An easy way to reduce the number of log disk writes is to include the action queries within an explicit transaction.

```
DECLARE @Count INT = 1;
DBCC SQLPERF(LOGSPACE);
BEGIN TRANSACTION
WHILE @Count <= 10000
    BEGIN
        INSERT  INTO dbo.Test1
                (C1)
        VALUES  (@Count % 256) ;
        SET @Count = @Count + 1 ;
        END
COMMIT
DBCC SQLPERF(LOGSPACE);
```

The defined transaction scope (between the `BEGIN TRANSACTION` and `COMMIT` pair of commands) expands the scope of atomicity to the multiple `INSERT` statements included within the transaction. This decreases the number of log disk writes and improves the performance of the database functionality. To test this theory, run the following T-SQL command before and after each of the `WHILE` loops:

```
DBCC SQLPERF(LOGSPACE);
```

This will show you the percentage of log space used. On running the first set of inserts on my database, the log went from 3.2 percent used to 3.3 percent. When running the second set of inserts, the log grew about 6 percent.

The best way is to work with sets of data rather than individual rows. A `WHILE` loop can be an inherently costly operation, like a cursor (more details on cursors in Chapter 23). So, running a query that avoids the `WHILE` loop and instead works from a set-based approach is even better.

```
SELECT TOP 10000
       IDENTITY(INT, 1, 1) AS n
INTO #Tally
FROM master.dbo.syscolumns AS scl,
     master.dbo.syscolumns AS sc2;
DBCC SQLPERF(LOGSPACE);
```

```
BEGIN TRANSACTION
INSERT INTO dbo.Test1 (C1)
SELECT TOP 1000
       (n % 256)
FROM #Tally AS t
COMMIT
```

Running this query with the `DBCC SQLPERF()` function before and after showed less than .01 percent growth of the used space within the log, and it ran in 41ms as compared to more than 2s for the `WHILE` loop.

One area of caution, however, is that by including too many data manipulation queries within a transaction, the duration of the transaction is increased. During that time, all other queries trying to access the resources referred to in the transaction are blocked. Rollback duration and recovery time during a restore increase because of long transactions.

Reduce Lock Overhead

By default, all four SQL statements (`SELECT`, `INSERT`, `UPDATE`, and `DELETE`) use database locks to isolate their work from that of other SQL statements. This lock management adds performance overhead to the query. The performance of a query can be improved by requesting fewer locks. By extension, the performance of other queries are also improved because they have to wait a shorter period of time to obtain their own locks.

By default, SQL Server can provide row-level locks. For a query working on a large number of rows, requesting a row lock on all the individual rows adds a significant overhead to the lock-management process. You can reduce this lock overhead by decreasing the lock granularity, say to the page level or table level. SQL Server performs the lock escalation dynamically by taking into consideration the lock overheads. Therefore, generally, it is not necessary to manually escalate the lock level. But, if required, you can control the concurrency of a query programmatically using lock hints as follows:

```
SELECT * FROM <TableName> WITH(PAGLOCK)  --Use page level lock
```

Similarly, by default, SQL Server uses locks for SELECT statements besides those for INSERT, UPDATE, and DELETE statements. This allows the SELECT statements to read data that isn't being modified. In some cases, the data may be quite static, and it doesn't go through much modification. In such cases, you can reduce the lock overhead of the SELECT statements in one of the following ways:

- Mark the database as READONLY.

```
ALTER DATABASE <DatabaseName> SET READ_ONLY
```

  This allows users to retrieve data from the database, but it prevents them from modifying the data. The setting takes effect immediately. If occasional modifications to the database are required, then it may be temporarily converted to READWRITE mode.

```
ALTER DATABASE <DatabaseName> SET READ_WRITE
<Database modifications>
ALTER DATABASE <DatabaseName> SET READONLY
```

- Use one of the snapshot isolations.

  SQL Server provides a mechanism to put versions of data into tempdb as updates are occurring, radically reducing locking overhead and blocking for read operations. You can change the isolation level of the database by using an ALTER statement.

```
ALTER DATABASE AdventureWorks2017 SET READ_COMMITTED_SNAPSHOT ON;
```

- Prevent SELECT statements from requesting any lock.

```
SELECT * FROM <TableName> WITH(NOLOCK)
```

  This prevents the SELECT statement from requesting any lock, and it is applicable to SELECT statements only. Although the NOLOCK hint can't be used directly on the tables referred to in the action queries (INSERT, UPDATE, and DELETE), it may be used on the data retrieval part of the action queries, as shown here:

```
DELETE Sales.SalesOrderDetail
FROM Sales.SalesOrderDetail AS sod WITH (NOLOCK)
    JOIN Production.Product AS p WITH (NOLOCK)
        ON sod.ProductID = p.ProductID
           AND p.ProductID = 0;
```

Just know that this leads to dirty reads, which can cause duplicate rows or missing rows and is therefore considered to be a last resort to control locking. In fact, this is considered to be quite dangerous and will lead to improper results. The best approach is to mark the database as read-only or use one of the snapshot isolation levels.

This is a huge topic, and a lot more can be said about it. I discuss the different types of lock requests and how to manage lock overhead in the next chapter. If you made any of the proposed changes to the database from this section, I recommend restoring from a backup.

Summary

As discussed in this chapter, to improve the performance of a database application, it is important to ensure that SQL queries are designed properly to benefit from performance enhancement techniques such as indexes, stored procedures, database constraints, and so on. Ensure that queries are resource friendly and don't prevent the use of indexes. In many cases, the optimizer has the ability to generate cost-effective execution plans irrespective of query structure, but it is still a good practice to design the queries properly in the first place. Even after you design individual queries for great performance, the overall performance of a database application may not be satisfactory. It is important not only to improve the performance of individual queries but also to ensure that they work well with other queries without causing serious blocking issues. In the next chapter, you will look into the different blocking aspects of a database application.

CHAPTER 21

Blocking and Blocked Processes

You would ideally like your database application to scale linearly with the number of database users and the volume of data. However, it is common to find that performance degrades as the number of users increases and as the volume of data grows. One cause for degradation, especially associated with ever-increasing scale, is blocking. In fact, database blocking is usually one of the biggest enemies of scalability for database applications.

In this chapter, I cover the following topics:

- The fundamentals of blocking in SQL Server
- The ACID properties of a transactional database
- Database lock granularity, escalation, modes, and compatibility
- ANSI isolation levels
- The effect of indexes on locking
- The information necessary to analyze blocking
- A SQL script to collect blocking information
- Resolutions and recommendations to avoid blocking
- Techniques to automate the blocking detection and information collection processes

G. Fritchey, *SQL Server 2017 Query Performance Tuning*, https://doi.org/10.1007/978-1-4842-3888-2_21

Blocking Fundamentals

In an ideal world, every SQL query would be able to execute concurrently, without any blocking by other queries. However, in the real world, queries *do* block each other, similar to the way a car crossing through a green traffic signal at an intersection blocks other cars waiting to cross the intersection. In SQL Server, this traffic management takes the form of the *lock manager,* which controls concurrent access to a database resource to maintain data consistency. The concurrent access to a database resource is controlled across multiple database connections.

I want to make sure things are clear before moving on. Three terms are used within databases that sound the same and are interrelated but have different meanings. These are frequently confused, and people often use the terms incorrectly and interchangeably. These terms are *locking, blocking,* and *deadlocking.* Locking is an integral part of the process of SQL Server managing multiple sessions. When a session needs access to a piece of data, a lock of some type is placed on it. This is different from blocking, which is when one session, or thread, needs access to a piece of data and has to wait for another session's lock to clear. Finally, deadlocking is when two sessions, or threads, form what is sometimes referred to as a *deadly embrace.* They are each waiting on the other for a lock to clear. Deadlocking could also be referred to as a permanent blocking situation, but it's one that won't resolve by waiting any period of time. Deadlocking will be covered in more detail in Chapter 22. So, locks can lead to blocks, and both locks and blocks play a part in deadlocks, but these are three distinct concepts. Please understand the differences between these terms and use them correctly. It will help in your understanding of the system, your ability to troubleshoot, and your ability to communicate with other database administrators and developers.

In SQL Server, a database connection is identified by a session ID. Connections may be from one or many applications and one or many users on those applications; as far as SQL Server is concerned, every connection is treated as a separate session. Blocking between two sessions accessing the same piece of data at the same time is a natural phenomenon in SQL Server. Whenever two sessions try to access a common database resource in conflicting ways, the lock manager ensures that the second session waits until the first session completes its work in conjunction with the management of transactions within the system. For example, a session might be modifying a table record while another session tries to delete the record. Since these two data access requests are incompatible, the second session will be blocked until the first session completes its task.

On the other hand, if the two sessions try to read a table concurrently, both requests are allowed to execute without blocking, since these data access requests are compatible with each other.

Usually, the effect of blocking on a session is quite small and doesn't affect its performance noticeably. At times, however, because of poor query and/or transaction design (or maybe bad luck), blocking can affect query performance significantly. In a database application, every effort should be made to minimize blocking and thereby increase the number of concurrent users who can use the database.

With the introduction of in-memory tables in SQL Server 2014, locking, at least for these tables, takes on whole new dimensions. I'll cover their behavior separately in Chapter 24.

Understanding Blocking

In SQL Server, a database query can execute as a logical unit of work in itself, or it can participate in a bigger logical unit of work. A bigger logical unit of work can be defined using the `BEGIN TRANSACTION` statement along with `COMMIT` and/or `ROLLBACK` statements. Every logical unit of work must conform to a set of four properties called *ACID* properties:

- Atomicity
- Consistency
- Isolation
- Durability

I cover these properties in the sections that follow because understanding how transactions work is fundamental to understanding blocking.

Atomicity

A logical unit of work must be *atomic*. That is, either all the actions of the logical unit of work are completed or no effect is retained. To understand the atomicity of a logical unit of work, consider the following example:

```
USE AdventureWorks2017;
GO
DROP TABLE IF EXISTS dbo.ProductTest;
GO
```

```
CREATE TABLE dbo.ProductTest (ProductID INT
                                    CONSTRAINT ValueEqualsOne CHECK
(ProductID = 1));
GO
--All ProductIDs are added into ProductTest as a logical unit of work
INSERT INTO dbo.ProductTest
SELECT p.ProductID
FROM Production.Product AS p;
GO
SELECT pt.ProductID
FROM dbo.ProductTest AS pt; --Returns 0 rows
```

SQL Server treats the preceding `INSERT` statement as a logical unit of work. The `CHECK` constraint on column `ProductID` of the `dbo.ProductTest` table allows only the value of `1`. Although the `ProductID` column in the `Production.Product` table starts with the value of `1`, it also contains other values. For this reason, the `INSERT` statement won't add any records at all to the `dbo.ProductTest` table, and an error is raised because of the `CHECK` constraint. Thus, atomicity is automatically ensured by SQL Server.

So far, so good. But in the case of a bigger logical unit of work, you should be aware of an interesting behavior of SQL Server. Imagine that the previous insert task consists of multiple `INSERT` statements. These can be combined to form a bigger logical unit of work, as follows:

```
BEGIN TRAN
 --Start:  Logical unit of work
--First:
INSERT  INTO dbo.ProductTest
        SELECT  p.ProductID
        FROM    Production.Product AS p;
--Second:
INSERT  INTO dbo.ProductTest
VALUES  (1);
COMMIT --End:   Logical unit of work
GO
```

With the dbo.ProductTest table already created in the preceding script, the BEGIN TRAN and COMMIT pair of statements defines a logical unit of work, suggesting that all the statements within the transaction should be atomic in nature. However, the default behavior of SQL Server doesn't ensure that the failure of one of the statements within a user-defined transaction scope will undo the effect of the prior statements. In the preceding transaction, the first INSERT statement will fail as explained earlier, whereas the second INSERT is perfectly fine. The default behavior of SQL Server allows the second INSERT statement to execute, even though the first INSERT statement fails. A SELECT statement, as shown in the following code, will return the row inserted by the second INSERT statement:

```
SELECT  *
FROM    dbo.ProductTest; --Returns a row with t1.c1 = 1
```

The atomicity of a user-defined transaction can be ensured in the following two ways:

- SET XACT_ABORT ON
- Explicit rollback

Let's look at these briefly.

SET XACT_ABORT ON

You can modify the atomicity of the INSERT task in the preceding section using the SET XACT_ ABORT ON statement.

```
SET XACT_ABORT ON;
GO
BEGIN TRAN
 --Start:  Logical unit of work
--First:
INSERT  INTO dbo.ProductTest
        SELECT  p.ProductID
        FROM    Production.Product AS p;
--Second:
INSERT  INTO dbo.ProductTest
VALUES  (1);
COMMIT
```

```
 --End:   Logical unit of work GO
SET XACT_ABORT OFF;
GO
```

The SET XACT_ABORT statement specifies whether SQL Server should automatically roll back and abort an entire transaction when a statement within the transaction fails. The failure of the first INSERT statement will automatically suspend the entire transaction, and thus the second INSERT statement will not be executed. The effect of SET XACT_ABORT is at the connection level, and it remains applicable until it is reconfigured or the connection is closed. By default, SET XACT_ABORT is OFF.

Explicit Rollback

You can also manage the atomicity of a user-defined transaction by using the TRY/CATCH error-trapping mechanism within SQL Server. If a statement within the TRY block of code generates an error, then the CATCH block of code will handle the error. If an error occurs and the CATCH block is activated, then the entire work of a user-defined transaction can be rolled back, and further statements can be prevented from execution, as follows:

```
BEGIN TRY
    BEGIN TRAN
    --Start: Logical unit of work
    --First:
    INSERT INTO dbo.ProductTest
    SELECT p.ProductID
    FROM Production.Product AS p

    Second:
    INSERT INTO dbo.ProductTest (ProductID)
    VALUES (1)
    COMMIT --End: Logical unit of work
END TRY
BEGIN CATCH
    ROLLBACK
    PRINT 'An error occurred'
    RETURN
END CATCH
```

The ROLLBACK statement rolls back all the actions performed in the transaction until that point. For a detailed description of how to implement error handling in SQL Server–based applications, please refer to the MSDN Library article titled "Using TRY...CATCH in Transact SQL" (http://bit.ly/PNlAHF).

Since the atomicity property requires that either all the actions of a logical unit of work are completed or no effects are retained, SQL Server *isolates* the work of a transaction from that of others by granting it exclusive rights on the affected resources. This means the transaction can safely roll back the effect of all its actions, if required. The exclusive rights granted to a transaction on the affected resources block all other transactions (or database requests) trying to access those resources during that time period. Therefore, although atomicity is required to maintain the integrity of data, it introduces the undesirable side effect of blocking.

Consistency

A unit of work should cause the state of the database to travel from one *consistent* state to another. At the end of a transaction, the state of the database should be fully consistent. SQL Server always ensures that the internal state of the databases is correct and valid by automatically applying all the constraints of the affected database resources as part of the transaction. SQL Server ensures that the state of internal structures, such as data and index layout, are correct after the transaction. For instance, when the data of a table is modified, SQL Server automatically identifies all the indexes, constraints, and other dependent objects on the table and applies the necessary modifications to all the dependent database objects as part of the transaction. That means that SQL Server will maintain the physical consistency of the data and the objects.

The logical consistency of the data is defined by the business rules and should be put in place by the developer of the database. A business rule may require changes to be applied on multiple tables, certain types of data to be restricted, or any number of other requirements. The database developer should accordingly define a logical unit of work to ensure that all the criteria of the business rules are taken care of. Further, the developer will ensure that the appropriate constructs are put in place to support the business rules that have been defined. SQL Server provides different transaction management features that the database developer can use to ensure the logical consistency of the data.

So, SQL Server works with the logical, business-defined, constraints that ensure a business-oriented data consistency to create a physical consistency on the underlying structures. The consistency characteristic of the logical unit of work blocks all other

transactions (or database requests) trying to access the affected objects during that time period. Therefore, even though consistency is required to maintain a valid logical and physical state of the database, it also introduces the same side effect of blocking.

Isolation

In a multiuser environment, more than one transaction can be executed simultaneously. These concurrent transactions should be isolated from one another so that the intermediate changes made by one transaction don't affect the data consistency of other transactions. The degree of *isolation* required by a transaction can vary. SQL Server provides different transaction isolation features to implement the degree of isolation required by a transaction.

Note Transaction isolation levels are explained later in the chapter in the "Isolation Levels" section.

The isolation requirements of a transaction operating on a database resource can block other transactions trying to access the resource. In a multiuser database environment, multiple transactions are usually executed simultaneously. It is imperative that the data modifications made by an ongoing transaction be protected from the modifications made by other transactions. For instance, suppose a transaction is in the middle of modifying a few rows in a table. During that period, to maintain database consistency, you must ensure that other transactions do not modify or delete the same rows. SQL Server logically isolates the activities of a transaction from that of others by blocking them appropriately, which allows multiple transactions to execute simultaneously without corrupting one another's work.

Excessive blocking caused by isolation can adversely affect the scalability of a database application. A transaction may inadvertently block other transactions for a long period of time, thereby hurting database concurrency. Since SQL Server manages isolation using locks, it is important to understand the locking architecture of SQL Server. This helps you analyze a blocking scenario and implement resolutions.

Note The fundamentals of database locks are explained later in the chapter in the "Capturing Blocking Information" section.

Durability

Once a transaction is completed, the changes made by the transaction should be *durable*. Even if the electrical power to the machine is tripped off immediately after the transaction is completed, the effect of all actions within the transaction should be retained. SQL Server ensures durability by keeping track of all pre- and post-images of the data under modification in a transaction log as the changes are made. Immediately after the completion of a transaction, SQL Server ensures that all the changes made by the transaction are retained—even if SQL Server, the operating system, or the hardware fails (excluding the log disk). During restart, SQL Server runs its database recovery feature, which identifies the pending changes from the transaction log for completed transactions and applies them to the database resources. This database feature is called *roll forward*.

The recovery interval period depends on the number of pending changes that need to be applied to the database resources during restart. To reduce the recovery interval period, SQL Server intermittently applies the intermediate changes made by the running transactions as configured by the recovery interval option. The recovery interval option can be configured using the `sp_configure` statement. The process of intermittently applying the intermediate changes is referred to as the *checkpoint* process. During restart, the recovery process identifies all uncommitted changes and removes them from the database resources by using the pre-images of the data from the transaction log.

Starting with SQL Server 2016, the default value of the `TARGET_RECOVERY_TIME` has been changed from 0, which means that the database will be doing all automatic checkpoints, to one minute. The default interval for automatic is also one minute, but now, the control is being set through the `TARGET_RECOVERY_TIME` value by default. If you need to change the frequency of the checkpoint operation, use `sp_configure` to change the recovery interval value. Setting this value means that the database is using indirect checkpoints. Instead of relying on the automatic checkpoints, you can use indirect checkpoints. This is a method to basically make the checkpoints occur all the time in order to meet the recovery interval. For systems with an extremely high number of data modifications, you might see high I/O because of indirect checkpoints. Starting in SQL Server 2016, all new databases created are automatically using indirect checkpoints because the `TARGET_INTERVAL_TIME` has been set. Any databases migrated from previous versions will be using whichever checkpoint method they had in that previous version. You may want to change their behavior as well. Using indirect checkpoints can result, for most systems, in a more consistent checkpoint behavior and faster recovery.

The durability property isn't a direct cause of most blocking since it doesn't require the actions of a transaction to be isolated from those of others. But in an indirect way, it increases the duration of the blocking. Since the durability property requires saving the pre- and post-images of the data under modification to the transaction log on disk, it increases the duration of the transaction and therefore the possibility of blocking.

Introduced in SQL Server 2014 is the ability to reduce latency, the time waiting on a query to commit and write to the log, by modifying the durability behavior of a given database. You can now use delayed durability. This means that when a transaction completes, it reports immediately to the application as a successful transaction, reducing latency. But the writes to the log have not yet occurred. This may also allow for more transactions to be completed while still waiting on the system to write all the output to the transaction log. While this may increase apparent speed within the system, as well as possibly reducing contention on transaction log I/O, it's inherently a dangerous choice. This is a difficult recommendation to make. Microsoft suggests three possible situations that may make it attractive.

- *You don't care about the possible loss of some data*: Since you can be in a situation where you need to restore to a point in time from log backups, by choosing to put a database in delayed durability you may lose some data when you have to go to a restore situation.
- *You have a high degree of contention during log writes*: If you're seeing a lot of waits while transactions get written to the log, delayed durability could be a viable solution. But, you're also going to want to be tolerant of data loss, as discussed earlier.
- *You're experiencing high overall resource contention*: A lot of resource contention on the server comes down to the locks being held longer. If you're seeing lots of contention and you're seeing long log writes or also seeing contention on the log and you have a high tolerance for data loss, this may be a viable way to help reduce the system's contention.

In other works, I recommend using delayed durability only if you meet all those criteria, with the first being the most important. Also, don't forget about the changes to the checkpoint behavior noted earlier. If you're in a high-volume system, with lots of data changes, you may need to adjust the recovery interval to assist with system behavior as well.

Note Out of the four ACID properties, the `isolation` property, which is also used to ensure atomicity and consistency, is the main cause of blocking in a SQL Server database. In SQL Server, isolation is implemented using locks, as explained in the next section.

Locks

When a session executes a query, SQL Server determines the database resources that need to be accessed; and, if required, the lock manager grants different types of locks to the session. The query is blocked if another session has already been granted the locks; however, to provide both transaction isolation and concurrency, SQL Server uses different lock granularities, as explained in the sections that follow.

Lock Granularity

SQL Server databases are maintained as files on the physical disk. In the case of a traditional nondatabase file such as an Excel file on a desktop machine, the file may be written to by only one user at a time. Any attempt to write to the file by other users fails. However, unlike the limited concurrency on a nondatabase file, SQL Server allows multiple users to modify (or access) contents simultaneously, as long as they don't affect one another's data consistency. This decreases blocking and improves concurrency among the transactions.

To improve concurrency, SQL Server implements lock granularities at the following resource levels and in this order:

- Row (`RID`)
- Key (`KEY`)
- Page (`PAG`)
- Extent (`EXT`)
- Heap or B-tree (`HoBT`)
- Table (`TAB`)
- File (`FIL`)

- Application (APP)
- MetaData (MDT)
- Allocation Unit (AU)
- Database (DB)

Let's take a look at these lock levels in more detail.

Row-Level Lock

This lock is maintained on a single row within a table and is the lowest level of lock on a database table. When a query modifies a row in a table, an RID lock is granted to the query on the row. For example, consider the transaction on the following test table:

```
DROP TABLE IF EXISTS dbo.Test1;
CREATE TABLE dbo.Test1 (C1 INT);
INSERT INTO dbo.Test1
VALUES (1);
GO

BEGIN TRAN
DELETE dbo.Test1
WHERE C1 = 1;

SELECT dtl.request_session_id,
       dtl.resource_database_id,
       dtl.resource_associated_entity_id,
       dtl.resource_type,
       dtl.resource_description,
       dtl.request_mode,
       dtl.request_status
FROM sys.dm_tran_locks AS dtl
WHERE dtl.request_session_id = @@SPID;
ROLLBACK
```

The dynamic management view sys.dm_tran_locks can be used to display the lock status. The query against sys.dm_tran_locks in Figure 21-1 shows that the DELETE statement acquired, among other locks, an exclusive RID lock on the row to be deleted.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	53	6	0	DATABASE		S	GRANT
2	53	6	72057594077577216	RID	1:121321:0	X	GRANT
3	53	6	72057594077577216	PAGE	1:121321	IX	GRANT
4	53	6	1940201962	OBJECT		IX	GRANT

Figure 21-1. *Output from sys.dm_tran_locks showing the row-level lock granted to the DELETE statement*

Note I explain lock modes later in the chapter in the "Lock Modes" section.

Granting an `RID` lock to the `DELETE` statement prevents other transactions from accessing the row.

The resource locked by the `RID` lock can be represented in the following format from the `resource_description` column:

```
FileID:PageID:Slot(row)
```

In the output from the query against `sys.dm_tran_locks` in Figure 21-1, the `DatabaseID` is displayed separately under the `resource_database_id` column. The `resource_description` column value for the `RID` type represents the remaining part of the `RID` resource as `1:121321:0`. In this case, a `FileID` of `1` is the primary data file, a `PageID` of `121321` is a page belonging to the `dbo.Test1` table identified by the `C1` column, and a `Slot (row)` of `0` represents the row position within the page. You can obtain the table name and the database name by executing the following SQL statements:

```
SELECT OBJECT_NAME(1940201962),
       DB_NAME(6);
```

The row-level lock provides very high concurrency since blocking is restricted to the row under effect.

Key-Level Lock

This is a row lock within an index, and it is identified as a `KEY` lock. As you know, for a table with a clustered index, the data pages of the table and the leaf pages of the clustered index are the same. Since both of the rows are the same for a table with a clustered index, only a `KEY` lock is acquired on the clustered index row, or limited range

of rows, while accessing the rows from the table (or the clustered index). For example, consider having a clustered index on the `Test1` table.

```
CREATE CLUSTERED INDEX TestIndex ON dbo.Test1(C1);
```

Next, rerun the following code:

```
BEGIN TRAN
DELETE  dbo.Test1
WHERE   C1 = 1 ;

SELECT  dtl.request_session_id,
        dtl.resource_database_id,
        dtl.resource_associated_entity_id,
        dtl.resource_type,
        dtl.resource_description,
        dtl.request_mode,
        dtl.request_status
FROM    sys.dm_tran_locks AS dtl
WHERE   dtl.request_session_id = @@SPID ;
ROLLBACK
```

The corresponding output from `sys.dm_tran_locks` shows a `KEY` lock instead of the `RID` lock, as you can see in Figure 21-2.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	52	6	72057594077904896	PAGE	1:34064	IX	GRANT
3	52	6	72057594077904896	KEY	(de42f79bc795)	X	GRANT
4	52	6	1940201962	OBJECT		IX	GRANT

Figure 21-2. *Output from sys.dm_tran_locks showing the key-level lock granted to the DELETE statement*

When you are querying `sys.dm_tran_locks`, you will be able to retrieve the database identifier, `resource_database_id`. You can also get information about what is being locked from `resource_associated_entity_id`; however, to get to the particular resource (in this case, the page on the key), you have to go to the `resource_ description` column for the value, which is `1:34064`. In this case, the `Index ID` of `1` is the clustered index on the `dbo.Test1` table. You also see the types of requests that are made: S, IX, X, and so on. I cover these in more detail in the upcoming "Lock Modes" section.

Note You'll learn about different values for the `IndId` column and how to determine the corresponding index name in this chapter's "Effect of Indexes on Locking" section.

Like the row-level lock, the key-level lock provides very high concurrency.

Page-Level Lock

A page-level lock is maintained on a single page within a table or an index, and it is identified as a `PAG` lock. When a query requests multiple rows within a page, the consistency of all the requested rows can be maintained by acquiring either `RID/KEY` locks on the individual rows or a `PAG` lock on the entire page. From the query plan, the lock manager determines the resource pressure of acquiring multiple `RID/KEY` locks, and if the pressure is found to be high, the lock manager requests a `PAG` lock instead.

The resource locked by the `PAG` lock may be represented in the following format in the `resource_description` column of `sys.dm_tran_locks`:

```
FileID:PageID
```

The page-level lock can increase the performance of an individual query by reducing its locking overhead, but it hurts the concurrency of the database by blocking access to all the rows in the page.

Extent-Level Lock

An extent-level lock is maintained on an extent (a group of eight contiguous data or index pages), and it is identified as an `EXT` lock. This lock is used, for example, when an `ALTER INDEX REBUILD` command is executed on a table and the pages of the table may be moved from an existing extent to a new extent. During this period, the integrity of the extents is protected using `EXT` locks.

Heap or B-tree Lock

A heap or B-tree lock is used to describe when a lock to either type of object could be made. The target object could be an unordered heap table, a table without a clustered index, or a B-tree object, usually referring to partitions. A setting within the `ALTER TABLE`

function allows you to exercise a level of control over how locking escalation (covered in the "Lock Escalation" section) is affected with the partitions. Because partitions can be across multiple filegroups, each one has to have its own data allocation definition. This is where the `HoBT` lock comes into play. It acts like a table-level lock but on a partition instead of on the table itself.

Table-Level Lock

This is the highest level of lock on a table, and it is identified as a `TAB` lock. A table-level lock on a table reserves access to the complete table and all its indexes.

When a query is executed, the lock manager automatically determines the locking overhead of acquiring multiple locks at the lower levels. If the resource pressure of acquiring locks at the row level or the page level is determined to be high, then the lock manager directly acquires a table-level lock for the query.

The resource locked by the `OBJECT` lock will be represented in `resource_description` in the following format:

```
ObjectID
```

A table-level lock requires the least overhead compared to the other locks and thus improves the performance of the individual query. On the other hand, since the table-level lock blocks all write requests on the entire table (including indexes), it can significantly hurt database concurrency.

Sometimes an application feature may benefit from using a specific lock level for a table referred to in a query. For instance, if an administrative query is executed during nonpeak hours, then a table-level lock may not impact the users of the system too much; however, it can reduce the locking overhead of the query and thereby improve its performance. In such cases, a query developer may override the lock manager's lock level selection for a table referred to in the query by using locking hints.

```
SELECT * FROM <TableName> WITH(TABLOCK)
```

But, be cautious when taking control away from SQL Server like this. Test it thoroughly prior to implementation.

Database-Level Lock

A database-level lock is maintained on a database and is identified as a DB lock. When an application makes a database connection, the lock manager assigns a database-level shared lock to the corresponding `session_id`. This prevents a user from accidentally dropping or restoring the database while other users are connected to it.

SQL Server ensures that the locks requested at one level respect the locks granted at other levels. For instance, once a user acquires a row-level lock on a table row, another user can't acquire a lock at any other level that may affect the integrity of the row. The second user may acquire a row-level lock on other rows or a page-level lock on other pages, but an incompatible page- or table-level lock containing the row won't be granted to other users.

The level at which locks should be applied need not be specified by a user or database administrator; the lock manager determines that automatically. It generally prefers row-level and key-level locks when accessing a small number of rows to aid concurrency. However, if the locking overhead of multiple low-level locks turns out to be very high, the lock manager automatically selects an appropriate higher-level lock.

Lock Operations and Modes

Because of the variety of operations that SQL Server needs to perform, an equally large and complex set of locking mechanisms are maintained. In addition to the different types of locks, there is an escalation path to change from one type of lock to another. The following sections describe these modes and processes, as well as their uses.

Lock Escalation

When a query is executed, SQL Server determines the required lock level for the database objects referred to in the query, and it starts executing the query after acquiring the required locks. During the query execution, the lock manager keeps track of the number of locks requested by the query to determine the need to escalate the lock level from the current level to a higher level.

The lock escalation threshold is determined by SQL Server during the course of a transaction. Row locks and page locks are automatically escalated to a table lock when a transaction exceeds its threshold. After the lock level is escalated to a table-level lock,

all the lower-level locks on the table are automatically released. This dynamic lock escalation feature of the lock manager optimizes the locking overhead of a query.

It is possible to establish a level of control over the locking mechanisms on a given table. For example, you can control whether lock escalation occurs. The following is the T-SQL syntax to make that change:

```
ALTER TABLE schema.table
SET (LOCK_ESCALATION = DISABLE);
```

This syntax will disable lock escalation on the table entirely (except for a few special circumstances). You can also set it to `TABLE`, which will cause the escalation to go to a table lock every single time. You can also set lock escalation on the table to `AUTO`, which will allow SQL Server to make the determination for the locking schema and any escalation necessary. If that table is partitioned, you may see the escalation change to the partition level. Again, exercise caution using these types of modifications to standard SQL Server behavior.

You also have the option to disable lock escalation on a wider basis by using trace flag 1224. This disables lock escalation based on the number of locks but leaves intact lock escalation based on memory pressure. You can also disable the memory pressure lock escalation as well as the number of locks by using trace flag 1211, but that's a dangerous choice and can lead to errors on your systems. I strongly suggest thorough testing before using either of these options.

Lock Modes

The degree of isolation required by different transactions may vary. For instance, consistency of data is not affected if two transactions read the data simultaneously; however, the consistency is affected if two transactions are allowed to modify the data simultaneously. Depending on the type of access requested, SQL Server uses different lock modes while locking resources.

- Shared (S)
- Update (U)
- Exclusive (X)

- Intent
  - Intent Shared (IS)
  - Intent Exclusive (IX)
  - Shared with Intent Exclusive (SIX)
- Schema
  - Schema Modification (Sch-M)
  - Schema Stability (Sch-S)
- Bulk Update (BU)
- Key-Range

Shared (S) Mode

Shared mode is used for read-only queries, such as a `SELECT` statement. It doesn't prevent other read-only queries from accessing the data simultaneously because the integrity of the data isn't compromised by the concurrent reads. However, concurrent data modification queries on the data are prevented to maintain data integrity. The (S) lock is held on the data until the data is read. By default, the (S) lock acquired by a `SELECT` statement is released immediately after the data is read. For example, consider the following transaction:

```
BEGIN TRAN
SELECT  *
FROM    Production.Product AS p
WHERE   p.ProductID = 1;
--Other queries
COMMIT
```

The (S) lock acquired by the `SELECT` statement is not held until the end of the transaction; instead, it is released immediately after the data is read by the `SELECT` statement under `read_ committed`, the default isolation level. This behavior of the (S) lock can be altered by using a higher isolation level or a lock hint.

Update (U) Mode

Update mode may be considered similar to the (S) lock, but it also includes an objective to modify the data as part of the same query. Unlike the (S) lock, the (U) lock indicates that the data is read for modification. Since the data is read with an objective to modify it, SQL Server does not allow more than one (U) lock on the data simultaneously. This rule helps maintain data integrity. Note that concurrent (S) locks on the data are allowed. The (U) lock is associated with an `UPDATE` statement, and the action of an `UPDATE` statement actually involves two intermediate steps: first read the data to be modified, and then modify the data.

Different lock modes are used in the two intermediate steps to maximize concurrency. Instead of acquiring an exclusive right while reading the data, the first step acquires a (U) lock on the data. In the second step, the (U) lock is converted to an exclusive lock for modification. If no modification is required, then the (U) lock is released; in other words, it's not held until the end of the transaction. Consider the following script, which would lead to blocking until the `UPDATE` statement is completed:

```
UPDATE Sales.Currency
SET Name = 'Euro'
WHERE CurrencyCode = 'EUR';
```

To understand the locking behavior of the intermediate steps of the `UPDATE` statement, you need to obtain data from `sys.dm_tran_locks` while queries run. You can obtain the lock status after each step of the `UPDATE` statement by following the steps outlined next. You're going have three connections open that I'll refer to as Connection 1, Connection 2, and Connection 3. This will require three different query windows in Management Studio. You'll run the queries in the connections I list in the order that I specify to arrive at a blocking situation. The point of this is to observe those blocks as they occur. Table 21-1 shows the different connections in different T-SQL query windows and the order of the queries to be run in them.

Table 21-1. *Order of the Scripts to Show UPDATE Blocking*

Script Order	T-SQL Window 1 (Connection 1)	T-SQL Window 2 (Connection 2)	T-SQL Window 3 (Connection 3)
1	BEGIN TRANSACTION LockTran2 --Retain an (S) lock on the resource SELECT * FROM Sales.Currency AS c WITH (REPEATABLEREAD) WHERE c.CurrencyCode = 'EUR' ; --Allow DMVs to be executed before second step of -- UPDATE statement is executed by transaction LockTran1 WAITFOR DELAY '00:00:10'; COMMIT		

(*continued*)

Table 21-1. (*continued*)

Script Order	T-SQL Window 1 (Connection 1)	T-SQL Window 2 (Connection 2)	T-SQL Window 3 (Connection 3)
2		BEGIN TRANSACTION LockTran1 UPDATE Sales. Currency SET Name = 'Euro' WHERE CurrencyCode = 'EUR'; -- NOTE: We're not committing yet	
3			SELECT dtl.request_ session_id, dtl.resource_database_id, dtl.resource_associated_ entity_id, dtl.resource_type, dtl.resource_ description, dtl.request_mode, dtl.request_status FROM sys.dm_tran_ locks AS dtl ORDER BY dtl.request_ session_id;

(*continued*)

Table 21-1. (*continued*)

Script Order	T-SQL Window 1 (Connection 1)	T-SQL Window 2 (Connection 2)	T-SQL Window 3 (Connection 3)
4) Wait 10 seconds			
5			`SELECT dtl.request_session_id, dtl.resource_database_id, dtl.resource_associated_entity_id, dtl.resource_type, dtl.resource_description, dtl.request_mode, dtl.request_status FROM sys.dm_tran_locks AS dtl ORDER BY dtl.request_session_id;`
6		`COMMIT`	

The `REPEATABLEREAD` locking hint, running in Connection 2, allows the `SELECT` statement to retain the (S) lock on the resource. The output from `sys.dm_tran_locks` in Connection 3 will provide the lock status after the first step of the `UPDATE` statement since the lock conversion to an exclusive (X) lock by the `UPDATE` statement is blocked by the `SELECT` statement. Next, let's look at the lock status provided by `sys.dm_tran_locks` as you go through the individual steps of the `UPDATE` statement.

Figure 21-3 shows the lock status after step 1 of the `UPDATE` statement (obtained from the output from `sys.dm_tran_locks` executed on the third connection, Connection 3, as explained previously).

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	52	6	72057594048675840	KEY	(0d881dadfc5c)	U	GRANT
3	52	6	72057594048675840	KEY	(0d881dadfc5c)	X	CONVERT
4	52	6	1589580701	OBJECT		IX	GRANT
5	52	6	72057594048675840	PAGE	1:12304	IX	GRANT
6	53	6	72057594048675840	PAGE	1:12304	IS	GRANT
7	53	6	1589580701	OBJECT		IS	GRANT
8	53	6	72057594048675840	KEY	(0d881dadfc5c)	S	GRANT
9	53	6	0	DATABASE		S	GRANT
10	54	6	0	DATABASE		S	GRANT
11	55	9	0	DATABASE		S	GRANT
12	56	6	0	DATABASE		S	GRANT

Figure 21-3. *Output from sys.dm_tran_locks showing the lock conversion state of an UPDATE statement*

Note The order of these rows is not that important. I've ordered by `session_id` in order to group the locks from each query.

- Figure 21-4 shows the lock status after step 2 of the `UPDATE` statement.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	52	6	72057594048675840	KEY	(0d881dadfc5c)	X	GRANT
3	52	6	1589580701	OBJECT		IX	GRANT
4	52	6	72057594048675840	PAGE	1:12304	IX	GRANT
5	53	6	0	DATABASE		S	GRANT
6	54	6	0	DATABASE		S	GRANT
7	55	9	0	DATABASE		S	GRANT
8	56	6	0	DATABASE		S	GRANT

Figure 21-4. *Output from sys.dm_tran_locks showing the final lock status held by the UPDATE statement*

From the `sys.dm_tran_locks` output after the first step of the `UPDATE` statement, you can note the following:

- A (U) lock is granted to the SPID on the data row.
- A conversion to an (X) lock on the data row is requested.

From the output of `sys.dm_tran_locks` after the second step of the `UPDATE` statement, you can see that the `UPDATE` statement holds only an (X) lock on the data row. Essentially, the (U) lock on the data row is converted to an (X) lock.

This is important, by not acquiring an exclusive lock at the first step, an UPDATE statement allows other transactions to read the data using the SELECT statement during that period. This is possible because (U) and (S) locks are compatible with each other. This increases database concurrency.

Note I discuss lock compatibility among different lock modes later in this chapter.

You may be curious to learn why a (U) lock is used instead of an (S) lock in the first step of the UPDATE statement. To understand the drawback of using an (S) lock instead of a (U) lock in the first step of the UPDATE statement, let's break the UPDATE statement into two steps.

1. Read the data to be modified using an (S) lock instead of a (U) lock.
2. Modify the data by acquiring an (X) lock.

Consider the following code:

```
BEGIN TRAN
--1.Read data to be modified using (S)lock instead of (U)lock.
--    Retain the (S)lock using REPEATABLEREAD locking hint, since
--    the original (U)lock is retained until the conversion to
--    (X)lock.
SELECT  *
FROM    Sales.Currency AS c WITH (REPEATABLEREAD)
WHERE   c.CurrencyCode = 'EUR' ;
--Allow another equivalent update action to start concurrently
WAITFOR DELAY '00:00:10' ;

--2. Modify the data by acquiring (X)lock
UPDATE  Sales.Currency WITH (XLOCK)
SET     Name = 'EURO'
WHERE   CurrencyCode = 'EUR' ;
COMMIT
```

If this transaction is executed from two connections simultaneously, then, after a delay, it causes a deadlock, as follows:

```
Msg 1205, Level 13, State 51, Line 13
Transaction (Process ID 58) was deadlocked on lock resources with another
process and has been chosen as the deadlock victim. Rerun the transaction.
```

Both transactions read the data to be modified using an (S) lock and then request an (X) lock for modification. When the first transaction attempts the conversion to the (X) lock, it is blocked by the (S) lock held by the second transaction. Similarly, when the second transaction attempts the conversion from (S) lock to the (X) lock, it is blocked by the (S) lock held by the first transaction, which in turn is blocked by the second transaction. This causes a circular block—and therefore, a deadlock.

Note Deadlocks are covered in more detail in Chapter 22.

To avoid this typical deadlock, the `UPDATE` statement uses a (U) lock instead of an (S) lock at its first intermediate step. Unlike an (S) lock, a (U) lock doesn't allow another (U) lock on the same resource simultaneously. This forces the second concurrent `UPDATE` statement to wait until the first `UPDATE` statement completes.

Exclusive (X) Mode

Exclusive mode provides an exclusive right on a database resource for modification by data manipulation queries such as `INSERT`, `UPDATE`, and `DELETE`. It prevents other concurrent transactions from accessing the resource under modification. Both the `INSERT` and `DELETE` statements acquire (X) locks at the very beginning of their execution. As explained earlier, the `UPDATE` statement converts to the (X) lock after the data to be modified is read. The (X) locks granted in a transaction are held until the end of the transaction.

The (X) lock serves two purposes.

- It prevents other transactions from accessing the resource under modification so that they see a value either before or after the modification, not a value undergoing modification.
- It allows the transaction modifying the resource to safely roll back to the original value before modification, if needed, since no other transaction is allowed to modify the resource simultaneously.

Intent Shared (IS), Intent Exclusive (IX), and Shared with Intent Exclusive (SIX) Modes

Intent Shared, Intent Exclusive, and Shared with Intent Exclusive locks indicate that the query intends to grab a corresponding (S) or (X) lock at a lower lock level. For example, consider the following transaction on the `Sales.Currency` table:

```
BEGIN TRAN
DELETE  Sales.Currency
WHERE   CurrencyCode = 'ALL';

SELECT  tl.request_session_id,
        tl.resource_database_id,
        tl.resource_associated_entity_id,
        tl.resource_type,
        tl.resource_description,
        tl.request_mode,
        tl.request_status
FROM    sys.dm_tran_locks tl;

ROLLBACK TRAN
```

Figure 21-5 shows the output from `sys.dm_tran_locks`.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	54	6	0	DATABASE		S	GRANT
3	55	9	0	DATABASE		S	GRANT
4	52	6	72057594053918720	KEY	(f9b93c451603)	X	GRANT
5	52	6	72057594053918720	PAGE	1:9336	IX	GRANT
6	52	6	1589580701	OBJECT		IX	GRANT
7	52	6	72057594048675840	KEY	(cadf591d32de)	X	GRANT
8	52	6	72057594048675840	PAGE	1:12304	IX	GRANT

Figure 21-5. *Output from sys.dm_tran_locks showing the intent locks granted at higher levels*

The (IX) lock at the table level (`PAGE`) indicates that the `DELETE` statement intends to acquire an (X) lock at a page, row, or key level. Similarly, the (IX) lock at the page level (`PAGE`) indicates that the query intends to acquire an (X) lock on a row in the page. The (IX) locks at the higher levels prevent another transaction from acquiring an incompatible lock on the table or on the page containing the row.

Flagging the intent lock—(IS) or (IX)—at a corresponding higher level by a transaction, while holding the lock at a lower level, prevents other transactions from acquiring an incompatible lock at the higher level. If the intent locks were not used, then a transaction trying to acquire a lock at a higher level would have to scan through the lower levels to detect the presence of lower-level locks. While the intent lock at the higher levels indicates the presence of a lower level lock, the locking overhead of acquiring a lock at a higher level is optimized. The intent locks granted to a transaction are held until the end of the transaction.

Only a single (SIX) lock can be placed on a given resource at once. This prevents updates made by other transactions. Other transactions can place (IS) locks on the lower-level resources while the (SIX) lock is in place.

Furthermore, there can be a combination of locks requested (or acquired) at a certain level and the intention of having a lock (or locks) at a lower level. For example, there can be (SIU) and (UIX) lock combinations indicating that an (S) or a (U) lock has been acquired at the corresponding level and that (U) or (X) lock(s) are intended at a lower level.

Schema Modification (Sch-M) and Schema Stability (Sch-S) Modes

Schema Modification and Schema Stability locks are acquired on a table by SQL statements that depend on the schema of the table. A DDL statement, working on the schema of a table, acquires an (Sch-M) lock on the table and prevents other transactions from accessing the table. An (Sch-S) lock is acquired for database activities that depend on the schema but do not modify the schema, such as a query compilation. It prevents an (Sch-M) lock on the table, but it allows other locks to be granted on the table.

Since, on a production database, schema modifications are infrequent, (Sch-M) locks don't usually become a blocking issue. And because (Sch-S) locks don't block other locks except (Sch-M) locks, concurrency is generally not affected by (Sch-S) locks either.

Bulk Update (BU) Mode

The Bulk Update lock mode is unique to bulk load operations. These operations are the older-style `bcp` (bulk copy), the `BULK INSERT` statement, and inserts from the `OPENROWSET` using the `BULK` option. As a mechanism for speeding up these processes, you can provide

a TABLOCK hint or set the option on the table for it to lock on bulk load. The key to (BU) locking mode is that it will allow multiple bulk operations against the table being locked but prevent other operations while the bulk process is running.

Key-Range Mode

The Key-Range mode is applicable only while the isolation level is set to Serializable (you'll learn more about transaction isolation levels in the later "Isolation Levels" section). The Key-Range locks are applied to a series, or range, of key values that will be used repeatedly while the transaction is open. Locking a range during a serializable transaction ensures that other rows are not inserted within the range, possibly changing result sets within the transaction. The range can be locked using the other lock modes, making this more like a combined locking mode rather than a distinctively separate locking mode. For the Key-Range lock mode to work, an index must be used to define the values within the range.

Lock Compatibility

SQL Server provides isolation to a transaction by preventing other transactions from accessing the same resource in an incompatible way. However, if a transaction attempts a compatible task on the same resource, then to increase concurrency, it won't be blocked by the first transaction. SQL Server ensures this kind of selective blocking by preventing a transaction from acquiring an incompatible lock on a resource held by another transaction. For example, an (S) lock acquired on a resource by a transaction allows other transactions to acquire an (S) lock on the same resource. However, an (Sch-M) lock on a resource by a transaction prevents other transactions from acquiring any lock on that resource.

Isolation Levels

The lock modes explained in the previous section help a transaction protect its data consistency from other concurrent transactions. The degree of data protection or isolation a transaction gets depends not only on the lock modes but also on the isolation level of the transaction. This level influences the behavior of the lock modes. For example, by default an (S) lock is released immediately after the data is read; it isn't held

until the end of the transaction. This behavior may not be suitable for some application functionality. In such cases, you can configure the isolation level of the transaction to achieve the desired degree of isolation.

SQL Server implements six isolation levels, four of them as defined by ISO:

- Read Uncommitted
- Read Committed
- Repeatable Read
- Serializable

Two other isolation levels provide row versioning, which is a mechanism whereby a version of the row is created as part of data manipulation queries. This extra version of the row allows read queries to access the data without acquiring locks against it. The extra two isolation levels are as follows:

- Read Committed Snapshot (actually part of the Read Committed isolation)
- Snapshot

The four ISO isolation levels are listed in increasing order of degree of isolation. You can configure them at either the connection or query level by using the `SET TRANSACTION ISOLATION LEVEL` statement or the locking hints, respectively. The isolation level configuration at the connection level remains effective until the isolation level is reconfigured using the `SET` statement or until the connection is closed. All the isolation levels are explained in the sections that follow.

Read Uncommitted

Read Uncommitted is the lowest of the four isolation levels, and it allows `SELECT` statements to read data without requesting an (S) lock. Since an (S) lock is not requested by a `SELECT` statement, it neither blocks nor is blocked by the (X) lock. It allows a `SELECT` statement to read data while the data is under modification. This kind of data read is called a *dirty read.*

Assume you have an application in which the amount of data modification is extremely minimal and that your application doesn't require much in the way of accuracy from the `SELECT` statement it issues to read data. In this case, you can use the Read Uncommitted isolation level to avoid having some other data modification activity block the `SELECT` statement.

You can use the following SET statement to configure the isolation level of a database connection to the Read Uncommitted isolation level:

```
SET TRANSACTION ISOLATION LEVEL READ UNCOMMITTED
```

You can also achieve this degree of isolation on a query basis using the NOLOCK locking hint.

```
SELECT  *
FROM    Production.Product AS p WITH (NOLOCK);
```

The effect of the locking hint remains applicable for the query and doesn't change the isolation level of the connection.

The Read Uncommitted isolation level avoids the blocking caused by a SELECT statement, but you should not use it if the transaction depends on the accuracy of the data read by the SELECT statement or if the transaction cannot withstand a concurrent change of data by another transaction.

It's important to understand what is meant by a dirty read. Lots of people think this means that, while a field is being updated from Tusa to Tulsa, a query can still read the previous value or even the updated value, prior to the commit. Although that is true, much more egregious data problems could occur. Since no locks are placed while reading the data, indexes may be split. This can result in extra or missing rows of data returned to the query. To be clear, using Read Uncommitted in any environment where data manipulation as well as data reads are occurring can result in unanticipated behaviors. The intention of this isolation level is for systems primarily focused on reporting and business intelligence, not online transaction processing. You may see radically incorrect data because of the use of uncommitted data. This fact cannot be over-emphasized.

Read Committed

The Read Committed isolation level prevents the dirty read caused by the Read Uncommitted isolation level. This means that (S) locks are requested by the SELECT statements at this isolation level. This is the default isolation level of SQL Server. If needed, you can change the isolation level of a connection to Read Committed by using the following SET statement:

```
SET TRANSACTION ISOLATION LEVEL READ COMMITTED
```

The Read Committed isolation level is good for most cases, but since the (S) lock acquired by the SELECT statement isn't held until the end of the transaction, it can cause nonrepeatable read or phantom read issues, as explained in the sections that follow.

The behavior of the Read Committed isolation level can be changed by the READ_COMMITTED_SNAPSHOT database option. When this is set to ON, row versioning is used by data manipulation transactions. This places an extra load on tempdb because previous versions of the rows being changed are stored there while the transaction is uncommitted. This allows other transactions to access data for reads without having to place locks on the data, which can improve the speed and efficiency of all the queries in the system without resulting in the issues generated by page splits with NOLOCK or READ UNCOMMITTED. In Azure SQL Database, the default setting is READ_COMMITTED_SNAPSHOT.

Next, modify the AdventureWorks2017 database so that READ_COMMITTED_SNAPSHOT is turned on.

```
ALTER DATABASE AdventureWorks2017 SET READ_COMMITTED_SNAPSHOT ON;
```

Now imagine a business situation. The first connection and transaction will be pulling data from the Production.Product table, acquiring the color of a particular item.

```
BEGIN TRANSACTION;
SELECT  p.Color
FROM    Production.Product AS p
WHERE   p.ProductID = 711;
```

A second connection is made with a new transaction that will be modifying the color of the same item.

```
BEGIN TRANSACTION ;
UPDATE  Production.Product
SET     Color = 'Coyote'
WHERE   ProductID = 711;
SELECT  p.Color
FROM    Production.Product AS p
WHERE   p.ProductID = 711;
```

Running the SELECT statement after updating the color, you can see that the color was updated. But if you switch back to the first connection and rerun the original SELECT statement (don't run the BEGIN TRAN statement again), you'll still see the color as Blue. Switch back to the second connection and finish the transaction.

```
COMMIT TRANSACTION;
```

Switching again to the first transaction, commit that transaction, and then rerun the original SELECT statement. You'll see the new color updated for the item, Coyote. You can reset the isolation level on AdventureWorks2017 before continuing.

```
ALTER DATABASE AdventureWorks2017 SET READ_COMMITTED_SNAPSHOT OFF;
```

Note If the tempdb is filled, data modification using row versioning will continue to succeed, but reads may fail since the versioned row will not be available. If you enable any type of row versioning isolation within your database, you must take extra care to maintain free space within tempdb.

Repeatable Read

The Repeatable Read isolation level allows a SELECT statement to retain its (S) lock until the end of the transaction, thereby preventing other transactions from modifying the data during that time. Database functionality may implement a logical decision inside a transaction based on the data read by a SELECT statement within the transaction. If the outcome of the decision is dependent on the data read by the SELECT statement, then you should consider preventing modification of the data by other concurrent transactions. For example, consider the following two transactions:

- *Normalize the price for* ProductID = *1*: For ProductID = 1, if Price > 10, then decrease the price by 10.
- *Apply a discount*: For products with Price > 10, apply a discount of 40 percent.

Now consider the following test table:

```
DROP TABLE IF EXISTS dbo.MyProduct;
GO
CREATE TABLE dbo.MyProduct (ProductID INT,
                            Price MONEY);
INSERT INTO dbo.MyProduct
VALUES (1, 15.0);
```

You can write the two transactions like this:

```
DECLARE @Price INT ;
BEGIN TRAN NormailizePrice
SELECT  @Price = mp.Price
FROM    dbo.MyProduct AS mp
WHERE   mp.ProductID = 1 ;
/*Allow transaction 2 to execute*/
WAITFOR DELAY '00:00:10' ;
IF @Price > 10
    UPDATE  dbo.MyProduct
    SET     Price = Price - 10
    WHERE   ProductID = 1 ;
COMMIT

--Transaction 2 from Connection 2
BEGIN TRAN ApplyDiscount
UPDATE  dbo.MyProduct
SET     Price = Price * 0.6 --Discount = 40%
WHERE   Price > 10 ;
COMMIT
```

On the surface, the preceding transactions may look good, and yes, they do work in a single-user environment. But in a multiuser environment, where multiple transactions can be executed concurrently, you have a problem here!

To figure out the problem, let's execute the two transactions from different connections in the following order:

1. Start transaction 1 first.
2. Start transaction 2 within ten seconds of the start of transaction 1.

As you may have guessed, at the end of the transactions, the new price of the product (with `ProductID = 1`) will be `-1.0`. Ouch—it appears that you're ready to go out of business!

The problem occurs because transaction 2 is allowed to modify the data while transaction 1 has finished reading the data and is about to make a decision on it. Transaction 1 requires a higher degree of isolation than that provided by the default isolation level (Read Committed).

As a solution, you want to prevent transaction 2 from modifying the data while transaction 1 is working on it. In other words, provide transaction 1 with the ability to read the data again later in the transaction without being modified by others. This feature is called *repeatable read.* Considering the context, the implementation of the solution is probably obvious. After re-creating the sample table, you can write this:

```
SET TRANSACTION ISOLATION LEVEL REPEATABLE READ ;
GO
--Transaction 1 from Connection 1
DECLARE @Price INT ;
BEGIN TRAN NormalizePrice
SELECT  @Price = Price
FROM    dbo.MyProduct AS mp
WHERE   mp.ProductID = 1 ;
/*Allow transaction 2 to execute*/
WAITFOR DELAY  '00:00:10' ;
IF @Price > 10
    UPDATE  dbo.MyProduct
    SET     Price = Price - 10
    WHERE   ProductID = 1 ;
COMMIT
GO
SET TRANSACTION ISOLATION LEVEL READ COMMITTED --Back to default
GO
```

Increasing the isolation level of transaction 1 to Repeatable Read will prevent transaction 2 from modifying the data during the execution of transaction 1. Consequently, you won't have an inconsistency in the price of the product. Since the intention isn't to release the (S) lock acquired by the SELECT statement until the end of the transaction, the effect of setting the isolation level to Repeatable Read can also be implemented at the query level using the lock hint.

```
DECLARE @Price INT ;
BEGIN TRAN NormalizePrice
SELECT  @Price = Price
FROM    dbo.MyProduct AS mp WITH (REPEATABLEREAD)
WHERE   mp.ProductID = 1 ;
/*Allow transaction 2 to execute*/
WAITFOR DELAY  '00:00:10'
IF @Price > 10
    UPDATE  dbo.MyProduct
    SET     Price = Price - 10
    WHERE   ProductID = 1 ;
COMMIT
```

This solution prevents the data inconsistency of MyProduct.Price, but it introduces another problem to this scenario. On observing the result of transaction 2, you realize that it could cause a deadlock. Therefore, although the preceding solution prevented the data inconsistency, it is not a complete solution. Looking closely at the effect of the Repeatable Read isolation level on the transactions, you see that it introduced the typical deadlock issue avoided by the internal implementation of an UPDATE statement, as explained previously. The SELECT statement acquired and retained an (S) lock instead of a (U) lock, even though it intended to modify the data later within the transaction. The (S) lock allowed transaction 2 to acquire a (U) lock, but it blocked the (U) lock's conversion to an (X) lock. The attempt of transaction 1 to acquire a (U) lock on the data at a later stage caused a circular block, resulting in a deadlock.

To prevent the deadlock and still avoid data corruption, you can use an equivalent strategy as adopted by the internal implementation of the UPDATE statement. Thus, instead of requesting an (S) lock, transaction 1 can request a (U) lock by using an UPDLOCK locking hint when executing the SELECT statement.

```
DECLARE @Price INT ;
BEGIN TRAN NormalizePrice
SELECT  @Price = Price
FROM    dbo.MyProduct AS mp WITH (UPDLOCK)
WHERE   mp.ProductID = 1 ;
/*Allow transaction 2 to execute*/
WAITFOR DELAY  '00:00:10'
IF @Price > 10
    UPDATE  dbo.MyProduct
    SET     Price = Price - 10
    WHERE   ProductID = 1 ;
COMMIT
```

This solution prevents both data inconsistency and the possibility of the deadlock. If the increase of the isolation level to Repeatable Read had not introduced the typical deadlock, then it would have done the job. Since there is a chance of a deadlock occurring because of the retention of an (S) lock until the end of a transaction, it is usually preferable to grab a (U) lock instead of holding the (S) lock, as just illustrated.

Serializable

Serializable is the highest of the six isolation levels. Instead of acquiring a lock only on the row to be accessed, the Serializable isolation level acquires a range lock on the row and the next row in the order of the data set requested. For instance, a SELECT statement executed at the Serializable isolation level acquires a (RangeS-S) lock on the row to be accessed and the next row in the order. This prevents the addition of rows by other transactions in the data set operated on by the first transaction, and it protects the first transaction from finding new rows in its data set within its transaction scope. Finding new rows in a data set within a transaction is also called a *phantom read.*

To understand the need for a Serializable isolation level, let's consider an example. Suppose a group (with GroupID = 10) in a company has a fund of $100 to be distributed

among the employees in the group as a bonus. The fund balance after the bonus payment should be $0. Consider the following test table:

```
DROP TABLE IF EXISTS dbo.MyEmployees;
GO
CREATE TABLE dbo.MyEmployees (EmployeeID INT,
                              GroupID INT,
                              Salary MONEY);
CREATE CLUSTERED INDEX i1 ON dbo.MyEmployees (GroupID);

--Employee 1 in group 10
INSERT INTO dbo.MyEmployees
VALUES (1, 10, 1000),
       --Employee 2 in group 10
       (2, 10, 1000),
       --Employees 3 & 4 in different groups
       (3, 20, 1000),
       (4, 9, 1000);
```

The described business functionality may be implemented as follows:

```
DECLARE @Fund MONEY = 100,
    @Bonus MONEY,
    @NumberOfEmployees INT;

BEGIN TRAN PayBonus
SELECT  @NumberOfEmployees = COUNT(*)
FROM    dbo.MyEmployees
WHERE   GroupID = 10;

/*Allow transaction 2 to execute*/
WAITFOR DELAY  '00:00:10';

IF @NumberOfEmployees > 0
    BEGIN
        SET @Bonus = @Fund / @NumberOfEmployees;
        UPDATE  dbo.MyEmployees
        SET     Salary = Salary + @Bonus
```

```
        WHERE   GroupID = 10;
        PRINT 'Fund balance =
' + CAST((@Fund - (@@ROWCOUNT * @Bonus)) AS VARCHAR(6)) + '   $';
    END
COMMIT
```

You'll see the returned value as a fund balance of $0 since the updates complete successfully. The PayBonus transaction works well in a single-user environment. However, in a multiuser environment, there is a problem.

Consider another transaction that adds a new employee to GroupID = 10 as follows and is executed concurrently (immediately after the start of the PayBonus transaction) from a second connection:

```
BEGIN TRAN NewEmployee
INSERT  INTO MyEmployees
VALUES  (5, 10, 1000);
COMMIT
```

The fund balance after the PayBonus transaction will be -$50! Although the new employee may like it, the group fund will be in the red. This causes an inconsistency in the logical state of the data.

To prevent this data inconsistency, the addition of the new employee to the group (or data set) under operation should be blocked. Of the five isolation levels discussed, only Snapshot isolation can provide a similar functionality, since the transaction has to be protected not only on the existing data but also from the entry of new data in the data set. The Serializable isolation level can provide this kind of isolation by acquiring a range lock on the affected row and the next row in the order determined by the MyEmployees.il index on the GroupID column. Thus, the data inconsistency of the PayBonus transaction can be prevented by setting the transaction isolation level to Serializable.

Remember to re-create the table first.

```
SET TRANSACTION ISOLATION LEVEL SERIALIZABLE;
GO
DECLARE @Fund MONEY = 100,
    @Bonus MONEY,
    @NumberOfEmployees INT;
```

```
BEGIN TRAN PayBonus
SELECT  @NumberOfEmployees = COUNT(*)
FROM    dbo.MyEmployees
WHERE   GroupID = 10;

/*Allow transaction 2 to execute*/
WAITFOR DELAY  '00:00:10';
IF @NumberOfEmployees > 0
    BEGIN
        SET @Bonus = @Fund / @NumberOfEmployees;
        UPDATE  dbo.MyEmployees
        SET     Salary = Salary + @Bonus
        WHERE   GroupID = 10;

        PRINT 'Fund balance =
' + CAST((@Fund - (@@ROWCOUNT * @Bonus)) AS VARCHAR(6)) + '   $';
    END
COMMIT
GO
--Back to default
SET TRANSACTION ISOLATION LEVEL READ COMMITTED ;
GO
```

The effect of the Serializable isolation level can also be achieved at the query level by using the HOLDLOCK locking hint on the SELECT statement, as shown here:

```
DECLARE @Fund MONEY = 100,
    @Bonus MONEY,
    @NumberOfEmployees INT ;

BEGIN TRAN PayBonus
SELECT  @NumberOfEmployees = COUNT(*)
FROM    dbo.MyEmployees WITH (HOLDLOCK)
WHERE   GroupID = 10 ;

/*Allow transaction 2 to execute*/
WAITFOR DELAY  '00:00:10' ;

IF @NumberOfEmployees > 0
```

```
    BEGIN
        SET @Bonus = @Fund / @NumberOfEmployees
        UPDATE  dbo.MyEmployees
        SET     Salary = Salary + @Bonus
        WHERE   GroupID = 10 ;

        PRINT 'Fund balance =
' + CAST((@Fund - (@@ROWCOUNT * @Bonus)) AS VARCHAR(6)) + '   $' ;
    END
COMMIT
```

You can observe the range locks acquired by the `PayBonus` transaction by querying `sys.dm_tran_locks` from another connection while the `PayBonus` transaction is executing, as shown in Figure 21-6.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	54	5	0	DATABASE		S	GRANT
2	53	5	0	DATABASE		S	GRANT
3	52	5	0	DATABASE		S	GRANT
4	52	5	72057594071678976	KEY	(fca1e333d991)	RangeS-S	GRANT
5	52	5	72057594071678976	KEY	(1c95cdbc1d2d)	RangeS-S	GRANT
6	53	5	72057594071678976	PAGE	1:24272	IX	GRANT
7	52	5	72057594071678976	PAGE	1:24272	IS	GRANT
8	52	5	72057594071678976	KEY	(241332e1ddb0)	RangeS-S	GRANT
9	53	5	2020202247	OBJECT		IX	GRANT
10	52	5	2020202247	OBJECT		IS	GRANT
11	52	5	72057594071678976	KEY	(69c872e07e60)	RangeS-S	GRANT
12	53	5	72057594071678976	KEY	(69c872e07e60)	RangeI-N	WAIT

Figure 21-6. *Output from sys.dm_tran_locks showing range locks granted to the serializable transaction*

The output of `sys.dm_tran_locks` shows that shared-range (RangeS-S) locks are acquired on three index rows: the first employee in `GroupID = 10`, the second employee in `GroupID = 10`, and the third employee in `GroupID = 20`. These range locks prevent the entry of any new employee in `GroupID = 10`.

The range locks just shown introduce a few interesting side effects.

- No new employee with a `GroupID` between 10 and 20 can be added during this period. For instance, an attempt to add a new employee with a `GroupID` of 15 will be blocked by the `PayBonus` transaction.

```
BEGIN TRAN NewEmployee
INSERT  INTO dbo.MyEmployees
VALUES  (6, 15, 1000);
COMMIT
```

- If the data set of the `PayBonus` transaction turns out to be the last set in the existing data ordered by the index, then the range lock required on the row, after the last one in the data set, is acquired on the last possible data value in the table.

  To understand this behavior, let's delete the employees with a `GroupID > 10` to make the `GroupID = 10` data set the last data set in the clustered index (or table).

```
DELETE  dbo.MyEmployees
WHERE   GroupID > 10;
```

Run the updated bonus and `newemployee` again. Figure 21-7 shows the resultant output of `sys.dm_tran_locks` for the `PayBonus` transaction.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	54	5	0	DATABASE		S	GRANT
2	53	5	0	DATABASE		S	GRANT
3	52	5	0	DATABASE		S	GRANT
4	52	5	72057594071678976	KEY	(ffffffffffff)	RangeS-S	GRANT
5	53	5	72057594071678976	KEY	(ffffffffffff)	RangeI-N	WAIT
6	52	5	72057594071678976	KEY	(e5d9a62bf821)	RangeS-S	GRANT
7	52	5	72057594071678976	KEY	(fca1e333d991)	RangeS-S	GRANT
8	52	5	72057594071678976	KEY	(1c95cdbc1d2d)	RangeS-S	GRANT
9	53	5	72057594071678976	PAGE	1:24272	IX	GRANT
10	52	5	72057594071678976	PAGE	1:24272	IS	GRANT
11	52	5	72057594071678976	KEY	(241332e1ddb0)	RangeS-S	GRANT
12	53	5	2020202247	OBJECT		IX	GRANT
13	52	5	2020202247	OBJECT		IS	GRANT

Figure 21-7. *Output from sys.dm_tran_locks showing extended range locks granted to the serializable transaction*

The range lock on the last possible row (KEY = ffffffffffff) in the clustered index, as shown in Figure 21-7, will block the addition of employees with all GroupIDs greater than or equal to 10. You know that the lock is on the last row, not because it's displayed in a visible fashion in the output of sys.dm_tran_locks but because you cleaned out everything up to that row previously. For example, an attempt to add a new employee with GroupID = 999 will be blocked by the PayBonus transaction.

```
BEGIN TRAN NewEmployee
INSERT  INTO dbo.MyEmployees
VALUES  (7, 999, 1000);
COMMIT
```

Guess what will happen if the table doesn't have an index on the GroupID column (in other words, the column in the WHERE clause)? While you're thinking, I'll re-create the table with the clustered index on a different column.

```
DROP TABLE IF EXISTS dbo.MyEmployees;
GO
CREATE TABLE dbo.MyEmployees (EmployeeID INT,
                              GroupID INT,
                              Salary MONEY);
CREATE CLUSTERED INDEX i1 ON dbo.MyEmployees (EmployeeID);

--Employee 1 in group 10
INSERT INTO dbo.MyEmployees
VALUES (1, 10, 1000),
       --Employee 2 in group 10
       (2, 10, 1000),
       --Employees 3 & 4 in different groups
       (3, 20, 1000),
       (4, 9, 1000);
```

Now rerun the updated bonus query and the new employee query. Figure 21-8 shows the resultant output of sys.dm_tran_locks for the PayBonus transaction.

Once again, the range lock on the last possible row (KEY = ffffffffffff) in the new clustered index, as shown in Figure 21-8, will block the addition of any new row to the table. I will discuss the reason behind this extensive locking later in the chapter in the "Effect of Indexes on the Serializable Isolation Level" section.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	54	5	0	DATABASE		S	GRANT
2	53	5	0	DATABASE		S	GRANT
3	52	5	0	DATABASE		S	GRANT
4	52	5	72057594071678976	KEY	(ffffffffffff)	RangeS-S	GRANT
5	53	5	72057594071678976	KEY	(ffffffffffff)	RangeI-N	WAIT
6	52	5	72057594071678976	KEY	(e5d9a62bf821)	RangeS-S	GRANT
7	52	5	72057594071678976	KEY	(ddfc91a29454)	RangeS-S	GRANT
8	52	5	72057594071678976	KEY	(fca1e333d991)	RangeS-S	GRANT
9	52	5	72057594071678976	KEY	(1c95cdbc1d2d)	RangeS-S	GRANT
10	53	5	72057594071678976	PAGE	1:24272	IX	GRANT
11	52	5	72057594071678976	PAGE	1:24272	IS	GRANT
12	52	5	72057594071678976	KEY	(241332e1ddb0)	RangeS-S	GRANT
13	53	5	2020202247	OBJECT		IX	GRANT
14	52	5	2020202247	OBJECT		IS	GRANT

Figure 21-8. *Output from sys.dm_tran_locks showing range locks granted to the serializable transaction with no index on the WHERE clause column*

As you've seen, the Serializable isolation level not only holds the share locks until the end of the transaction like the Repeatable Read isolation level but also prevents any new row from appearing in the data set by holding range locks. Because this increased blocking can hurt database concurrency, you should avoid the Serializable isolation level. If you have to use Serializable, then be sure you have good indexes and queries in place to optimize performance in order to minimize the size and length of your transactions.

Snapshot

Snapshot isolation is the second of the row-versioning isolation levels available in SQL Server since SQL Server 2005. Unlike Read Committed Snapshot isolation, Snapshot isolation requires an explicit call to `SET TRANSACTION ISOLATION LEVEL` at the start of the transaction. It also requires setting the isolation level on the database. Snapshot isolation is meant as a more stringent isolation level than the Read Committed Snapshot isolation. Snapshot isolation will attempt to put an exclusive lock on the data it intends to modify. If that data already has a lock on it, the snapshot transaction will fail. It provides transaction-level read consistency, which makes it more applicable to financial-type systems than Read Committed Snapshot.

Effect of Indexes on Locking

Indexes affect the locking behavior on a table. On a table with no indexes, the lock granularities are RID, PAG (on the page containing the RID), and TAB. Adding indexes to the table affects the resources to be locked. For example, consider the following test table with no indexes:

```
DROP TABLE IF EXISTS dbo.Test1;
GO

CREATE TABLE dbo.Test1 (C1 INT,
                        C2 DATETIME);

INSERT INTO dbo.Test1
VALUES (1, GETDATE());
```

Next, observe the locking behavior on the table for the transaction:

```
BEGIN TRAN LockBehavior
UPDATE  dbo.Test1 WITH (REPEATABLEREAD)  --Hold all acquired locks
SET     C2 = GETDATE()
WHERE   C1 = 1 ;
--Observe lock behavior from another connection
WAITFOR DELAY  '00:00:10' ;
COMMIT
```

Figure 21-9 shows the output of sys.dm_tran_locks applicable to the test table.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	62	6	0	DATABASE		S	GRANT
3	55	9	0	DATABASE		S	GRANT
4	62	6	2020202247	OBJECT		IX	GRANT
5	62	6	72057594078232576	PAGE	1:42448	IX	GRANT
6	62	6	72057594078232576	RID	1:42448:0	X	GRANT

Figure 21-9. *Output from sys.dm_tran_locks showing the locks granted on a table with no index*

The following locks are acquired by the transaction:

- An (IX) lock on the table
- An (IX) lock on the page containing the data row
- An (X) lock on the data row within the table

When the `resource_type` is an object, the `resource_associated_entity_id` column value in `sys.dm_tran_locks` indicates the `objectid` of the object on which the lock is placed. You can obtain the specific object name on which the lock is acquired from the `sys.object` system table, as follows:

```
SELECT OBJECT_NAME(<object_id>);
```

The effect of the index on the locking behavior of the table varies with the type of index on the `WHERE` clause column. The difference arises from the fact that the leaf pages of the nonclustered and clustered indexes have a different relationship with the data pages of the table. Let's look into the effect of these indexes on the locking behavior of the table.

Effect of a Nonclustered Index

Because the leaf pages of the nonclustered index are separate from the data pages of the table, the resources associated with the nonclustered index are also protected from corruption. SQL Server automatically ensures this. To see this in action, create a nonclustered index on the test table.

```
CREATE NONCLUSTERED INDEX iTest ON dbo.Test1(C1);
```

On running the `LockBehavior` transaction again and querying `sys.dm_tran_locks` from a separate connection, you get the result shown in Figure 21-10.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	62	6	0	DATABASE		S	GRANT
3	55	9	0	DATABASE		S	GRANT
4	62	6	72057594078298112	PAGE	1:50688	IU	GRANT
5	62	6	2020202247	OBJECT		IX	GRANT
6	62	6	72057594078232576	PAGE	1:42448	IX	GRANT
7	62	6	72057594078232576	RID	1:42448:0	X	GRANT
8	62	6	72057594078298112	KEY	(bb13f7b7fe64)	U	GRANT

Figure 21-10. *Output from sys.dm_tran_locks showing the effect of a nonclustered index on locking behavior*

The following locks are acquired by the transaction:

- An (IU) lock on the page containing the nonclustered index row
- A (U) lock on the nonclustered index row within the index page
- An (IX) lock on the table
- An (IX) lock on the page containing the data row
- An (X) lock on the data row within the data page

Note that only the row-level and page-level locks are directly associated with the nonclustered index. The next higher level of lock granularity for the nonclustered index is the table-level lock on the corresponding table.

Thus, nonclustered indexes introduce an additional locking overhead on the table. You can avoid the locking overhead on the index by using the `ALLOW_ROW_LOCKS` and `ALLOW_PAGE_LOCKS` options in `ALTER INDEX`. Understand, though, that this is a trade-off that could involve a loss of performance, and it requires careful testing to ensure it doesn't negatively impact your system.

```
ALTER INDEX iTest ON dbo.Test1
    SET (ALLOW_ROW_LOCKS = OFF ,ALLOW_PAGE_LOCKS= OFF);

BEGIN TRAN LockBehavior
UPDATE  dbo.Test1 WITH (REPEATABLEREAD)  --Hold all acquired locks
SET     C2 = GETDATE()
WHERE   C1 = 1;

--Observe lock behavior using sys.dm_tran_locks
--from another connection
WAITFOR DELAY  '00:00:10';
COMMIT

ALTER INDEX iTest ON dbo.Test1
    SET (ALLOW_ROW_LOCKS = ON ,ALLOW_PAGE_LOCKS= ON);
```

You can use these options when working with an index to enable/disable the `KEY` locks and `PAG` locks on the index. Disabling just the `KEY` lock causes the lowest lock granularity on the index to be the `PAG` lock. Configuring lock granularity on the index remains effective until it is reconfigured.

Note Modifying locks like this should be a last resort after many other options have been tried. This could cause significant locking overhead that would seriously impact the performance of the system.

Figure 21-11 displays the output of `sys.dm_tran_locks` executed from a separate connection.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	62	6	0	DATABASE		S	GRANT
3	55	9	0	DATABASE		S	GRANT
4	62	6	2020202247	OBJECT		X	GRANT

Figure 21-11. *Output from sys.dm_tran_locks showing the effect of sp_index option on lock granularity*

The only lock acquired by the transaction on the test table is an (X) lock on the table.

You can see from the new locking behavior that disabling the KEY lock escalates lock granularity to the table level. This will block every concurrent access to the table or to the indexes on the table; consequently, it can seriously hurt the database concurrency. However, if a nonclustered index becomes a point of contention in a blocking scenario, then it may be beneficial to disable the PAG locks on the index, thereby allowing only KEY locks on the index.

Note Using this option can have serious side effects. You should use it only as a last resort.

Effect of a Clustered Index

Since for a clustered index the leaf pages of the index and the data pages of the table are the same, the clustered index can be used to avoid the overhead of locking additional pages (leaf pages) and rows introduced by a nonclustered index. To understand the locking overhead associated with a clustered index, convert the preceding nonclustered index to a clustered index.

```
CREATE CLUSTERED INDEX iTest ON dbo.Test1(C1) WITH DROP_EXISTING;
```

If you run the locking script again and query `sys.dm_tran_locks` in a different connection, you should see the resultant output for the `LockBehavior` transaction on `iTest` shown in Figure 21-12.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
1	52	6	0	DATABASE		S	GRANT
2	62	6	0	DATABASE		S	GRANT
3	55	9	0	DATABASE		S	GRANT
4	62	6	72057594078363648	KEY	(de42f79bc795)	X	GRANT
5	62	6	2020202247	OBJECT		IX	GRANT
6	62	6	72057594078363648	PAGE	1:62608	IX	GRANT

Figure 21-12. *Output from sys.dm_tran_locks showing the effect of a clustered index on locking behavior*

The following locks are acquired by the transaction:

- An (IX) lock on the table
- An (IX) lock on the page containing the clustered index row
- An (X) lock on the clustered index row within the table or clustered index

The locks on the clustered index row and the leaf page are actually the locks on the data row and data page, too, since the data pages and the leaf pages are the same. Thus, the clustered index reduced the locking overhead on the table compared to the nonclustered index.

Reduced locking overhead of a clustered index is another benefit of using a clustered index over a heap.

Effect of Indexes on the Serializable Isolation Level

Indexes play a significant role in determining the amount of blocking caused by the Serializable isolation level. The availability of an index on the `WHERE` clause column (that causes the data set to be locked) allows SQL Server to determine the order of the rows to be locked. For instance, consider the example used in the section on the Serializable isolation level. The `SELECT` statement uses a filter on the `GroupID` column to form its data set, like so:

```
DECLARE @NumberOfEmployees INT;
SELECT  @NumberOfEmployees = COUNT(*)
```

```
FROM    dbo.MyEmployees WITH (HOLDLOCK)
WHERE   GroupID = 10;
```

A clustered index is available on the `GroupID` column, allowing SQL Server to acquire a (RangeS-S) lock on the row to be accessed and the next row in the correct order.

If the index on the `GroupID` column is removed, then SQL Server cannot determine the rows on which the range locks should be acquired since the order of the rows is no longer guaranteed. Consequently, the `SELECT` statement acquires an (IS) lock at the table level instead of acquiring lower-granularity locks at the row level, as shown in Figure 21-13.

	request_session_id	resource_database_id	resource_associated_entity_id	resource_type	resource_description	request_mode	request_status
11	62	6	2004202190	OBJECT		IS	GRANT

Figure 21-13. *Output from sys.dm_tran_locks showing the locks granted to a SELECT statement with no index on the WHERE clause column*

By failing to have an index on the filter column, you significantly increase the degree of blocking caused by the Serializable isolation level. This is another good reason to have an index on the `WHERE` clause columns.

Capturing Blocking Information

Although blocking is necessary to isolate a transaction from other concurrent transactions, sometimes it may rise to excessive levels, adversely affecting database concurrency. In the simplest blocking scenario, the lock acquired by a session on a resource blocks another session requesting an incompatible lock on the resource. To improve concurrency, it is important to analyze the cause of blocking and apply the appropriate resolution.

In a blocking scenario, you need the following information to have a clear understanding of the cause of the blocking:

- *The connection information of the blocking and blocked sessions*: You can obtain this information from the `sys.dm_os_waiting_tasks` dynamic management view.
- *The lock information of the blocking and blocked sessions*: You can obtain this information from the `sys.dm_tran_locks` DMO.

- *The SQL statements last executed by the blocking and blocked sessions:* You can use the `sys.dm_exec_requests` DMV combined with `sys.dm_exec_sql_text` and `sys.dm_exec_queryplan` or Extended Events to obtain this information.

You can also obtain the following information from SQL Server Management Studio by running the Activity Monitor. The Processes page provides connection information of all SPIDs. This shows blocked SPIDS, the process blocking them, and the head of any blocking chain with details on how long the process has been running, its SPID, and other information. It is possible to put Extended Events to work using the blocking report to gather a lot of the same information. For immediate checks on locking, use the DMOs; for extended monitoring and historical tracking, you'll want to use Extended Events. You can find more on this in the "Extended Events and the blocked_process_report Event" section.

To provide more power and flexibility to the process of collecting blocking information, a SQL Server administrator can use SQL scripts to provide the relevant information listed here.

Capturing Blocking Information with SQL

To arrive at enough information about blocked and blocking processes, you can bring several dynamic management views into play. This query will show information necessary to identify blocked processes based on those that are waiting. You can easily add filtering to access only those processes blocked for a certain period of time or only within certain databases, among other options.

```
SELECT  dtl.request_session_id AS WaitingSessionID,
        der.blocking_session_id AS BlockingSessionID,
        dowt.resource_description,
        der.wait_type,
        dowt.wait_duration_ms,
        DB_NAME(dtl.resource_database_id) AS DatabaseName,
        dtl.resource_associated_entity_id AS WaitingAssociatedEntity,
        dtl.resource_type AS WaitingResourceType,
        dtl.request_type AS WaitingRequestType,
        dest.[text] AS WaitingTSql,
        dtlbl.request_type BlockingRequestType,
```

```
        destbl.[text] AS BlockingTsql
FROM    sys.dm_tran_locks AS dtl
JOIN    sys.dm_os_waiting_tasks AS dowt
        ON dtl.lock_owner_address = dowt.resource_address
JOIN    sys.dm_exec_requests AS der
        ON der.session_id = dtl.request_session_id
CROSS APPLY sys.dm_exec_sql_text(der.sql_handle) AS dest
LEFT JOIN sys.dm_exec_requests derbl
        ON derbl.session_id = dowt.blocking_session_id
OUTER APPLY sys.dm_exec_sql_text(derbl.sql_handle) AS destbl
LEFT JOIN sys.dm_tran_locks AS dtlbl
        ON derbl.session_id = dtlbl.request_session_id;
```

To understand how to analyze a blocking scenario and the relevant information provided by the blocker script, consider the following example. First, create a test table.

```
DROP TABLE IF EXISTS dbo.BlockTest;
GO

CREATE TABLE dbo.BlockTest (C1 INT,
                            C2 INT,
                            C3 DATETIME);

INSERT INTO dbo.BlockTest
VALUES (11, 12, GETDATE()),
       (21, 22, GETDATE());
```

Now open three connections and run the following two queries concurrently. Once you run them, use the blocker script in the third connection. Execute the following code in one connection:

```
BEGIN TRAN User1
UPDATE  dbo.BlockTest
SET     C3 = GETDATE();
```

Next, execute this code while the `User1` transaction is executing:

```
BEGIN TRAN User2
SELECT  C2
FROM    dbo.BlockTest
WHERE   C1 = 11;
COMMIT
```

This creates a simple blocking scenario where the `User1` transaction blocks the `User2` transaction.

The output of the blocker script provides information immediately useful to begin resolving blocking issues. First, you can identify the specific session information, including the session ID of both the blocking and waiting sessions. You get an immediate resource description from the waiting resource, the wait type, and the length of time in milliseconds that the process has been waiting. It's that value that allows you to provide a filter to eliminate short-term blocks, which are part of normal processing.

The database name is supplied because blocking can occur anywhere in the system, not just in AdventureWorks2017. You'll want to identify it where it occurs. The resources and types from the basic locking information are retrieved for the waiting process.

The blocking request type is displayed, and both the waiting T-SQL and blocking T-SQL, if available, are displayed. Once you have the object where the block is occurring, having the T-SQL so that you can understand exactly where and how the process is either blocking or being blocked is a vital part of the process of eliminating or reducing the amount of blocking. All this information is available from one simple query. Figure 21-14 shows the sample output from the earlier blocked process.

Figure 21-14. *Output from the blocker script*

Be sure to go back to Connection 1 and commit or roll back the transaction.

Extended Events and the blocked_process_report Event

Extended Events provides an event called `blocked_process_report`. This event works off the blocked process threshold that you need to provide to the system configuration. This script sets the threshold to five seconds:

```
EXEC sp_configure 'show advanced option', '1';
RECONFIGURE;
EXEC sp_configure
    'blocked process threshold',
    5;
RECONFIGURE;
```

This would normally be a very low value in most systems. If you have an established performance service level agreement (SLA), you could use that as the threshold. Once the value is set, you can configure alerts so that e-mails, tweets, or instant messages are sent if any process is blocked longer than the value you set. It also acts as a trigger for the extended event. The default value for the `blocked process threshold` is zero, meaning that it never actually fires. If you are going to use Extended Events to track blocked processes, you will want to adjust this value from the default.

To set up a session that captures the `blocked_process_report`, first open the Extended Events session properties window. (Although you should use scripts to set up this event in a production environment, I'll show how to use the GUI.) Provide the session with a name and then navigate to the Events page. Type **block** into the "Event library" text box, which will find the `blocked_process_report` event. Select that event by clicking the right arrow. You should see something similar to Figure 21-15.

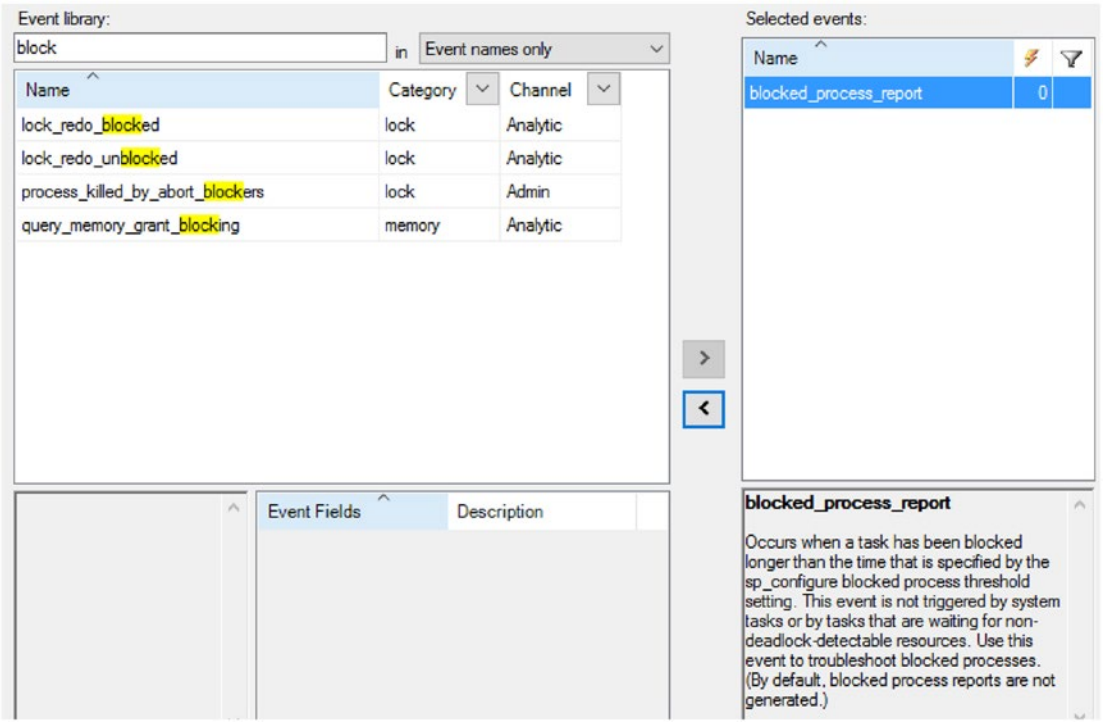
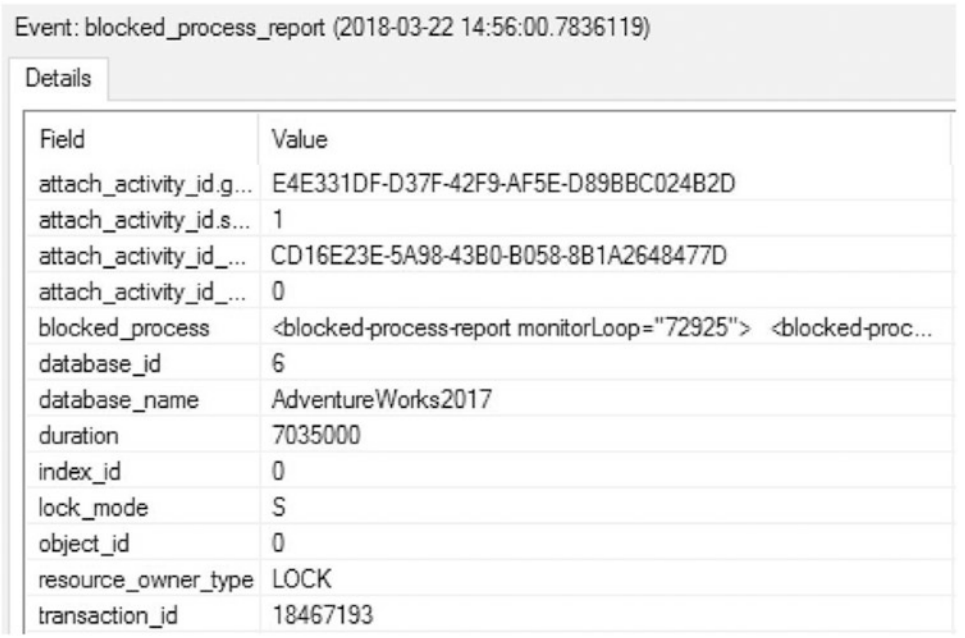


Figure 21-15. *The blocked process report event selected in the Extended Events window*

The event fields are all preselected for you. If you still have the queries running from the previous section that created the block, all you need to do now is click the Run button to capture the event. Otherwise, go back to the queries we used to generate the blocked process report in the previous section and run them in two different connections. After the blocked process threshold is passed, you'll see the event fire…and fire. It will fire every five seconds if that's how you've configured it and you're leaving the connections running. The output in the live data stream looks like Figure 21-16.


Event: blocked_process_report (2018-03-22 14:56:00.7836119)

Details

Field	Value
attach_activity_id.g...	E4E331DF-D37F-42F9-AF5E-D89BBC024B2D
attach_activity_id.s...	1
attach_activity_id_...	CD16E23E-5A98-43B0-B058-8B1A2648477D
attach_activity_id_...	0
blocked_process	<blocked-process-report monitorLoop="72925"> <blocked-proc...
database_id	6
database_name	AdventureWorks2017
duration	7035000
index_id	0
lock_mode	S
object_id	0
resource_owner_type	LOCK
transaction_id	18467193

Figure 21-16. *Output from the blocked_process_report event*

Some of the information is self-explanatory; to get into the details, you need to look at the XML generated in the `blocked_process` field.

```
<blocked-process-report monitorLoop="72925">
 <blocked-process>
  <process id="process1edc0b0c108" taskpriority="0" logused="0"
   waitresource="RID: 6:1:72793:0" waittime="7035" ownerId="18467193"
   transactionname="User2" lasttranstarted="2018-03-22T14:55:53.743"
   XDES="0x1edf1bc0490" lockMode="S" schedulerid="1" kpid="14036"
   status="suspended" spid="53" sbid="0" ecid="0" priority="0" trancount="1"
   lastbatchstarted="2018-03-22T14:55:53.743" lastbatchcompleted="2018-
   03-22T14:55:53.740" lastattention="1900-01-01T00:00:00.740"
   clientapp="Microsoft SQL Server Management Studio - Query" hostname="WIN-
   8A2LQANSO51" hostpid="5540" loginname="WIN-8A2LQANSO51\Administrator"
   isolationlevel="read committed (2)" xactid="18467193" currentdb="6"
   lockTimeout="4294967295" clientoption1="671090784" clientoption2="390200">
   <executionStack>
    <frame line="2" stmtstart="24" stmtend="118" sqlhandle="0x02000000ccf3e60
     45e680885750c3f36d7cc549d8ff01368000000000000000000000000000000000000000"/>
```

```
    <frame line="2" stmtstart="36" stmtend="134" sqlhandle="0x0200000063e12d309
     fa7874804b7b56c7be7beecf2a0255b0000000000000000000000000000000000000000"/>
   </executionStack>
   <inputbuf>
BEGIN TRAN User2
SELECT  C2
FROM    dbo.BlockTest
WHERE   C1 = 11;
COMMIT   </inputbuf>
  </process>
 </blocked-process>
 <blocking-process>
  <process status="sleeping" spid="62" sbid="0" ecid="0" priority="0"
   trancount="1" lastbatchstarted="2018-03-22T14:55:50.923"
   lastbatchcompleted="2018-03-22T14:55:50.927" lastattention="1900-01-
   01T00:00:00.927" clientapp="Microsoft SQL Server Management Studio -
   Query" hostname="WIN-8A2LQANSO51" hostpid="5540" loginname="WIN-
   8A2LQANSO51\Administrator" isolationlevel="read committed
   (2)" xactid="18467189" currentdb="6" lockTimeout="4294967295"
   clientoption1="671090784" clientoption2="390200">
   <executionStack />
   <inputbuf>
BEGIN TRAN User1
UPDATE  dbo.BlockTest
SET     C3 = GETDATE();   </inputbuf>
  </process>
 </blocking-process>
</blocked-process-report>
```

The elements are clear if you look through this XML. `<blocked-process>` shows information about the process that was blocked, including familiar information such as the session ID (labeled with the old-fashioned SPID here), the database ID, and so on. You can see the query in the `<inputbuf>` element. Details such as the `lockMode` are available within the `<process>` element. Note that the XML doesn't include some of the other information that you can easily get from T-SQL queries, such as the query string of the blocked and waiting processes. But with the SPID available, you can get them from

the cache, if available, or you can combine the Blocked Process report with other events such as `rpc_starting` to show the query information. However, doing so will add to the overhead of using those events long term within your database. If you know you have a blocking problem, this can be part of a short-term monitoring project to capture the necessary blocking information.

Blocking Resolutions

Once you've analyzed the cause of a block, the next step is to determine any possible resolutions. Here are a few techniques you can use to do this:

- Optimize the queries executed by blocking and blocked SPIDs.
- Decrease the isolation level.
- Partition the contended data.
- Use a covering index on the contended data.

Note A detailed list of recommendations to avoid blocking appears later in the chapter in the "Recommendations to Reduce Blocking" section.

To understand these resolution techniques, let's apply them in turn to the preceding blocking scenario.

Optimize the Queries

Optimizing the queries executed by the blocking and blocked processes helps reduce the blocking duration. In the blocking scenario, the queries executed by the processes participating in the blocking are as follows:

- Blocking process:

```
BEGIN TRAN User1
UPDATE  dbo.BlockTest
SET     C3 = GETDATE();
```

- Blocked process:

```
BEGIN TRAN User2
SELECT  C2
FROM    dbo.BlockTest
WHERE   C1 = 11;
COMMIT
```

Note that beyond the missing `COMMIT` for the first query, running `UPDATE` without a `WHERE` clause is certainly potentially problematic and will not perform well. It will get worse over time as the data scales. However, it is just a test for demonstration purposes.

Next, let's analyze the individual SQL statements executed by the blocking and blocked SPIDs to optimize their performance.

- The `UPDATE` statement of the blocking SPID accesses the data without a `WHERE` clause. This makes the query inherently costly on a large table. If possible, break the action of the `UPDATE` statement into multiple batches using appropriate `WHERE` clauses. Remember to try to use set-based operations such as a `TOP` statement to limit the rows. If the individual `UPDATE` statements of the batch are executed in separate transactions, then fewer locks will be held on the resource within one transaction and for shorter time periods. This could also help reduce or avoid lock escalation.
- The `SELECT` statement executed by the blocked SPID has a `WHERE` clause on the `C1` column. From the index structure on the test table, you can see that there is no index on this column. To optimize the `SELECT` statement, you could create a clustered index on the `C1` column.

```
CREATE CLUSTERED INDEX i1 ON dbo.BlockTest(C1);
```

Note Since the `example` table fits within one page, adding the clustered index won't make much difference to the query performance. However, as the number of rows in the table increases, the beneficial effect of the index will become more pronounced.

Optimizing the queries reduces the duration for which the locks are held by the processes. The query optimization reduces the impact of blocking, but it doesn't prevent the blocking completely. However, as long as the optimized queries execute within acceptable performance limits, a small amount of blocking may be ignored.

Decrease the Isolation Level

Another approach to resolve blocking can be to use a lower isolation level, if possible. The SELECT statement of the User2 transaction gets blocked while requesting an (S) lock on the data row. The isolation level of this transaction can be mitigated by taking advantage of SNAPSHOT isolation level Read Committed Snapshot so that the (S) lock is not requested by the SELECT statement. The Read Committed Snapshot isolation level can be configured for the connection using the SET statement.

```
SET TRANSACTION ISOLATION LEVEL SNAPSHOT;
GO
BEGIN TRAN User2
SELECT  C2
FROM    dbo.BlockTest
WHERE   C1 = 11;
COMMIT
GO
--Back to default
SET TRANSACTION ISOLATION LEVEL READ COMMITTED;
GO
```

This example shows the utility of reducing the isolation level. Using this SNAPSHOT isolation is radically preferred over using any of the methods that produce dirty reads that could lead to incorrect data or missing or extra rows.

Partition the Contended Data

When dealing with large data sets or data that can be discretely stored, it is possible to apply table partitioning to the data. Partitioned data is split horizontally, that is, by certain values (such as splitting sales data up by month, for example). This allows the transactions to execute concurrently on the individual partitions, without blocking each

other. These separate partitions are treated as a single unit for querying, updating, and inserting; only the storage and access are separated by SQL Server. It should be noted that partitioning is available only in the Developer and Enterprise editions of SQL Server.

In the preceding blocking scenario, the data could be separated by date. This would entail setting up multiple filegroups if you're concerned with performance (or just put everything on `PRIMARY` if you're worried about management) and splitting the data per a defined rule. Once the `UPDATE` statement gets a `WHERE` clause, then it and the original `SELECT` statement will be able to execute concurrently on two separate partitions. This does require that the `WHERE` clause filters only on the partition key column. As soon as you get other conditions in the mix, you're unlikely to benefit from partition elimination, which means performance could be much worse, not better.

Note Partitioning, if done properly, can improve both performance and concurrency on large data sets. But, partitioning is almost exclusively a data management solution, not a performance tuning option.

In a blocking scenario, you should analyze whether the query of the blocking or the blocked process can be fully satisfied using a covering index. If the query of one of the processes can be satisfied using a covering index, then it will prevent the process from requesting locks on the contended resource. Also, if the other process doesn't need a lock on the covering index (to maintain data integrity), then both processes will be able to execute concurrently without blocking each other.

For instance, in the preceding blocking scenario, the `SELECT` statement by the blocked process can be fully satisfied by a covering index on the `C1` and `C2` columns.

```
CREATE NONCLUSTERED INDEX iAvoidBlocking ON dbo.BlockTest(C1,  C2) ;
```

The transaction of the blocking process need not acquire a lock on the covering index since it accesses only the `C3` column of the table. The covering index will allow the `SELECT` statement to get the values for the `C1` and `C2` columns without accessing the base table. Thus, the `SELECT` statement of the blocked process can acquire an (S) lock on the covering-index row without being blocked by the (X) lock on the data row acquired by the blocking process. This allows both transactions to execute concurrently without any blocking.

Consider a covering index as a mechanism to "duplicate" part of the table data in which consistency is automatically maintained by SQL Server. This covering index, if mostly read-only, can allow some transactions to be served from the "duplicate" data while the base table (and other indexes) can continue to serve other transactions. The trade-offs to this approach are the need for additional storage and the potential for additional overhead during data modification.

Recommendations to Reduce Blocking

Single-user performance and the ability to scale with multiple users are both important for a database application. In a multiuser environment, it is important to ensure that the database operations don't hold database resources for a long time. This allows the database to support a large number of operations (or database users) concurrently without serious performance degradation. The following is a list of tips to reduce/avoid database blocking:

- Keep transactions short.
  - Perform the minimum steps/logic within a transaction.
  - Do not perform costly external activity within a transaction, such as sending an acknowledgment e-mail or performing activities driven by the end user.
  - Optimize queries.
  - Create indexes as required to ensure optimal performance of the queries within the system.
  - Avoid a clustered index on frequently updated columns. Updates to clustered index key columns require locks on the clustered index and all nonclustered indexes (since their row locator contains the clustered index key).
  - Consider using a covering index to serve the blocked `SELECT` statements.

- Use query timeouts or a resource governor to control runaway queries. For more on the resource governor, consult Books Online: http://bit.ly/1jiPhfS.
  - Avoid losing control over the scope of the transactions because of poor error-handling routines or application logic.
  - Use `SET XACT_ABORT ON` to avoid a transaction being left open on an error condition within the transaction.
  - Execute the following SQL statement from a client error handler (`TRY/CATCH`) after executing a SQL batch or stored procedure containing a transaction.

    ```
    IF @@TRANCOUNT > 0 ROLLBACK
    ```

- Use the lowest isolation level required.
  - Consider using row versioning, one of the `SNAPSHOT` isolation levels, to help reduce contention.

Automation to Detect and Collect Blocking Information

In addition to capturing information using extended events, you can automate the process of detecting a blocking condition and collecting the relevant information using SQL Server Agent. SQL Server provides the Performance Monitor counters shown in Table 21-2 to track the amount of wait time.

Table 21-2. *Performance Monitor Counters*

Object	Counter	Instance	Description
`SQLServer:Locks` (for SOL Server named instance `MSSOL$<InstanceName>:Locks`)	`Average Wait Time(ms)`	`_Total`	Average amount of wait time for each lock that resulted in a wait
	`Lock Wait Time (ms)`	`_Total`	Total wait time for locks in the last second

You can create a combination of SQL Server alerts and jobs to automate the following process:

1. Determine when the average amount of wait time exceeds an acceptable amount of blocking using the `Average Wait Time (ms)` counter. Based on your preferences, you can use the `Lock Wait Time (ms)` counter instead.
2. Once you've established the minimum wait, set `Blocked Process Threshold`. When the average wait time exceeds the limit, notify the SQL Server DBA of the blocking situation through e-mail.
3. Automatically collect the blocking information using the blocker script or a trace that relies on the Blocked Process report for a certain period of time.

To set up the Blocked Process report to run automatically, first create the SQL Server job, called Blocking Analysis, so that it can be used by the SQL Server alert you'll create later. You can create this SQL Server job from SQL Server Management Studio to collect blocking information by following these steps:

1. Generate an Extended Events script (as detailed in Chapter 6) using the `blocked_process_report` event.
2. Run the script to create the session on the server, but don't start it yet.
3. In Management Studio, expand the server by selecting *<ServerName>* ➤ SQL Server Agent ➤ Jobs. Finally, right-click and select New Job.
4. On the General page of the New Job dialog box, enter the job name and other details.
5. On the Steps page, click New and enter the command to start and stop the session through T-SQL, as shown in Figure 21-17.

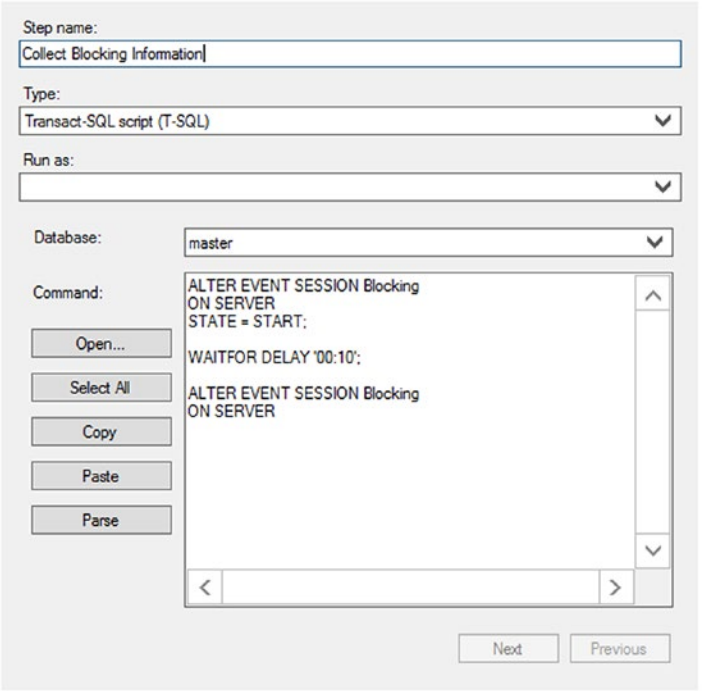


Figure 21-17. *Entering the command to run the blocker script*

You can do this using the following command:

```
ALTER EVENT SESSION Blocking
ON SERVER
STATE = START;

WAITFOR DELAY '00:10';

ALTER EVENT SESSION Blocking
ON SERVER
STATE = STOP;
```

The output of the session is determined by how you defined the target or targets when you created it.

1. Return to the New Job dialog box by clicking OK.
2. Click OK to create the SQL Server job. The SQL Server job will be created with an enabled and runnable state to collect blocking information for ten minutes using the trace script.

You can create a SQL Server alert to automate the following tasks:

- Inform the DBA via e-mail, SMS text, or pager.
- Execute the Blocking Analysis job to collect blocking information for ten minutes.

You can create the SQL Server alert from SQL Server Enterprise Manager by following these steps:

1. In Management Studio, while still in the SQL Agent area of the Object Explorer, right-click Alerts and select New Alert.
2. On the General page of the new alert's Properties dialog box, enter the alert name and other details, as shown in Figure 21-18. The specific object you need to capture information from for your instance is `Locks` (`MSSQL$GF2008:Locks` in Figure 21-18). I chose `500ms` as an example of a stringent SLA that wants to know when queries extend beyond that value.

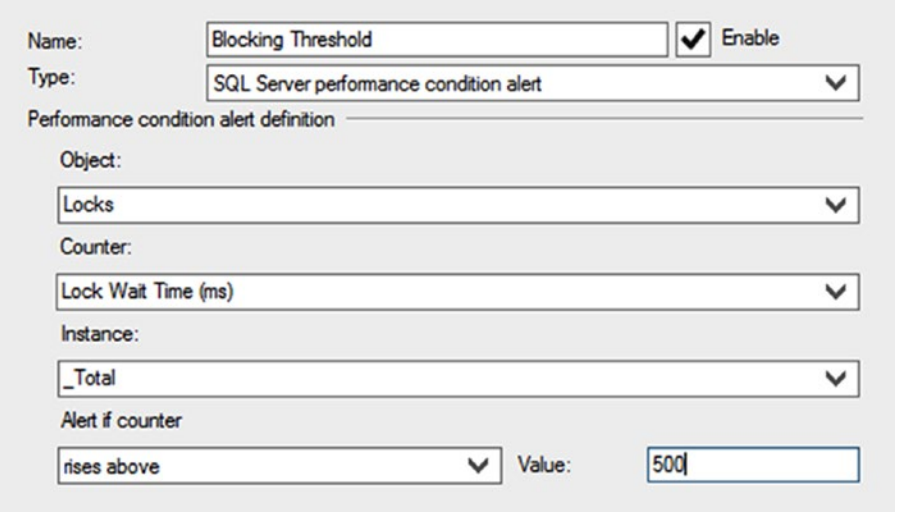


Figure 21-18. *Entering the alert name and other details*

1. On the Response page, define the response you think appropriate, such as alerting an operator.
2. Return to the new alert's Properties dialog box by clicking OK.
3. On the Response page, enter the remaining information shown in Figure 21-19.

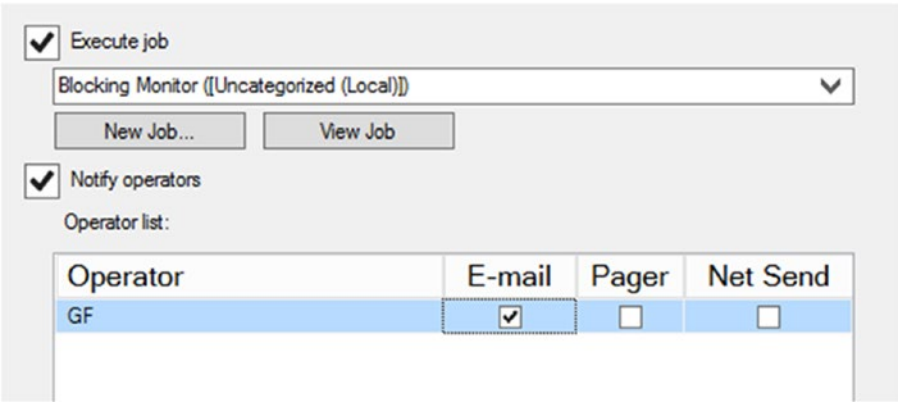


Figure 21-19. *Entering the actions to be performed when the alert is triggered*

4. The Blocking Analysis job is selected to automatically collect the blocking information.
5. Once you've finished entering all the information, click OK to create the SQL Server alert. The SQL Server alert will be created in the enabled state to perform the intended tasks.
6. Ensure that the SQL Server Agent is running.

Together, the SQL Server alert and the job will automate the blocking detection and the information collection process. This automatic collection of the blocking information will ensure that a good amount of the blocking information will be available whenever the system gets into a massive blocking state.

Summary

Even though blocking is inevitable and is in fact essential to maintain isolation among transactions, it can sometimes adversely affect database concurrency. In a multiuser database application, you must minimize blocking among concurrent transactions.

SQL Server provides different techniques to avoid/reduce blocking, and a database application should take advantage of these techniques to scale linearly as the number of database users increases. When an application faces a high degree of blocking, you can collect the relevant blocking information using various tools to understand the root cause of the blocking. The next step is to use an appropriate technique to either avoid or reduce blocking.

Blocking not only can hurt concurrency but can lead to an abrupt termination of a database request in the case of mutual blocking between processes or even within a process. We will cover this event, known as a *deadlock*, in the next chapter.

CHAPTER 22

Causes and Solutions for Deadlocks

In the preceding chapter, I discussed how blocking works. Blocking is one of the primary causes of poor performance. Blocking can lead to a special situation referred to as a *deadlock*, which in turn means that deadlocks are fundamentally a performance problem. When a deadlock occurs between two or more transactions, SQL Server allows one transaction to complete and terminates the other transaction, rolling back the transaction. SQL Server then returns an error to the corresponding application, notifying the user that he has been chosen as a deadlock victim. This leaves the application with only two options: resubmit the transaction or apologize to the end user. To successfully complete a transaction and avoid the apologies, it is important to understand what might cause a deadlock and the ways to handle a deadlock.

In this chapter, I cover the following topics:

- Deadlock fundamentals
- Error handling to catch a deadlock
- Ways to analyze the cause of a deadlock
- Techniques to resolve a deadlock

Deadlock Fundamentals

A *deadlock* is a special blocking scenario in which two processes get blocked by each other. Each process, while holding its own resources, attempts to access a resource that is locked by the other process. This will lead to a blocking scenario known as a *deadly embrace,* as illustrated in Figure 22-1.

G. Fritchey, *SQL Server 2017 Query Performance Tuning*, https://doi.org/10.1007/978-1-4842-3888-2_22

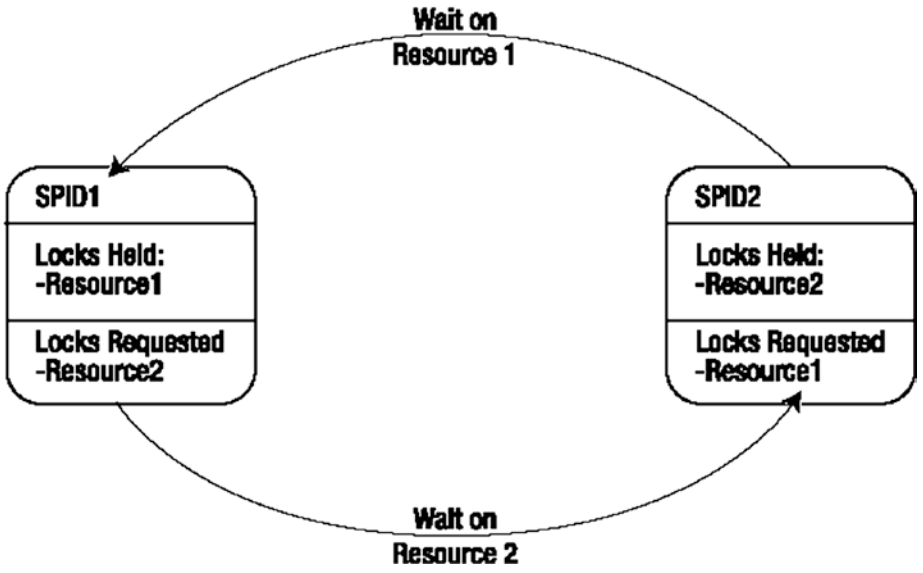


Figure 22-1. *A deadlock scenario*

Deadlocks also frequently occur when two processes attempt to escalate their locking mechanisms on the same resource. In this case, each of the two processes has a shared lock on a resource, such as an `RID`, and each attempts to promote the lock from shared to exclusive; however, neither can do so until the other releases its shared lock. This too leads to one of the processes being chosen as a deadlock victim.

Finally, it is possible for a single process to get a deadlock during parallel operations. During parallel operations, it's possible for a thread to be holding a lock on one resource, A, while waiting for another resource, B; at the same time, another thread can have a lock on B while waiting for A. This is as much a deadlock situation as when multiple processes are involved but instead involves multiple threads from one process. This is a rare event, but it is possible and is generally considered a bug that has probably been fixed by a Cumulative Update.

Deadlocks are an especially nasty type of blocking because a deadlock cannot resolve on its own, even if given an unlimited period of time. A deadlock requires an external process to break the circular blocking.

SQL Server has a deadlock detection routine, called a *lock monitor,* that regularly checks for the presence of deadlocks in SQL Server. Once a deadlock condition is detected, SQL Server selects one of the sessions participating in the deadlock as a *victim* to break the circular blocking. The victim is usually the process with the lowest estimated cost since this implies that process will be the easiest one for SQL Server to roll back. This

operation involves withdrawing all the resources held by the victim session. SQL Server does so by rolling back the uncommitted transaction of the session picked as a victim.

Deadlocks are a performance issue and, like any performance issue, need to be dealt with. Like other performance issues, there is a general threshold of pain. The occasional rare deadlock is not a cause for alarm. However, frequent and consistent deadlocks certainly are. Just as you may get a query that on rare occasions runs a little long and doesn't need a lot of tuning attention, you may run into deadlock situations that also don't need your focus. Be sure you're working on the most painful parts of your system.

Choosing the Deadlock Victim

SQL Server determines the session to be a deadlock victim by evaluating the cost of undoing the transaction of the participating sessions, and it selects the one with the least estimated cost. You can exercise some control over the session to be chosen as a victim by setting the deadlock priority of its connection to `LOW`.

```
SET DEADLOCK_PRIORITY LOW;
```

This steers SQL Server toward choosing this particular session as a victim in the event of a deadlock. You can reset the deadlock priority of the connection to its normal value by executing the following `SET` statement:

```
SET DEADLOCK_PRIORITY NORMAL;
```

The `SET` statement allows you to mark a session as a `HIGH` deadlock priority, too. This won't prevent deadlocks on a given session, but it will reduce the likelihood of a given session being picked as the victim. You can even set the priority level to a number value from –10 for the lowest priority up to 10 for the highest.

Caution Setting the deadlock priority is not something that should be applied promiscuously. You could accidently set the priority on a report that causes mission-critical processes to be chosen as a victim. Careful testing is necessary with this setting.

In the event of a tie, one of the processes is chosen as a victim and rolled back as if it had the least cost. Some processes are invulnerable to being picked as a deadlock victim. These processes are marked as such in the deadlock graph and will never be chosen as

a deadlock victim. The most common example that I've seen occurs when processes are already involved in a rollback.

Using Error Handling to Catch a Deadlock

When SQL Server chooses a session as a victim, it raises an error with the error number. You can use the TRY/CATCH construct within T-SQL to handle the error. SQL Server ensures the consistency of the database by automatically rolling back the transaction of the victim session. The rollback ensures that the session is returned to the same state it was in before the start of its transaction. On determining a deadlock situation in the error handler, it is possible to attempt to restart the transaction within T-SQL a number of times before returning the error to the application.

Take the following T-SQL statement as an example of one method for handling a deadlock error:

```
DECLARE @retry AS TINYINT = 1,
        @retrymax AS TINYINT = 2,
        @retrycount AS TINYINT = 0;
WHILE @retry = 1 AND @retrycount <= @retrymax
BEGIN
    SET @retry = 0;

    BEGIN TRY
        UPDATE HumanResources.Employee
        SET LoginID = '54321'
        WHERE BusinessEntityID = 100;
    END TRY
    BEGIN CATCH
        IF (ERROR_NUMBER() = 1205)
        BEGIN
            SET @retrycount = @retrycount + 1;
            SET @retry = 1;
        END
    END CATCH
END
```

The TRY/CATCH methodology allows you to capture errors. You can then check the error number using the ERROR_NUMBER() function to determine whether you have a deadlock. Once a deadlock is established, it's possible to try restarting the transaction a set number of times—two, in this case. Using error trapping will help your application deal with intermittent or occasional deadlocks, but the best approach is to analyze the cause of the deadlock and resolve it, if possible.

Deadlock Analysis

You can sometimes prevent a deadlock from happening by analyzing the causes. You need the following information to do this:

- The sessions participating in the deadlock
- The resources involved in the deadlock
- The queries executed by the sessions

Collecting Deadlock Information

You have four ways to collect the deadlock information.

- Use Extended Events.
- Set trace flag 1222.
- Set trace flag 1204.
- Use trace events.

Trace flags are used to customize certain SQL Server behavior such as, in this case, generating the deadlock information. But, they're an older way to capture this information. Within SQL Server, on every instance since 2008, there is an Extended Events session called system_health. This session runs automatically, and one of the events it gathers by default is the deadlock graph. This is the easiest way to get immediate access to deadlock information without having to modify your server in any way. The system_health session is also how you get deadlock information from an Azure SQL Database.

The system_health session writes to disk by default. The files are limited in size and number, so depending the activity on your system, you may find that the deadlock information is missing if the deadlock you're investigating occurred some time in the past. If you need to gather information for longer periods of time and ensure that you capture as many events as possible, Extended Events provides several ways to gather the deadlock information. This is probably the best method you can apply to your server for collecting deadlock information. You can use these options:

- lock_deadlock: Displays basic information about a deadlock occurrence
- lock_deadlock_chain: Captures information from each participant in a deadlock
- xml:deadlock_report: Displays an XML deadlock graph with the cause of the deadlock

The deadlock graph generates XML output. After Extended Events captures the deadlock event, you can view the deadlock graph within SSMS either by using the event viewer or by opening the XML file if you output your event results there. While similar information is displayed in all three events, for basic deadlock information, the easiest to understand is the xml:deadlock_report. When specifically monitoring for deadlocks, in a situation where you're attempting to deal with one in particular, I recommend also capturing the lock_deadlock_chain so that you have more detailed information about the individual sessions involved in the deadlock if you need it. For most situations, the deadlock graph should provide the information you need.

To retrieve the graph directly from the system_health session, you can query the output like this:

```
DECLARE @path NVARCHAR(260)
--to retrieve the local path of system_health files
SELECT @path = dosdlc.path
FROM sys.dm_os_server_diagnostics_log_configurations AS dosdlc;

SELECT @path = @path + N'system_health_*';

WITH fxd
AS (SELECT CAST(fx.event_data AS XML) AS Event_Data
    FROM sys.fn_xe_file_target_read_file(@path,
```

```
                                        NULL,
                                        NULL,
                                        NULL) AS fx )
SELECT dl.deadlockgraph
FROM
(   SELECT dl.query('.') AS deadlockgraph
    FROM fxd
        CROSS APPLY event_data.nodes('(/event/data/value/deadlock)') AS
d(dl) ) AS dl;
```

You can open the deadlock graph in Management Studio. You can search the XML, but the deadlock graph generated from the XML works almost like an execution plan for deadlocks, as shown in Figure 22-2.

Figure 22-2. *A deadlock graph as displayed in the Profiler*

I'll show you how to use this in the "Analyzing the Deadlock" section later in this chapter.

The two trace flags that generate deadlock information can be used individually or together to generate different sets of information. Usually people will prefer to run one or the other because they write a lot of information into the error log of SQL Server. The trace flags write the information gathered into the log file on the server where the deadlock event occurred. Trace flag 1222 provides the most detailed information on the deadlock.

Trace flag 1204 provides deadlock information that helps you analyze the cause of a deadlock. It sorts the information by each of the nodes involved in the deadlock. Trace flag 1222 provides detailed deadlock information, but it breaks the information down differently. Trace flag 1222 sorts the information by resource and processes, and it provides even more information. Both sets of data will be discussed in the "Analyzing the Deadlock" section.

The `DBCC TRACEON` statement is used to turn on (or enable) the trace flags. A trace flag remains enabled until it is disabled using the `DBCC TRACEOFF` statement. If the server is

restarted, this trace flag will be cleared. You can determine the status of a trace flag using the `DBCC TRACESTATUS` statement. Setting both of the deadlock trace flags looks like this:

```
DBCC TRACEON (1222, -1);
DBCC TRACEON (1204, -1);
```

To ensure that the trace flags are always set, it is possible to make them part of the SQL Server startup in the SQL Server Configuration Manager by following these steps:

1. Open the Properties dialog box of the instance of SQL Server.
2. Switch to the Startup Parameters tab of the Properties dialog box, as shown in Figure 22-3.

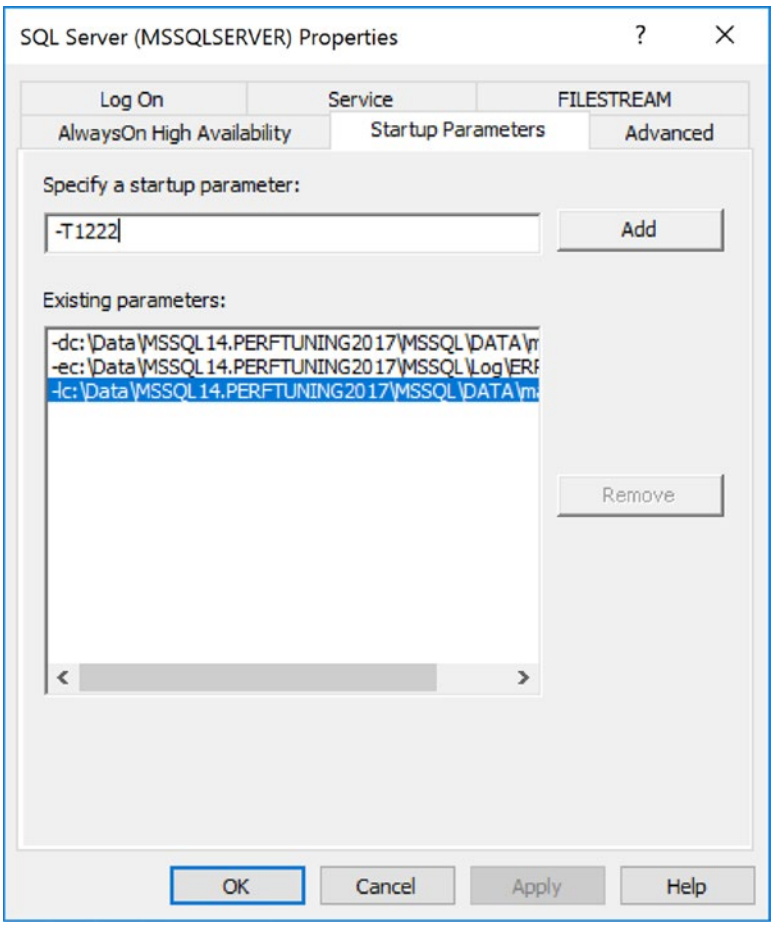


Figure 22-3. *A SQL Server instance's Properties dialog box showing the Startup Parameters tab*

3. Type **-T1222** in the "Specify a startup parameter" text box, and click Add to add trace flag 1222.
4. Click the OK button to close all the dialog boxes.

These trace flag settings will be in effect after you restart your SQL Server instance.

For most systems, using the `system_health` session is an easier and more efficient mechanism. It's installed and enabled by default. You don't have to do anything to get it running. The `system_health` session doesn't add noise to your servers error log, making it cleaner and easier to deal with as well. The trace flags are still available for use, and older systems may find they're necessary. However, more modern systems just won't need them.

Analyzing the Deadlock

To analyze the cause of a deadlock, let's consider a straightforward little example. I'm going to use the `system_health` session to show the deadlock information.

In one connection, execute this script:

```
BEGIN TRAN
UPDATE Purchasing.PurchaseOrderHeader
SET Freight = Freight * 0.9 -- 10% discount on shipping
WHERE PurchaseOrderID = 1255;
```

In a second connection, execute this script:

```
BEGIN TRANSACTION
UPDATE Purchasing.PurchaseOrderDetail
SET OrderQty = 4
WHERE ProductID = 448
      AND PurchaseOrderID = 1255;
```

Each of these scripts opens a transaction and manipulates data, but neither commits or rolls back the transaction. Switch back to the first transaction and run this additional query:

```
UPDATE  Purchasing.PurchaseOrderDetail
SET     OrderQty = 2
WHERE   ProductID = 448
        AND PurchaseOrderID = 1255;
```

Unfortunately, after possibly a few seconds, the first connection faces a deadlock.

```
Msg 1205, Level 13, State 51, Line 1
Transaction (Process ID 52) was deadlocked on lock resources with another
process and has been chosen as the deadlock victim. Rerun the transaction.
```

Any idea what's wrong here?

Let's analyze the deadlock by examining the deadlock graph collected through the trace event. There is a separate tab in the event explorer window for the `xml:deadlock_report` event. Opening that tab will show you the deadlock graph (see Figure 22-4).

Figure 22-4. *A deadlock graph displayed in the Profiler tool*

From the deadlock graph displayed in Figure 22-4, it's fairly clear that two processes were involved: session 53 on the left and session 63 on the right. Session 53, the one with the big *X* crossing it out (blue on the deadlock graph screen), was chosen as the deadlock victim. Two different keys were in question. The top key was owned by session 53, as indicated by the arrow pointing to the session object, named `Owner Mode`, and marked with an `X` for exclusive. Session 63 was attempting to request the same key for an update. The other key was owned by session 63, with session 53 requesting an update, indicated by the `U`. You can see the exact HoBt ID, object ID, object name, and index name for the objects in question for the deadlock. For a classic, simple deadlock like this, you have most of the information you need. The last piece would be the queries running from each process. These are available if you over the mouse over each session, as shown in Figure 22-5.

Figure 22-5. *The T-SQL statement for the deadlock victim*

The T-SQL statement for each side of the deadlock can be read in this manner so that you can focus exactly where the information is contained.

This visual representation of the deadlock can do the job. However, you may need to drill down into the underlying XML to examine some details of the deadlock, such as the isolation level of the processes involved. If you open that XML file directly from the extended event value, you can find a lot more information available than the simple set displayed for you in the graphical deadlock graph. Take a look at Figure 22-6.

```
<deadlock>
 <victim-list>
  <victimProcess id="process179b3f3b468" />
 </victim-list>
 <process-list>
  <process id="process179b3f3b468" taskpriority="0" logused="400" wa
   <executionStack>
    <frame procname="adhoc" line="1" stmtend="240" sqlhandle="0x0200
unknown    </frame>
    <frame procname="adhoc" line="1" stmtend="240" sqlhandle="0x0200
unknown    </frame>
   </executionStack>
   <inputbuf>
UPDATE  Purchasing.PurchaseOrderDetail
SET     OrderQty = 2
WHERE   ProductID = 448
        AND PurchaseOrderID = 1255;
   </inputbuf>
  </process>
  <process id="process179b7b63468" taskpriority="0" logused="9800" w
```

Figure 22-6. *The XML information that defines the deadlock graph*

If you look through this, you can see some of the information on display in the deadlock graph, but you also see a whole lot more. For example, part of this deadlock actually involves code that I did not write or execute as part of the example. There's a trigger on the table called `uPurchaseOrderDetail`. You can also see the code I used to generate the deadlock. All this information can help you identify exactly which pieces of code lead to the deadlock. You also get information such as the `sqlhandle`, which you can then use in combination with DMOs to pull statements and execution plans out of the cache or out of the Query Store. Because the plan is created before the query is run, it will be available for you even for the queries that were chosen as the deadlock victim.

It's worth taking some time to explore this XML in a little more detail. Table 22-1 shows some of the elements from the extended event and the information it represents.

Table 22-1. *XML Deadlock Graph Data*

Entry in Log	Description
`<deadlock>` `<victim-list>`	The beginning of the deadlock information. It starts laying out the victim processes.
`<victimProcess id="process179b3f3b468" />`	Physical memory address of the process picked to be the deadlock victim.
`<process-list>`	Processes that define the deadlock victim. There may be more than one.

`<process179b3f3b468" />`
`</victim-list>`
`<process-list>`
`<process id="process179b3f3b468" taskpriority="0" logused="400" waitresource="KEY: 6:72057594050904064 (4ab5f0d47ad5)" waittime="3703" ownerId="179351993" transactionname="user_transaction" lasttranstarted="2018-03-25T11:28:18.140" XDES="0x179b4bdc490" lockMode="U" schedulerid="1" kpid="2168" status="suspended" spid="53" sbid="0" ecid="0" priority="0" trancount="2" lastbatchstarted="2018-03-25T11:29:05.377" lastbatchcompleted="2018-03-25T11:29:05.363" lastattention="1900-01-01T00:00:00.363" clientapp="Microsoft SQL Server Management Studio - Query" hostname="WIN-8A2LQANSO51" hostpid="7028" loginname="WIN-8A2LQANSO51\Administrator"` **`isolationlevel="read committed (2)"`** `xactid="179351993" currentdb="6" lockTimeout="4294967295" clientoption1="671090784" clientoption2="390200">`
	All the information about the session picked as the deadlock victim. Note the highlighted isolation level, which is a key for helping identify the root cause of a deadlock.

(*continued*)

Table 22-1. (*continued*)

Entry in Log	Description
<executionStack> <frame procname="adhoc" line="1" stmtend="240" sqlhandle="0x02000000d0c7f31a30fb1ad425c34357fe8ef6326793e7aa0000000000000000000000000000000000000000000000"> unknown </frame> <frame procname="adhoc" line="1" stmtend="240" sqlhandle="0x02000000e7794d32ae3080d4a3217fdd3d1499f2e322d46e0000000000000000000000000000000000000000000000"> unknown </frame> </executionStack> <inputbuf> UPDATE Purchasing.PurchaseOrderDetail SET OrderQty = 2 WHERE ProductID = 448 AND PurchaseOrderID = 1255; </inputbuf> </process>	
<process id="process179b7b63468" taskpriority="0" logused="9800" waitresource="KEY: 6:72057594050969600 (4bc08edebc6b)" waittime="44833" ownerId="179352664" transactionname="user_transaction" lasttranstarted="2018-03-25T11:28:24.163" XDES="0x179bc2a8490" lockMode="U" schedulerid="1" kpid="3784" status="suspended" spid="63" sbid="0" ecid="0" priority="0" trancount="2" lastbatchstarted="2018-03-25T11:28:23.960" lastbatchcompleted="2018-03-25T11:28:23.920" lastattention="1900-01-01T00:00:00.920" clientapp="Microsoft SQL Server Management Studio - Query" hostname="WIN-8A2LQANSO51" hostpid="7028" loginname="WIN-8A2LQANSO51\Administrator" **isolationlevel="read committed (2)"** xactid="179352664" currentdb="6" lockTimeout="4294967295" clientoption1="673319008" clientoption2="390200">	The second process defined.

(*continued*)

Table 22-1. (*continued*)

Entry in Log	Description
<frame procname="AdventureWorks2017.Purchasing.uPurchaseOrderDetail" line="39" stmtstart="2732" stmtend="3830" **sqlhandle="0x0300060025999f1142d8ef0019a800000000000000000000000000000000000000000000000000000000000000000000"**> UPDATE [Purchasing].[PurchaseOrderHeader] SET [Purchasing].[PurchaseOrderHeader].[SubTotal] = (SELECT SUM([Purchasing].[PurchaseOrderDetail].[LineTotal]) FROM [Purchasing].[PurchaseOrderDetail] WHERE [Purchasing].[PurchaseOrderHeader].[PurchaseOrderID] = [Purchasing].[PurchaseOrderDetail].[PurchaseOrderID]) WHERE [Purchasing].[PurchaseOrderHeader].[PurchaseOrderID] IN (SELECT inserted.[PurchaseOrderID] FROM inserted </frame>	You can see that this is a trigger, referred to as a procname, uPurchaseOrderDetail. It has the sqlhandle, highlighted, so that you can retrieve it from the cache or the Query Store. It also shows the code of the trigger.
<frame procname="adhoc" line="2" stmtstart="38" stmtend="278" sqlhandle="0x02000000352f5b347ab7d87fc940e4f04e534f1c825a28b4000000000000000000000000000000000000000000000000">unknown </frame> </executionStack> <inputbuf> BEGIN TRANSACTION UPDATE Purchasing.PurchaseOrderDetail SET OrderQty = 4 WHERE ProductID = 448 AND PurchaseOrderID = 1255; </inputbuf>	The next statement in the batch and the code being called.

(*continued*)

Table 22-1. (*continued*)

Entry in Log	Description
<resource-list> <keylock hobtid="72057594050904064" dbid="6" objectname="AdventureWorks2017. Purchasing.PurchaseOrderDetail" indexname="PK_ PurchaseOrderDetail_PurchaseOrderID_ PurchaseOrderDetailID" id="lock17992a41a00" mode="X" associatedObjectId="72057594050904064"> <owner-list> <owner id="process179b7b63468" mode="X" /> </owner-list> <waiter-list> <waiter id="process179b3f3b468" mode="U" requestType="wait" /> </waiter-list> </keylock> **<keylock hobtid="72057594050969600" dbid="6" objectname="AdventureWorks2017. Purchasing.PurchaseOrderHeader" indexname="PK_PurchaseOrderHeader_ PurchaseOrderID" id="lock179b7a1a880" mode="X" associatedObjectId="72057594050969600">** <owner-list> <owner id="process179b3f3b468" mode="X" /> </owner-list> <waiter-list> <waiter id="process179b7b63468" mode="U" requestType="wait" /> </waiter-list> </keylock> </resource-list>	The objects that caused the conflict. Within this is the definition of the primary key from the `Purchasing.PurchaseOrderDetail` table. You can see which process from the earlier code owned which resource. You can also see the information defining the processes that were waiting. This is everything you need to discern where the issue exists.

This information is a bit more difficult to read through than the clean set of data provided by the graphical deadlock graph. However, it is a similar set of information, just more detailed. You can see, highlighted in bold near the bottom, the definition of one of the keys associated with the deadlock. You can also see, just before it, that the text of the execution plans is available through the Extended Events tool's XML output, just like the deadlock graph. You get everything you need to isolate the cause of the deadlock either way.

The information gathered by trace flag 1222 is almost identical to the XML data in every regard. The main differences are the formatting and location. The output from 1222 is located in the SQL Server error log, and it's in text format instead of nice, clean XML. The information collected by trace flag 1204 is completely different from either of the other two sets of data and doesn't provide nearly as much detail. Trace flag 1204 is also much more difficult to interpret. For all these reasons, I suggest you stick to using Extended Events if you can—or trace flag 1222 if you can't—to capture deadlock data. You also have the `system_health` session that captures a number of events by default, including deadlocks. It's a great resource if you are unprepared for capturing this information. Just remember that it keeps only four 5MB files online. As these fill, the data in the oldest file is lost. Depending on the number of transactions in your system and the number of deadlocks or other events that could fill these files, you may have only recent data available. Further, as mentioned earlier, since the `system_health` session uses the ring buffer to capture events, you can expect some event loss, so your deadlock events could go missing.

This example demonstrated a classic circular reference. Although not immediately obvious, the deadlock was caused by a trigger on the `Purchasing.PurchaseOrderDetail` table. When `Quantity` is updated on the `Purchasing.PurchaseOrderDetail` table, it attempts to update the `Purchasing.PurchaseOrderHeader` table. When the first two queries are run, each within an open transaction, it's just a blocking situation. The second query is waiting on the first to clear so that it can also update the `Purchasing.PurchaseOrderHeader` table. But when the third query (that is, the second within the first transaction) is introduced, a circular reference is created. The only way to resolve it is to kill one of the processes.

Before proceeding, be sure to roll back any open transactions.

Here's the obvious question at this stage: can you avoid this deadlock? If the answer is "yes," then how?

Avoiding Deadlocks

The methods for avoiding a deadlock scenario depend upon the nature of the deadlock. The following are some of the techniques you can use to avoid a deadlock:

- Access resources in the same physical order.
- Decrease the number of resources accessed.
- Minimize lock contention.
- Tune queries.

Accessing Resources in the Same Physical Order

One of the most commonly adopted techniques for avoiding a deadlock is to ensure that every transaction accesses the resources in the same physical order. For instance, suppose that two transactions need to access two resources. If each transaction accesses the resources in the same physical order, then the first transaction will successfully acquire locks on the resources without being blocked by the second transaction. The second transaction will be blocked by the first while trying to acquire a lock on the first resource. This will cause a typical blocking scenario without leading to a circular blocking and a deadlock.

If the resources are not accessed in the same physical order (as demonstrated in the earlier deadlock analysis example), this can cause a circular blocking between the two transactions.

- Transaction 1:
  - Access Resource 1
  - Access Resource 2
- Transaction 2:
  - Access Resource 2
  - Access Resource 1

In the current deadlock scenario, the following resources are involved in the deadlock:

- Resource 1, `hobtid=72057594046578688`: This is the index row within index `PK_ PurchaseOrderDetail_PurchaseOrderId_ PurchaseOrderDetailId` on the `Purchasing.PurchaseOrderDetail` table.
- Resource 2, `hobtid=72057594046644224`: This is the row within clustered index `PK_ PurchaseOrderHeader_PurchaseOrderId` on the `Purchasing.PurchaseOrderHeader` table.

Both sessions attempt to access the resource; unfortunately, the order in which they access the key is different.

It's common with some of the generated code produced by tools such as nHibernate and Entity Framework to see objects being referenced in a different order in different queries. You'll have to work with your development team to see that type of issue eliminated within the generated code.

Decreasing the Number of Resources Accessed

A deadlock involves at least two resources. A session holds the first resource and then requests the second resource. The other session holds the second resource and requests the first resource. If you can prevent the sessions (or at least one of them) from accessing one of the resources involved in the deadlock, then you can prevent the deadlock. You can achieve this by redesigning the application, which is a solution highly resisted by developers late in the project. However, you can consider using the following features of SQL Server without changing the application design:

- Convert a nonclustered index to a clustered index.
- Use a covering index for a `SELECT` statement.

Convert a Nonclustered Index to a Clustered Index

As you know, the leaf pages of a nonclustered index are separate from the data pages of the heap or the clustered index. Therefore, a nonclustered index takes two locks: one for the base (either the cluster or the heap) and one for the nonclustered index. However, in the case of a clustered index, the leaf pages of the index and the data pages of the table

are the same; it requires one lock, and that one lock protects both the clustered index and the table because the leaf pages and the data pages are the same. This decreases the number of resources to be accessed by the same query, compared to a nonclustered index. But, it is completely dependent on this being an appropriate clustered index. There's nothing magical about the clustered index that simply applying it to any column would help. You still need to assess whether it's appropriate.

Use a Covering Index for a SELECT Statement

You can also use a covering index to decrease the number of resources accessed by a `SELECT` statement. Since a `SELECT` statement can get everything from the covering index itself, it doesn't need to access the base table. Otherwise, the `SELECT` statement needs to access both the index and the base table to retrieve all the required column values. Using a covering index stops the `SELECT` statement from accessing the base table, leaving the base table free to be locked by another session.

Minimizing Lock Contention

You can also resolve a deadlock by avoiding the lock request on one of the contended resources. You can do this when the resource is accessed only for reading data. Modifying a resource will always acquire an exclusive (X) lock on the resource to maintain the consistency of the resource; therefore, in a deadlock situation, identify the resource accesses that are read-only and try to avoid their corresponding lock requests by using the dirty read feature, if possible. You can use the following techniques to avoid the lock request on a contended resource:

- Implement row versioning.
- Decrease the isolation level.
- Use locking hints.

Implement Row Versioning

Instead of attempting to prevent access to resources using a more stringent locking scheme, you could implement row versioning through the `READ_COMMITTED_SNAPSHOT` isolation level or through the `SNAPSHOT` isolation level. The row versioning isolation levels are used to reduce blocking, as outlined in Chapter 21. Because they reduce blocking,

which is the root cause of deadlocks, they can also help with deadlocks. By introducing READ_COMMITTED_SNAPSHOT with the following T-SQL, you can have a version of the rows available in tempdb, thus potentially eliminating the contention caused by the lock in the preceding deadlock scenario:

```
ALTER DATABASE AdventureWorks2017
SET READ_COMMITTED_SNAPSHOT ON;
```

This will allow any necessary reads without causing lock contention since the reads are on a different version of the data. There is overhead associated with row versioning, especially in tempdb and when marshaling data from multiple resources instead of just the table or indexes used in the query. But that trade-off of increased tempdb overhead versus the benefit of reduced deadlocking and increased concurrency may be worth the cost.

Decrease the Isolation Level

Sometimes the (S) lock requested by a SELECT statement contributes to the formation of circular blocking. You can avoid this type of circular blocking by reducing the isolation level of the transaction containing the SELECT statement to READ COMMITTED SNAPSHOT. This will allow the SELECT statement to read the data without requesting an (S) lock and thereby avoid the circular blocking. You may also see issues of this type around cursors because they tend to have pessimistic concurrency.

Also check to see whether the connections are setting themselves to be SERIALIZABLE. Sometimes online connection string generators will include this option, and developers will use it completely by accident. MSDTC will use serializable by default, but it can be changed.

Use Locking Hints

I absolutely do not recommend this approach. However, you can potentially resolve the deadlock presented in the preceding technique using the following locking hints:

- NOLOCK
- READUNCOMMITTED

Like the `READ UNCOMMITTED` isolation level, the `NOLOCK` or `READUNCOMMITTED` locking hint will avoid the (S) locks requested by a given session, thereby preventing the formation of circular blocking.

The effect of the locking hint is at a query level and is limited to the table (and its indexes) on which it is applied. The `NOLOCK` and `READUNCOMMITTED` locking hints are allowed only in `SELECT` statements and the data selection part of the `INSERT`, `DELETE`, and `UPDATE` statements.

The resolution techniques of minimizing lock contention introduce the side effect of a dirty read, which may not be acceptable in every transaction. A dirty read can involve missing rows or extra rows because of page splits and rearranging pages. Therefore, use these resolution techniques only in situations in which a low quality of data is acceptable.

Tune the Queries

At its root, deadlocking is about performance. If all the queries complete execution before resource contention is possible, then you can completely avoid the issue entirely.

Summary

As you learned in this chapter, a deadlock is the result of conflicting blocking between processes and is reported to an application with the error number 1205. You can analyze the cause of a deadlock by collecting the deadlock information using various resources, but the extended event `xml:deadlock_report` is probably the best.

You can use a number of techniques to avoid a deadlock; which technique is applicable depends upon the type of queries executed by the participating sessions, the locks held and requested on the involved resources, and the business rules governing the degree of isolation required. Generally, you can resolve a deadlock by reconfiguring the indexes and the transaction isolation levels. However, at times you may need to redesign the application or automatically reexecute the transaction on a deadlock. Just remember, at its core, deadlocks are a performance problem, and anything you can do to make the queries run faster will help to mitigate, if not eliminate, deadlocks in your queries.

In the next chapter, I cover the performance aspects of cursors and how to optimize the cost overhead of using cursors.

CHAPTER 23

Row-by-Row Processing

It is common to find database applications that use cursors to process one row at a time. Developers tend to think about processing data in a row-by-row fashion. Oracle even uses something called *cursors* as a high-speed data access mechanism. Cursors in SQL Server are different. Because data manipulation through a cursor in SQL Server incurs significant additional overhead, database applications should avoid using cursors. T-SQL and SQL Server are designed to work best with sets of data, not one row at a time. Jeff Moden famously termed this type of processing RBAR (pronounced, "ree-bar"), meaning row by agonizing row. However, if a cursor must be used, then use a cursor with the least cost.

In this chapter, I cover the following topics:

- The fundamentals of cursors
- A cost analysis of different characteristics of cursors
- The benefits and drawbacks of a default result set over cursors
- Recommendations to minimize the cost overhead of cursors

Cursor Fundamentals

When a query is executed by an application, SQL Server returns a set of data consisting of rows. Generally, applications can't process multiple rows together; instead, they process one row at a time by walking through the result set returned by SQL Server. This functionality is provided by a *cursor*, which is a mechanism to work with one row at a time out of a multirow result set.

G. Fritchey, *SQL Server 2017 Query Performance Tuning*, https://doi.org/10.1007/978-1-4842-3888-2_23

T-SQL cursor processing usually involves the following steps:

1. Declare the cursor to associate it with a SELECT statement and define the characteristics of the cursor.
2. Open the cursor to access the result set returned by the SELECT statement.
3. Retrieve a row from the cursor. Optionally, modify the row through the cursor.
4. Move to additional rows in the result set.
5. Once all the rows in the result set are processed, close the cursor and release the resources assigned to the cursor.

You can create cursors using T-SQL statements or the data access layers used to connect to SQL Server. Cursors created using data access layers are commonly referred to as *client* cursors. Cursors written in T-SQL are referred to as *server* cursors. The following is an example of a server cursor processing query results from a table:

```
--Associate a SELECT statement to a cursor and define the
--cursor's characteristics
USE AdventureWorks2017;
GO
SET NOCOUNT ON
DECLARE MyCursor CURSOR /*<cursor characteristics>*/
FOR
SELECT adt.AddressTypeID,
       adt.Name,
       adt.ModifiedDate
FROM Person.AddressType AS adt;

--Open the cursor to access the result set returned by the
--SELECT statement
OPEN MyCursor;

--Retrieve one row at a time from the result set returned by
--the SELECT statement
```

```
DECLARE @AddressTypeId INT,
        @Name VARCHAR(50),
        @ModifiedDate DATETIME;

FETCH NEXT FROM MyCursor
INTO @AddressTypeId,
     @Name,
     @ModifiedDate;

WHILE @@FETCH_STATUS = 0
BEGIN
    PRINT 'NAME =   ' + @Name;

    --Optionally, modify the row through the cursor
    UPDATE Person.AddressType
    SET Name = Name + 'z'
    WHERE CURRENT OF MyCursor;

    --Move through to additional rows in the data set
    FETCH NEXT FROM MyCursor
    INTO @AddressTypeId,
         @Name,
         @ModifiedDate;
END

--Close the cursor and release all resources assigned to the
--cursor
CLOSE MyCursor;
DEALLOCATE MyCursor;
```

Part of the overhead of the cursor depends on the cursor characteristics. The characteristics of the cursors provided by SQL Server and the data access layers can be broadly classified into three categories.

- *Cursor location*: Defines the location of the cursor creation
- *Cursor concurrency*: Defines the degree of isolation and synchronization of a cursor with the underlying content
- *Cursor type*: Defines the specific characteristics of a cursor

Before looking at the costs of cursors, I'll take a few pages to introduce the various characteristics of cursors. You can undo the changes to the `Person.AddressType` table with this query:

```
UPDATE Person.AddressType
SET Name = LEFT(Name, LEN(Name) - 1);
```

Cursor Location

Based on the location of its creation, a cursor can be classified into one of two categories.

- Client-side cursors
- Server-side cursors

The T-SQL cursors are always created on SQL Server. However, the database API cursors can be created on either the client or server side.

Client-Side Cursors

As its name signifies, a *client-side cursor is* created on the machine running the application, whether the app is a service, a data access layer, or the front end for the user. It has the following characteristics:

- It is created on the client machine.
- The cursor metadata is maintained on the client machine.
- It is created using the data access layers.
- It works against most of the data access layers (OLEDB providers and ODBC drivers).
- It can be a forward-only or static cursor.

Note Cursor types, including forward-only and static cursor types, are described later in the chapter in the "Cursor Types" section.

Server-Side Cursors

A *server-side cursor* is created on the SQL Server machine. It has the following characteristics:

- It is created on the server machine.
- The cursor metadata is maintained on the server machine.
- It is created using either data access layers or T-SQL statements.
- A server-side cursor created using T-SQL statements is tightly integrated with SQL Server.
- It can be any type of cursor. (Cursor types are explained later in the chapter.)

Note The cost comparison between client-side and server-side cursors is covered later in the chapter in the "Cost Comparison on Cursor Type" section.

Cursor Concurrency

Depending on the required degree of isolation and synchronization with the underlying content, cursors can be classified into the following concurrency models:

- *Read-only*: A nonupdatable cursor
- *Optimistic*: An updatable cursor that uses the optimistic concurrency model (no locks retained on the underlying data rows)
- *Scroll locks*: An updatable cursor that holds a lock on any data row to be updated

Read-Only

A read-only cursor is nonupdatable; no locks are held on the base tables. While fetching a cursor row, whether an (S) lock will be acquired on the underlying row depends upon the isolation level of the connection and any locking hints used in the `SELECT` statement

for the cursor. However, once the row is fetched, by default the locks are released. The following T-SQL statement creates a read-only T-SQL cursor:

```
DECLARE MyCursor CURSOR READ_ONLY FOR
SELECT adt.Name
FROM Person.AddressType AS adt
WHERE adt.AddressTypeID = 1;
```

Using as minimal locking overhead as possible makes the read-only type of cursor faster and safer. Just remember that you cannot manipulate data through the read-only cursor, which is the sacrifice you make for improved performance.

Optimistic

The optimistic with values concurrency model makes a cursor updatable. No locks are held on the underlying data. The factors governing whether an (S) lock will be acquired on the underlying row are the same as for a read-only cursor.

The optimistic concurrency model uses row versioning to determine whether a row has been modified since it was read into the cursor, instead of locking the row while it is read into the cursor. Version-based optimistic concurrency requires a `ROWVERSION` column in the underlying user table on which the cursor is created. The `ROWVERSION` data type is a binary number that indicates the relative sequence of modifications on a row. Each time a row with a `ROWVERSION` column is modified, SQL Server stores the current value of the global `ROWVERSION` value, `@@DBTS`, in the `ROWVERSION` column; it then increments the `@@DBTS` value.

Before applying a modification through the optimistic cursor, SQL Server determines whether the current `ROWVERSION` column value for the row matches the `ROWVERSION` column value for the row when it was read into the cursor. The underlying row is modified only if the `ROWVERSION` values match, indicating that the row hasn't been modified by another user in the meantime. Otherwise, an error is raised. In case of an error, refresh the cursor with the updated data.

If the underlying table doesn't contain a `ROWVERSION` column, then the cursor defaults to value-based optimistic concurrency, which requires matching the current value of the row with the value when the row was read into the cursor. The version-based concurrency control is more efficient than the value-based concurrency control since it requires less processing to determine the modification of the underlying row. Therefore,

for the best performance of a cursor with the optimistic concurrency model, ensure that the underlying table has a ROWVERSION column.

The following T-SQL statement creates an optimistic T-SQL cursor:

```
DECLARE MyCursor CURSOR OPTIMISTIC FOR
SELECT adt.Name
FROM Person.AddressType AS adt
WHERE adt.AddressTypeID = 1;
```

A cursor with scroll locks concurrency holds a (U) lock on the underlying row until another cursor row is fetched or the cursor is closed. This prevents other users from modifying the underlying row when the cursor fetches it. The scroll locks concurrency model makes the cursor updatable.

The following T-SQL statement creates a T-SQL cursor with the scroll locks concurrency model:

```
DECLARE MyCursor CURSOR SCROLL_LOCKS FOR
SELECT adt.Name
FROM Person.AddressType AS adt
WHERE adt.AddressTypeID = 1;
```

Since locks are held on a row being referenced (until another cursor row is fetched or the cursor is closed), it blocks all the other users trying to modify the row during that period. This hurts database concurrency but ensures that you won't get errors if you're modifying data through the cursor.

Cursor Types

Cursors can be classified into the following four types:

- Forward-only cursors
- Static cursors
- Keyset-driven cursors
- Dynamic cursors

Let's take a closer look at these four types in the sections that follow.