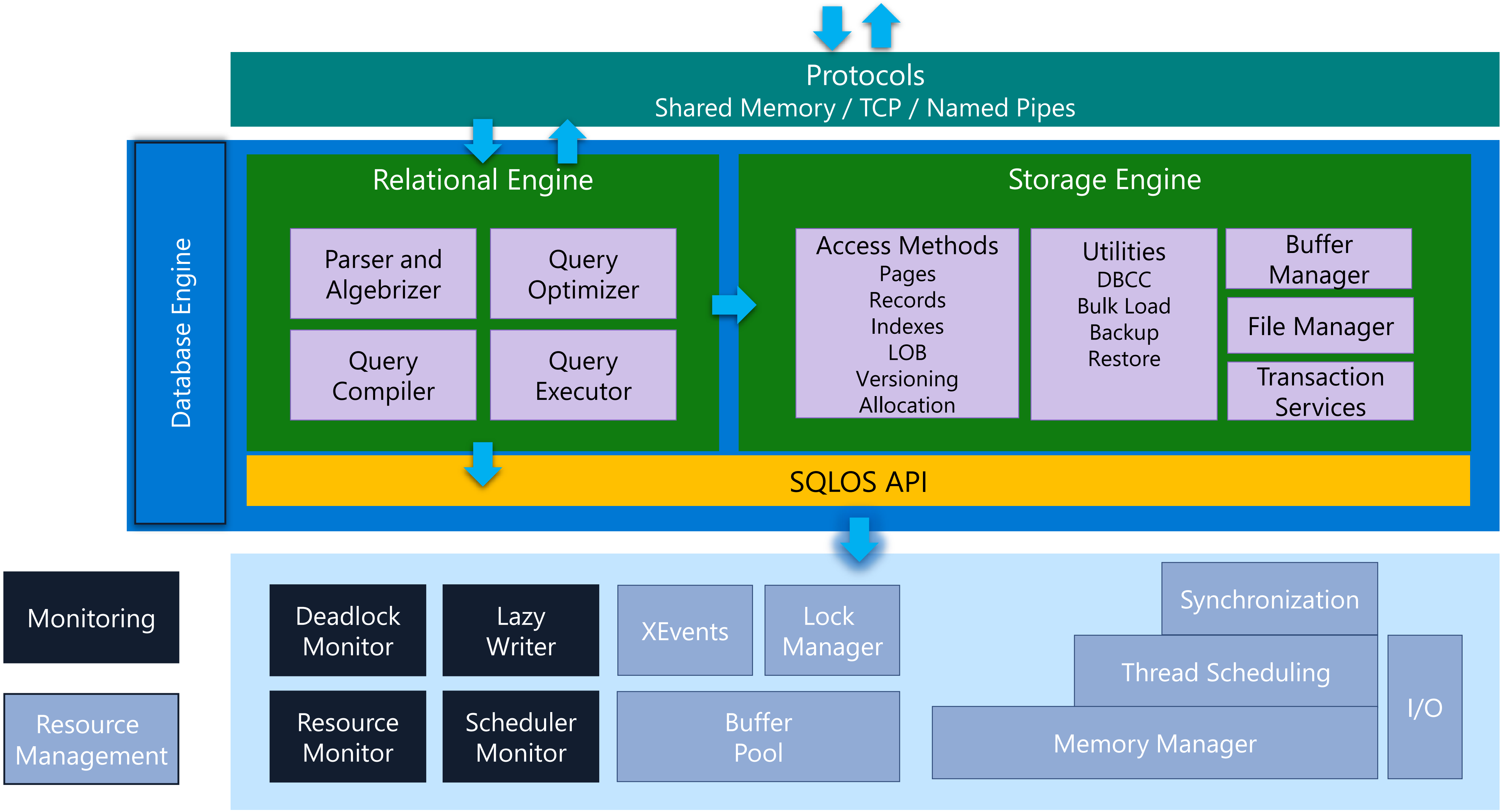
Inside the Database Engine



Protocols

Shared Memory / TCP / Named Pipes

Database Engine

Relational Engine

Parser and Algebrizer

Query Optimizer

Query Compiler

Query Executor

Storage Engine

Access Methods
Pages
Records
Indexes
LOB
Versioning
Allocation

Utilities
DBCC
Bulk Load
Backup
Restore

Buffer Manager

File Manager

Transaction Services

SQLOS API

Monitoring

Resource Management

Deadlock Monitor

Lazy Writer

XEvents

Lock Manager

Resource Monitor

Scheduler Monitor

Buffer Pool

Synchronization

Thread Scheduling

Memory Manager

I/O

Two Main Functions of SQLOS

Management

- Memory Manager
- Process Scheduler
- Synchronization
- I/O
- Support for Non-Uniform Memory Access (NUMA) and Resource Governor

Monitoring

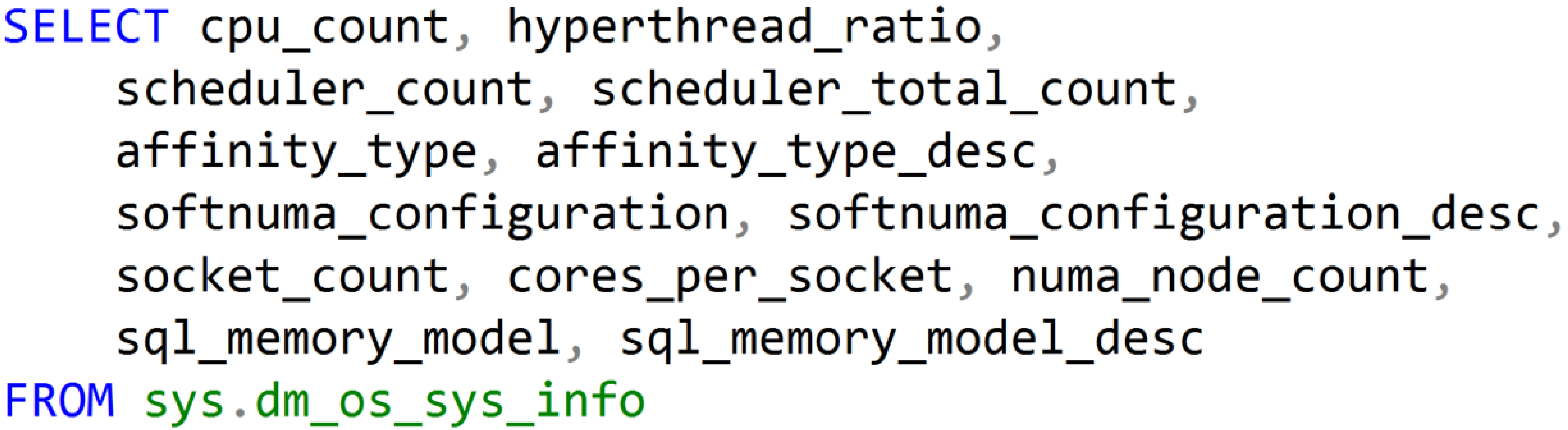
- Resource Monitor
- Deadlock Monitor
- Scheduler Monitor
- Lazy Writer (Buffer Pool management)
- Dynamic Management Views (DMVs)
- Extended Events
- Dedicated Administrator Connection (DAC)

Dynamic Management Views and Functions

Category	Description
sys.dm_exec_%	Execution and connection information
sys.dm_os_%	Operating system related information
sys.dm_tran_%	Transaction management information
sys.dm_io_%	I/O related information
sys.dm_db_%	Database information

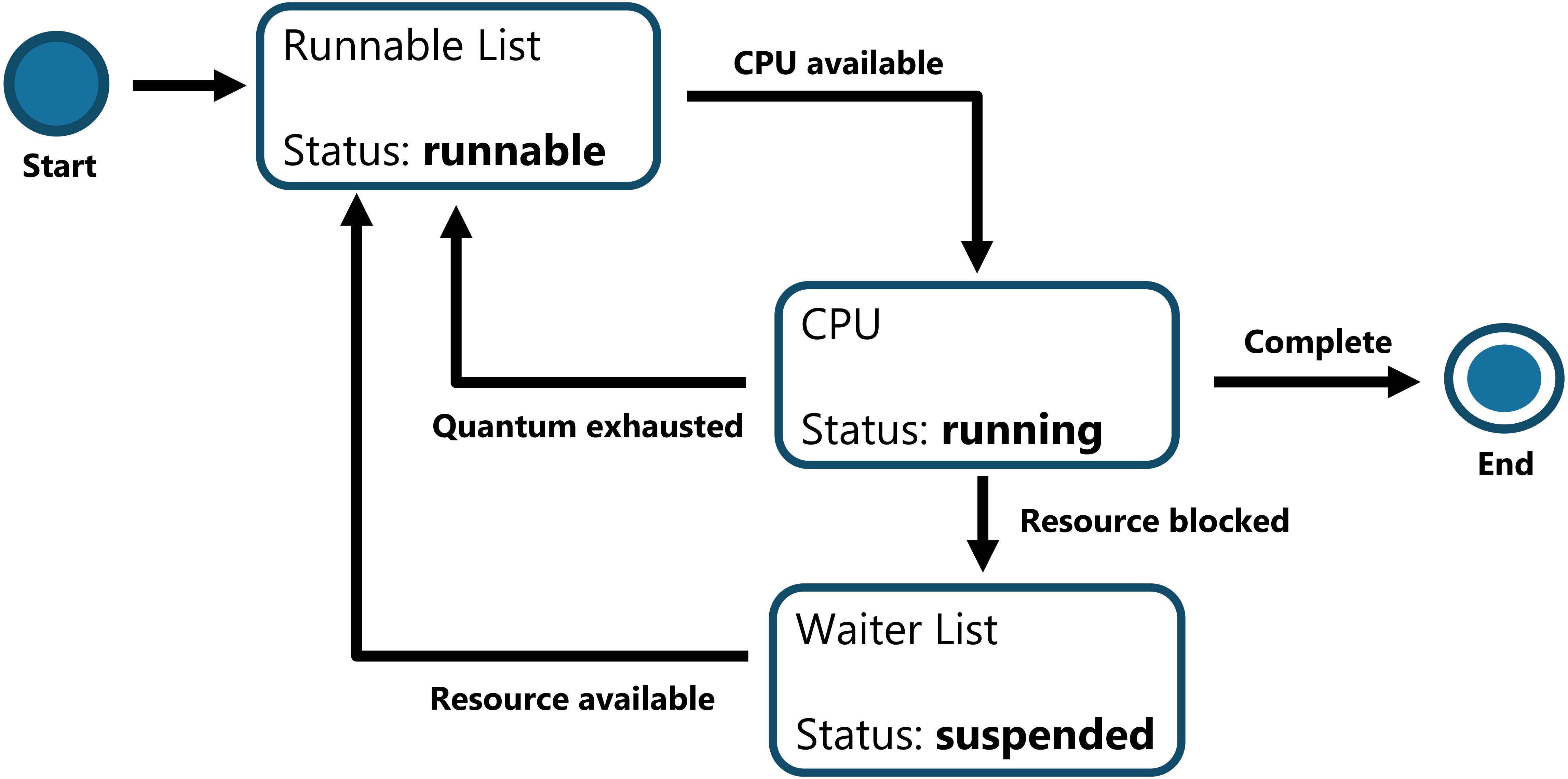
Using Dynamic Management Objects (DMOs)

- Must reference using the sys schema
- Two basic types:
  - Real-time state information
  - Historical information



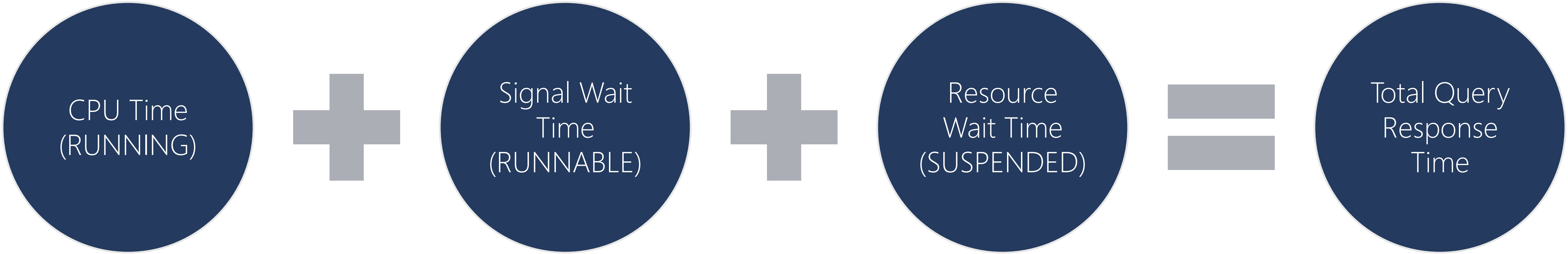
```
SELECT cpu_count, hyperthread_ratio,
    scheduler_count, scheduler_total_count,
    affinity_type, affinity_type_desc,
    softnuma_configuration, softnuma_configuration_desc,
    socket_count, cores_per_socket, numa_node_count,
    sql_memory_model, sql_memory_model_desc
FROM sys.dm_os_sys_info
```

Yielding


Start
Runnable List
Status: **runnable**
CPU available
CPU
Status: **running**
Complete
End
Quantum exhausted
Resource blocked
Waiter List
Status: **suspended**
Resource available

Task Execution Model

- The full cycle between the several task states, for how many times it needs to cycle, is what we experience as the total query response time.



CPU Time (RUNNING) + Signal Wait Time (RUNNABLE) + Resource Wait Time (SUSPENDED) = Total Query Response Time

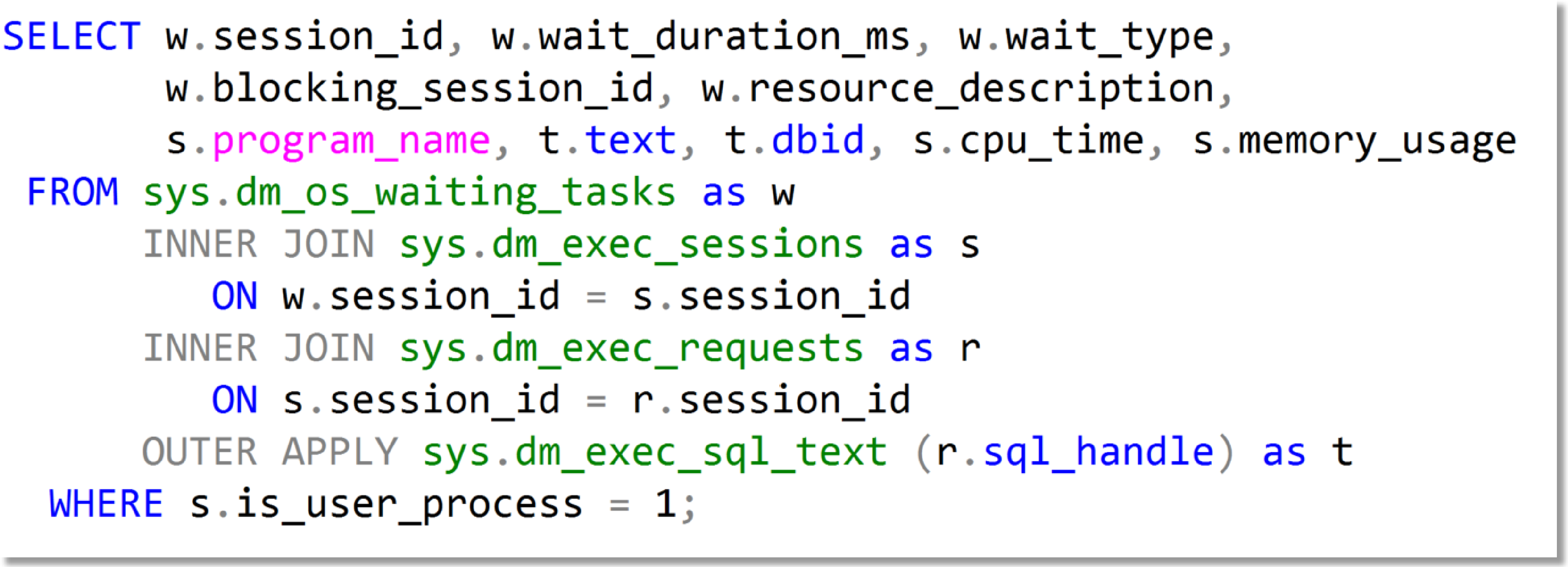
Thread States and Queues

Runnable: The thread is currently in the Runnable Queue waiting to execute. (First In, First Out).

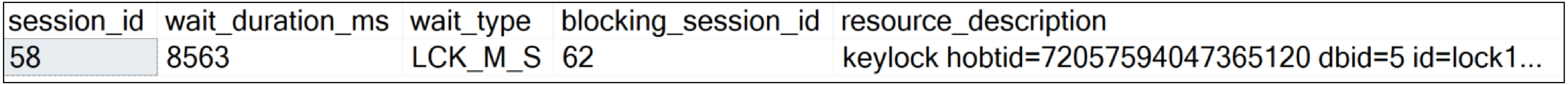
Running: One active thread executing on a processor.

Suspended: Placed on a Waiter List waiting for a resource other than a processor. (No specific order).

Waiting Tasks DMV



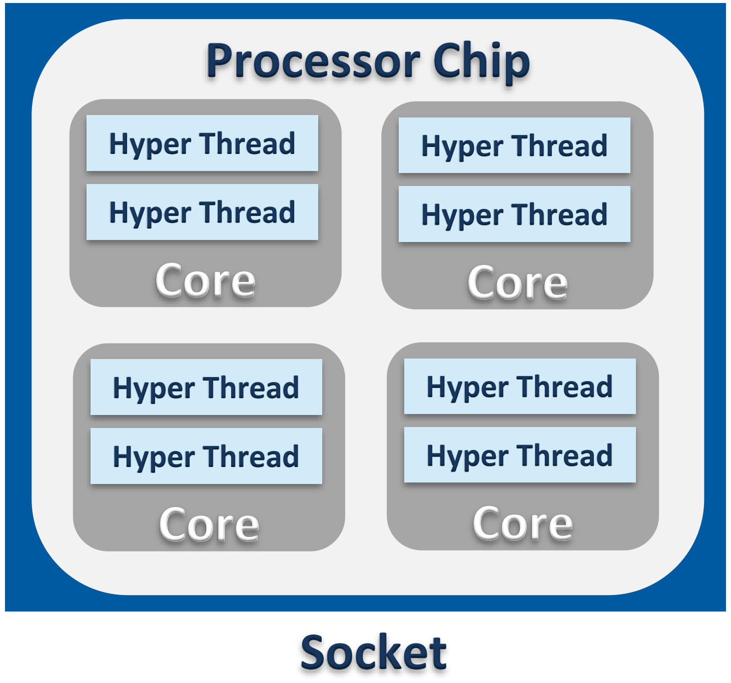
```sql
SELECT w.session_id, w.wait_duration_ms, w.wait_type,
       w.blocking_session_id, w.resource_description,
       s.program_name, t.text, t.dbid, s.cpu_time, s.memory_usage
 FROM sys.dm_os_waiting_tasks as w
      INNER JOIN sys.dm_exec_sessions as s
         ON w.session_id = s.session_id
      INNER JOIN sys.dm_exec_requests as r
         ON s.session_id = r.session_id
      OUTER APPLY sys.dm_exec_sql_text (r.sql_handle) as t
  WHERE s.is_user_process = 1;
```



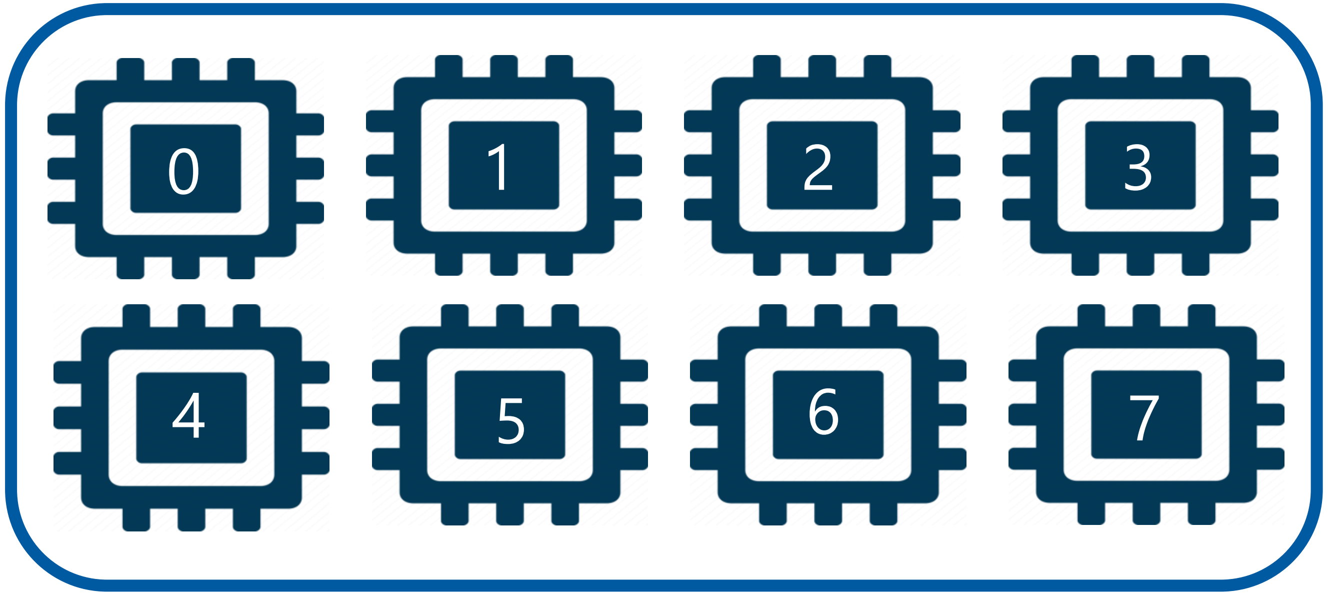
session_id	wait_duration_ms	wait_type	blocking_session_id	resource_description
58	8563	LCK_M_S	62	keylock hobtid=72057594047365120 dbid=5 id=lock1...

CPU Architecture

Physical Hardware



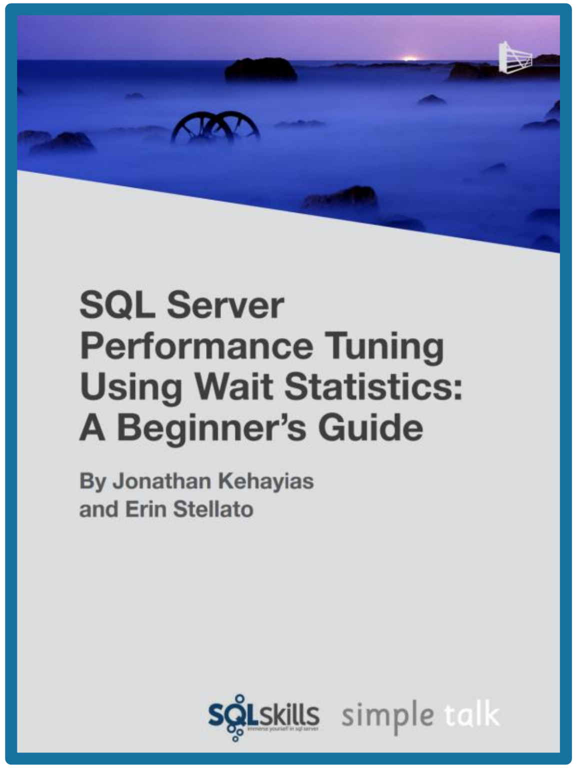
Logical Processors as seen by the OS



Troubleshooting Wait Types

Aaron Bertrand – Top Wait Types
https://sqlperformance.com/2018/10/sql-performance/top-wait-stats

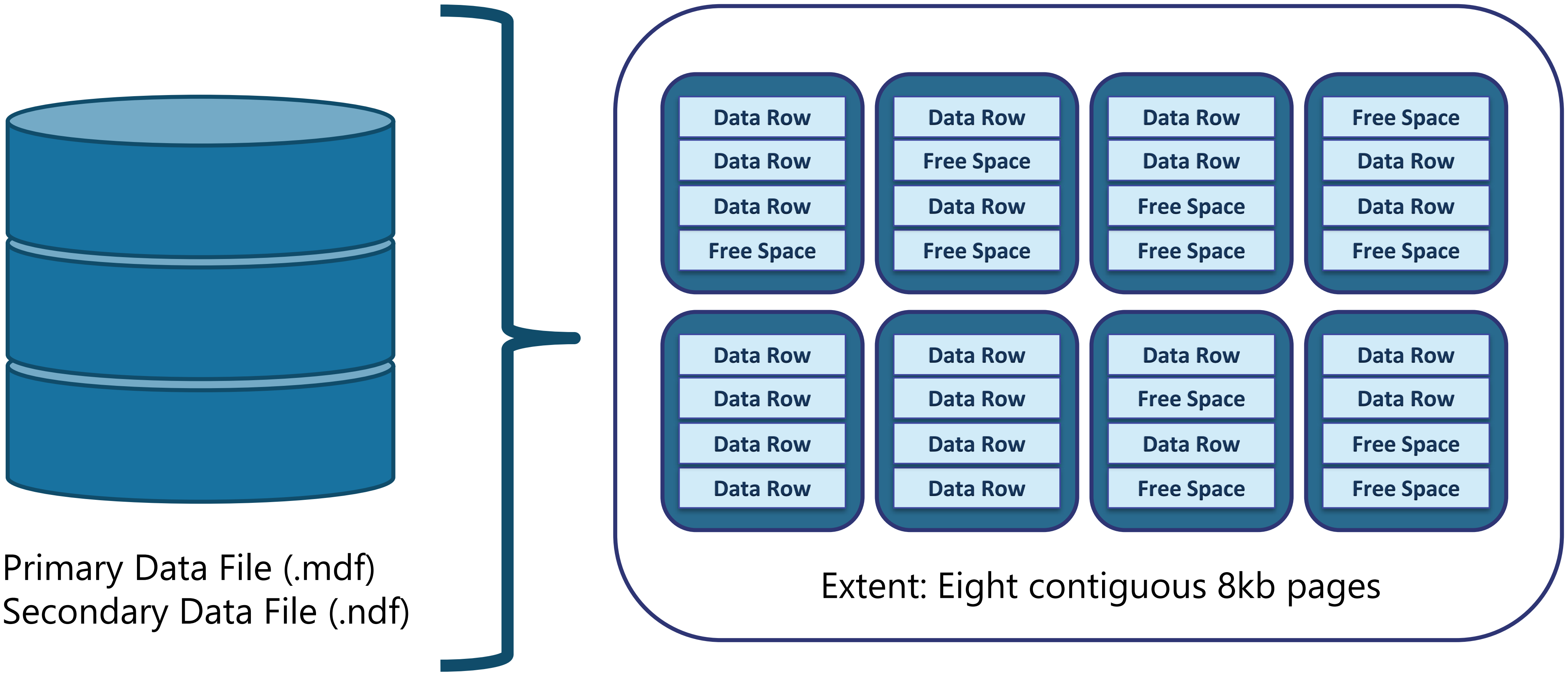
Paul Randal – SQL Skills Wait Types Library
https://www.sqlskills.com/help/waits/



SQL Server
Performance Tuning
Using Wait Statistics:
A Beginner's Guide

By Jonathan Kehayias
and Erin Stellato

SQL Server Object Allocation



Primary Data File (.mdf)
Secondary Data File (.ndf)

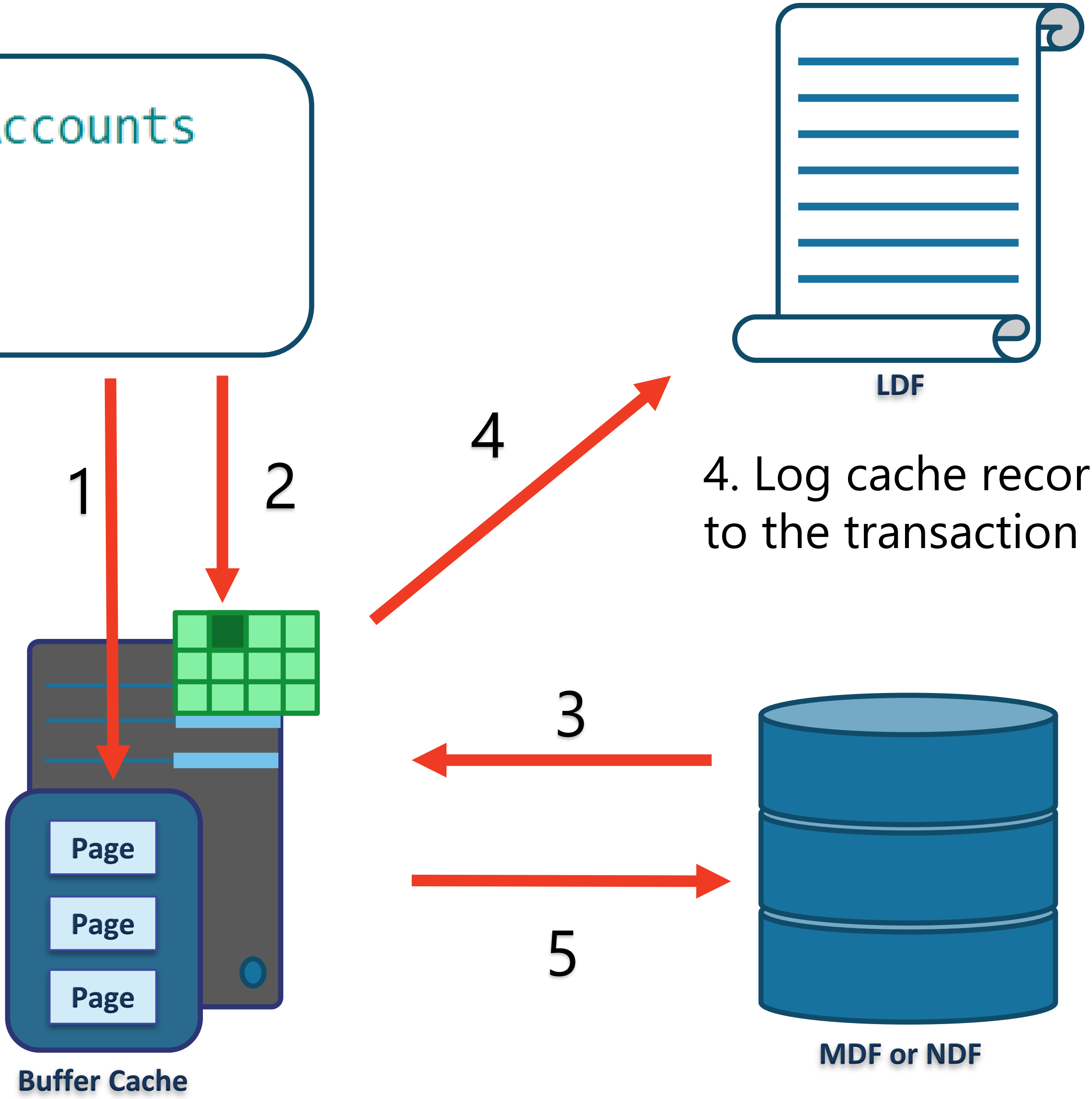
Extent: Eight contiguous 8kb pages

Uniform extents: Pages used by a single object.

Mixed extents: Pages used by different objects.

SQL Server Disk I/O (Write-Ahead Logging)

```
UPDATE Accounting.BankAccounts
SET Balance -= 200
WHERE AcctID = 1
```



1. Data modification is sent to buffer cache in memory.

2. Modification is recorded in the log cache.

3. Data pages are located or read into the buffer cache and then modified.

4. Log cache record is flushed to the transaction log

5. At checkpoint, dirty data pages are written to the database file.

Log Buffer Flushing

SQL Server will flush the log buffer to the log file

- SQL Server gets a commit request of a transaction that changes data.
- The log buffer fills up. (Max size 60kb.)
- SQL Server needs to harden dirty data pages (checkpoints)
- Manually request a log buffer flush using the sys.sp_flush_log procedure

Log buffer flushing results in a WRITELOG wait type.

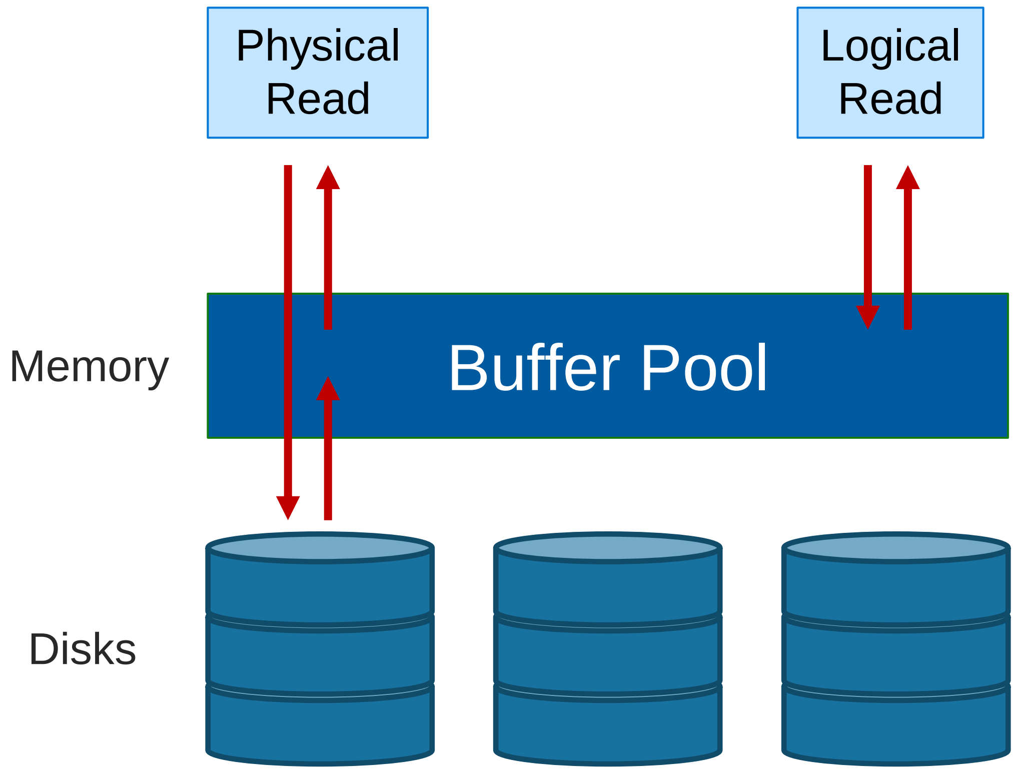
SQL Server Buffer Pool

Stores 8 kilobytes (KB) pages of data to avoid repeated disk I/O.

- Pages held in the buffer until the space is needed by something else.

Lazy Writer searches for eligible buffers.

- If the buffer is dirty, an asynchronous write (lazy write) is posted so that the buffer can later be freed.
- If the buffer is not dirty, it is freed.



Checkpoints

Flushes dirty pages from the buffer pool to the disk. Frequency of checkpoints varies based on the database activity and recovery interval.

Automatic (default) – Database engine issues checkpoints automatically based on the server level “recovery interval” configuration option

Indirect (new in SQL Server 2012) – Database engine issues checkpoints automatically based on the database level TARGET_RECOVERY_TIME

```
ALTER DATABASE [AdventureWorksPTO] SET TARGET_RECOVERY_TIME = 60 SECONDS
```

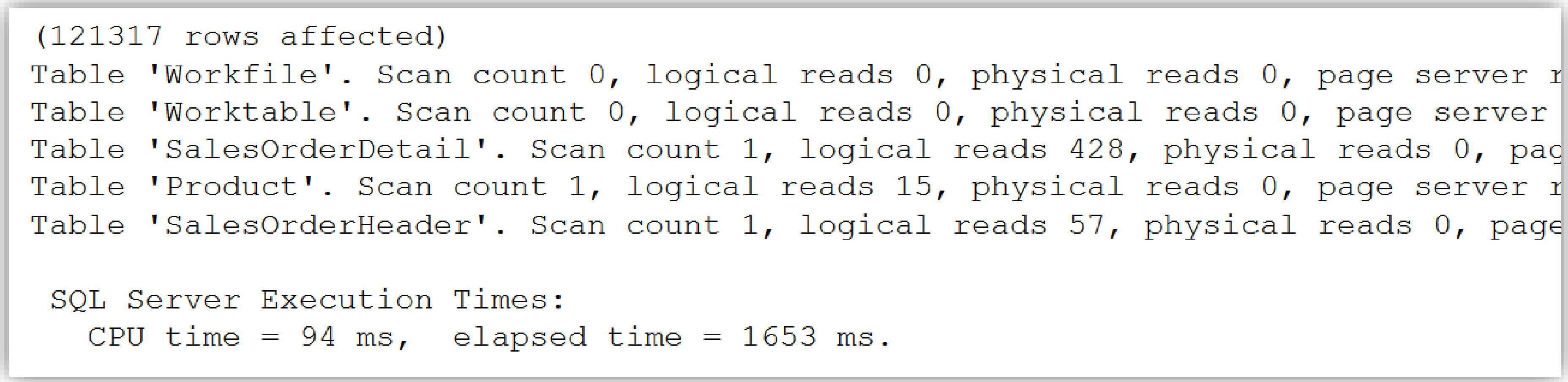
Manual – Issued in the current database for your connection when you execute the T-SQL CHECKPOINT command

Internal – Issued by various server operations

SET STATISTICS IO

```
SET STATISTICS IO ON
GO
SET STATISTICS TIME ON
SELECT SOH.SalesOrderID, SOH.CustomerID,
OrderQty, UnitPrice, P.Name
FROM Sales.SalesOrderHeader AS SOH
JOIN Sales.SalesOrderDetail AS SOD
ON SOH.SalesOrderID = SOD.SalesOrderID
JOIN Production.Product AS P
ON P.ProductID = SOD.ProductID
SET STATISTICS IO, TIME OFF
```

Used to identify physical reads and logical reads for a query



```
(121317 rows affected)
Table 'Workfile'. Scan count 0, logical reads 0, physical reads 0, page server r
Table 'Worktable'. Scan count 0, logical reads 0, physical reads 0, page server
Table 'SalesOrderDetail'. Scan count 1, logical reads 428, physical reads 0, pag
Table 'Product'. Scan count 1, logical reads 15, physical reads 0, page server r
Table 'SalesOrderHeader'. Scan count 1, logical reads 57, physical reads 0, page

 SQL Server Execution Times:
   CPU time = 94 ms,  elapsed time = 1653 ms.
```

Page types

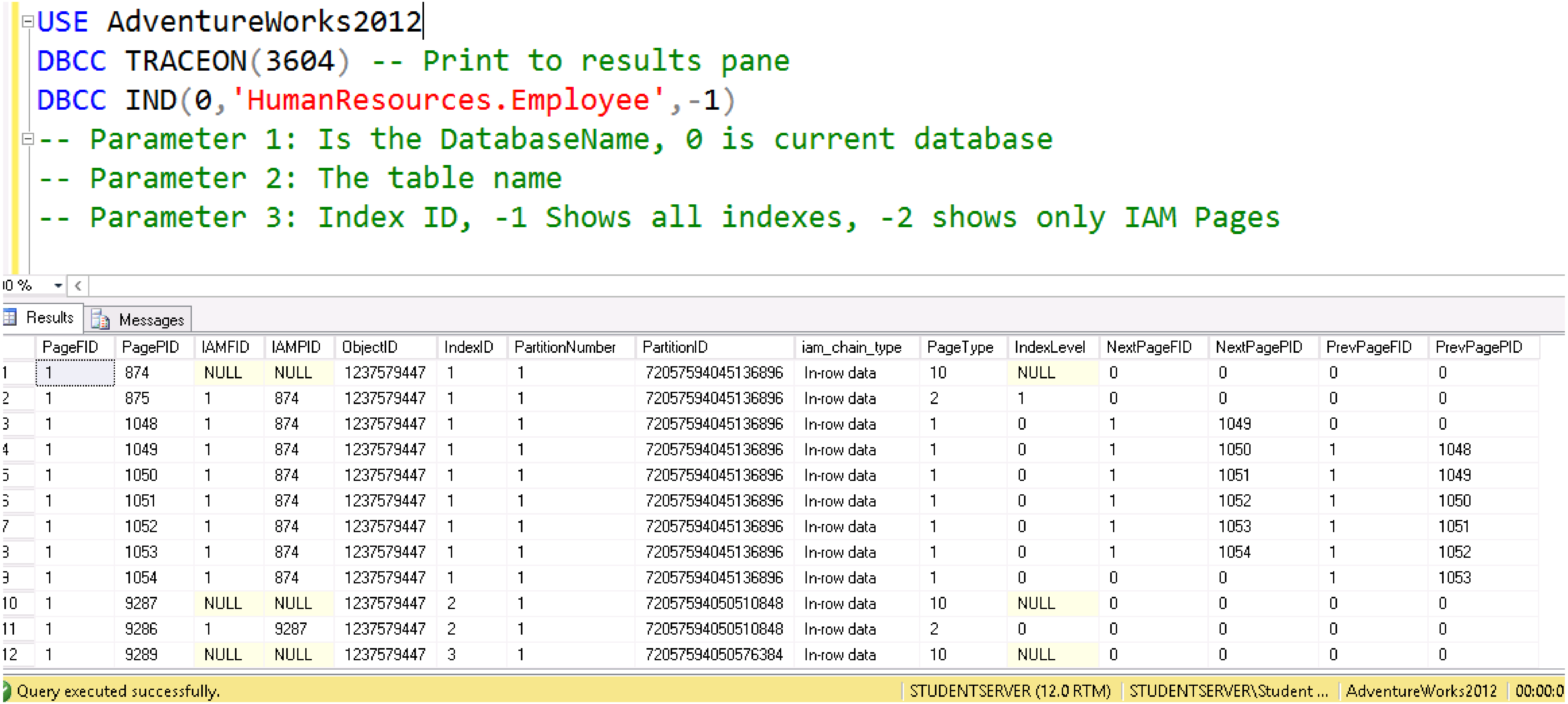
Types	Page Type (ID)	Description
Data and Index	Data (1)	Data rows with all data, except text, ntext, image, nvarchar(max), varchar(max), varbinary(max), and xml data, when **text in row** is set to **ON**
	Index (2)	Index Entries
	Text/Image (3 or 4)	Large Object Data Type, variable length columns when the data row exceeds 8 kilobytes (KB)
Allocation	GAM, SGAM (8 and 9)	Extent Allocation information
	PFS (11)	Information about page allocation and free space available on pages
	IAM (10)	Information about extents used by a table or index per allocation unit
Restore	Bulk Changed Map (17)	Information about extents modified by bulk operations since the last BACKUP LOG statement per allocation unit
	Differential Changed Map (16)	Information about extents that have changed since the last BACKUP DATABASE statement per allocation unit
Metadata	Boot (13)	Information about the database; Each database has only one Boot page
	File Header (15)	Information about the file. It is the first page (page 0) in every file

The Role of Allocation Maps and PFS in Object Allocation

PFS and IAM are used to determine when an object needs a new extent allocated

GAMs and SGAMs are used to allocate the extent

DBCC IND

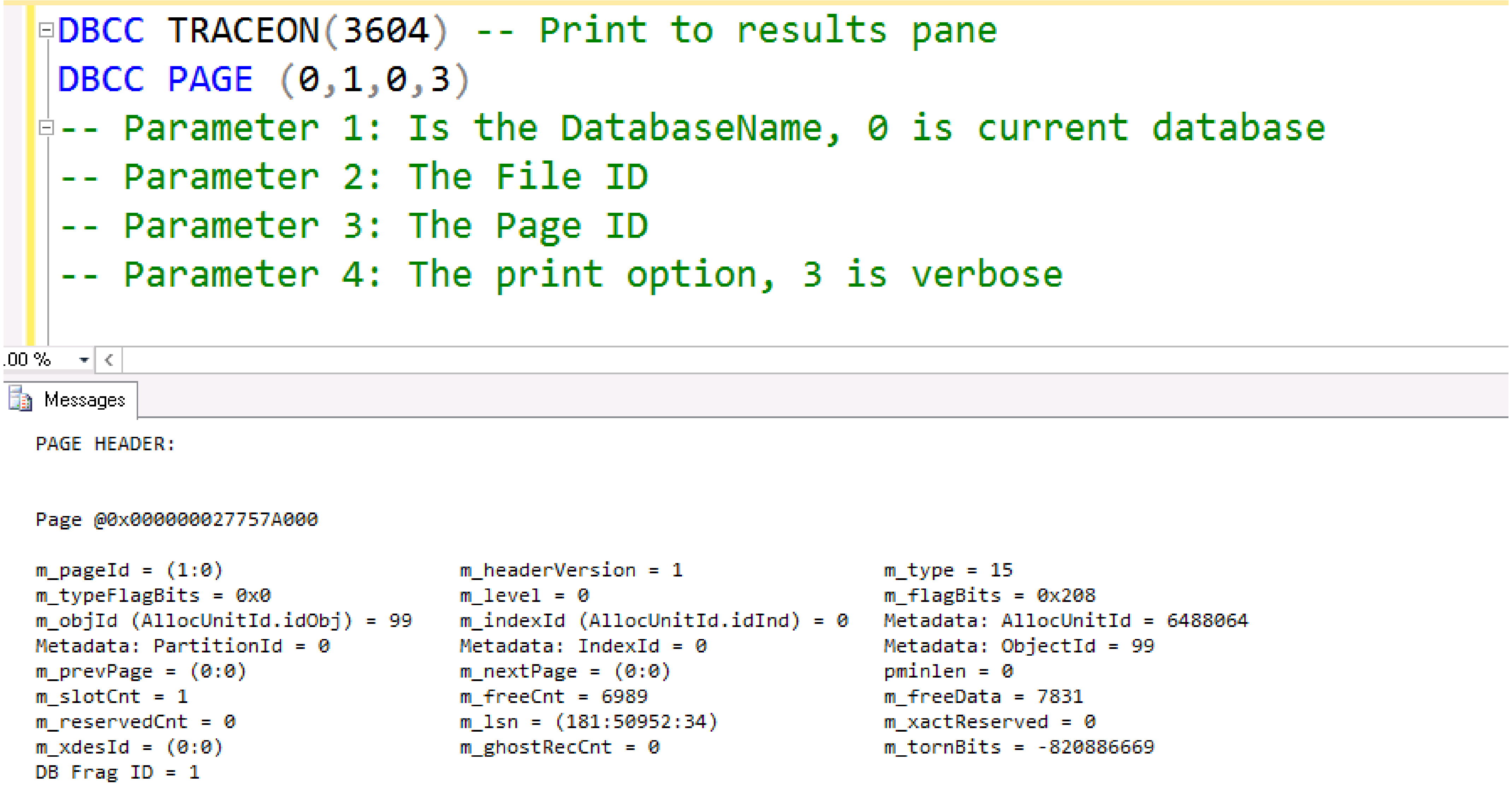


```sql
USE AdventureWorks2012
DBCC TRACEON(3604) -- Print to results pane
DBCC IND(0,'HumanResources.Employee',-1)
-- Parameter 1: Is the DatabaseName, 0 is current database
-- Parameter 2: The table name
-- Parameter 3: Index ID, -1 Shows all indexes, -2 shows only IAM Pages
```

	PageFID	PagePID	IAMFID	IAMPID	ObjectID	IndexID	PartitionNumber	PartitionID	iam_chain_type	PageType	IndexLevel	NextPageFID	NextPagePID	PrevPageFID	PrevPagePID
1	1	874	NULL	NULL	1237579447	1	1	72057594045136896	In-row data	10	NULL	0	0	0	0
2	1	875	1	874	1237579447	1	1	72057594045136896	In-row data	2	1	0	0	0	0
3	1	1048	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	1	1049	0	0
4	1	1049	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	1	1050	1	1048
5	1	1050	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	1	1051	1	1049
6	1	1051	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	1	1052	1	1050
7	1	1052	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	1	1053	1	1051
8	1	1053	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	1	1054	1	1052
9	1	1054	1	874	1237579447	1	1	72057594045136896	In-row data	1	0	0	0	1	1053
10	1	9287	NULL	NULL	1237579447	2	1	72057594050510848	In-row data	10	NULL	0	0	0	0
11	1	9286	1	9287	1237579447	2	1	72057594050510848	In-row data	2	0	0	0	0	0
12	1	9289	NULL	NULL	1237579447	3	1	72057594050576384	In-row data	10	NULL	0	0	0	0

Query executed successfully. | STUDENTSERVER (12.0 RTM) | STUDENTSERVER\Student ... | AdventureWorks2012 | 00:00:0

DBCC PAGE



```
DBCC TRACEON(3604) -- Print to results pane
DBCC PAGE (0,1,0,3)
-- Parameter 1: Is the DatabaseName, 0 is current database
-- Parameter 2: The File ID
-- Parameter 3: The Page ID
-- Parameter 4: The print option, 3 is verbose
```

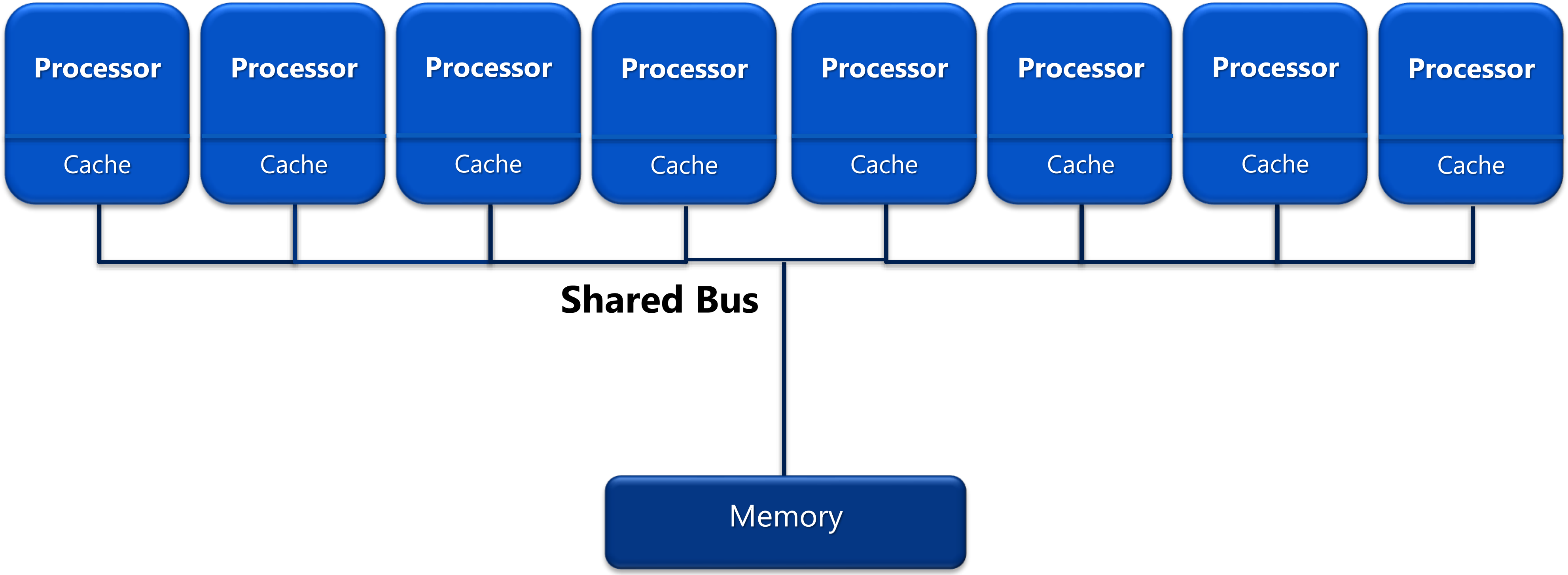
```
PAGE HEADER:


Page @0x000000027757A000

m_pageId = (1:0)                    m_headerVersion = 1                 m_type = 15
m_typeFlagBits = 0x0                m_level = 0                         m_flagBits = 0x208
m_objId (AllocUnitId.idObj) = 99    m_indexId (AllocUnitId.idInd) = 0   Metadata: AllocUnitId = 6488064
Metadata: PartitionId = 0           Metadata: IndexId = 0               Metadata: ObjectId = 99
m_prevPage = (0:0)                  m_nextPage = (0:0)                  pminlen = 0
m_slotCnt = 1                       m_freeCnt = 6989                    m_freeData = 7831
m_reservedCnt = 0                   m_lsn = (181:50952:34)              m_xactReserved = 0
m_xdesId = (0:0)                    m_ghostRecCnt = 0                   m_tornBits = -820886669
DB Frag ID = 1
```

SQL Server 2014 VLF Growth Improvement

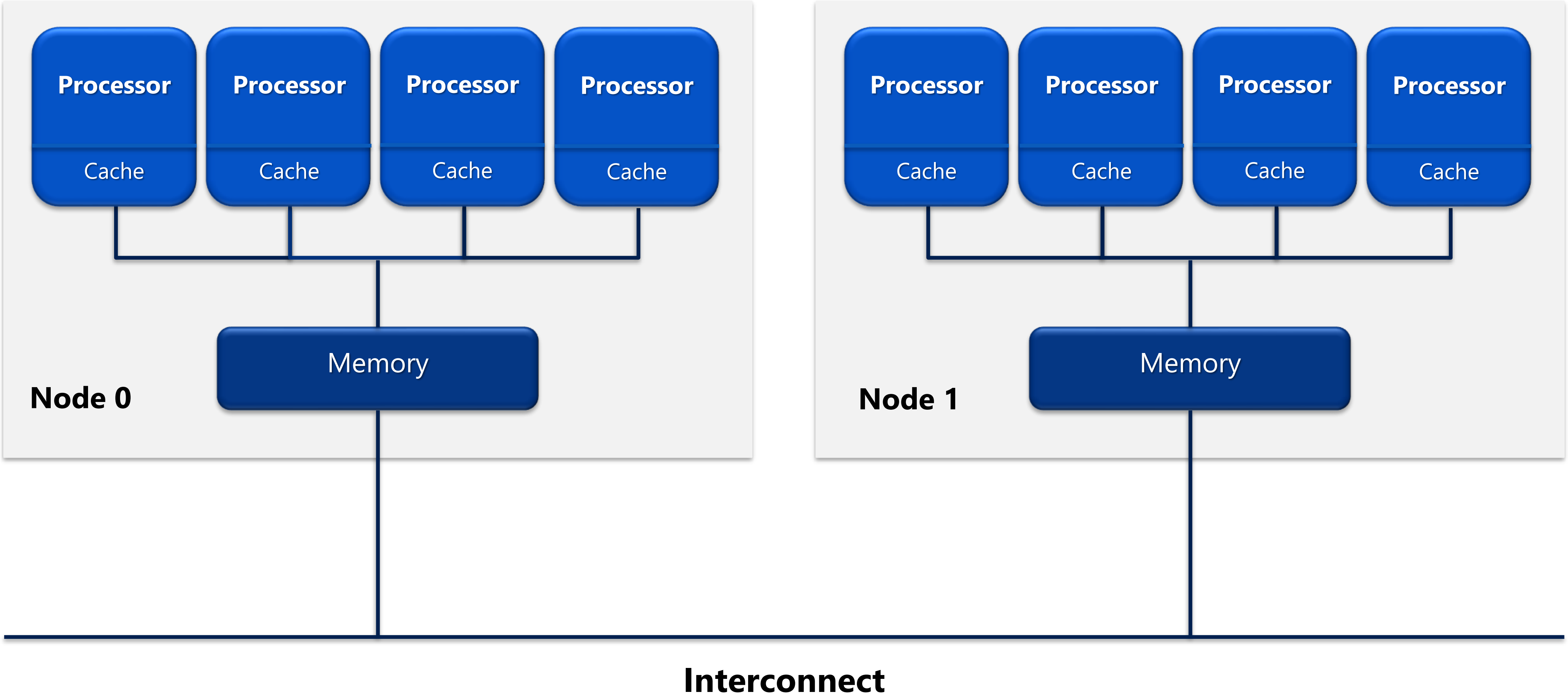
- Is the growth size less than 1/8 the size of the current log size?
  - Yes: create 1 new VLF equal to the growth size
  - No: use the previous formula
- Example of a 256 MB log file with an autogrowth setting of 5 MB
  - 2012 and earlier: 10 auto-grows of 5MB would add 4 VLFs x 10 auto-grows
  - 2014 and later: 10 auto-grows of 5MB each would only create 10 VLFs

Grow Iterations + Log size	Up to SQL Server 2012	From SQL Server 2014
0 (256 MB)	8	8
10 (306 MB)	48	18
20 (356 MB)	88	28
80 (656 MB)	328	88
250 (1.2 GB)	1008	258
3020 (15 GB)	12091	3028

Symmetric Multi-Processing (SMP)



Non-Uniform Memory Access (NUMA)



SQL Server Configuration

Processor Configuration Settings And Best Practices

Affinity Mask

- Assigns CPUs for SQL Server use
- Set via sp_configure or Alter Server Configuration
- Only required in specific scenarios

Max Degree of Parallelism (MAXDOP)

- Maximum number of processors that are used for the execution of a query in a parallel plan. This option determines the number of threads that are used for the query plan operators that perform the work in parallel.

Cost Threshold for Parallelism

- Only queries with a cost that is higher than this value will be considered for parallelism
- Only required when dealing with excessive parallelism

Max Worker Threads

- Number of threads SQL Server can allocate
- Recommended value is 0. SQL Server will dynamically set the Max based on CPUs and CPU architecture

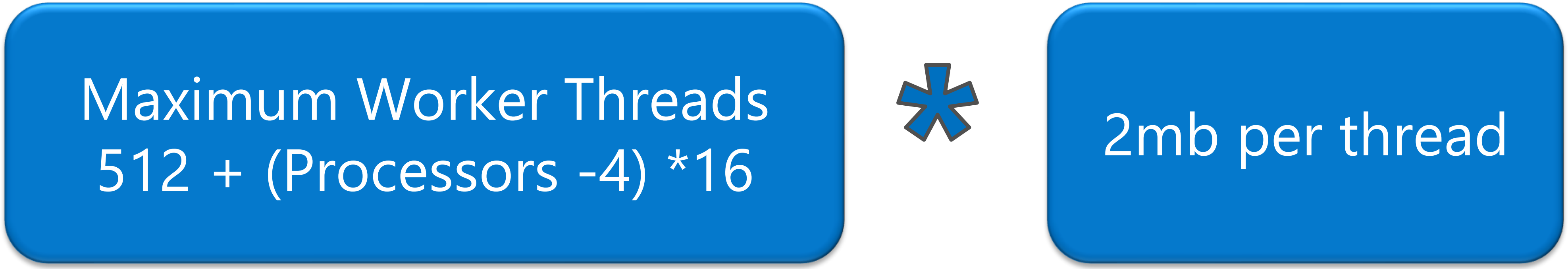
SQL Server Configuration

MAXDOP Setting and Best Practices

Best Practice Recommendations (documented in KB 2806535):

Server with single NUMA node	Less than or equal to 8 logical processors	Keep MAXDOP at or below # of logical processors
Server with single NUMA node	Greater than 8 logical processors	Keep MAXDOP at 8
Server with multiple NUMA nodes	Less than or equal to 16 logical processors per NUMA node	Keep MAXDOP at or below # of logical processors per NUMA node
Server with multiple NUMA nodes	Greater than 16 logical processors per NUMA node	Keep MAXDOP at half the number of logical processors per NUMA node with a MAX value of 16

How to determine Thread Stack Memory



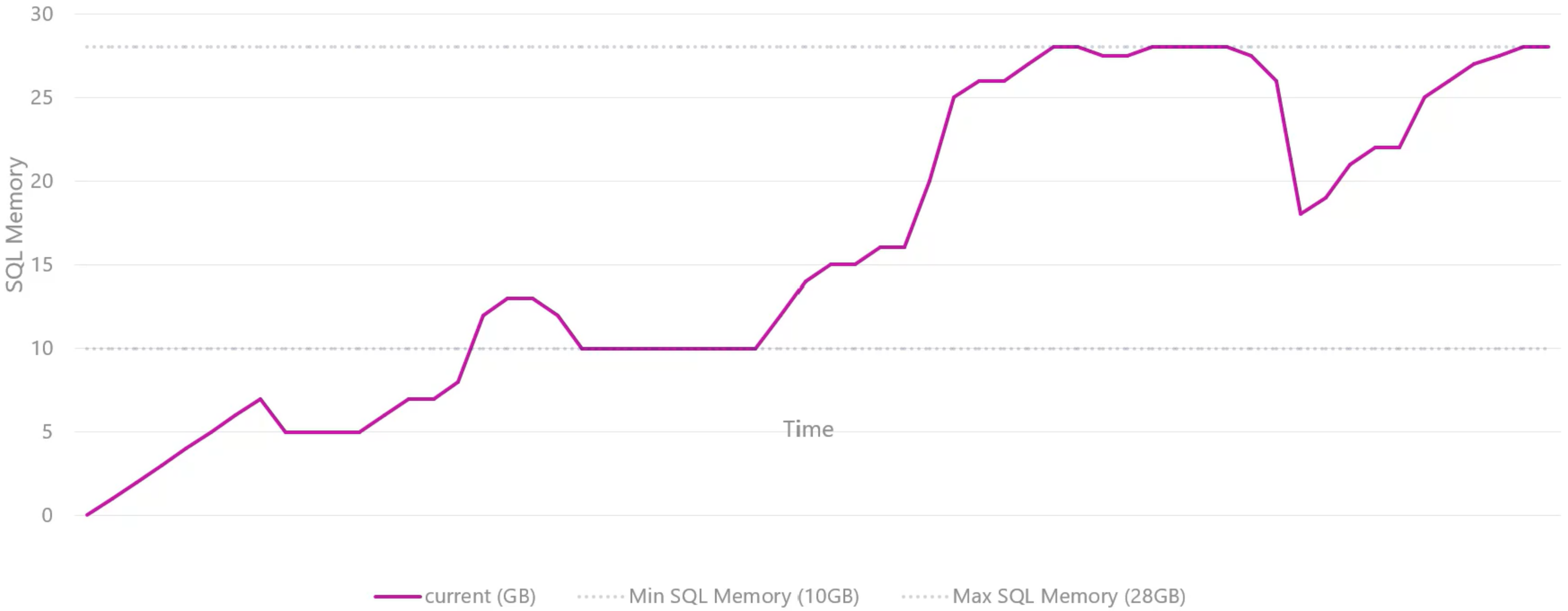
Maximum Worker Threads
512 + (Processors -4) *16

*

2mb per thread

Cores	Threads	Memory (MB)
4	512	1,024
8	576	1,152
16	704	1,408
32	960	1,920
64	1,472	2,944
80	1,728	3,456

Dynamic Memory Management

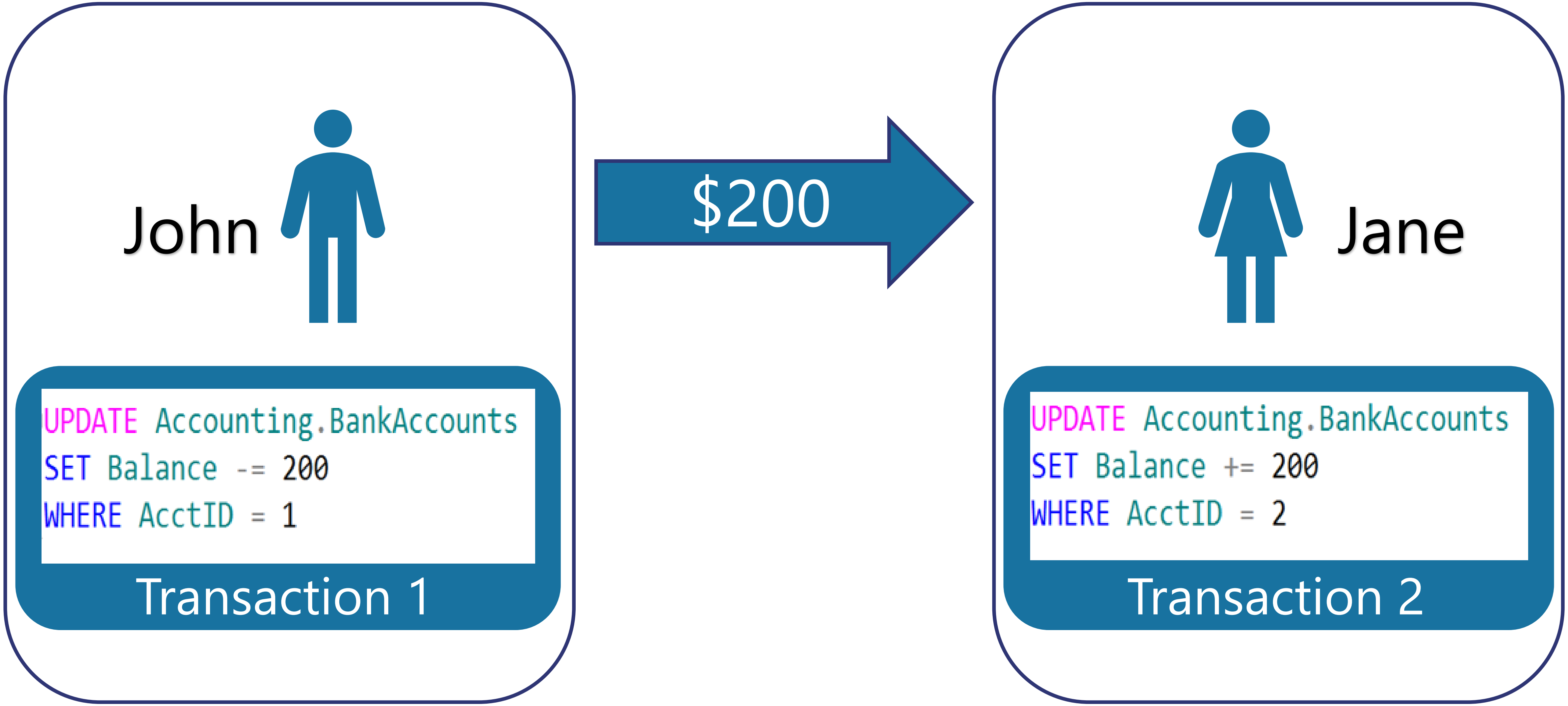


What is a Transaction?

A transaction is a series of one or more statements that need to operate as a single logical unit of work.

To qualify as a transaction, the logical unit of work must possess all four of the ACID properties.

Logical Units of Work – Auto Commit Transactions



John

$200

Jane

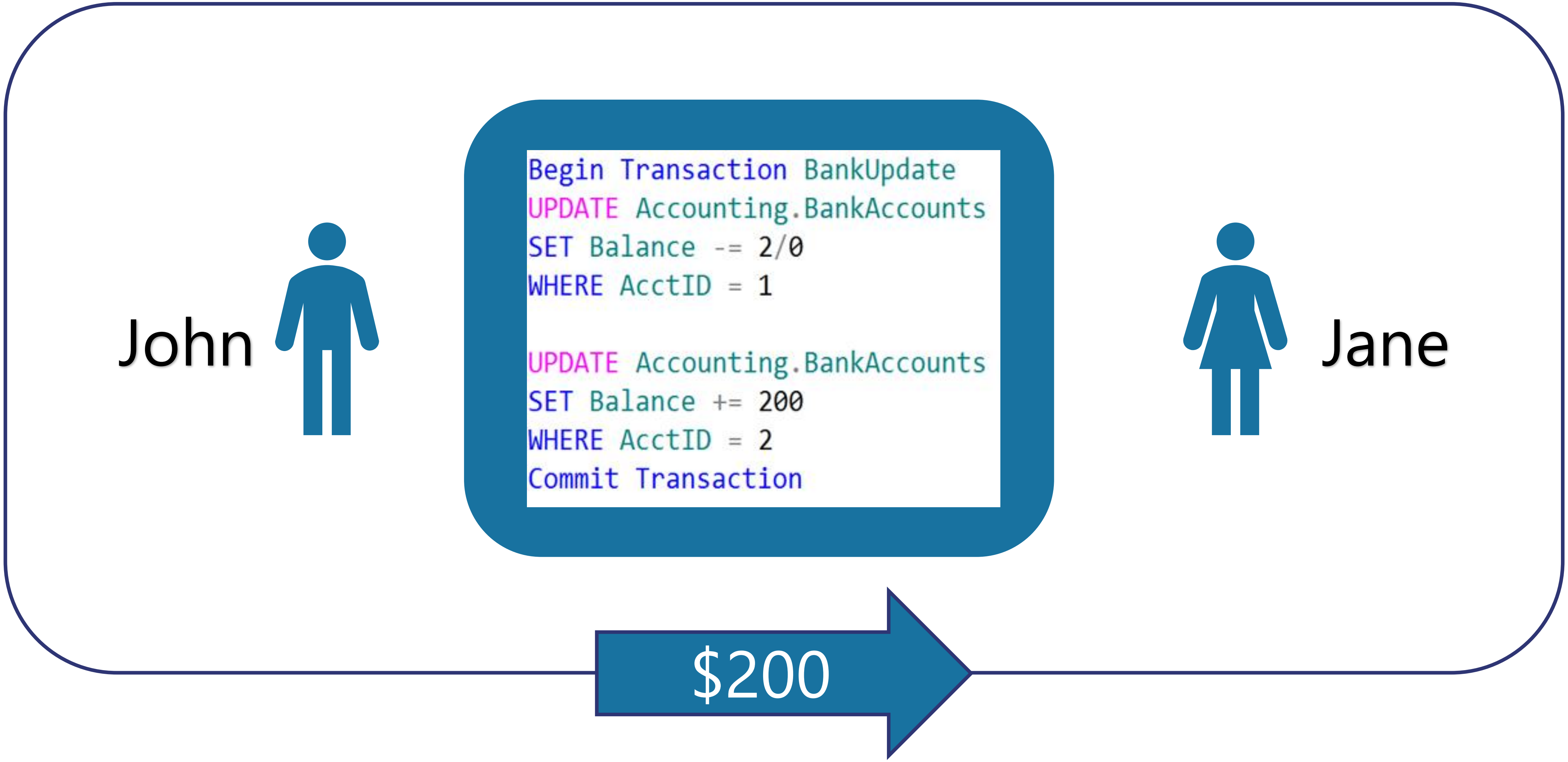
```
UPDATE Accounting.BankAccounts
SET Balance -= 200
WHERE AcctID = 1
```

Transaction 1

```
UPDATE Accounting.BankAccounts
SET Balance += 200
WHERE AcctID = 2
```

Transaction 2

Single Logical Unit of Work – Explicit Transactions



John

```
Begin Transaction BankUpdate
UPDATE Accounting.BankAccounts
SET Balance -= 2/0
WHERE AcctID = 1

UPDATE Accounting.BankAccounts
SET Balance += 200
WHERE AcctID = 2
Commit Transaction
```

Jane

$200

Transactions must pass the ACID test

Atomicity – All or Nothing

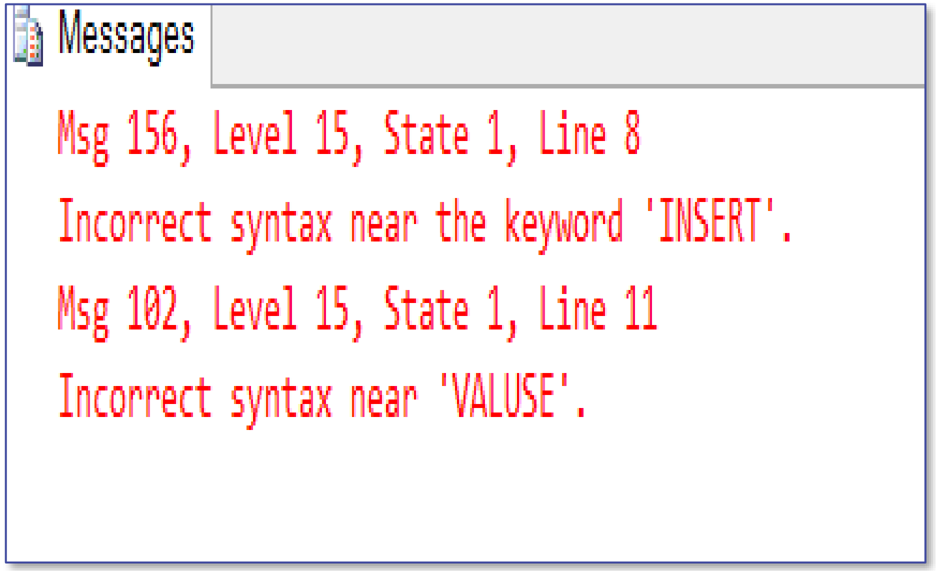
Consistent – Only valid data

Isolated – No interference

Durable – Data is recoverable

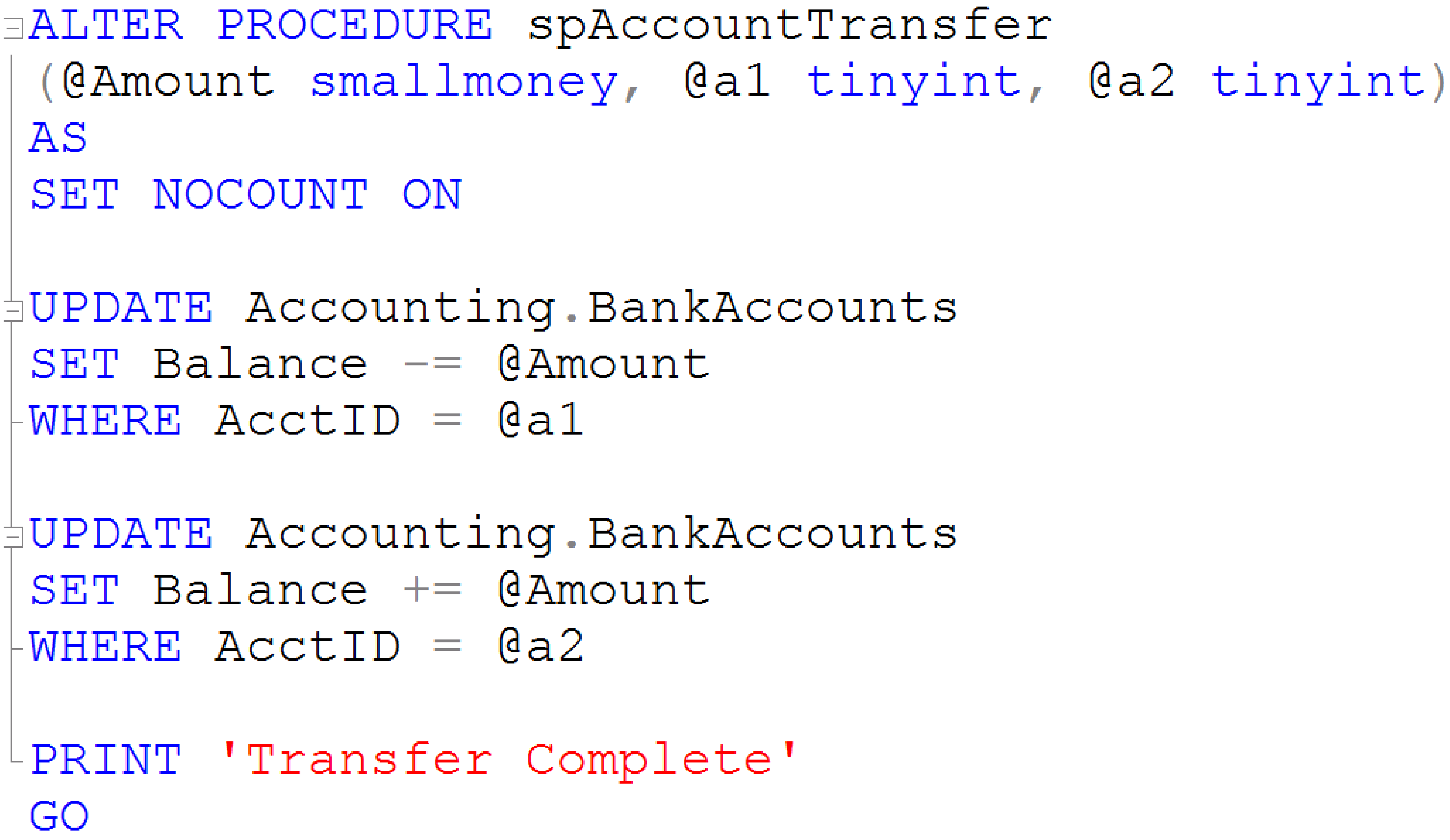
Working with Transactions

```
CREATE SCHEMA Accounting Authorization dbo
CREATE TABLE BankAccounts
 (AcctID int IDENTITY,
  AcctName char(15),
  Balance money,
  ModifiedDate date)

INSERT INTO Accounting.BankAccounts
VALUES('John',500, GETDATE())
INSERT INTO Accounting.BankAccounts
VALUSE('Jane', 750, GETDATE())
```



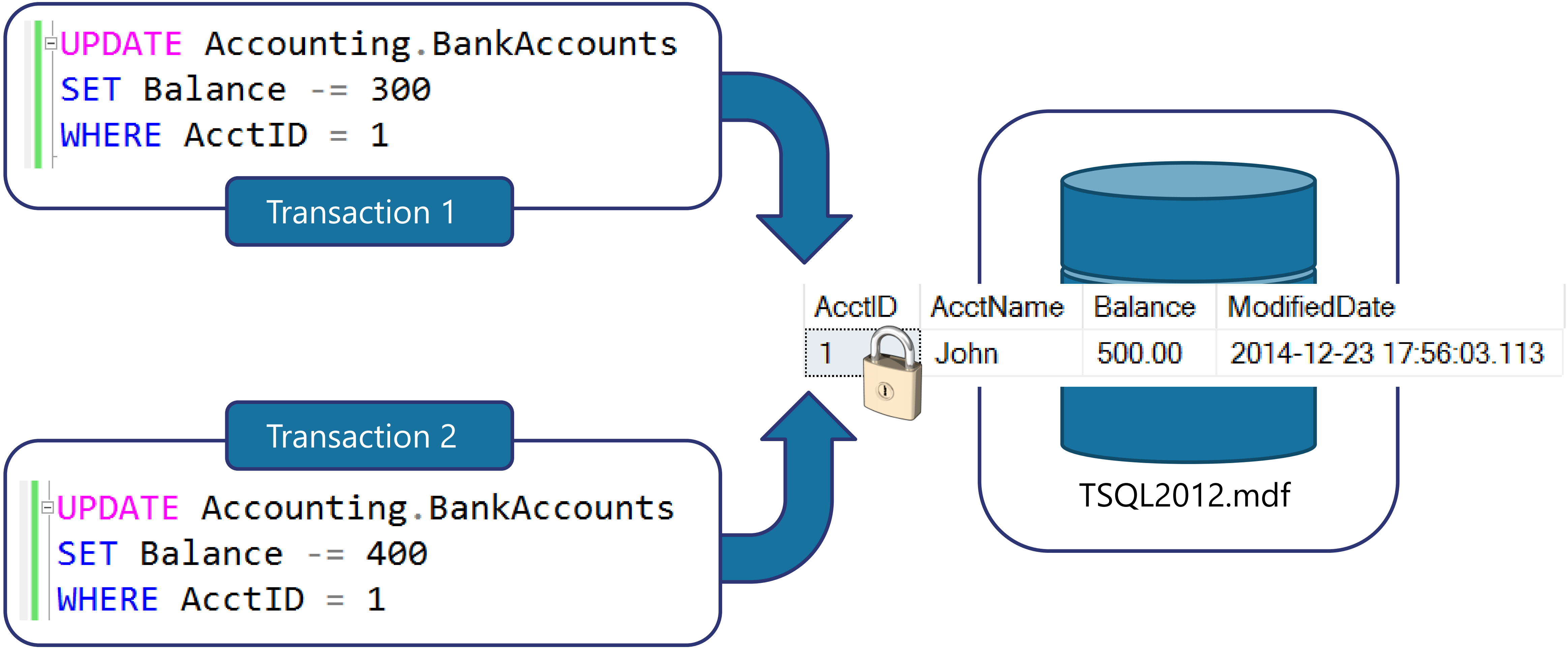
```
Msg 156, Level 15, State 1, Line 8
Incorrect syntax near the keyword 'INSERT'.
Msg 102, Level 15, State 1, Line 11
Incorrect syntax near 'VALUSE'.
```

Creating Stored Procedures



```
ALTER PROCEDURE spAccountTransfer
(@Amount smallmoney, @a1 tinyint, @a2 tinyint)
AS
SET NOCOUNT ON

UPDATE Accounting.BankAccounts
SET Balance -= @Amount
WHERE AcctID = @a1

UPDATE Accounting.BankAccounts
SET Balance += @Amount
WHERE AcctID = @a2

PRINT 'Transfer Complete'
GO
```

What is a Lock?



```sql
UPDATE Accounting.BankAccounts
SET Balance -= 300
WHERE AcctID = 1
```

Transaction 1

Transaction 2

```sql
UPDATE Accounting.BankAccounts
SET Balance -= 400
WHERE AcctID = 1
```

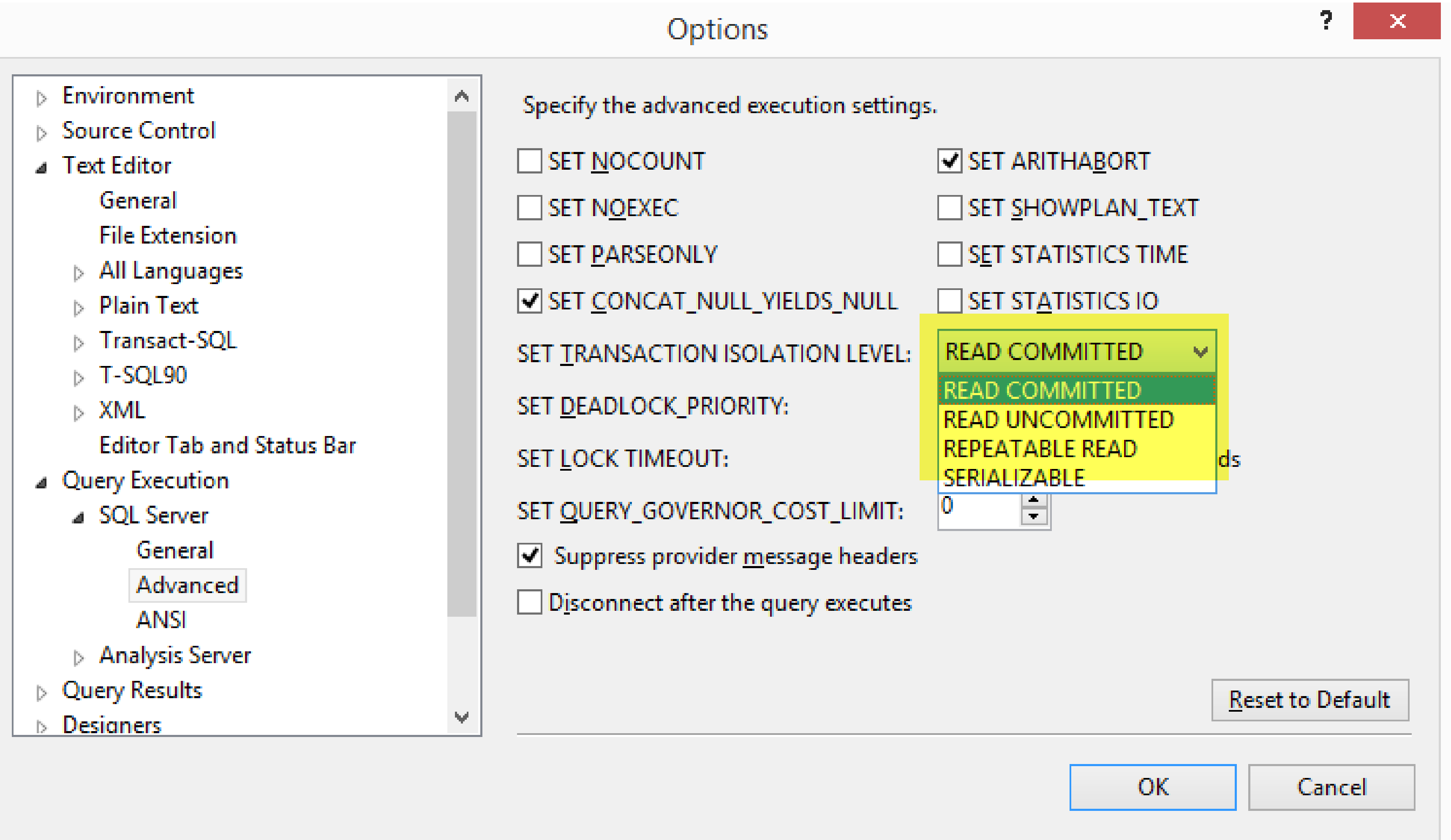
AcctID	AcctName	Balance	ModifiedDate
1	John	500.00	2014-12-23 17:56:03.113

TSQL2012.mdf

Transaction Isolation Levels

Isolation Level	Dirty Read	Lost Update	Nonrepeatable Read	Phantoms
Read uncommitted	Yes	Yes	Yes	Yes
Read committed (default)	No	Yes	Yes	Yes
Repeatable read	No	No	No	Yes
Serializable	No	No	No	No
Snapshot	No	No	No	No

Isolation Levels



Options

Specify the advanced execution settings.

☐ SET NOCOUNT
☐ SET NOEXEC
☐ SET PARSEONLY
☑ SET CONCAT_NULL_YIELDS_NULL
☑ SET ARITHABORT
☐ SET SHOWPLAN_TEXT
☐ SET STATISTICS TIME
☐ SET STATISTICS IO

SET TRANSACTION ISOLATION LEVEL: READ COMMITTED
- READ COMMITTED
- READ UNCOMMITTED
- REPEATABLE READ
- SERIALIZABLE

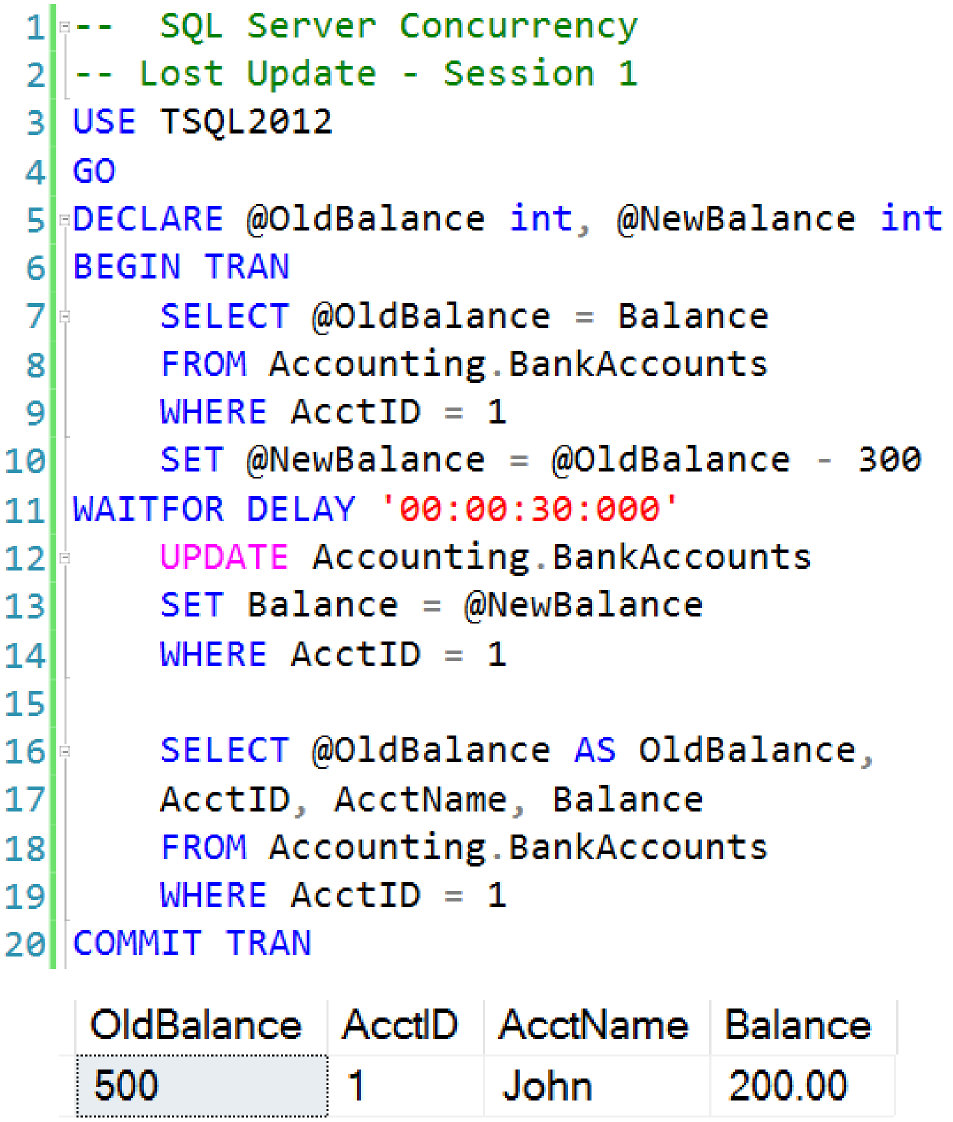
SET DEADLOCK_PRIORITY:

SET LOCK TIMEOUT: ds

SET QUERY_GOVERNOR_COST_LIMIT: 0

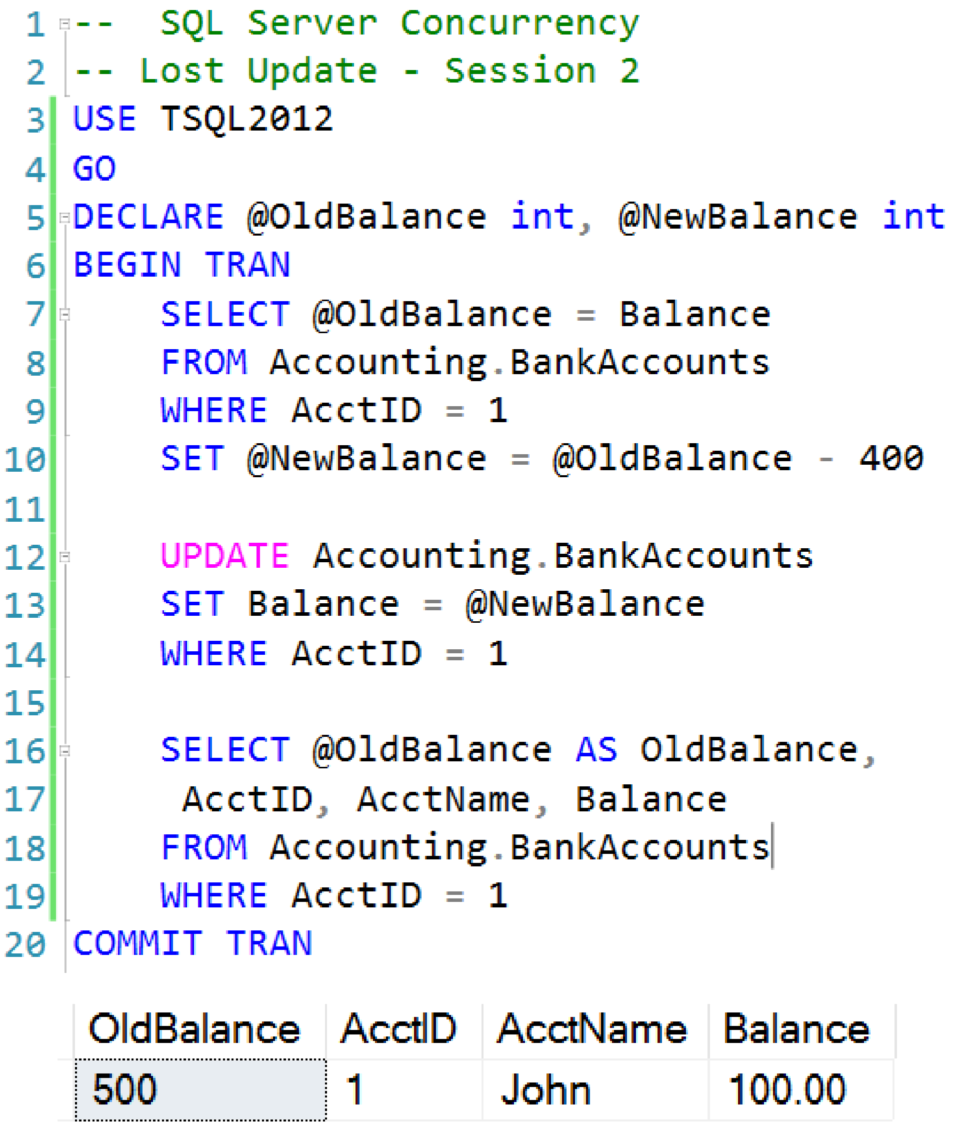
☑ Suppress provider message headers
☐ Disconnect after the query executes

Lost Updates



```sql
--  SQL Server Concurrency
-- Lost Update - Session 1
USE TSQL2012
GO
DECLARE @OldBalance int, @NewBalance int
BEGIN TRAN
    SELECT @OldBalance = Balance
    FROM Accounting.BankAccounts
    WHERE AcctID = 1
    SET @NewBalance = @OldBalance - 300
WAITFOR DELAY '00:00:30:000'
    UPDATE Accounting.BankAccounts
    SET Balance = @NewBalance
    WHERE AcctID = 1

    SELECT @OldBalance AS OldBalance,
    AcctID, AcctName, Balance
    FROM Accounting.BankAccounts
    WHERE AcctID = 1
COMMIT TRAN
```

OldBalance	AcctID	AcctName	Balance
500	1	John	200.00



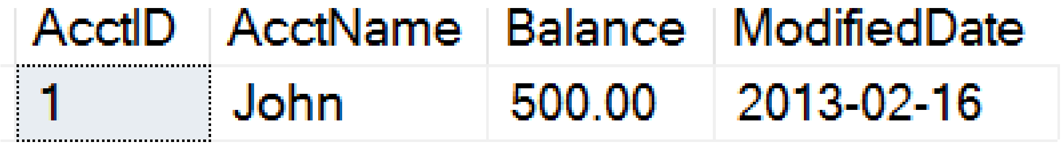
```sql
--  SQL Server Concurrency
-- Lost Update - Session 2
USE TSQL2012
GO
DECLARE @OldBalance int, @NewBalance int
BEGIN TRAN
    SELECT @OldBalance = Balance
    FROM Accounting.BankAccounts
    WHERE AcctID = 1
    SET @NewBalance = @OldBalance - 400

    UPDATE Accounting.BankAccounts
    SET Balance = @NewBalance
    WHERE AcctID = 1

    SELECT @OldBalance AS OldBalance,
     AcctID, AcctName, Balance
    FROM Accounting.BankAccounts
    WHERE AcctID = 1
COMMIT TRAN
```

OldBalance	AcctID	AcctName	Balance
500	1	John	100.00

Uncommitted dependency (dirty read)

```
--  SQL Server Concurrency
-- Dirty Read - Session 1
USE TSQL2012
GO
SET TRANSACTION ISOLATION LEVEL
READ UNCOMMITTED
BEGIN TRAN
    UPDATE Accounting.BankAccounts
    SET Balance -= 300
    WHERE AcctID = 1
        WAITFOR DELAY '00:00:10:000'
    ROLLBACK TRAN
    SELECT AcctID, AcctName, Balance
    FROM Accounting.BankAccounts
    WHERE AcctID = 1
```

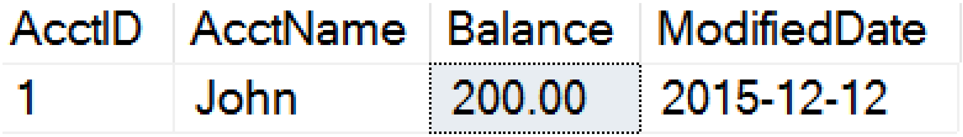
Clean Read



AcctID	AcctName	Balance	ModifiedDate
1	John	500.00	2013-02-16

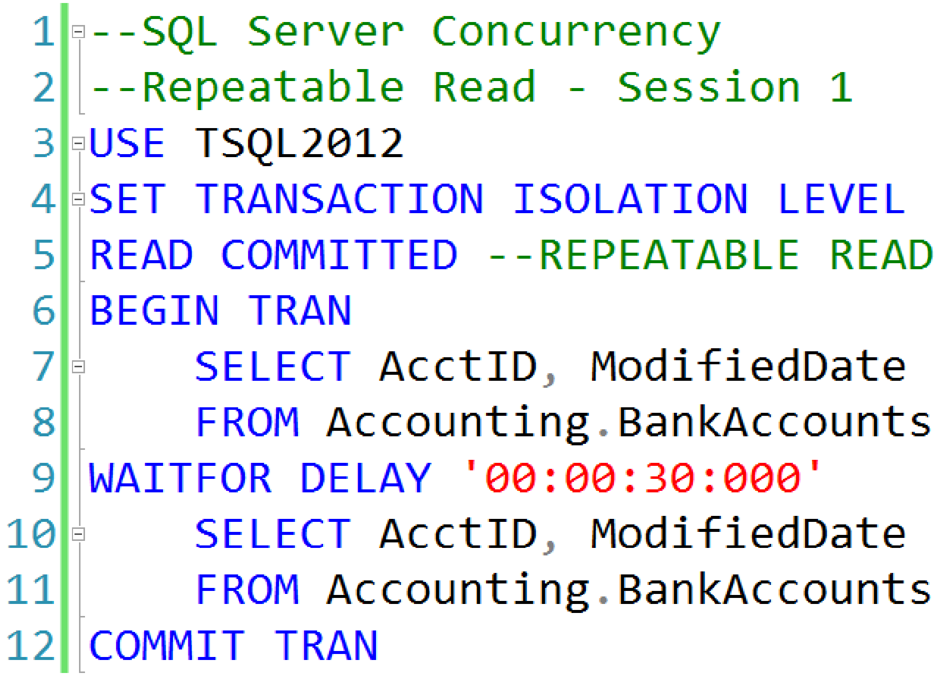
```
--SQL Server Concurrency
--Dirty Read - Session 2
USE TSQL2012
SET TRANSACTION ISOLATION LEVEL
READ UNCOMMITTED
    SELECT * FROM Accounting.BankAccounts
    WHERE AcctID = 1
```

Dirty Read

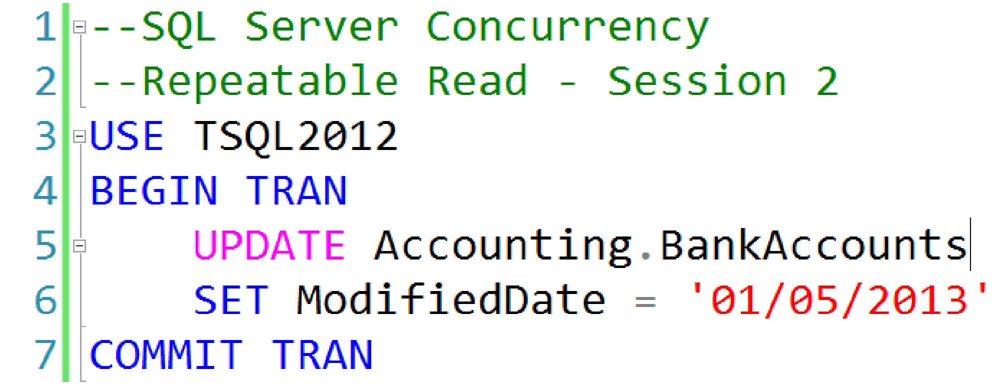


AcctID	AcctName	Balance	ModifiedDate
1	John	200.00	2015-12-12

Inconsistent analysis (non-repeatable read)

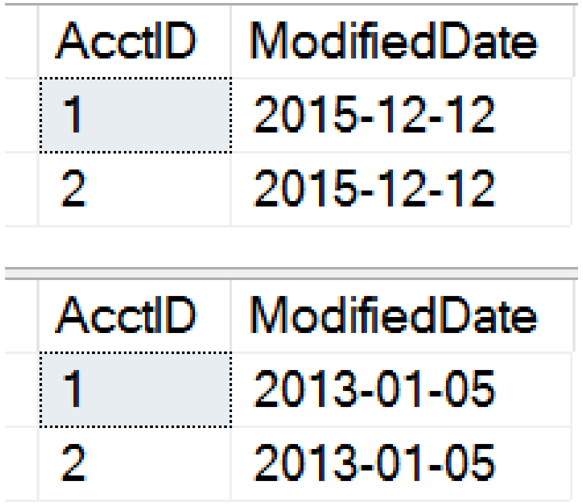


```
--SQL Server Concurrency
--Repeatable Read - Session 1
USE TSQL2012
SET TRANSACTION ISOLATION LEVEL
READ COMMITTED --REPEATABLE READ
BEGIN TRAN
     SELECT AcctID, ModifiedDate
     FROM Accounting.BankAccounts
WAITFOR DELAY '00:00:30:000'
     SELECT AcctID, ModifiedDate
     FROM Accounting.BankAccounts
COMMIT TRAN
```



```
--SQL Server Concurrency
--Repeatable Read - Session 2
USE TSQL2012
BEGIN TRAN
     UPDATE Accounting.BankAccounts
     SET ModifiedDate = '01/05/2013'
COMMIT TRAN
```

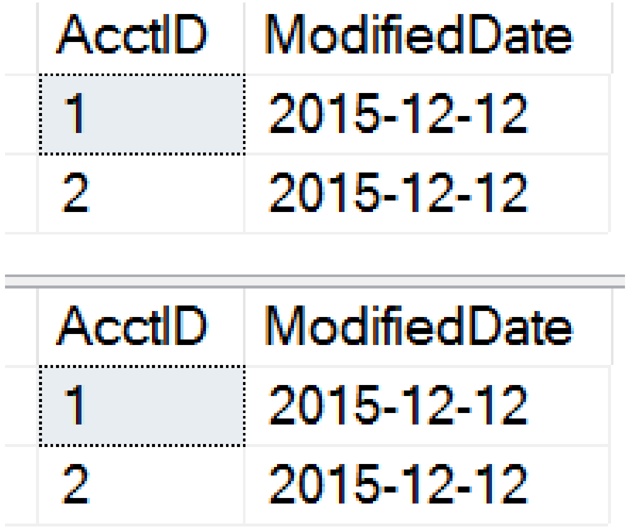
READ COMMITTED



AcctID	ModifiedDate
1	2015-12-12
2	2015-12-12

AcctID	ModifiedDate
1	2013-01-05
2	2013-01-05

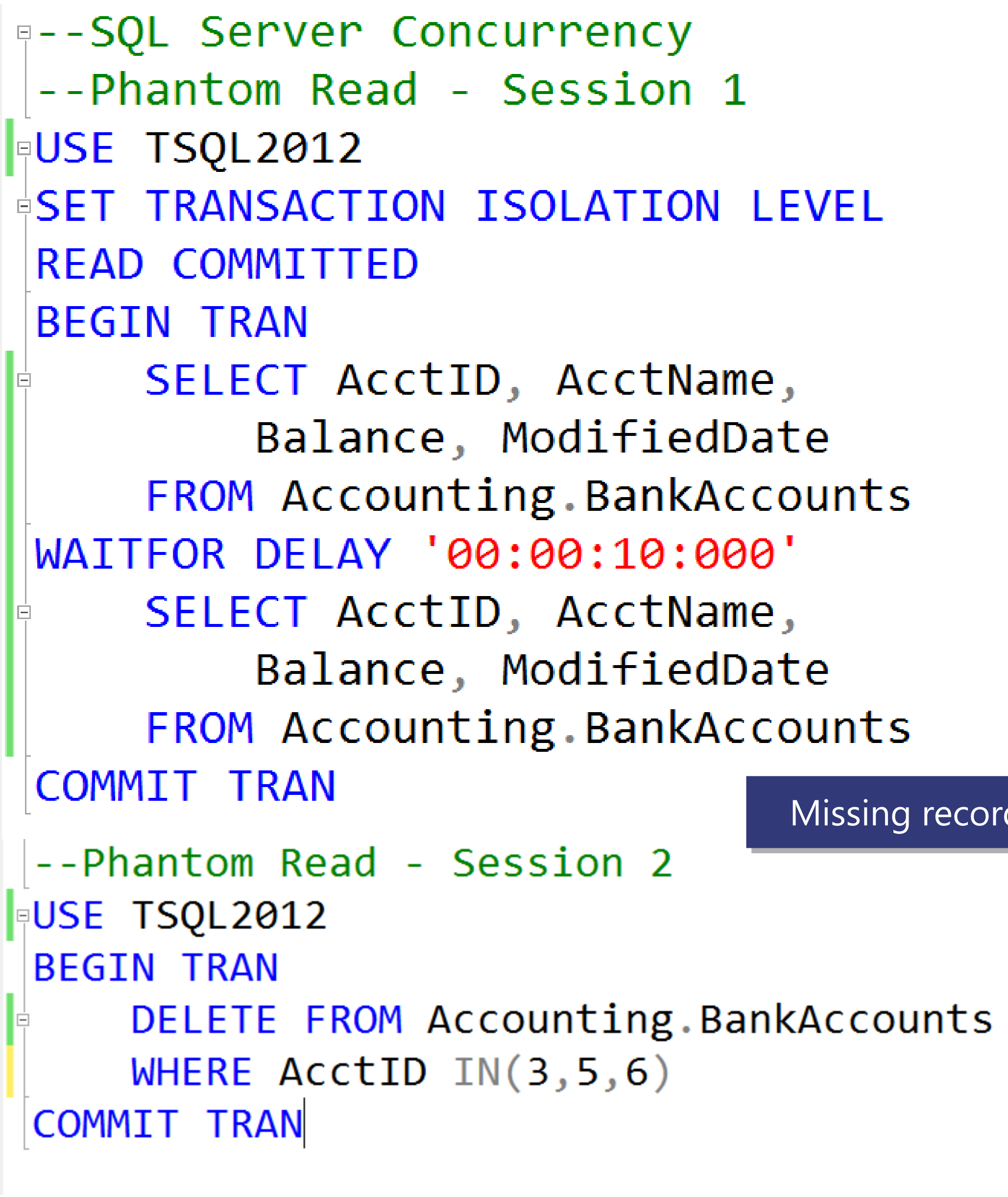
REPEATABLE READ



AcctID	ModifiedDate
1	2015-12-12
2	2015-12-12

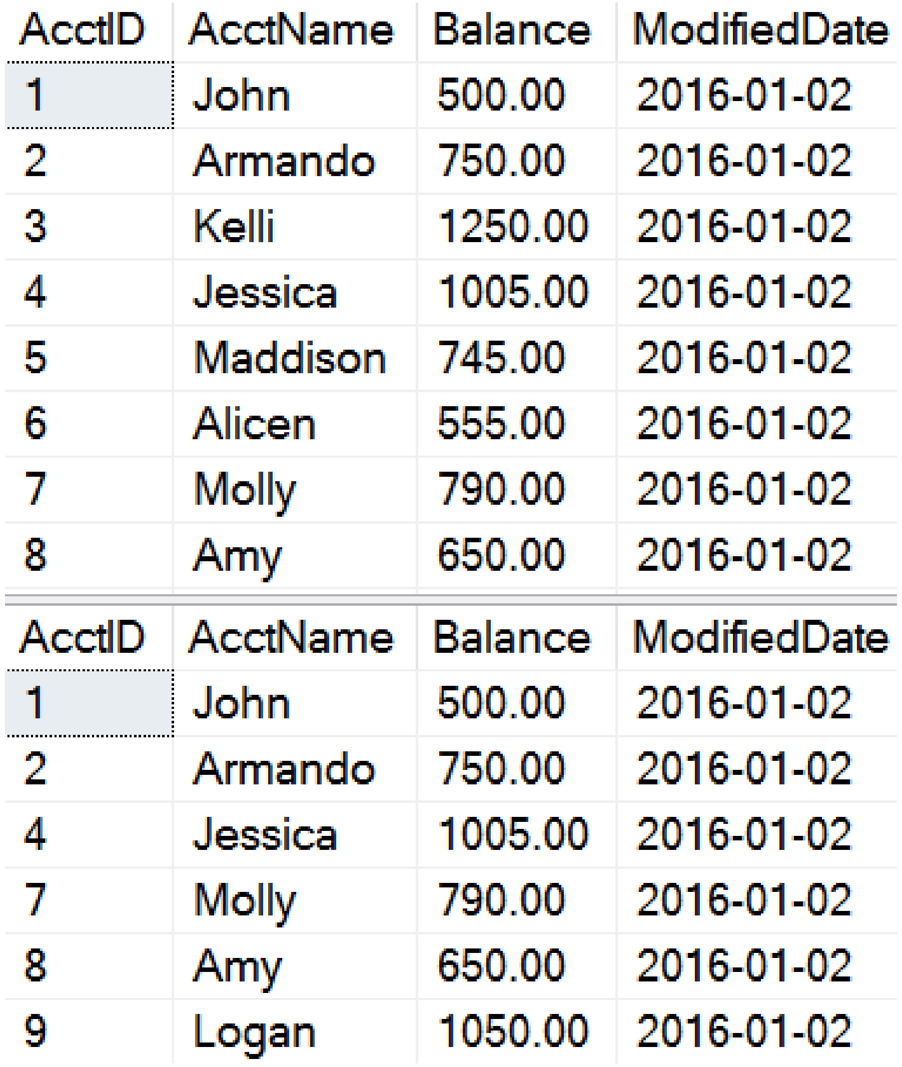
AcctID	ModifiedDate
1	2015-12-12
2	2015-12-12

Phantom Reads



```
--SQL Server Concurrency
--Phantom Read - Session 1
USE TSQL2012
SET TRANSACTION ISOLATION LEVEL
READ COMMITTED
BEGIN TRAN
    SELECT AcctID, AcctName,
        Balance, ModifiedDate
    FROM Accounting.BankAccounts
WAITFOR DELAY '00:00:10:000'
    SELECT AcctID, AcctName,
        Balance, ModifiedDate
    FROM Accounting.BankAccounts
COMMIT TRAN

--Phantom Read - Session 2
USE TSQL2012
BEGIN TRAN
    DELETE FROM Accounting.BankAccounts
    WHERE AcctID IN(3,5,6)
COMMIT TRAN
```

Missing records

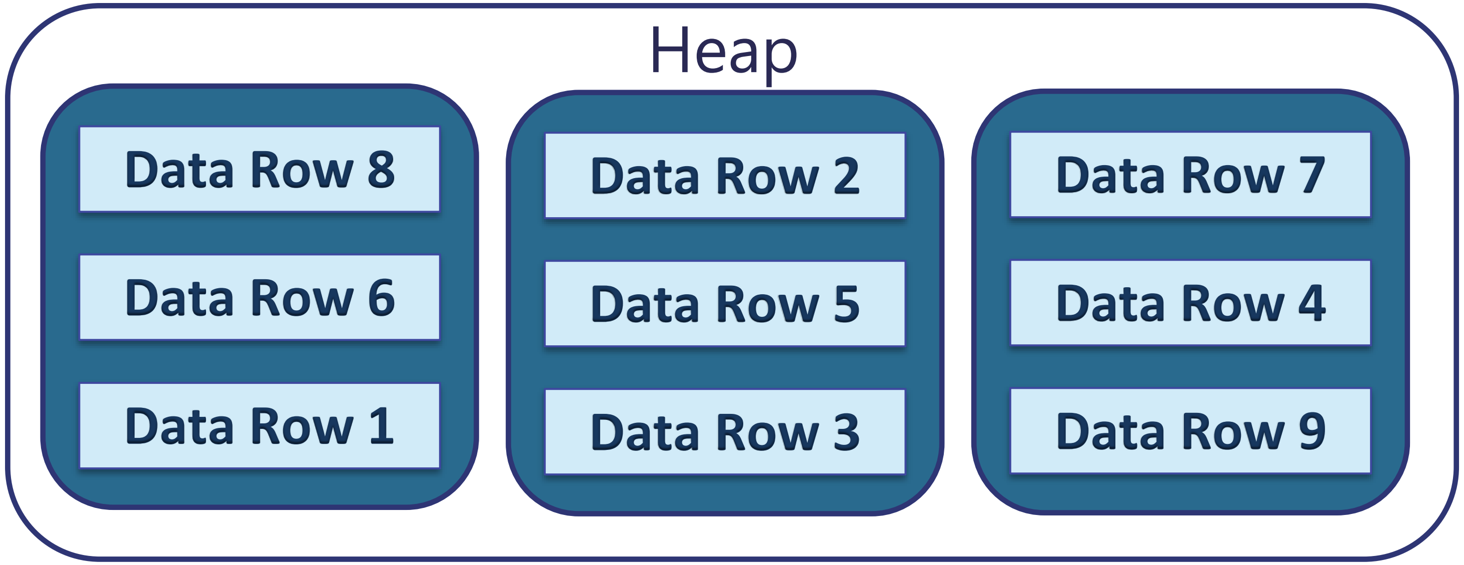


AcctID	AcctName	Balance	ModifiedDate
1	John	500.00	2016-01-02
2	Armando	750.00	2016-01-02
3	Kelli	1250.00	2016-01-02
4	Jessica	1005.00	2016-01-02
5	Maddison	745.00	2016-01-02
6	Alicen	555.00	2016-01-02
7	Molly	790.00	2016-01-02
8	Amy	650.00	2016-01-02

AcctID	AcctName	Balance	ModifiedDate
1	John	500.00	2016-01-02
2	Armando	750.00	2016-01-02
4	Jessica	1005.00	2016-01-02
7	Molly	790.00	2016-01-02
8	Amy	650.00	2016-01-02
9	Logan	1050.00	2016-01-02

How Data is Stored in Data Pages

Data stored in a Heap is not stored in any order and normally does not have a Primary Key.



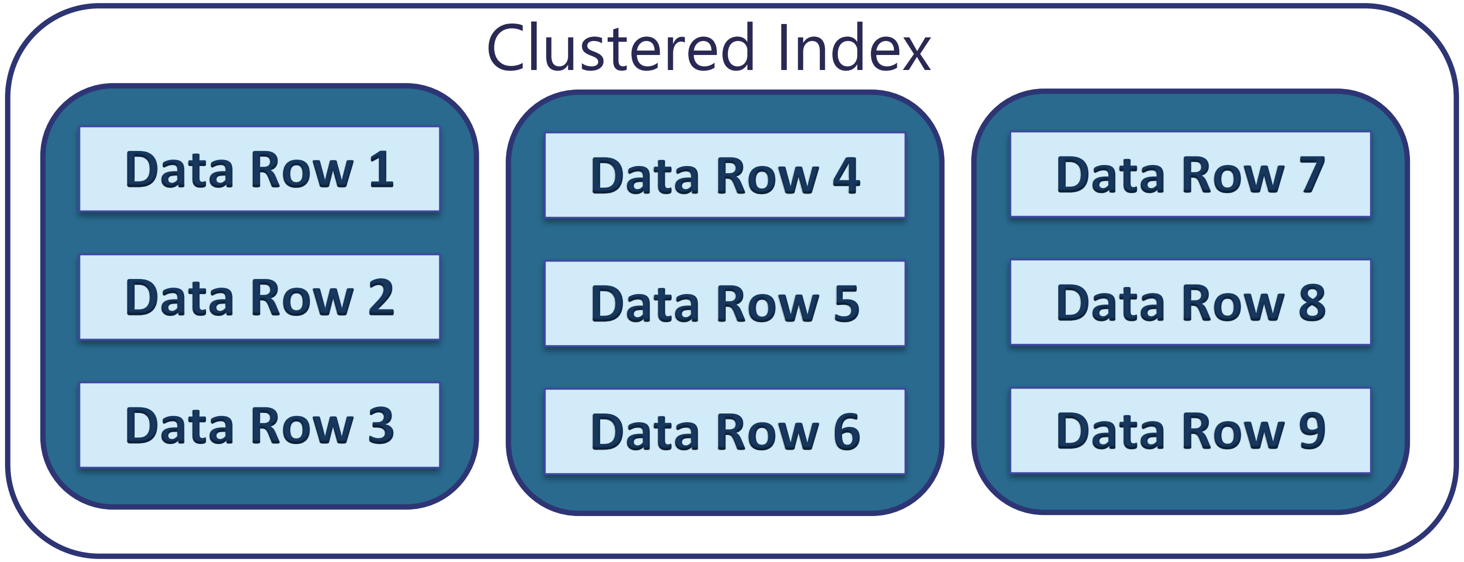
Heap

Data Row 8
Data Row 6
Data Row 1

Data Row 2
Data Row 5
Data Row 3

Data Row 7
Data Row 4
Data Row 9

Clustered Index data is stored in sorted order by the Clustering key. In many cases, this is the same value as the Primary Key.



Clustered Index

Data Row 1
Data Row 2
Data Row 3

Data Row 4
Data Row 5
Data Row 6

Data Row 7
Data Row 8
Data Row 9

Characteristics of a Good Clustering Key

Narrow

- Use a data type with a small number of bytes to conserver space in tables and indexes

Unique

- To avoid SQL adding a 4-byte uniquifier

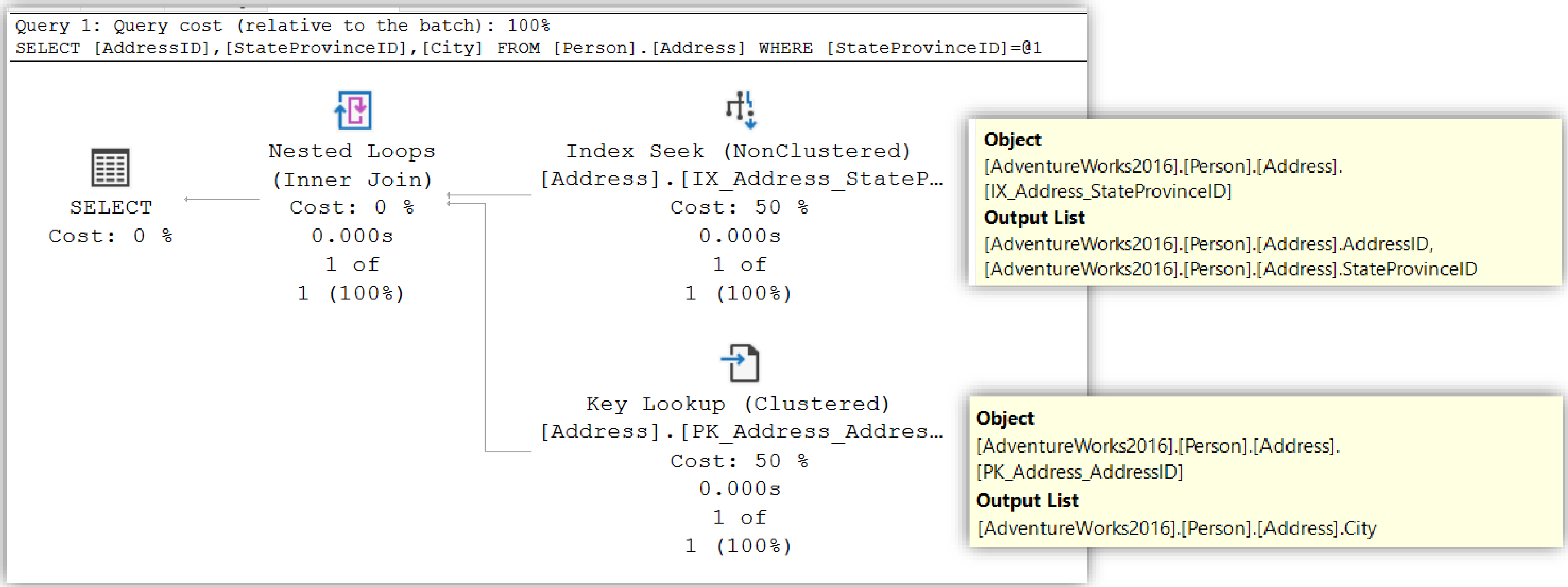
Static

- Allows data to stay constant without constant changes which could lead to page splits

Increasing

- Allows better write performance and reduces fragmentation issues

Key Lookup



```
Query 1: Query cost (relative to the batch): 100%
SELECT [AddressID],[StateProvinceID],[City] FROM [Person].[Address] WHERE [StateProvinceID]=@1
```

SELECT
Cost: 0 %

Nested Loops
(Inner Join)
Cost: 0 %
0.000s
1 of
1 (100%)

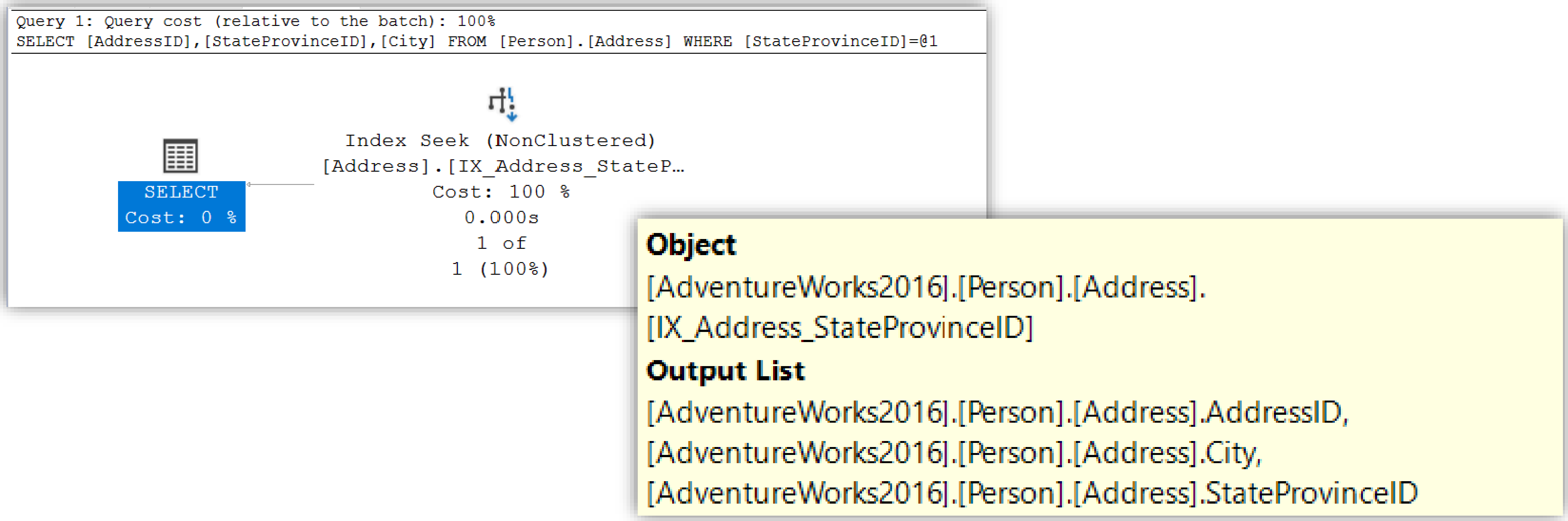
Index Seek (NonClustered)
[Address].[IX_Address_StateP…
Cost: 50 %
0.000s
1 of
1 (100%)

Key Lookup (Clustered)
[Address].[PK_Address_Addres…
Cost: 50 %
0.000s
1 of
1 (100%)

Object
[AdventureWorks2016].[Person].[Address].
[IX_Address_StateProvinceID]
Output List
[AdventureWorks2016].[Person].[Address].AddressID,
[AdventureWorks2016].[Person].[Address].StateProvinceID

Object
[AdventureWorks2016].[Person].[Address].
[PK_Address_AddressID]
Output List
[AdventureWorks2016].[Person].[Address].City

Non-Clustered Index with Included Column



```
Query 1: Query cost (relative to the batch): 100%
SELECT [AddressID],[StateProvinceID],[City] FROM [Person].[Address] WHERE [StateProvinceID]=@1
```

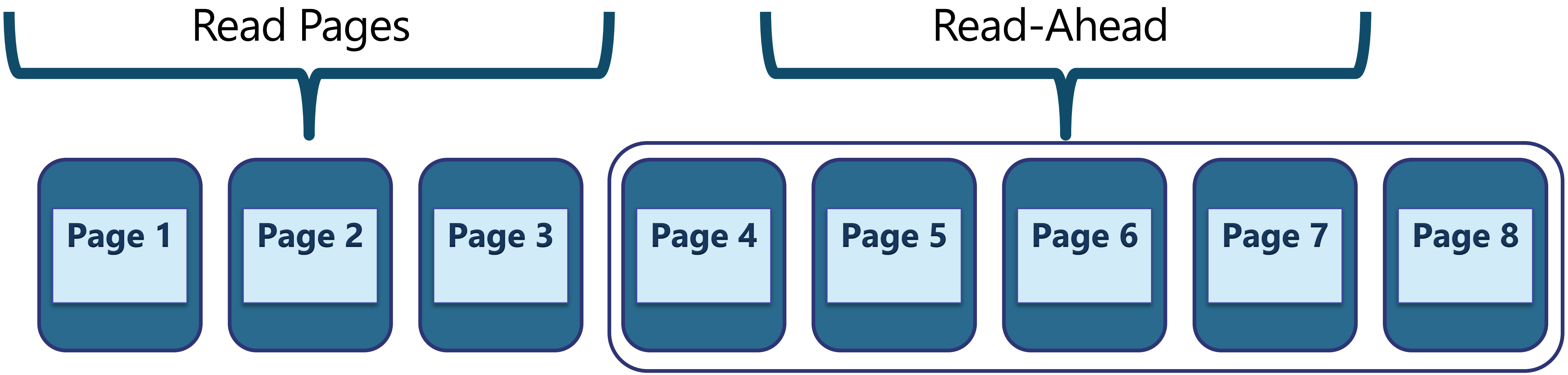
Object

[AdventureWorks2016].[Person].[Address].
[IX_Address_StateProvinceID]

Output List

[AdventureWorks2016].[Person].[Address].AddressID,
[AdventureWorks2016].[Person].[Address].City,
[AdventureWorks2016].[Person].[Address].StateProvinceID

Read-Ahead Scans



- Read-ahead anticipates the data and index pages needed to fulfill a query execution plan and brings the pages into the buffer cache before they are used by the query.
- The read-ahead mechanism allows the Database Engine to read up to 64 contiguous pages (512KB) from one file.

Columnstore Index Types

SQL Server 2012

- Only Non-Clustered, Non-Updatable Columnstore Indexes.
- Only available in Enterprise Edition.

SQL Server 2014

- Introduced Updatable, Clustered Columnstore Indexes
- Only available in Enterprise Edition.

SQL Server 2016

- Introduced Updatable, Non-Clustered Columnstore Indexes
- Available on Standard Edition. (Service Pack 1)

SQL Server 2019

- Online rebuilds for Clustered Columnstore Indexes.

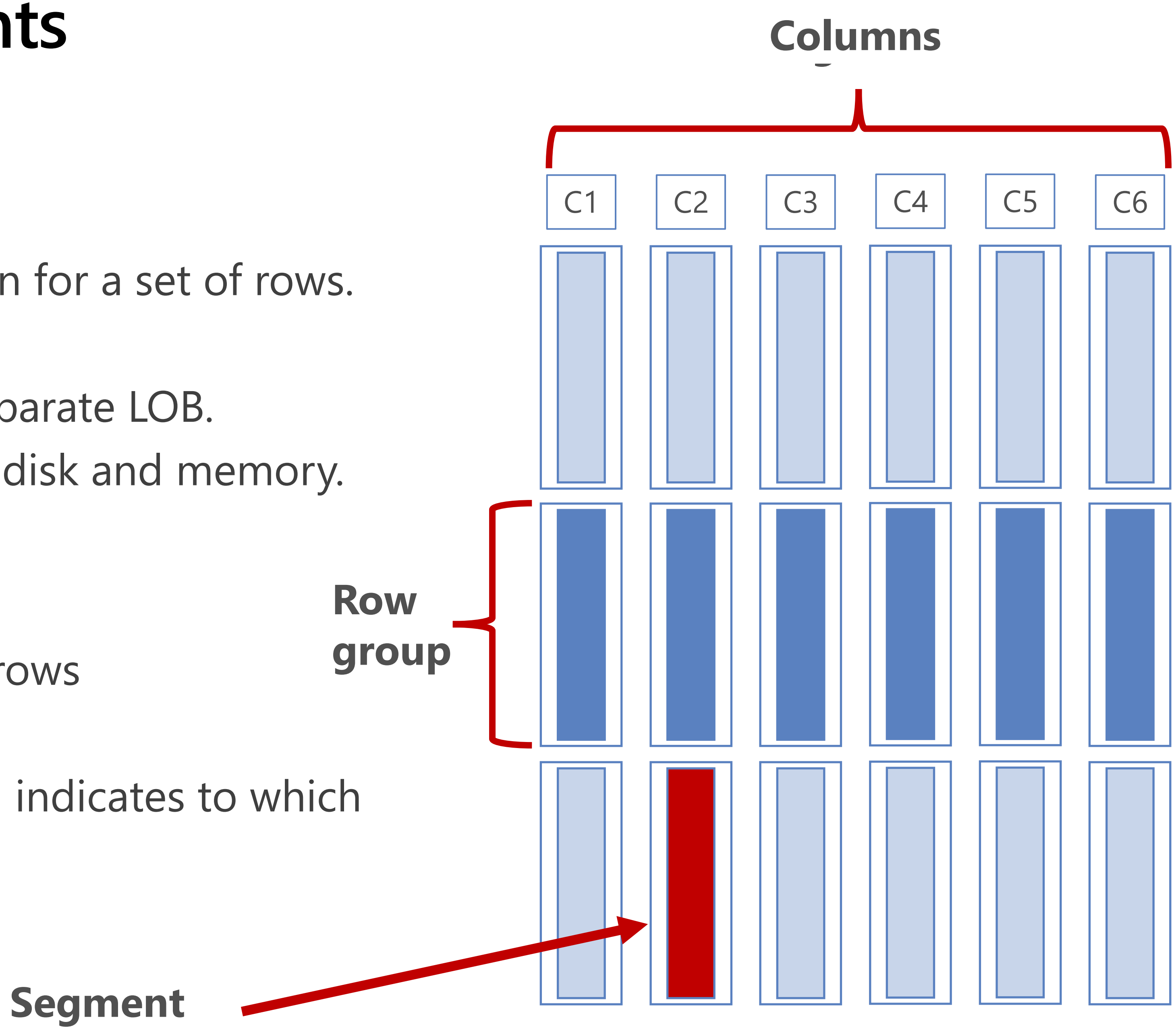
Row Groups & Segments

Segment

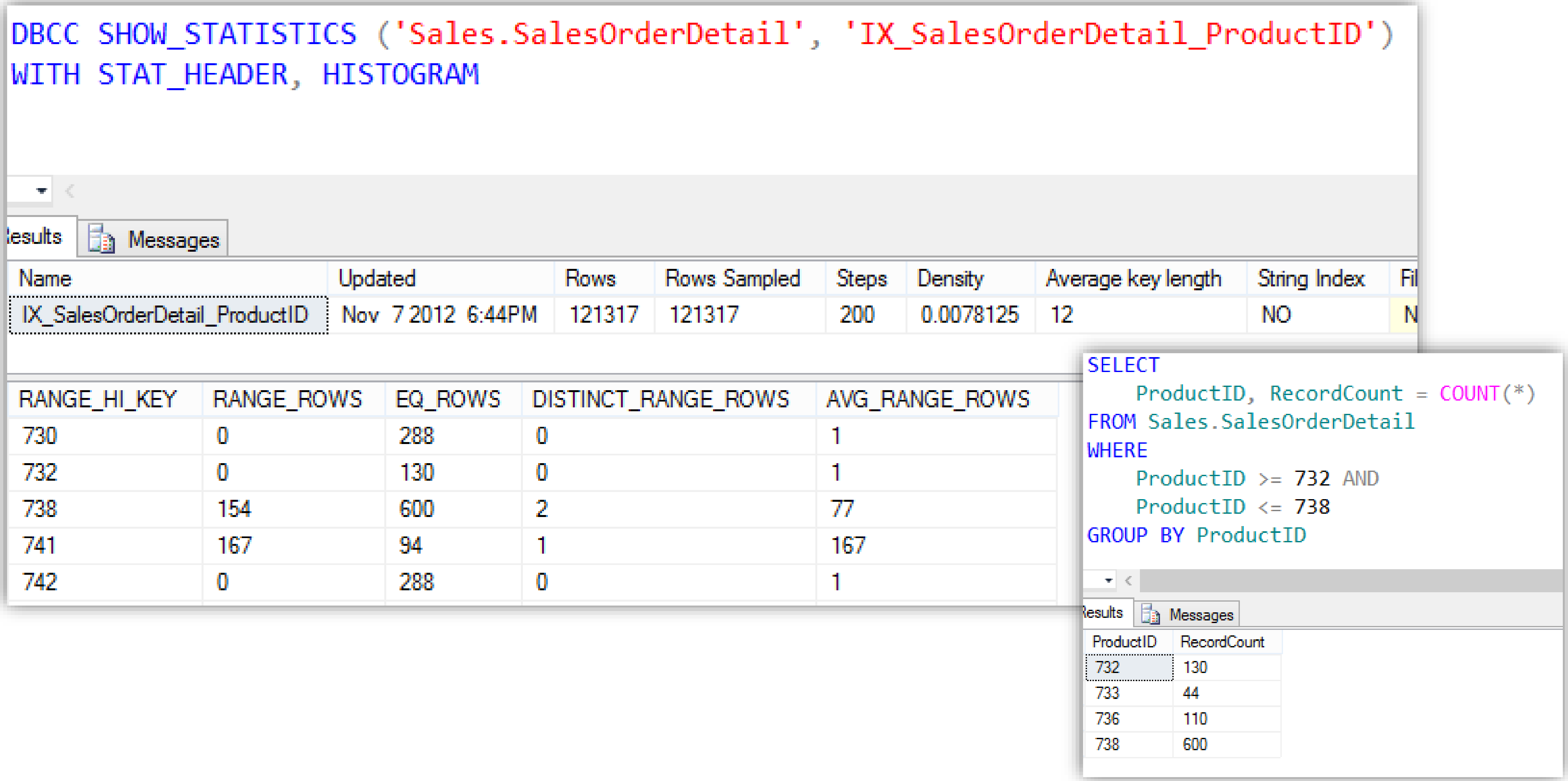
- Contains values for one column for a set of rows.
- Segments are compressed.
- Each segment is stored in a separate LOB.
- It is a unit of transfer between disk and memory.

Row Group

- Segments for the same set of rows comprise a row group.
- Position of a value in a column indicates to which row it belongs to.



Showing Statistics



```sql
DBCC SHOW_STATISTICS ('Sales.SalesOrderDetail', 'IX_SalesOrderDetail_ProductID')
WITH STAT_HEADER, HISTOGRAM
```

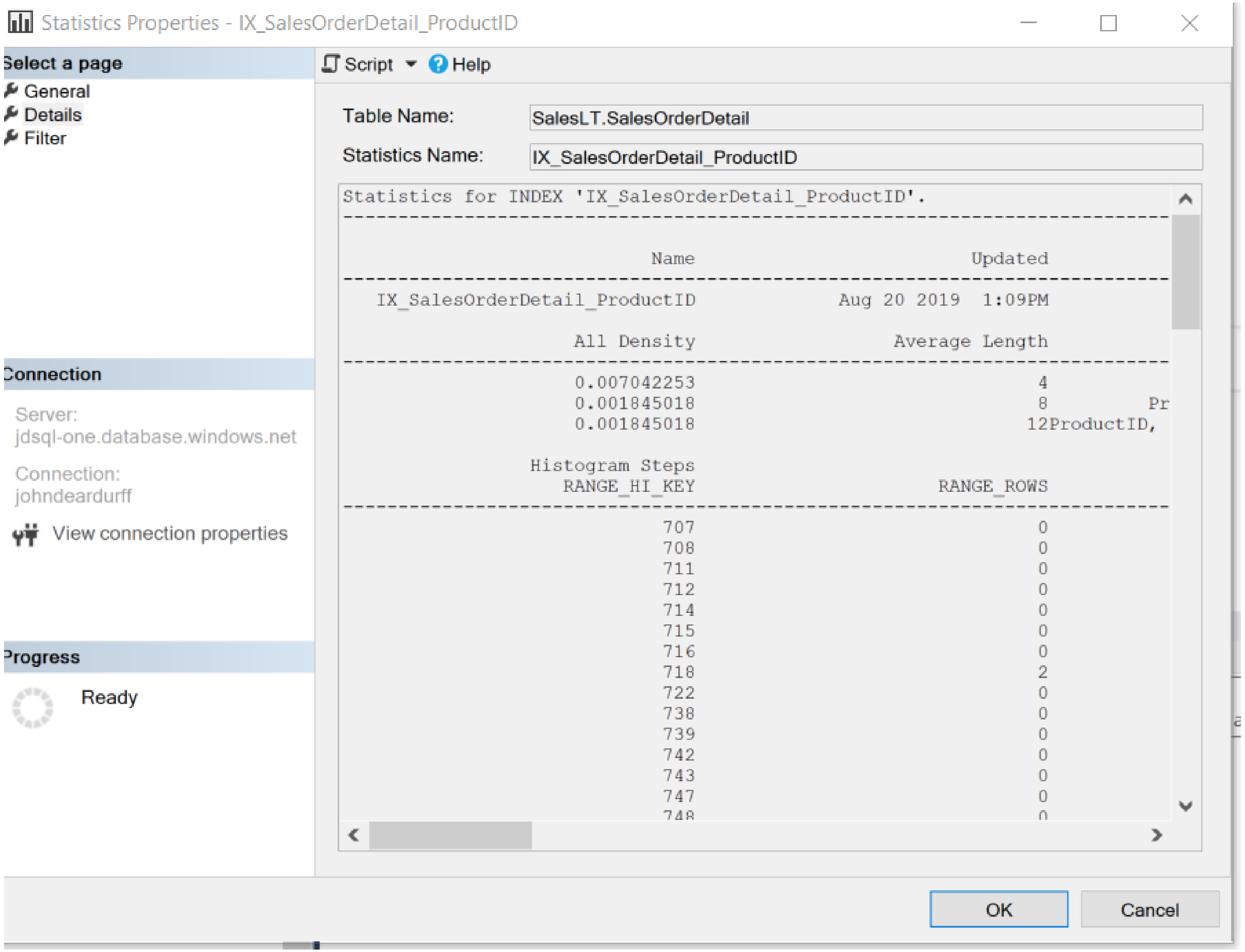
Name	Updated	Rows	Rows Sampled	Steps	Density	Average key length	String Index	Fil
IX_SalesOrderDetail_ProductID	Nov 7 2012 6:44PM	121317	121317	200	0.0078125	12	NO	N

RANGE_HI_KEY	RANGE_ROWS	EQ_ROWS	DISTINCT_RANGE_ROWS	AVG_RANGE_ROWS
730	0	288	0	1
732	0	130	0	1
738	154	600	2	77
741	167	94	1	167
742	0	288	0	1

```sql
SELECT
    ProductID, RecordCount = COUNT(*)
FROM Sales.SalesOrderDetail
WHERE
    ProductID >= 732 AND
    ProductID <= 738
GROUP BY ProductID
```

ProductID	RecordCount
732	130
733	44
736	110
738	600

Cardinality Estimator and Statistics



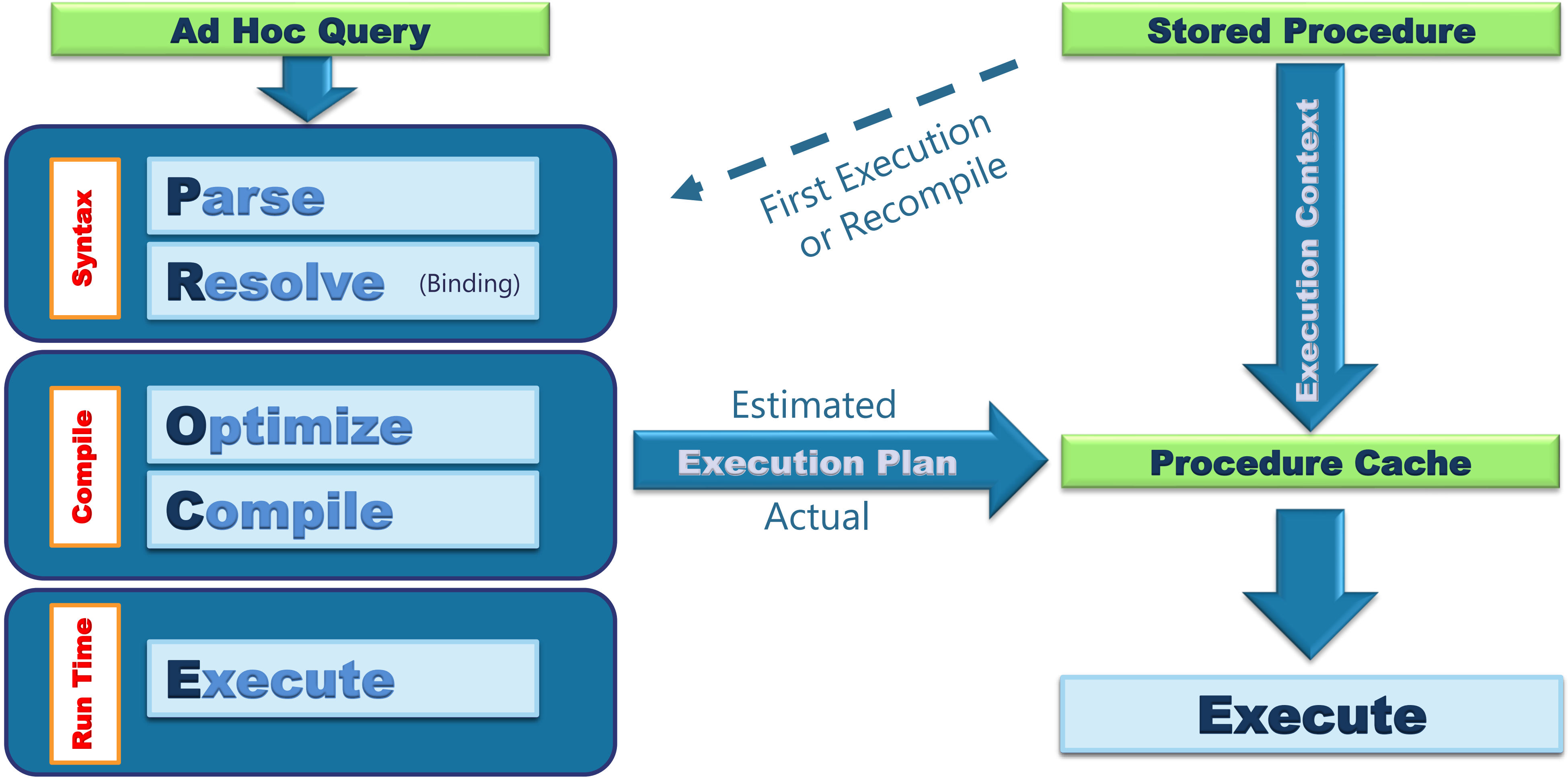
Statistics Properties - IX_SalesOrderDetail_ProductID

Table Name: SalesLT.SalesOrderDetail

Statistics Name: IX_SalesOrderDetail_ProductID

```
Statistics for INDEX 'IX_SalesOrderDetail_ProductID'.
--------------------------------------------------------------------------------

                                      Name                         Updated
--------------------------------------------------------------------------------
    IX_SalesOrderDetail_ProductID              Aug 20 2019   1:09PM

                             All Density                   Average Length
--------------------------------------------------------------------------------
                             0.007042253                                4
                             0.001845018                                8          Pr
                             0.001845018                               12ProductID,

                         Histogram Steps
                            RANGE_HI_KEY                       RANGE_ROWS
--------------------------------------------------------------------------------
                                     707                                0
                                     708                                0
                                     711                                0
                                     712                                0
                                     714                                0
                                     715                                0
                                     716                                0
                                     718                                2
                                     722                                0
                                     738                                0
                                     739                                0
                                     742                                0
                                     743                                0
                                     747                                0
                                     748                                0
```

How Queries are Processed



Ad Hoc Query

Syntax

Parse

Resolve (Binding)

Compile

Optimize

Compile

Run Time

Execute

Stored Procedure

First Execution or Recompile

Execution Context

Estimated

Execution Plan

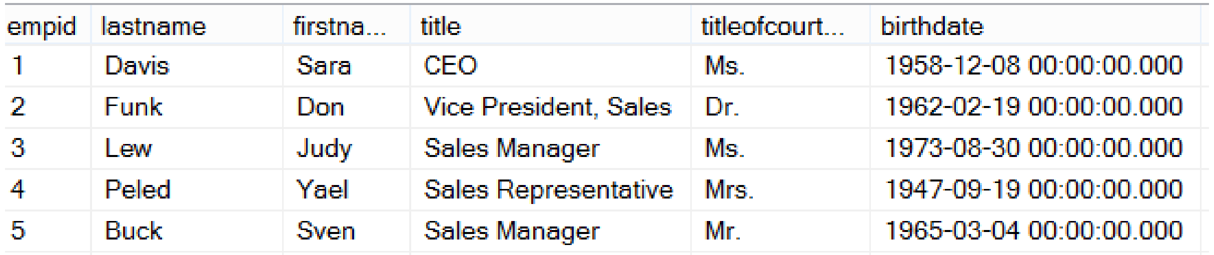
Actual

Procedure Cache

Execute

SQL

Sets



empid	lastname	firstna...	title	titleofcourt...	birthdate
1	Davis	Sara	CEO	Ms.	1958-12-08 00:00:00.000
2	Funk	Don	Vice President, Sales	Dr.	1962-02-19 00:00:00.000
3	Lew	Judy	Sales Manager	Ms.	1973-08-30 00:00:00.000
4	Peled	Yael	Sales Representative	Mrs.	1947-09-19 00:00:00.000
5	Buck	Sven	Sales Manager	Mr.	1965-03-04 00:00:00.000

What does the binding step resolve?

User permissions are checked.

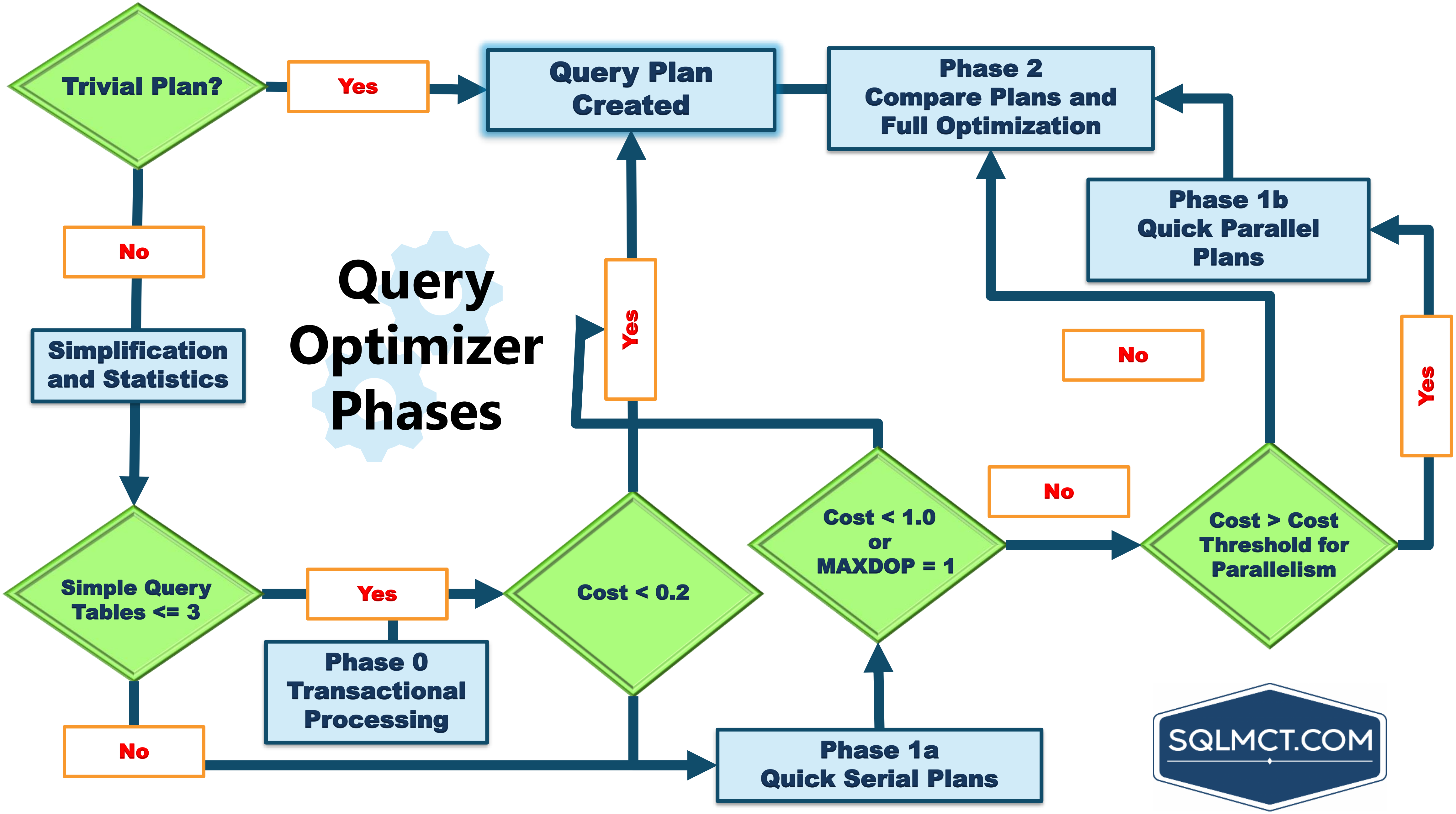
Does a cached plan exist?

Object names (Tables, Views, Columns, etc.) to see if they exist.

Resolve aliases of columns and tables

Data types and if implicit data type conversions are needed.

Query Optimizer Phases



Trivial Plan?

Yes

Query Plan Created

Phase 2
Compare Plans and
Full Optimization

No

Simplification and Statistics

Phase 1b
Quick Parallel
Plans

Yes

No

Yes

Simple Query
Tables <= 3

Yes

Phase 0
Transactional
Processing

Cost < 0.2

Cost < 1.0
or
MAXDOP = 1

No

Cost > Cost
Threshold for
Parallelism

No

Phase 1a
Quick Serial Plans

SQLMCT.COM

Query Simplification phases

Constant Folding: Expressions with constant values are reduced

- **Quantity = 2 + 3** becomes **Quantity = 5**
- **10 < 20** becomes **True**

Contradiction Detection: Removes criteria that doesn’t match table constraints

- **Constraint:** Age > 18
- **Contradiction:** WHERE Age < 18

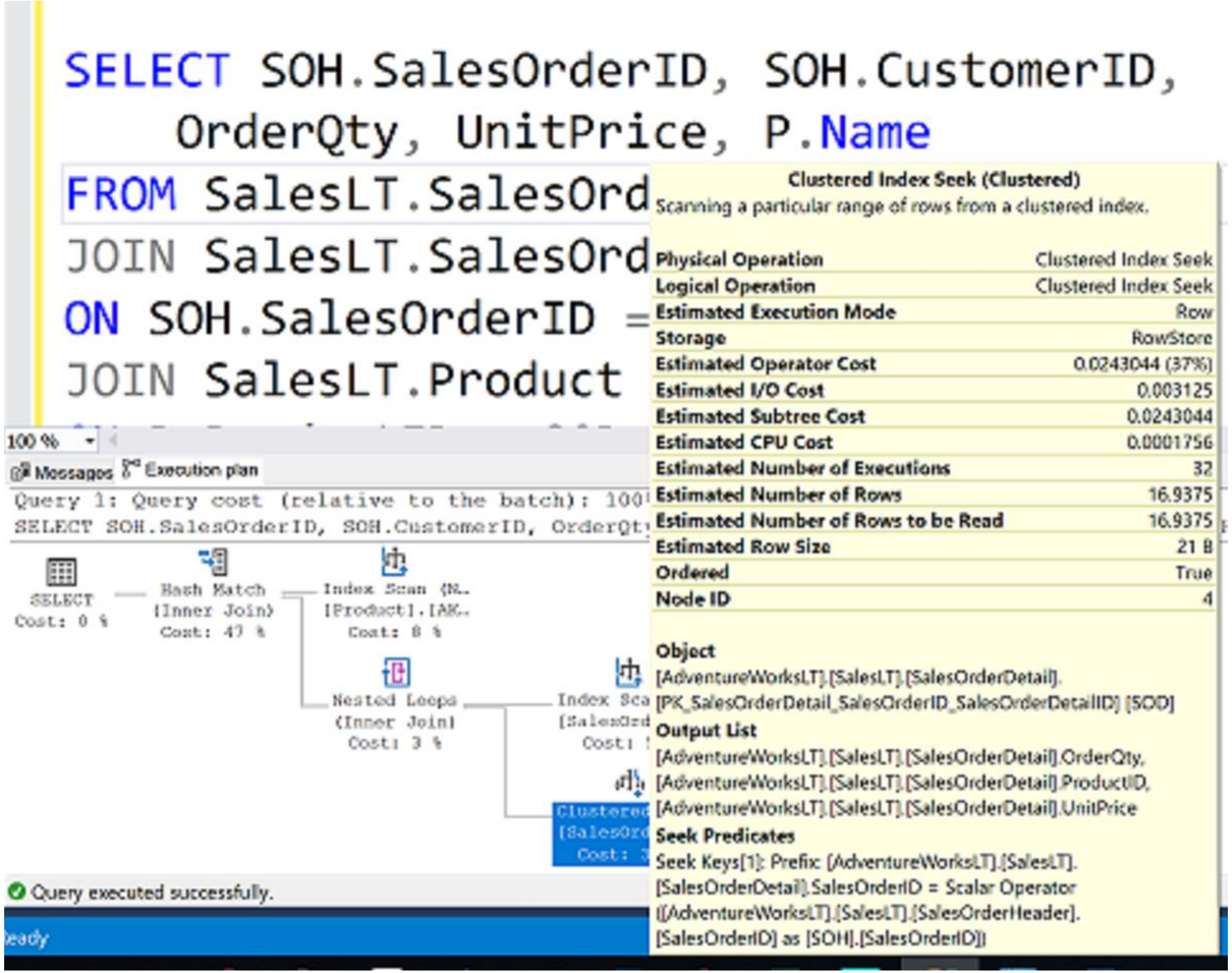
Domain Simplification: Reduces complex ranges to simple ranges

- **Complex range:** ID > 10 and ID < 20 or ID > 30 and < 50
- **Simplified range:** ID > 10 and < 50

Join Simplification: Removes redundant joins that are not necessary

Predicate Pushdown: Perform calculations only on rows returned

What is an Execution Plan?



```
SELECT SOH.SalesOrderID, SOH.CustomerID,
    OrderQty, UnitPrice, P.Name
FROM SalesLT.SalesOrd
JOIN SalesLT.SalesOrd
ON SOH.SalesOrderID =
JOIN SalesLT.Product
```

```
Query 1: Query cost (relative to the batch): 100
SELECT SOH.SalesOrderID, SOH.CustomerID, OrderQt
```

Clustered Index Seek (Clustered)

Scanning a particular range of rows from a clustered index.

Physical Operation	Clustered Index Seek
Logical Operation	Clustered Index Seek
Estimated Execution Mode	Row
Storage	RowStore
Estimated Operator Cost	0.0243044 (37%)
Estimated I/O Cost	0.003125
Estimated Subtree Cost	0.0243044
Estimated CPU Cost	0.0001756
Estimated Number of Executions	32
Estimated Number of Rows	16.9375
Estimated Number of Rows to be Read	16.9375
Estimated Row Size	21 B
Ordered	True
Node ID	4

Object

[AdventureWorksLT].[SalesLT].[SalesOrderDetail].[PK_SalesOrderDetail_SalesOrderID_SalesOrderDetailID] [SOD]

Output List

[AdventureWorksLT].[SalesLT].[SalesOrderDetail].OrderQty,
[AdventureWorksLT].[SalesLT].[SalesOrderDetail].ProductID,
[AdventureWorksLT].[SalesLT].[SalesOrderDetail].UnitPrice

Seek Predicates

Seek Keys[1]: Prefix: [AdventureWorksLT].[SalesLT].[SalesOrderDetail].SalesOrderID = Scalar Operator ([AdventureWorksLT].[SalesLT].[SalesOrderHeader].[SalesOrderID] as [SOH].[SalesOrderID])

Query executed successfully.

How to see the query plan

Text and XML

	Command	Execute query?	Include estimated row counts & stats (Estimated Query Plan)	Include actual row counts & stats (Actual Query Plan)
Text Plan	SET SHOWPLAN_TEXT ON	No	No	No
	SET SHOWPLAN_ALL ON	No	Yes	No
	SET STATISTICS PROFILE ON	Yes	Yes	Yes
XML Plan	SET SHOWPLAN_XML ON	No	Yes	No
	SET STATISTICS PROFILE XML	Yes	Yes	Yes

How to see the query plan

Graphical execution plan

Estimated Execution Plan (Before Execution)

- The compiled plan.

Actual Execution Plan (After Execution)

•The same as the compiled plan plus its execution context.

•This includes runtime information available after the execution completes, such as execution warnings, or in newer versions of the Database Engine, the elapsed and CPU time used during execution.

Live Query Statistics (During Execution)

•The same as the compiled plan plus its execution context.

•This includes runtime information during execution progress and is updated every second. Runtime information includes for example the actual number of rows flowing through the operators.

•Enables rapid identification of potential bottlenecks.

What to look for in a query plan

Warnings	• Information about possible issues with the plan
Top Left Operator	• Overall properties of the plan
Expensive Operators	• Look from most expensive to least expensive
Data Flow Statistics	• Thicker arrows mean more data is being passed
Nested Loop Operator	• Possible to create index that covers query
Scans vs Seeks	• Not necessarily bad, but could indicate I/O issues
Skewed Estimates	• Statistics could be stale or invalid

Execution Plan Table Operators

Data stored in a Heap is not stored in any order and normally does not have a Primary Key.

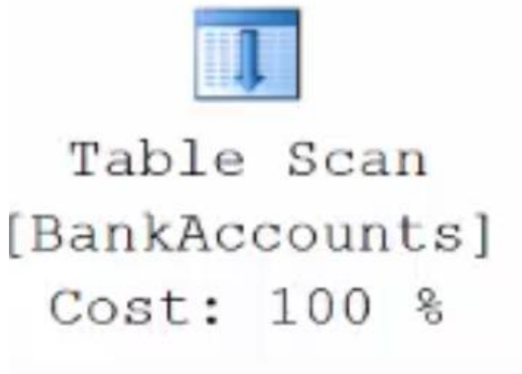
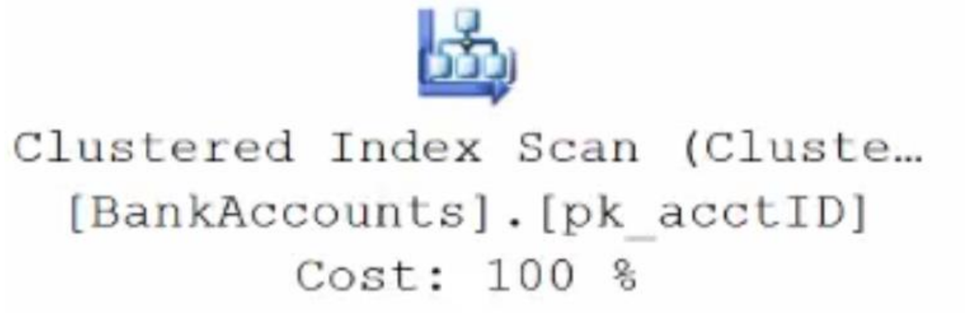


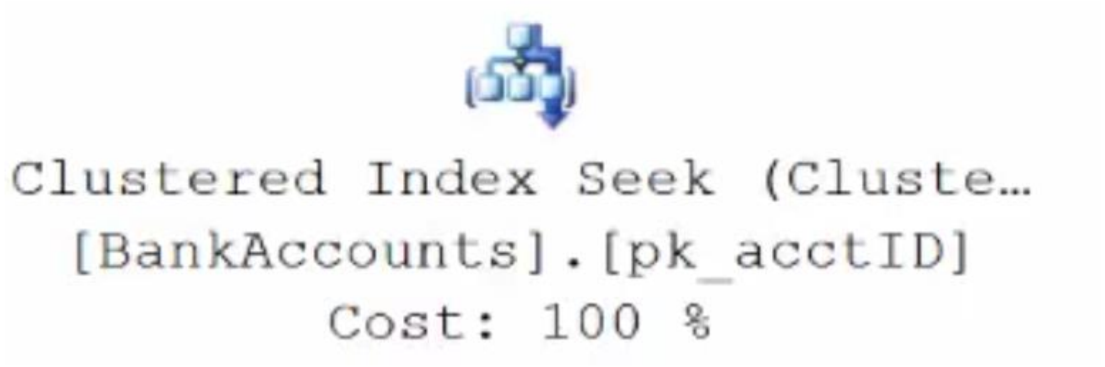
Table Scan
[BankAccounts]
Cost: 100 %

Clustered Index data is stored in sorted order by the Clustering key. In many cases, this is the same value as the Primary Key.



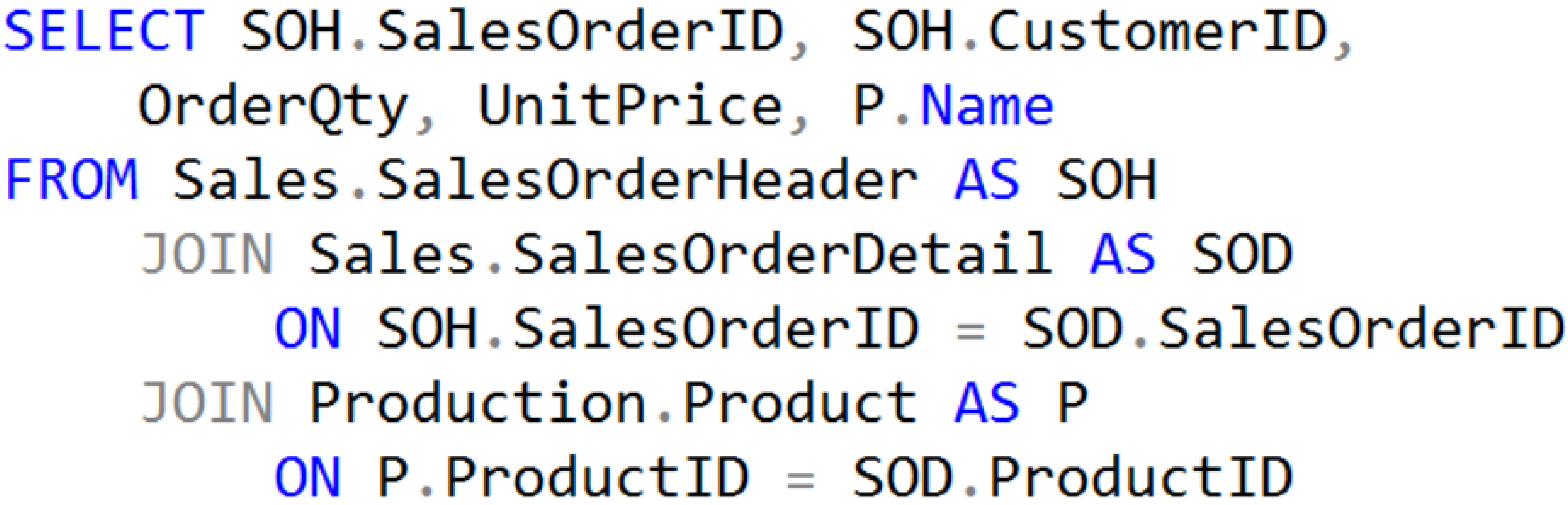
Clustered Index Scan (Cluste…
[BankAccounts].[pk_acctID]
Cost: 100 %

Using a WHERE statement on an Index could possibly have the Execution Plan seek the Index instead of scan.



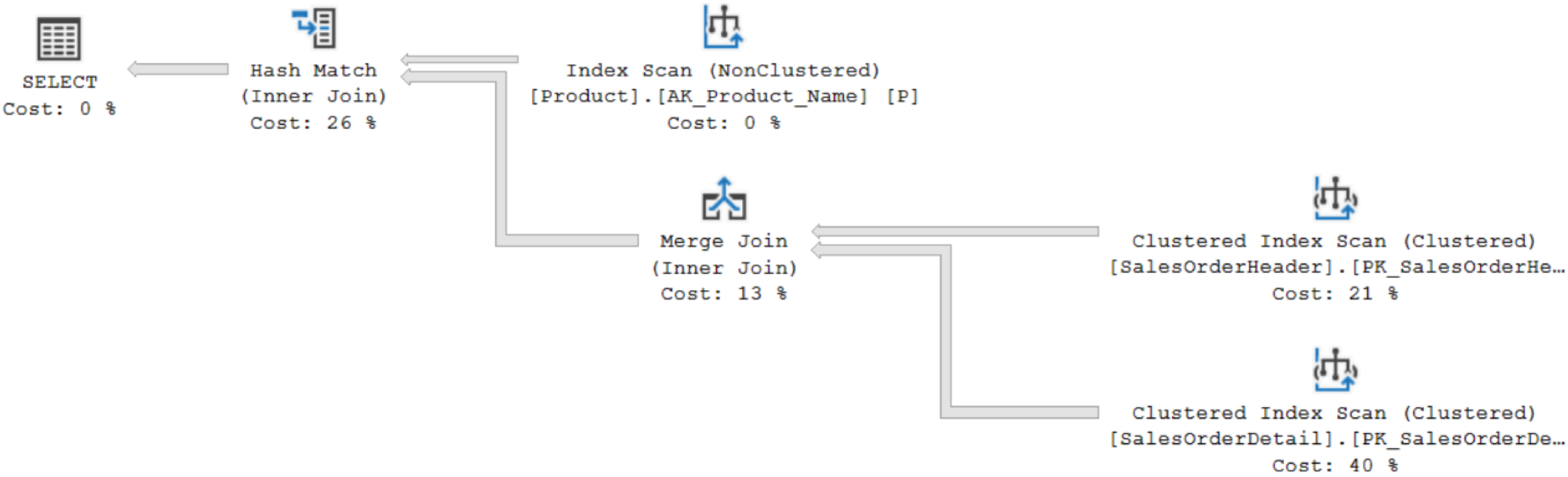
Clustered Index Seek (Cluste…
[BankAccounts].[pk_acctID]
Cost: 100 %

Execution Plan Join Operators (Code)



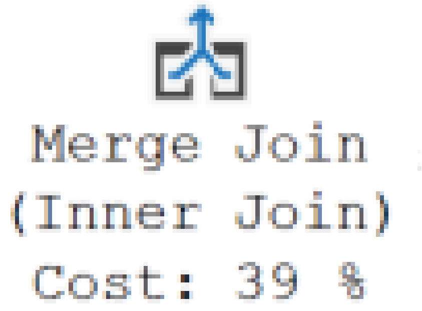
```sql
SELECT SOH.SalesOrderID, SOH.CustomerID,
    OrderQty, UnitPrice, P.Name
FROM Sales.SalesOrderHeader AS SOH
    JOIN Sales.SalesOrderDetail AS SOD
        ON SOH.SalesOrderID = SOD.SalesOrderID
    JOIN Production.Product AS P
        ON P.ProductID = SOD.ProductID
```

Execution Plan Join Operators (Plan)


SELECT
Cost: 0 %
Hash Match
(Inner Join)
Cost: 26 %
Index Scan (NonClustered)
[Product].[AK_Product_Name] [P]
Cost: 0 %
Merge Join
(Inner Join)
Cost: 13 %
Clustered Index Scan (Clustered)
[SalesOrderHeader].[PK_SalesOrderHe…
Cost: 21 %
Clustered Index Scan (Clustered)
[SalesOrderDetail].[PK_SalesOrderDe…
Cost: 40 %

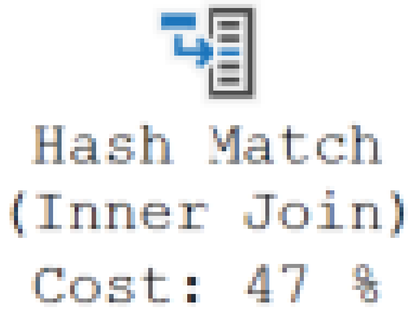
Execution Plan Join Operators

A Merge Join is useful if both table inputs are in the same sorted order on the same value.



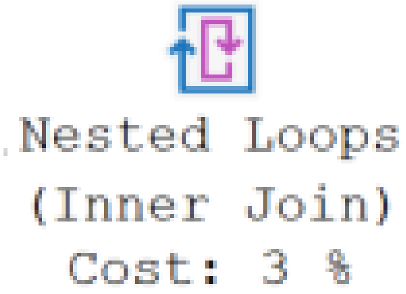
Merge Join
(Inner Join)
Cost: 39 %

A Hash Match is used when the tables being joined are not in the same sorted order.



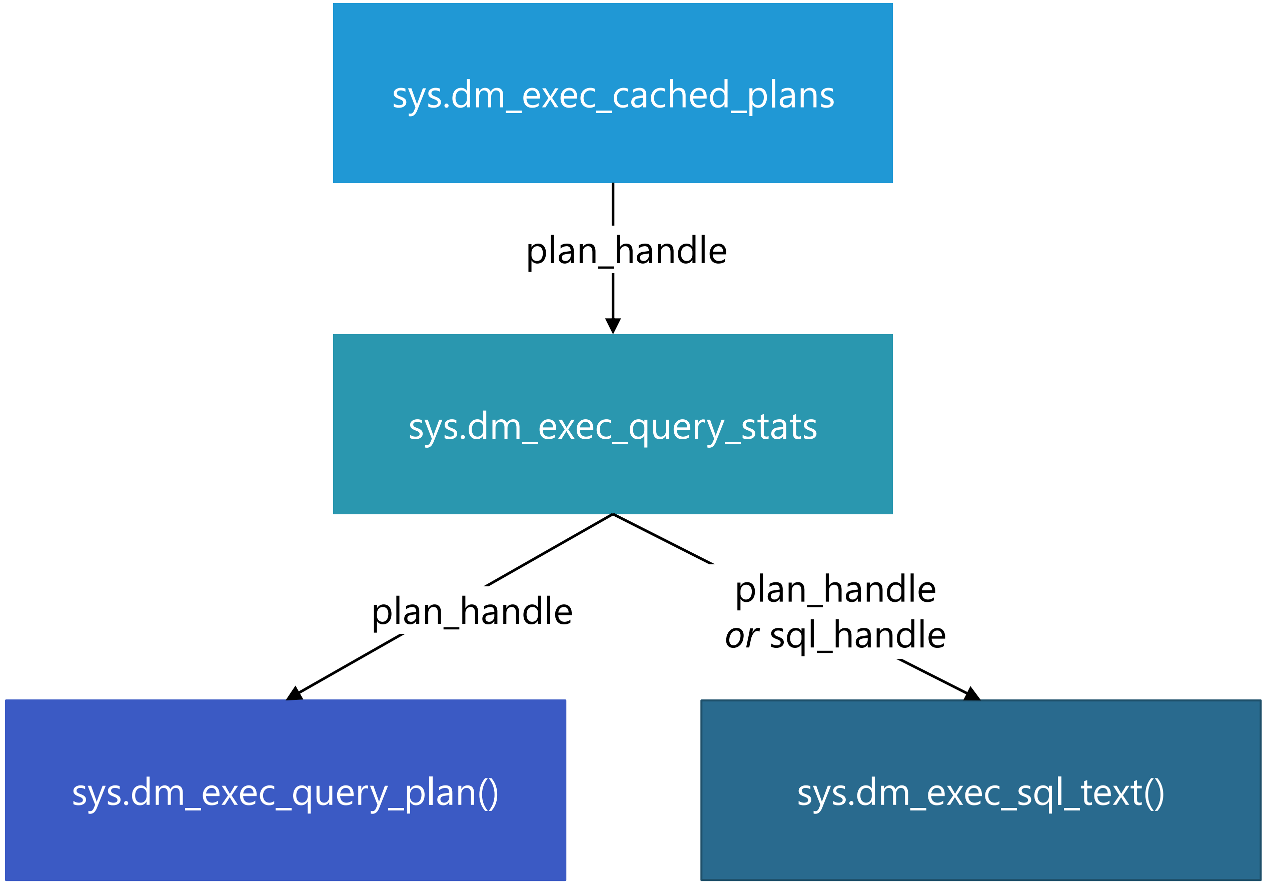
Hash Match
(Inner Join)
Cost: 47 %

A Nested Loop is use when a small (outer) table is used to lookup a value in a larger (inner) table.



Nested Loops
(Inner Join)
Cost: 3 %

Relationships between DMOs



sys.dm_exec_cached_plans

plan_handle

sys.dm_exec_query_stats

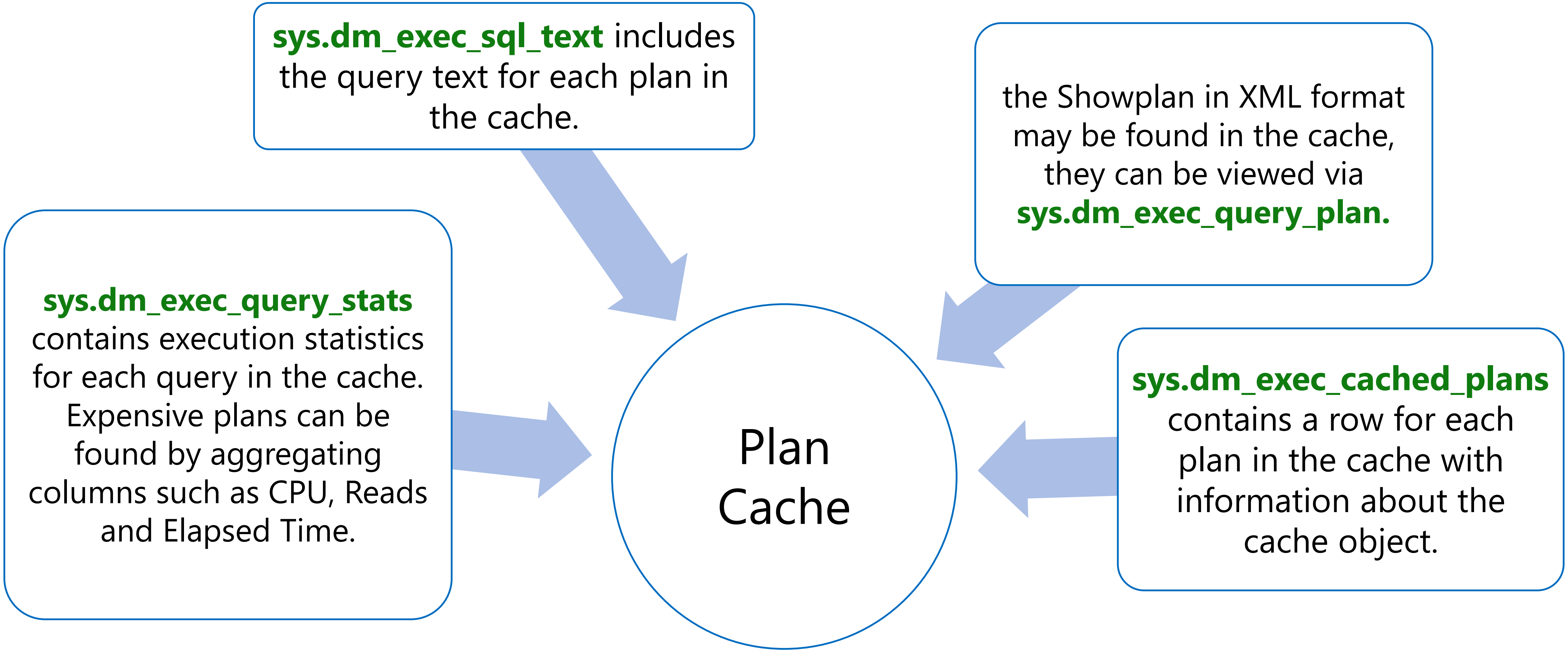
plan_handle

plan_handle
or sql_handle

sys.dm_exec_query_plan()

sys.dm_exec_sql_text()

Queries in the Plan Cache



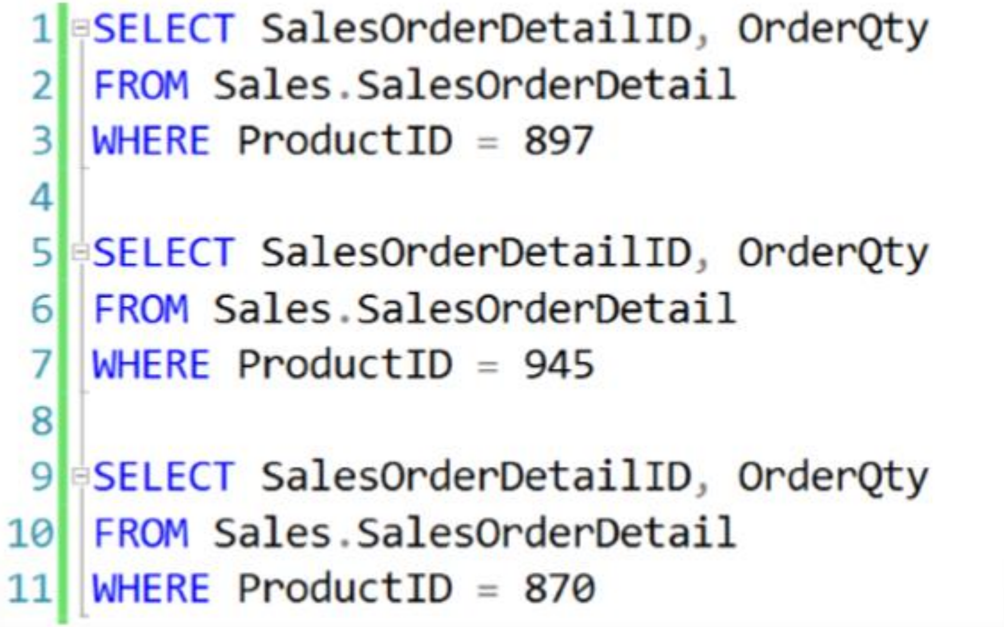
sys.dm_exec_sql_text includes the query text for each plan in the cache.

the Showplan in XML format may be found in the cache, they can be viewed via **sys.dm_exec_query_plan.**

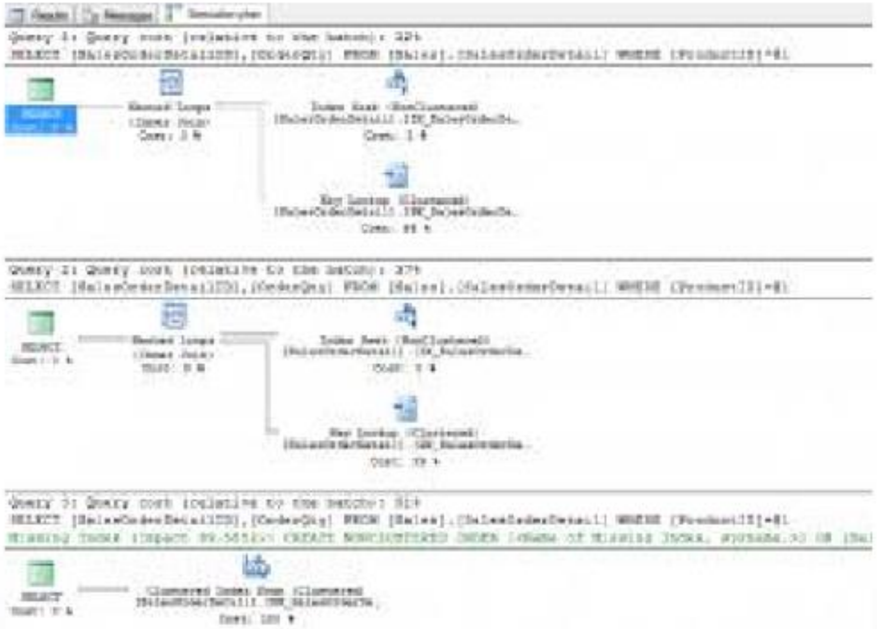
sys.dm_exec_query_stats contains execution statistics for each query in the cache. Expensive plans can be found by aggregating columns such as CPU, Reads and Elapsed Time.

sys.dm_exec_cached_plans contains a row for each plan in the cache with information about the cache object.

Parameter Sniffing



```sql
SELECT SalesOrderDetailID, OrderQty
FROM Sales.SalesOrderDetail
WHERE ProductID = 897

SELECT SalesOrderDetailID, OrderQty
FROM Sales.SalesOrderDetail
WHERE ProductID = 945

SELECT SalesOrderDetailID, OrderQty
FROM Sales.SalesOrderDetail
WHERE ProductID = 870
```



Results
Messages
Execution plan

```
Query 1: Query cost (relative to the batch): 22%
SELECT [SalesOrderDetailID],[OrderQty] FROM [Sales].[SalesOrderDetail] WHERE [ProductID]=@1
```

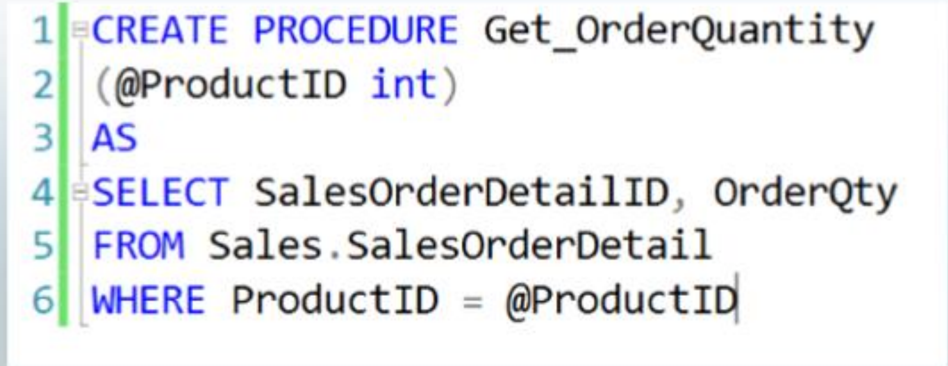
SELECT
Nested Loops
(Inner Join)
Index Seek (NonClustered)
[SalesOrderDetail].[IX_SalesOrderDe...
Key Lookup (Clustered)
[SalesOrderDetail].[PK_SalesOrderDe...

```
Query 2: Query cost (relative to the batch): 27%
SELECT [SalesOrderDetailID],[OrderQty] FROM [Sales].[SalesOrderDetail] WHERE [ProductID]=@1
```

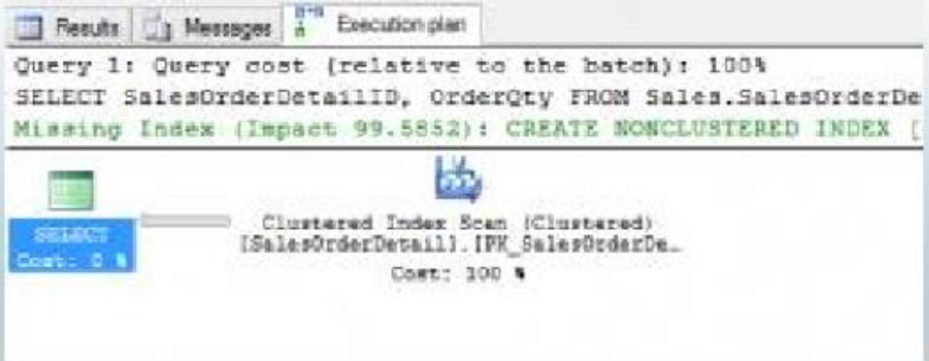
SELECT
Nested Loops
(Inner Join)
Index Seek (NonClustered)
[SalesOrderDetail].[IX_SalesOrderDe...
Key Lookup (Clustered)
[SalesOrderDetail].[PK_SalesOrderDe...

```
Query 3: Query cost (relative to the batch): 51%
SELECT [SalesOrderDetailID],[OrderQty] FROM [Sales].[SalesOrderDetail] WHERE [ProductID]=@1
Missing Index (Impact 99.5852): CREATE NONCLUSTERED INDEX [<Name of Missing Index, sysname,>] ON [Sal
```

SELECT
Cost: 0 %
Clustered Index Scan (Clustered)
[SalesOrderDetail].[PK_SalesOrderDe...
Cost: 100 %



```sql
CREATE PROCEDURE Get_OrderQuantity
(@ProductID int)
AS
SELECT SalesOrderDetailID, OrderQty
FROM Sales.SalesOrderDetail
WHERE ProductID = @ProductID
```



Results
Messages
Execution plan

```
Query 1: Query cost (relative to the batch): 100%
SELECT SalesOrderDetailID, OrderQty FROM Sales.SalesOrderDe
Missing Index (Impact 99.5852): CREATE NONCLUSTERED INDEX [
```

SELECT
Cost: 0 %
Clustered Index Scan (Clustered)
[SalesOrderDetail].[PK_SalesOrderDe...
Cost: 100 %

Microsoft