential_and_full_backup_time = '19:50:00', @full_backup_day = 3,
@backup_location = 'E:\SQLBackups\', @print_output_only = 1;
```

This will perform a full backup as the current time is within 10 minutes of the designated full backup time, the full backup day has been set to Tuesday (3), and the backup statements will be printed rather than executed. The command string output is as follows:

```
BACKUP DATABASE [AdventureWorks2012]
TO DISK = 'E:\SQLBackups\AdventureWorks2012_12012015195529.bak';

BACKUP DATABASE [AdventureWorks2014]
TO DISK = 'E:\SQLBackups\AdventureWorks2014_12012015195529.bak';

BACKUP DATABASE [AdventureWorksDW2012]
TO DISK = 'E:\SQLBackups\AdventureWorksDW2012_12012015195529.bak';

BACKUP DATABASE [AdventureWorksDW2014]
TO DISK = 'E:\SQLBackups\AdventureWorksDW2014_12012015195529.bak';
```

If you change `@print_output_only` to zero and execute the stored procedure again, you can verify that the backup files in the directory are output as shown in Figure 11-3.

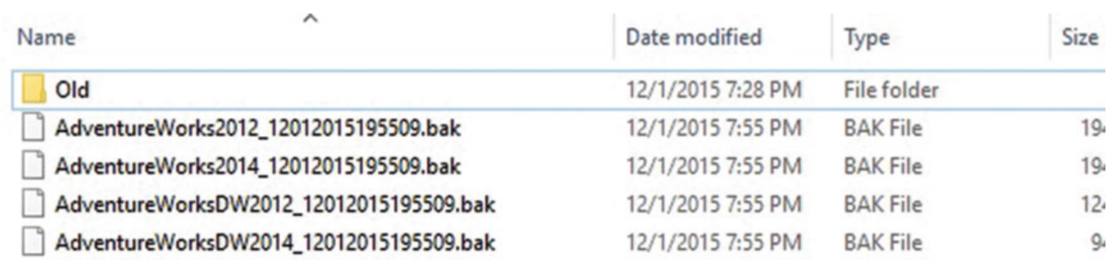


Figure 11-3. *Full backup files created in the dynamic backup script in Listing 11-3*

All four full backups are there with the names that you assigned. Now, let's execute the stored procedure for a differential backup situation:

```
EXEC dbo.backup_plan @differential_and_full_backup_time = '19:50:00', @full_backup_day = 3,
@backup_location = 'E:\SQLBackups\', @print_output_only = 1;
```

The resulting command string is as follows:

```
BACKUP DATABASE [AdventureWorks2012]
TO DISK = 'E:\SQLBackups\AdventureWorks2012_12012015200242.dif'
WITH DIFFERENTIAL;

BACKUP DATABASE [AdventureWorks2014]
TO DISK = 'E:\SQLBackups\AdventureWorks2014_12012015200242.dif'
WITH DIFFERENTIAL;

BACKUP DATABASE [AdventureWorksDW2012]
TO DISK = 'E:\SQLBackups\AdventureWorksDW2012_12012015200242.dif'
WITH DIFFERENTIAL;

BACKUP DATABASE [AdventureWorksDW2014]
TO DISK = 'E:\SQLBackups\AdventureWorksDW2014_12012015200242.dif'
WITH DIFFERENTIAL;
```

In this case, today is not the correct day for a full backup, but it is time for a differential backup. If you execute this with `@print_output_only` set to zero, you can verify that the backup files were correctly generated in Figure 11-4.

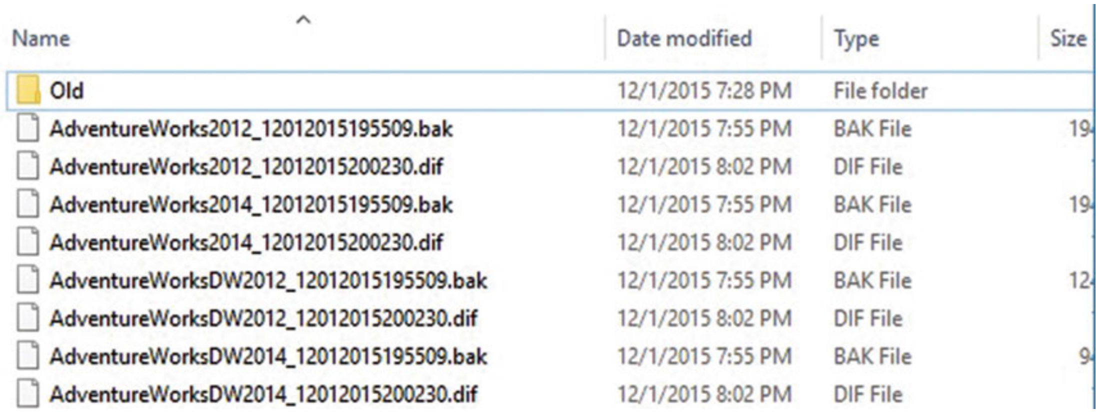


Figure 11-4. *Differential backup files created in the dynamic backup script in Listing 11-3*

In addition to the four full backups created earlier, you can now confirm that four differential backups have been created in the same folder. Lastly, let's run a command that will trigger a transaction log backup:

```
EXEC dbo.backup_plan @differential_and_full_backup_time = '00:00:00', @full_backup_day = 1,
@backup_location = 'E:\SQLBackups\', @print_output_only = 1;
```

Here, the full backup day is Sunday and the full/differential backup time is midnight. Since it is currently none of these times, a transaction log backup is taken instead. The resulting command string is as follows:

```
BACKUP LOG [AdventureWorks2014]
TO DISK = 'E:\SQLBackups\AdventureWorks2014_12012015200631.trn'
```

Note that only a single database is getting backed up. This may at first glance appear to be an error, since you explicitly told this stored procedure to run backups against four databases, but in fact is correct. You cannot run transaction log backups on any database in the simple recovery mode. On my server, three of the four databases included in this backup plan are in simple recovery and were therefore explicitly omitted from that step. You can verify this with the following query:

```
SELECT
        name,
        recovery_model_desc
from sys.databases
WHERE name IN ('AdventureWorks2012', 'AdventureWorks2014', 'AdventureWorksDW2012',
'AdventureWorksDW2014');
```

The results of this query confirm this finding, as shown in Figure 11-5.

	name	recovery_model_desc
1	AdventureWorks2012	SIMPLE
2	AdventureWorks2014	FULL
3	AdventureWorksDW2012	SIMPLE
4	AdventureWorksDW2014	SIMPLE

***Figure 11-5.** Verifying the recovery model for a specific set of databases*

■ **Note** Production databases should be set to the full recovery mode or given unique treatment so that important data is backed up as frequently as necessary!

When you execute the stored proc with `@print_output_only` set to zero, the output folder can be inspected and the appropriate results verified in Figure 11-6.

Name	Date modified	Type	Size
Old	12/1/2015 7:28 PM	File folder	
AdventureWorks2012_12012015195509.bak	12/1/2015 7:55 PM	BAK File	19
AdventureWorks2012_12012015200230.dif	12/1/2015 8:02 PM	DIF File	
AdventureWorks2014_12012015195509.bak	12/1/2015 7:55 PM	BAK File	19
AdventureWorks2014_12012015200230.dif	12/1/2015 8:02 PM	DIF File	
AdventureWorks2014_12012015200435.trn	12/1/2015 8:04 PM	TRN File	
AdventureWorksDW2012_12012015195509.bak	12/1/2015 7:55 PM	BAK File	12
AdventureWorksDW2012_12012015200230.dif	12/1/2015 8:02 PM	DIF File	
AdventureWorksDW2014_12012015195509.bak	12/1/2015 7:55 PM	BAK File	9
AdventureWorksDW2014_12012015200230.dif	12/1/2015 8:02 PM	DIF File	

***Figure 11-6.** Additional transaction log backup taken with the script in Listing 11-3*

A single new file was added: a transaction log backup for `AdventureWorks2014`, which happens to be in the `FULL` recovery mode, as shown.

This stored procedure illustrates a basic framework for building your own customized backup plan, providing complete control over all of the details. As an added bonus, you can accomplish your tasks using a single job and stored procedure, rather than potentially many maintenance plans and/or maintenance plan tasks.

Some possibilities for additional functionality include:

- Logging of backup time and duration for each operation.
- Cleanup of old backup records in MSDB.
- Cleanup of old backup files from the output location.
- Customized alerts if backups fail or take longer than a specific time limit.
- Try/catch blocks in order to manage any errors in the stored procedure.

There are certainly many other options available for your consideration. In this example, all databases (except for a handful of system ones) were backed up, but you could just as easily have omitted the WHERE clause or adjusted it so that you backed up a specific set of databases on the server. Additionally, system databases could be managed separately if they had a unique set of rules to follow.

The backup times for this stored procedure were determined by the job run time, but could also be built in as stored proc parameters. Both scenarios work and which one you use depends on how you prefer to manage that data. An additional option that would go well with parameters is to store metadata in a permanent control table. This would provide information about databases to backup, frequency, and type and could easily be customized to fit the needs of your environment.

If running a stored procedure in SQL Server seems limiting for the operations you are considering, then you could use PowerShell or SSIS to provide better access to the file system and Windows functionality. As with the index maintenance example, the limits to your success with this model are primarily time and creativity.

Saving Generated Scripts

Dynamic SQL can be written as part of stored procedures in order to execute as needed by an application, but it also be saved for later. Dynamic SQL can be used to generate a command string that is then saved to a file or a new stored procedure in order to be executed at a future time or as part of another application.

This flexibility can be convenient when there is a process with many steps in which certain ones must execute on a rigid schedule. For example, you may wish to generate a script based on the schema in a database at midnight, but not return the data itself until a data load completes at 4AM. Alternatively, you may wish to review the SQL file or save it elsewhere for posterity, prior to or in addition to executing it. One other way to accomplish this and avoid moving data into the operating system is to store it in a table.

Saving Scripts to a Table

The simplest method of saving a command string is to insert it into a table. This allows for additional flexibility in that you could add timestamps to commands or save old commands. To facilitate this process, you will create a table to store the command data, as shown in Listing 11-4.

Listing 11-4. Table to Store Dynamic SQL Output

```
CREATE TABLE dbo.sql_command
(       command_id INT NOT NULL IDENTITY(1,1) CONSTRAINT PK_sql_commands PRIMARY KEY
        CLUSTERED,
        sql_command NVARCHAR(MAX) NOT NULL,
        time_stamp DATETIME NOT NULL CONSTRAINT DF_sql_commands_time_stamp DEFAULT
        (CURRENT_TIMESTAMP)    );
```

Note that there is an additional column that stores a default timestamp. This ensures that any TSQL that is saved can be associated easily with the time it was generated. In order to demonstrate using this table, let's modify the index defragmentation stored procedure from earlier in order to insert to it, rather than print to the GUI, as shown in Listing 11-5.

Listing 11-5. Index Maintenance Stored Procedure with an Output-To-Table Option

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name =
'index_maintenance_demo_output')
BEGIN
        DROP PROCEDURE dbo.index_maintenance_demo_output;
END
GO

CREATE PROCEDURE dbo.index_maintenance_demo_output
        @reorganization_percentage TINYINT = 10,
        @rebuild_percentage TINYINT = 35,
        @print_results_to_file_only BIT = 1
AS
BEGIN
        DECLARE @sql_command NVARCHAR(MAX) = '';
        DECLARE @parameter_list NVARCHAR(MAX) = '@reorganization_percentage TINYINT,
        @rebuild_percentage TINYINT'
        DECLARE @database_name NVARCHAR(MAX);
        DECLARE @database_list TABLE
                (database_name NVARCHAR(MAX) NOT NULL);

        INSERT INTO @database_list
                (database_name)
        VALUES
                ('AdventureWorks2012'),
                ('AdventureWorks2014'),
                ('AdventureWorksDW2012'),
                ('AdventureWorksDW2014');

        CREATE TABLE #index_maintenance
        (       database_name NVARCHAR(MAX),
                schema_name NVARCHAR(MAX),
                object_name NVARCHAR(MAX),
                index_name NVARCHAR(MAX),
                index_type_desc NVARCHAR(MAX),
                page_count BIGINT,
                avg_fragmentation_in_percent FLOAT,
                index_operation NVARCHAR(MAX));

        SELECT @sql_command = @sql_command + '
        USE [' + database_name + ']

        INSERT INTO #index_maintenance
                (database_name, schema_name, object_name, index_name, index_type_desc,
                page_count, avg_fragmentation_in_percent, index_operation)
        SELECT
                CAST(SD.name AS NVARCHAR(MAX)) AS database_name,
                CAST(SS.name AS NVARCHAR(MAX)) AS schema_name,
                CAST(SO.name AS NVARCHAR(MAX)) AS object_name,
                CAST(SI.name AS NVARCHAR(MAX)) AS index_name,
                IPS.index_type_desc,
```

```
        IPS.page_count,
        IPS.avg_fragmentation_in_percent, -- Be sure to filter as much as
        possible...this can return a lot of data if you dont filter by database and
        table.
        CAST(CASE
                WHEN IPS.avg_fragmentation_in_percent >= @rebuild_percentage THEN
                ''REBUILD''
                WHEN IPS.avg_fragmentation_in_percent >= @reorganization_percentage
                THEN ''REORGANIZE''
        END AS NVARCHAR(MAX)) AS index_operation
FROM sys.dm_db_index_physical_stats(NULL, NULL, NULL, NULL , NULL) IPS
INNER JOIN sys.databases SD
ON SD.database_id = IPS.database_id
INNER JOIN sys.indexes SI
ON SI.index_id = IPS.index_id
INNER JOIN sys.objects SO
ON SO.object_id = SI.object_id
AND IPS.object_id = SO.object_id
INNER JOIN sys.schemas SS
ON SS.schema_id = SO.schema_id
WHERE alloc_unit_type_desc = ''IN_ROW_DATA''
AND index_level = 0
AND SD.name = ''' + database_name + '''
AND IPS.avg_fragmentation_in_percent >= @reorganization_percentage
AND SI.name IS NOT NULL -- Only review index, not heap data.
AND SO.is_ms_shipped = 0 -- Do not perform maintenance on system objects
ORDER BY SD.name ASC;'
FROM @database_list
WHERE database_name IN (SELECT name FROM sys.databases);

EXEC sp_executesql @sql_command, @parameter_list, @reorganization_percentage,
@rebuild_percentage;

SELECT @sql_command = '';
SELECT @sql_command = @sql_command +
'        USE [' + database_name + ']
        ALTER INDEX [' + index_name + '] ON [' + schema_name + '].[' + object_name + ']
        ' + index_operation + ';
'
FROM #index_maintenance;

IF @print_results_to_file_only = 1
        INSERT INTO dbo.sql_command
                (sql_command)
        SELECT
                @sql_command
ELSE
        EXEC sp_executesql @sql_command;

DROP TABLE #index_maintenance;
END
```

Note that the only difference, aside from renaming a few variables, is to perform an INSERT to dbo.sql_command rather than print the output. Let's execute the stored procedure a few times and then review the contents of the table:

```
EXEC dbo.index_maintenance_demo_output @reorganization_percentage = 10,
@rebuild_percentage = 35, @print_results_to_file_only = 1;
EXEC dbo.index_maintenance_demo_output @reorganization_percentage = 20,
@rebuild_percentage = 50, @print_results_to_file_only = 1;
EXEC dbo.index_maintenance_demo_output @reorganization_percentage = 30,
@rebuild_percentage = 75, @print_results_to_file_only = 1;
EXEC dbo.index_maintenance_demo_output @reorganization_percentage = 5,
@rebuild_percentage = 10, @print_results_to_file_only = 1;
```

These all pass different values for the parameters, but otherwise are the same. Reviewing the new table reveals that the command strings were saved as expected, along with timestamps, as shown in Figure 11-7.

command_id	sql_command	time_stamp
2	USE [AdventureWorks2012] ALTER INDEX [PK_ProductCostHistory_ProductID_StartDate] ON [Production].[ProductCostHistory] REBUILD; USE [Ad...	2015-12-06 13:16:27.597
3	USE [AdventureWorks2012] ALTER INDEX [PK_ProductCostHistory_ProductID_StartDate] ON [Production].[ProductCostHistory] REBUILD; USE [Ad...	2015-12-06 13:16:27.743
4	USE [AdventureWorks2012] ALTER INDEX [PK_ProductCostHistory_ProductID_StartDate] ON [Production].[ProductCostHistory] REORGANIZE; US...	2015-12-06 13:16:27.893
5	USE [AdventureWorks2012] ALTER INDEX [PK_ProductCostHistory_ProductID_StartDate] ON [Production].[ProductCostHistory] REBUILD; USE [Ad...	2015-12-06 13:16:28.040

Figure 11-7. *ALTER INDEX statements created by the script in Listing 11-5*

Once here, they could be executed at any time in the future or reviewed by a DBA or developer to ensure that the command strings are being generated correctly. In addition to delaying execution, this tactic can be excellent for debugging problematic Dynamic SQL, or simply allowing for command strings to be logged prior to execution. The script in Listing 11-6 is an adaption of the backup script from earlier, which will write the generated command strings to a physical SQL file.

Listing 11-6. Backup Maintenance Script that Outputs the Command String to a File

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'backup_plan_output')
BEGIN
        DROP PROCEDURE dbo.backup_plan_output;
END
GO

CREATE PROCEDURE dbo.backup_plan_output
        @differential_and_full_backup_time TIME = '00:00:00', -- Default to midnight
        @full_backup_day TINYINT = 1, -- Default to Sunday
        @backup_location NVARCHAR(MAX) = 'E:\SQLBackups\', -- Default to my backup folder
        @sql_data_location NVARCHAR(MAX) = 'E:\SQLData\', -- Default to my SQL data file
        folder
        @sql_server_name NVARCHAR(MAX) = 'SSANDILE\EDSQLSERVER14',
        -- Server name to operate on
        @print_output_to_file_only BIT = 1
AS
BEGIN
        SET NOCOUNT ON;
        DECLARE @current_time TIME = CAST(CURRENT_TIMESTAMP AS TIME);
        DECLARE @current_day TINYINT = DATEPART(DW, CURRENT_TIMESTAMP);
```

```
DECLARE @datetime_string NVARCHAR(MAX) = FORMAT(CURRENT_TIMESTAMP ,
'MMddyyyyHHmmss');
DECLARE @sql_command NVARCHAR(MAX) = '';
DECLARE @bcp_command VARCHAR(4000);

DECLARE @database_list TABLE
        (database_name NVARCHAR(MAX) NOT NULL, recovery_model_desc NVARCHAR(MAX));

INSERT INTO @database_list
        (database_name, recovery_model_desc)
SELECT
        name,
        recovery_model_desc
FROM sys.databases
WHERE databases.name NOT IN ('msdb', 'master', 'TempDB', 'model');

-- Check if a full backup is to be taken now.
IF (@current_day = @full_backup_day) AND (@current_time BETWEEN @differential_and_
full_backup_time AND DATEADD(MINUTE, 10, @differential_and_full_backup_time))
BEGIN
        SELECT @sql_command = @sql_command +
        'BACKUP DATABASE [' + database_name + '] TO DISK = ''''' + @backup_location
        + database_name + '_' + @datetime_string + '.bak'''';'
        FROM @database_list;

        IF @print_output_to_file_only = 1
                BEGIN
                        SELECT @bcp_command =
                        'bcp "SELECT ''' + @sql_command + '''" queryout ' + @sql_
                        data_location + 'TempOutput.sql -c -T -S' + @sql_server_name
                        + ' -dAdventureWorks2014';
                        EXEC xp_cmdshell @bcp_command;
                        SELECT @bcp_command = 'type "' + @sql_data_location +
                        'TempOutput.sql" >> "' + @sql_data_location +
                        'QueryOutput.sql"';
                        EXEC xp_cmdshell @bcp_command;
                END
        ELSE
                EXEC sp_executesql @sql_command;
END
ELSE -- Check if a differential backup is to be taken now.
IF (@current_day <> @full_backup_day) AND (@current_time BETWEEN @differential_and_
full_backup_time AND DATEADD(MINUTE, 10, @differential_and_full_backup_time))
BEGIN
        SELECT @sql_command = '';
        SELECT @sql_command = @sql_command +
        'BACKUP DATABASE [' + database_name + '] TO DISK = ''''' + @backup_location
        + database_name + '_' + @datetime_string + '.dif'''' WITH DIFFERENTIAL;'
        FROM @database_list;
```

```
            IF @print_output_to_file_only = 1
                    BEGIN
                            SELECT @bcp_command =
                            'bcp "SELECT ''' + @sql_command + '''" queryout ' +
                            @sql_data_location + 'TempOutput.sql -c -T -S' +
                            @sql_server_name + ' -dAdventureWorks2014';
                            EXEC xp_cmdshell @bcp_command;
                            SELECT @bcp_command = 'type "' + @sql_data_location +
                            'TempOutput.sql" >> "' + @sql_data_location +
                            'QueryOutput.sql"';
                            EXEC xp_cmdshell @bcp_command;
                    END
            ELSE
                    EXEC sp_executesql @sql_command;
    END
    ELSE -- If neither full or differential, then take a transaction log backup
    BEGIN
            SELECT @sql_command = '';
            SELECT @sql_command = @sql_command +
            'BACKUP LOG [' + database_name + '] TO DISK = ''''' + @backup_location +
            database_name + '_' + @datetime_string + '.trn'''''
            FROM @database_list
            WHERE recovery_model_desc = 'FULL';

            IF @print_output_to_file_only = 1
                    BEGIN
                            SELECT @bcp_command =
                            'bcp "SELECT ''' + @sql_command + '''" queryout ' +
                            @sql_data_location + 'TempOutput.sql -c -T -S' +
                            @sql_server_name + ' -dAdventureWorks2014';
                            EXEC xp_cmdshell @bcp_command;
                            SELECT @bcp_command = 'type "' + @sql_data_location +
                            'TempOutput.sql" >> "' + @sql_data_location +
                            '\QueryOutput.sql"';
                            EXEC xp_cmdshell @bcp_command;
                    END
            ELSE
                    EXEC sp_executesql @sql_command;
    END
END
GO
```

Instead of printing the command string, this script outputs it to a file. Note that since BCP will by default overwrite the destination file, you must insert each new command string to an intermediary file, `TempOutput.sql`, prior to appending the output to its final destination, `QueryOutput.sql`. File paths and the server name have been parameterized in order to make this proc more versatile. Let's run some examples from earlier:

```
EXEC dbo.backup_plan_output @differential_and_full_backup_time = '13:55:00', @full_backup_
day = 3, @backup_location = 'E:\SQLBackups\',
         @sql_data_location = 'E:\SQLData\', @sql_server_name = 'SSANDILE\EDSQLSERVER14',
         @print_output_to_file_only = 1;
```

```
EXEC dbo.backup_plan_output @differential_and_full_backup_time = '13:55:00', @full_backup_
day = 1, @backup_location = 'E:\SQLBackups\',
         @sql_data_location = 'E:\SQLData\', @sql_server_name = 'SSANDILE\EDSQLSERVER14',
         @print_output_to_file_only = 1;
EXEC dbo.backup_plan_output @differential_and_full_backup_time = '10:00:00', @full_backup_
day = 1, @backup_location = 'E:\SQLBackups\',
         @sql_data_location = 'E:\SQLData\', @sql_server_name = 'SSANDILE\EDSQLSERVER14',
         @print_output_to_file_only = 1;
```

When run, no backups are taken. Instead, the command strings are sent to the indicated text files. The following are the contents of `QueryOutput.sql`:

```
BACKUP DATABASE [AdventureWorks2012] TO DISK = 'e:\SQLBackups\AdventureWorks2012_
12062015140236.dif' WITH DIFFERENTIAL;BACKUP DATABASE [AdventureWorks2014] TO DISK =
'e:\SQLBackups\AdventureWorks2014_12062015140236.dif' WITH DIFFERENTIAL;BACKUP DATABASE
[AdventureWorksDW2012] TO DISK = 'e:\SQLBackups\AdventureWorksDW2012_12062015140236.dif'
WITH DIFFERENTIAL;BACKUP DATABASE [AdventureWorksDW2014] TO DISK = 'e:\SQLBackups\
AdventureWorksDW2014_12062015140236.dif' WITH DIFFERENTIAL;

BACKUP DATABASE [AdventureWorks2012] TO DISK = 'e:\SQLBackups\
AdventureWorks2012_12062015140236.bak';BACKUP DATABASE [AdventureWorks2014] TO DISK =
'e:\SQLBackups\AdventureWorks2014_12062015140236.bak';BACKUP DATABASE [AdventureWorksDW2012]
TO DISK = 'e:\SQLBackups\AdventureWorksDW2012_12062015140236.bak';BACKUP DATABASE
[AdventureWorksDW2014] TO DISK = 'e:\SQLBackups\AdventureWorksDW2014_12062015140236.bak';

BACKUP LOG [AdventureWorks2014] TO DISK = 'e:\SQLBackups\AdventureWorks2014_12062015140236.trn'
```

The output file lacks spacing, as BCP works best with single-line TSQL queries. If you wanted to improve the spacing, you could easily add intermediary steps into the BCP commands in order to insert newlines into the file. Regardless, the output is functionally correct and will perform the requested backups to the specified output folder.

Note the use of `xp_cmdshell` in the stored procedure. This is typically used when it is necessary to run file operations or OS commands from within SQL Server. Typically, this is only used in restricted or private environments, as it can be a security threat when allowed on a public server. Consider your use-case carefully before implementing it, and if your server is in a public environment, use SSIS, PowerShell, or another tool instead.

By default, `xp_cmdshell` is disabled, but you can enable it with the TSQL in Listing 11-7.

Listing 11-7. Enabling xp_cmdshell

```
EXEC sp_configure 'show advanced options', 1
GO
RECONFIGURE
GO
EXEC sp_configure 'xp_cmdshell', 1
GO
RECONFIGURE
GO
```

For more information on the pros and cons of `xp_cmdshell`, see Chapters 2 and 4, which cover SQL Injection and security, respectively. Alternatively, PowerShell can be used to control OS operations in order to avoid its use.

Executing TSQL on Other Servers

When managing multiple servers, there often are times when you'll need to execute TSQL from the current server that will run remotely on another SQL Server. While these TSQL statements are not being executed with Dynamic SQL, the statement creation and execution is very similar and worth a short demonstration.

Consider a scenario in which you have a centralized reporting server and want to pull data from the local server, in addition to others that you have onsite. You would want to loop through each server, pulling data from each and returning it to the target data store locally. First, let's create a simple log table for the next example:

```
CREATE TABLE dbo.recent_product_counts
	(	count_id INT NOT NULL IDENTITY(1,1) CONSTRAINT PK_recent_product_counts
	PRIMARY KEY CLUSTERED,
		product_count INT NOT NULL,
		server_name NVARCHAR(128),
		sample_time DATETIME NOT NULL CONSTRAINT DF_recent_product_counts DEFAULT
		(CURRENT_TIMESTAMP));
```

With a place to store the results, you'll create a stored procedure that illustrates using OPENQUERY in order to return a specific row count from a remote server and store the results in this table. This can be seen in Listing 11-8.

Listing 11-8. Using Dynamic SQL and OPENQUERY to Retrieve Data from Remote Servers

```
IF EXISTS (SELECT * FROM sys.procedures WHERE procedures.name = 'get_product_count_all_
servers')
BEGIN
	DROP PROCEDURE dbo.get_product_count_all_servers;
END
GO

CREATE PROCEDURE dbo.get_product_count_all_servers
AS
BEGIN
	SET NOCOUNT ON;
	DECLARE @sql_command NVARCHAR(MAX) = '';

	SELECT
		name AS server_name
	INTO #servers
	FROM sys.servers;

	SELECT @sql_command = @sql_command + '
	INSERT INTO AdventureWorks2014.dbo.recent_product_counts
		(product_count, server_name)
	SELECT
		product_count,
		''' + server_name + '''
	FROM OPENQUERY([' + server_name + '], ''SELECT COUNT(*) AS product_count FROM
	AdventureWorks2014.Production.Product WHERE ModifiedDate >= ''''2/8/2014'''''');'
	FROM #servers
```

```
        WHERE server_name <> @@SERVERNAME;

        SELECT @sql_command = @sql_command + '
        INSERT INTO AdventureWorks2014.dbo.recent_product_counts
                (product_count, server_name)
        SELECT
                COUNT(*),
                @@SERVERNAME
        FROM AdventureWorks2014.Production.Product WHERE ModifiedDate >= ''2/8/2014''';

        EXEC sp_executesql @sql_command;

        DROP TABLE #servers;
END
```

There are two sections in this stored procedure: The first will generate TSQL to access all servers in `sys.servers` that are not the local server. The second manages the local server only, as the syntax to access it does not require `OPENQUERY`. After running this query twice, the contents of `recent_product_counts` are shown in Figure 11-8.

count_id	product_count	server_name	sample_time
1	504	SANDILE\EDSQLSERVER2016	2015-12-06 14:50:22.927
2	504	SANDILE\EDSQLSERVER14	2015-12-06 14:50:22.927
3	504	SANDILE\EDSQLSERVER2016	2015-12-06 14:52:09.200
4	504	SANDILE\EDSQLSERVER14	2015-12-06 14:52:09.203

Figure 11-8. *Product counts collected from multiple servers, using the proc in Listing 11-8*

In the case of my computer, there is only one other server available to query, but if there were more, each would be included in the result set. The `ModifiedDate` used in the stored procedure would typically be a current day, week, or month of interest based on the current date and time, but since the data in `AdventureWorks` is static, you need to look back a bit further in order to collect meaningful counts.

It is not necessary to query for all SQL Servers in `sys.servers` either. A custom list could be created, or a server table could be created and accessed in order to manage any number of local or remove servers. Also note the use of many apostrophes in the command string text. Since `OPENQUERY` requires an apostrophe-delimited string, as does `sp_executesql`, you need to double the number of apostrophes used. This ensures that you maintain the correct number of string delimiters when the final queries are passed to each SQL Server for execution.

Debug often when nesting strings in a manner like this to ensure that you get the apostrophe count correct. Printing the command string prior to execution will help to ensure that the output is as expected. When in doubt, start from scratch and build the statement up one level at a time, until it is complete. In this example, the number of apostrophes is doubled as the entire TSQL statement is nested in another string, but different applications of Dynamic SQL may result in slightly different results.

The rewards for writing this sort of Dynamic SQL carefully will outweigh any of the complexities of nesting strings within each other. Being able to efficiently retrieve important data from other servers without loops, maintenance plans, or SSIS packages can be beneficial when looking for a simple solution to a data access need such as this.

Conclusion

This chapter presented a variety of applications that used many of the techniques presented in this book. Many of these scripts were very open-ended, allowing for a great deal of customization as they are built and implemented. List generation allowed for the avoidance of cursors and loops when building command strings, making execution very efficient.

There are countless other tasks that will present themselves over time in which Dynamic SQL or many of its related topics will be invaluable for solving. Even when you're not developing new applications, knowledge of these tools allows you to be vigilant when reviewing others' work or when troubleshooting performance or application problems.

Be creative and willing to write something new, even if little content is available to get you started. Many great tools have been built as a result of the question, "Why hasn't anyone done this yet?!" This book has provided a starting point, but as new versions of SQL Server and other database tools are released, and as the complexity of software applications increases with time, the opportunity for novel solutions increases.

Even if you think an idea is a dead end, explore it anyway and doubly so if someone else is claiming it's a dead end. I would wager that over half of the "brilliant solutions" I've come up with have lead to absolutely nothing of use. The remainder are what keep me optimistic about database development and optimization throughout my career.

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E. Pollack, *Dynamic SQL*, DOI 10.1007/978-1-4842-1811-2

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