Microsoft

SQL Server Architecture, Scheduling, and Waits

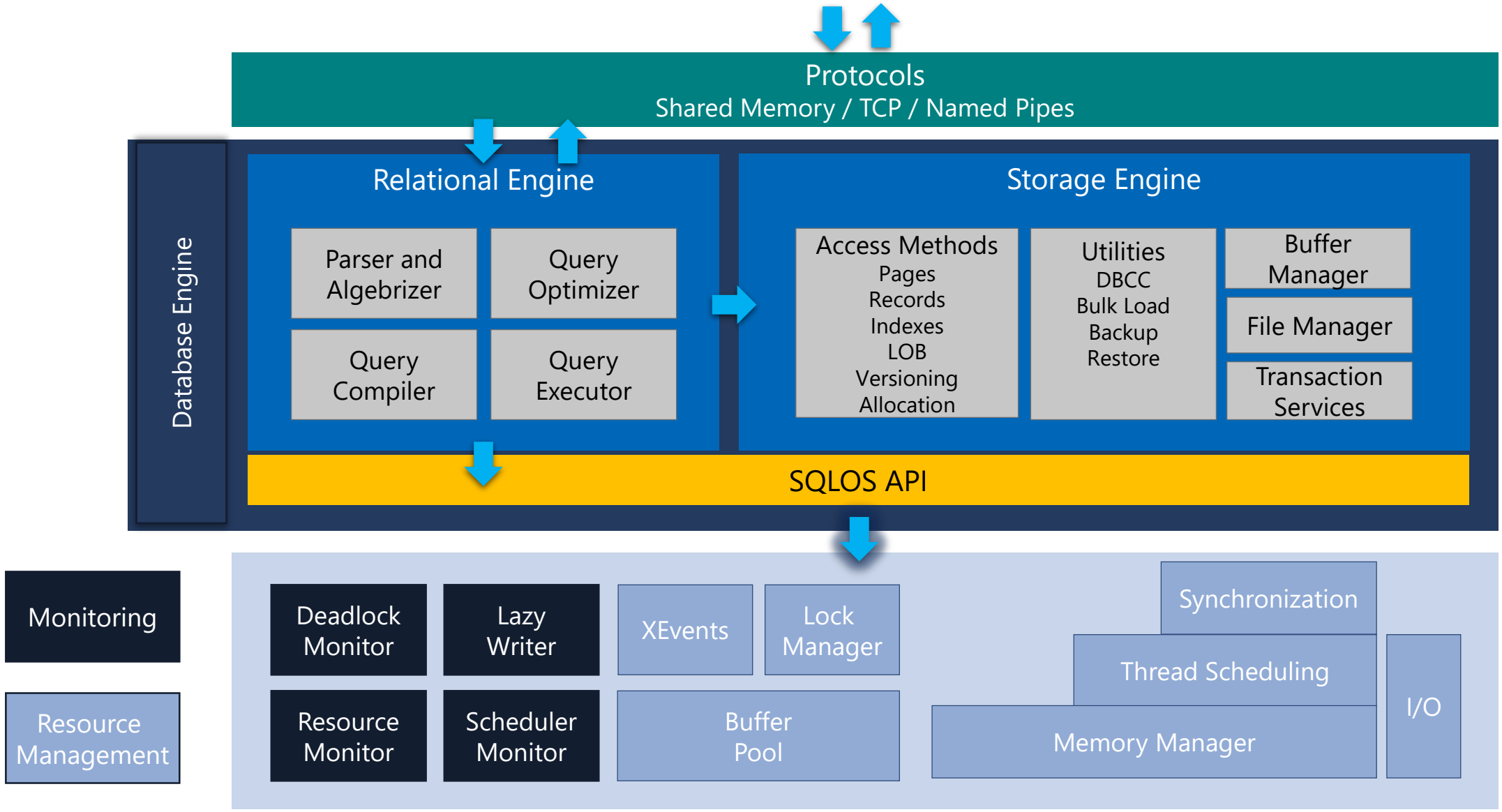
Module 1

Learning Units covered in this Module

- Lesson 1: Introduction to SQL Operating System
- Lesson 2: SQL Server Task Scheduling
- Lesson 3: SQL Server Waits and Queues

Lesson 1: Introduction to SQL Operating System

Inside the Database Engine



SQL Server Operating System (SQLOS)

Application layer between Microsoft SQL Server components and the Windows Operating System.

Centralizes resource allocation to provide more efficient management and accounting.

The SQLOS is used by the SQL Server relational database engine for system-level services.

Abstracts the concepts of resource management from components, providing:

- **Scheduling and synchronization support**
- **Memory management and caching**
- **Resource governance**
- **Diagnostics and debug infrastructure**
- **Scalability and performance optimization**

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

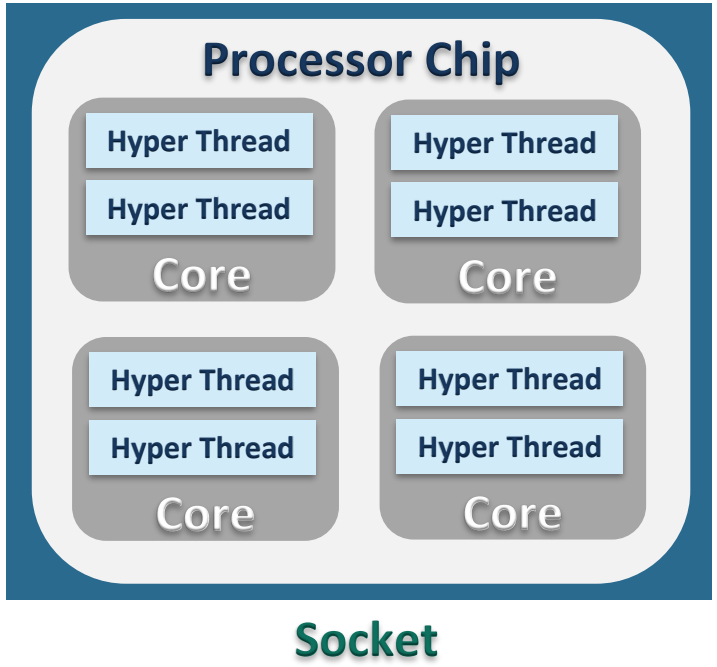
Using Dynamic Management Objects (DMOs)

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

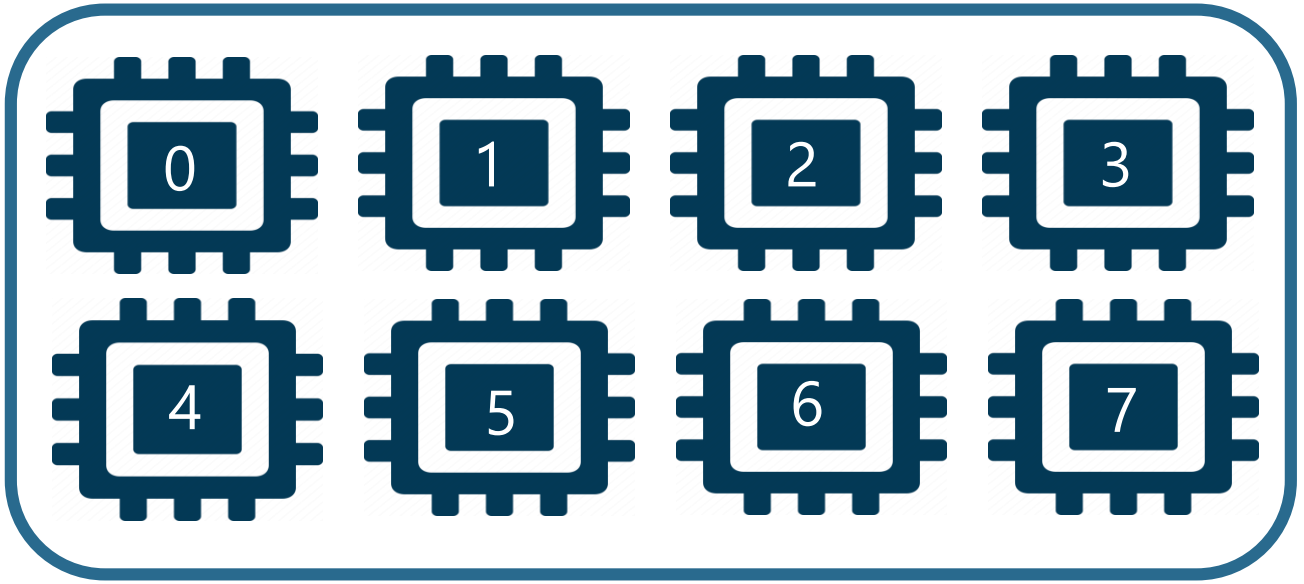
```
SELECT cpu_count, hyperthread_ratio,
    scheduler_count, scheduler_total_count,
    affinity_type, affinity_type_desc,
    softnuma_configuration, softnuma_configuration_desc,
    socket_count, cores_per_socket, numa_node_count,
    sql_memory_model, sql_memory_model_desc
FROM sys.dm_os_sys_info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

CPU Architecture

Physical Hardware



Logical Processors as seen by the OS



SQL Server Configuration

Processor Configuration Settings

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

Demonstration

Dynamic Management Views

Questions?

Lesson 2: SQL Server Task Scheduling

Microsoft SQL Server Scheduling Terminology

Batch

- A statement or set of statements submitted to SQL Server by the user (a query), also referred to as a request
- Monitor with sys.dm_exec_requests

Task

- A batch will have one or more tasks (aligns with statements)
- Monitor with sys.dm_os_tasks

Worker Thread

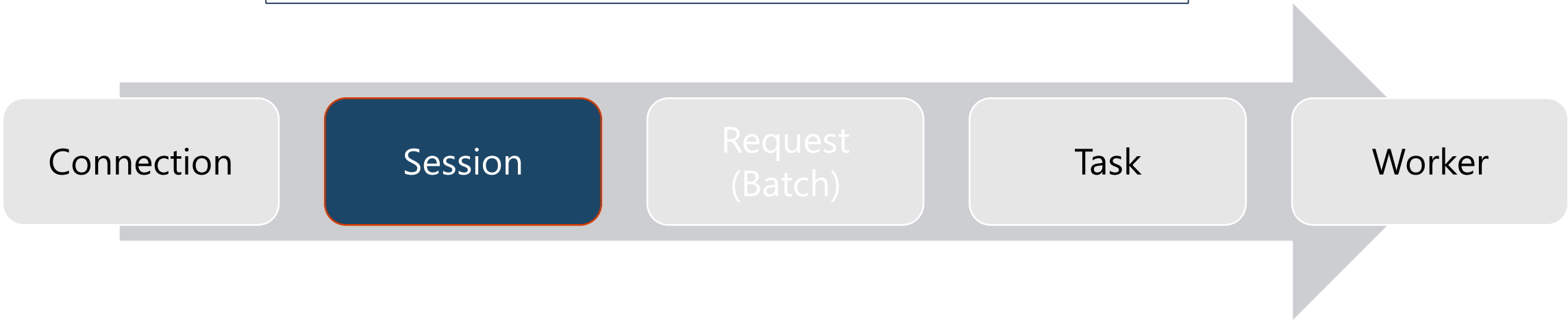
- Each task will be assigned to a single worker thread for the life of the task
- Monitor with sys.dm_os_workers

Hierarchy of Common Terms

```
SELECT *
FROM sys.dm_exec_connections;
-- relevant data:
-- session_id --> spid
-- most_recent_sql_handle --> last query
-- net_transport, protocol_type --> connectivity
```

Hierarchy of Common Terms

```
SELECT *
FROM sys.dm_exec_sessions;
-- relevant data:
-- session_id --> spid
-- host_name, program_name --> client identity
-- login_name, nt_user_name --> login identity
-- status --> activity
-- database_id --> database being accessed
-- open_transaction_count --> blocking identification
```



Hierarchy of Common Terms

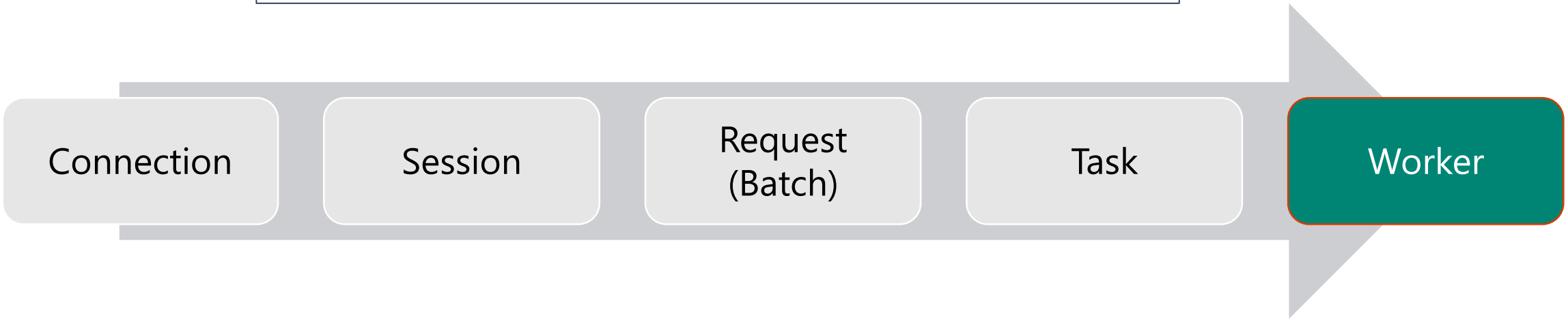
```
SELECT *
FROM sys.dm_exec_requests;
-- relevant data:
-- session_id --> spid
-- status --> background, running, runnable, suspended
-- sql_handle, offset --> query text
-- database_id --> database being accessed
-- wait_type, wait_time --> blocking information
-- open_transaction_count --> blocking others
-- cpu_time, total_elapsed_time, reads, writes --> telemetry
```

Hierarchy of Common Terms

```
SELECT *
FROM sys.dm_os_tasks;
-- relevant data:
-- task_state --> running, suspended
-- pending_io_* --> I/O activity
-- scheduler_id -->processor info
-- session_id --> spid
```

Hierarchy of Common Terms

```
SELECT *
FROM sys.dm_os_workers;
-- relevant data:
-- worker_address --> memory address of the worker
-- wait_start_ms_ticks --> Point in time worker Suspended.
-- wait_resumed_ms_ticks --> Worker in Runnable state.
-- state -- > Running, Runnable, Suspended
```



Scheduling Types

Non-Preemptive (Cooperative)

- SQL Server manages CPU scheduling for most activity (instead of the operating system).
- SQL Server decides when a thread should wait or get switched out (known as yielding).
- SQL Server developers also programmed some predetermined voluntary yields to avoid starvation of other threads

Preemptive

- Preemption is the act of an operating system temporarily interrupting an executing task.
- Higher priority tasks can preempt lower priority tasks.
- Preemptive mode used in SQL Server for external code calls, CLR with an UNSAFE assemblies, extended stored procedures

SQL Server Task Scheduling

One SQLOS Scheduler per core/logical processor

Handles scheduling tasks, I/O, and synchronization of resources

Work requests are balanced across schedulers based on the number of active tasks

Monitor using sys.dm_os_schedulers

Worker Migration – better use of schedulers in SQL Server 2019

Yielding

In SQL Server, each thread is assigned a quantum (duration 4ms), with SQL Server using a cooperative model to ensure its CPU resources are shared amongst all the threads that are in a runnable state, preventing the ‘starving’ condition of any individual thread.

By design, a worker owns the scheduler until it yields to another worker on the same scheduler.

When no worker is currently on the Runnable list, the **yielding worker is allowed another quantum** or performs the necessary idle scheduler maintenance.

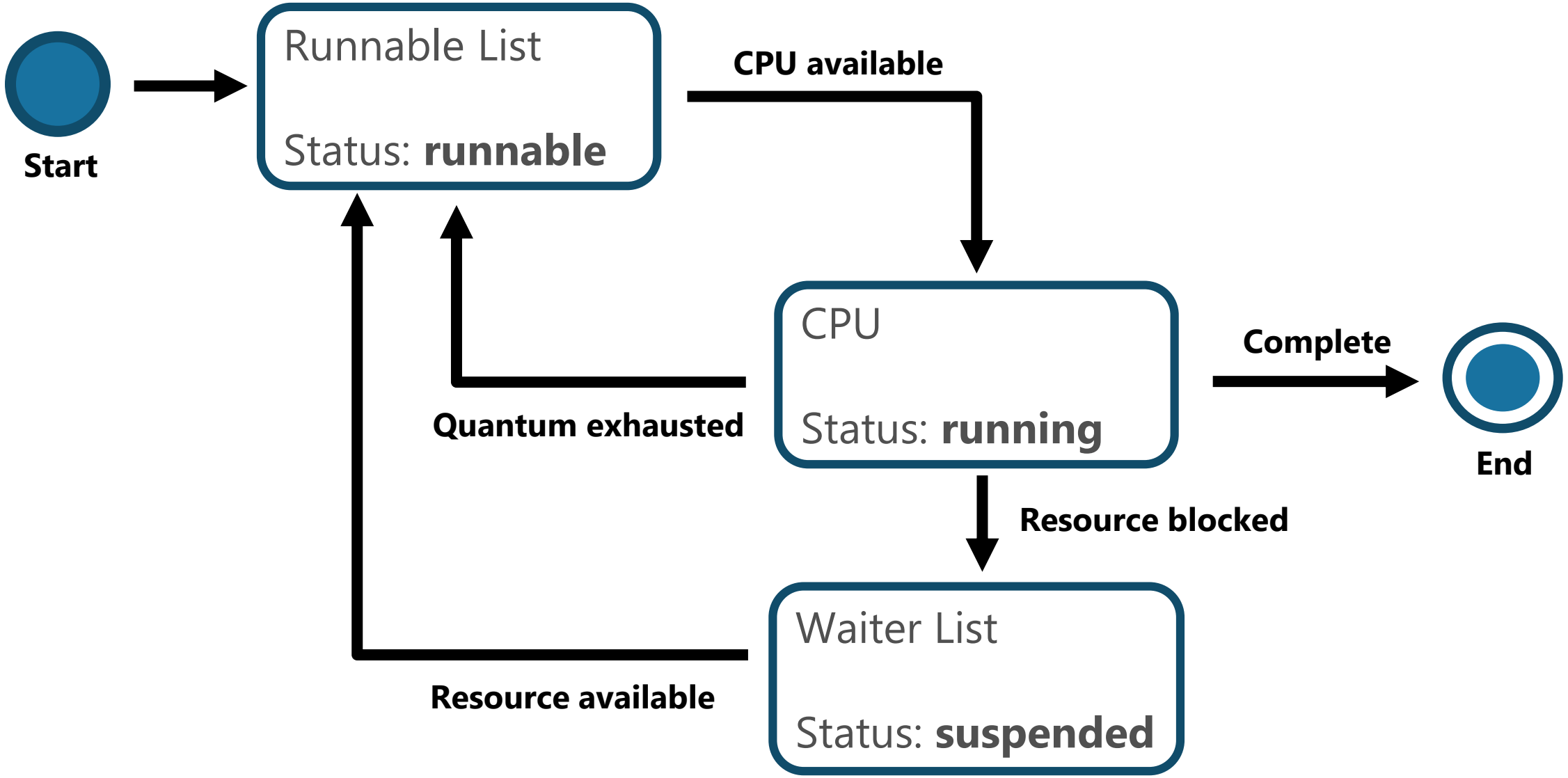
Thread States and Queues

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).

Yielding


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

Demonstration

Runnable Tasks

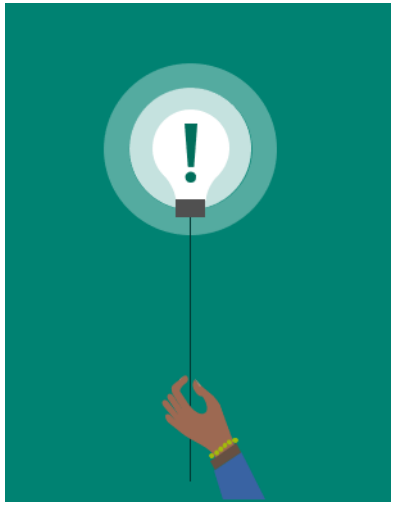
Questions?

Lesson 3: SQL Server Waits and Queues

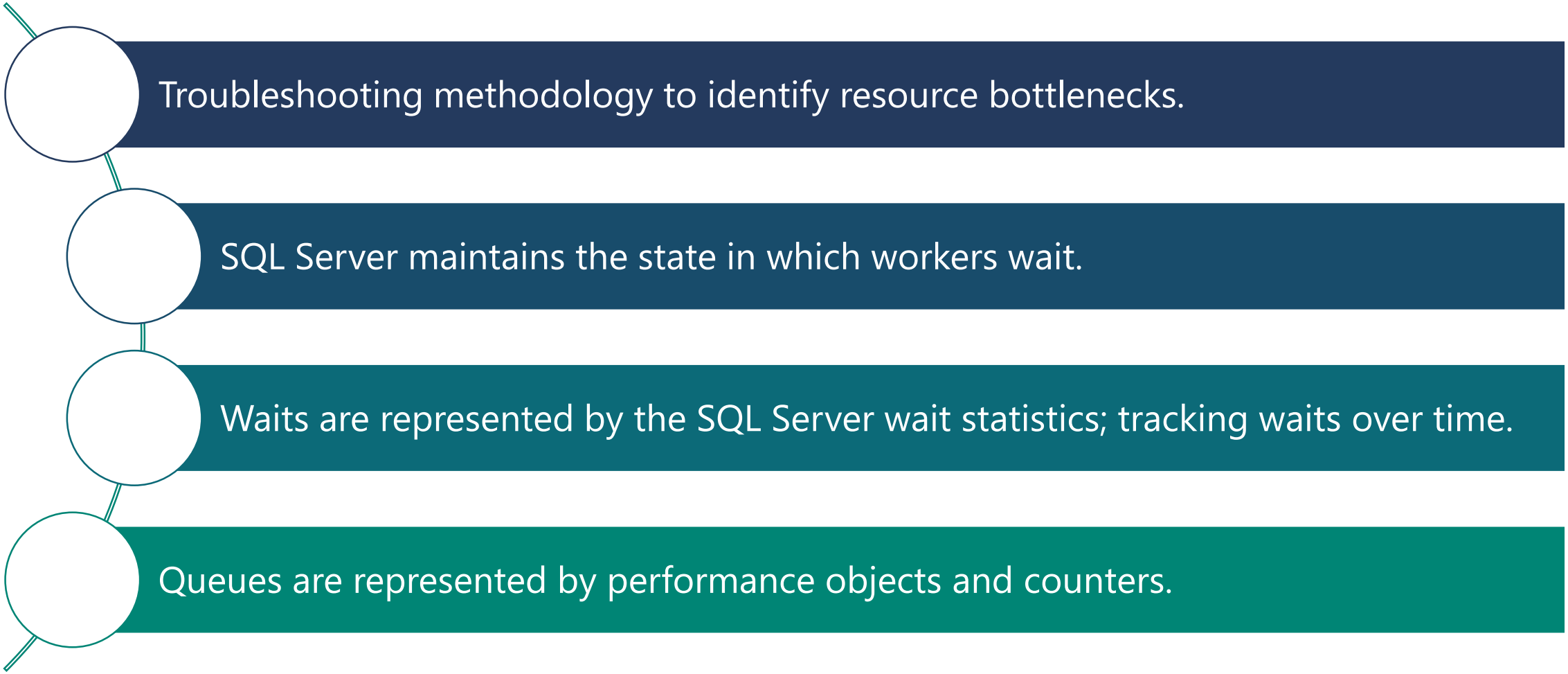
Objectives

After completing this learning, you will be able to:

- Understand common wait types
- Troubleshoot the resource bottleneck



Waits and Queues



Using Waits and Queues

Useful to assist in troubleshooting an active performance issue

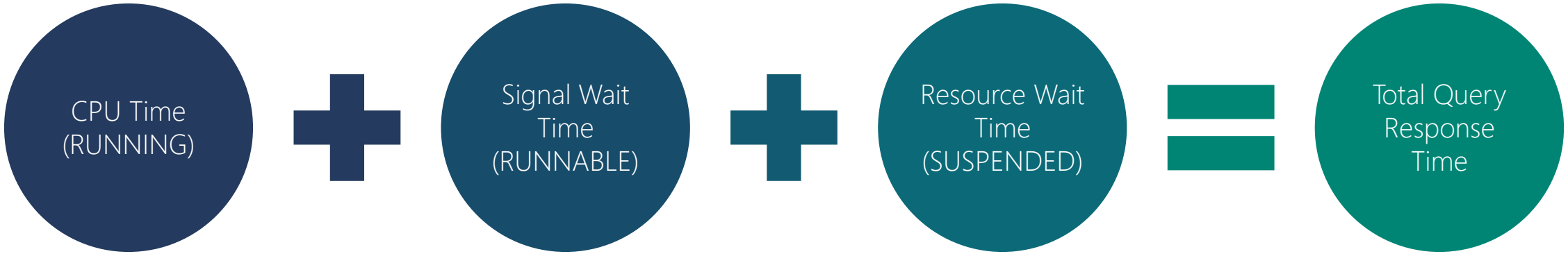
Valuable to track the resources SQL Server is regularly waiting on

Useful for workload measurements and benchmarking

Valuable for identifying performance trends

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.



Task Execution Model

Status: Running

session_id 51	Running

Runnable Queue (Signal Waits)
Status: Runnable

session_id 51	Runnable
session_id 64	Runnable
session_id 87	Runnable
session_id 52	Runnable
session_id 56	Runnable

SPID56 moved to the bottom of the Runnable queue.

Wait Queue (Resource Waits)
Status: Suspended

session_id 73	LCK_M_S
session_id 59	NETWORKIO
~~session_id 56~~	~~Runnable~~
session_id 55	RESOURCE_SEMAPHORE
session_id 60	IO_Completion

Relevant Dynamic Management Views (DMVs)

sys.dm_os_wait_stats

- Returns information about all the waits encountered by threads that ran.
- Includes wait type, number of tasks that waited in the specific wait type, total and max wait times, and the amount of signal waits.

sys.dm_os_waiting_tasks

- Returns information about the wait queue of tasks actively waiting on some resource.

sys.dm_exec_requests

- Returns information about each request that is in-flight.
- Includes session owning the request and status of the request, which will reflect the status of one or more tasks assigned to the request.

Waiting Tasks DMV

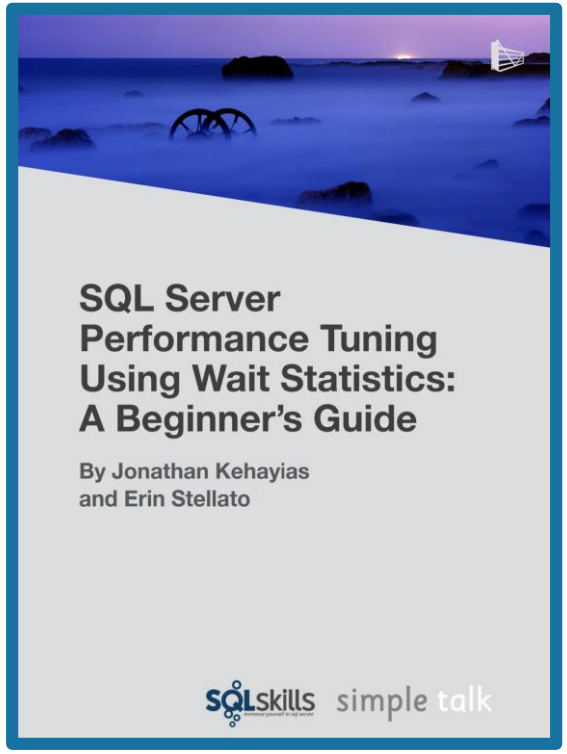
```
SELECT w.session_id, w.wait_duration_ms, w.wait_type,
       w.blocking_session_id, w.resource_description,
       s.program_name, t.text, t.dbid, s.cpu_time, s.memory_usage
 FROM sys.dm_os_waiting_tasks as w
      INNER JOIN sys.dm_exec_sessions as s
         ON w.session_id = s.session_id
      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...

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/



Notable Waits

CPU related waits

SOS_SCHEDULER_YIELD

- Normally means a thread has yielded after exhausting the 4ms quantum.
- Might indicate CPU pressure if very high overall percentage of Processor Time. Example: Large amount of Signal Waits (Runnable Queue)

CXPACKET

- If it's an OLTP system, check for parallelism issues if above 20%
- If combined with a high number of PAGEIOLATCH_xx waits, it could be due to large parallel table scans going on because of incorrect non-clustered indexes, or out-of-date statistics causing a bad query plan

Notable Waits

PAGE access related waits

PAGELATCH_xx

- Indicates contention for access to buffers (in-memory copies of pages).
- If PFS, SGAM, and GAM then it is allocation contention (updating allocation metadata), namely in TempDB.

PAGEIOLATCH_xx

- Indicates I/O problems in data pages.
- Validate disk and memory perfmon counters and the SQL Errorlogs (for error 833 “I/O taking longer than 15 seconds”).
- Examine the virtual file stats DMV.

Notable Waits

I/O related waits

IO_COMPLETION

- If on TempDB, usually means spilling or high static cursor rate

ASYNC_IO_COMPLETION

- Usually when not using Instant File Initialization, or waiting on backups

WRITELOG

- Waiting for a log flush to disk
- Examine the I/O latency for the log file
- Can show up with PREEMPTIVE_OS_WRITEFILEGATHERER in aggressive autogrow scenarios

Notable Waits

Memory related

CMEMTHREAD

- Contention in the insertion of entries into the plan cache

RESOURCE_SEMAPHORE

- Indicates queries are waiting for execution memory (memory grants).
- Look for plans with excessive hashing or large sorts.
- Confirm with the Memory Grants Pending and Memory Grants Outstanding perfmon counters.

Notable Waits

Other common waits

THREADPOOL

- Look for high blocking or contention problems with workers.
- This will not show up in sys.dm_exec_requests.

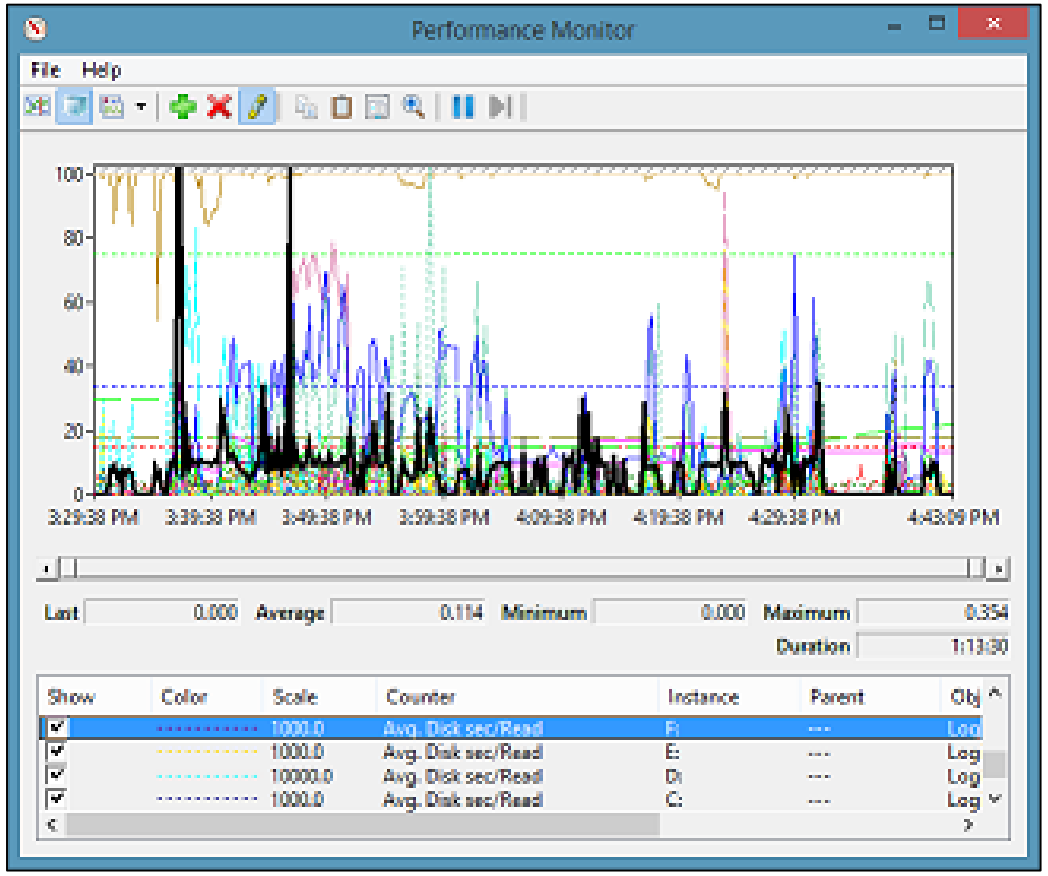
LCK_xx

- Indicates contention for access to locked resources such as index keys or pages.
- Examine the transactions Isolation Level, maybe using a less concurrent such as SERIALIZABLE.
- Look for queries that do large serialized UPSERTs.

Performance Monitor Counters

Important Operating System Counters

- % Processor Time
  - Less than 80% is preferred



Performance Monitor Counters

Execution Statistics

SQL Errors\Errors/sec

- Error types must be investigated and possibly resolved.

SQL Statistics\Batch Requests/sec

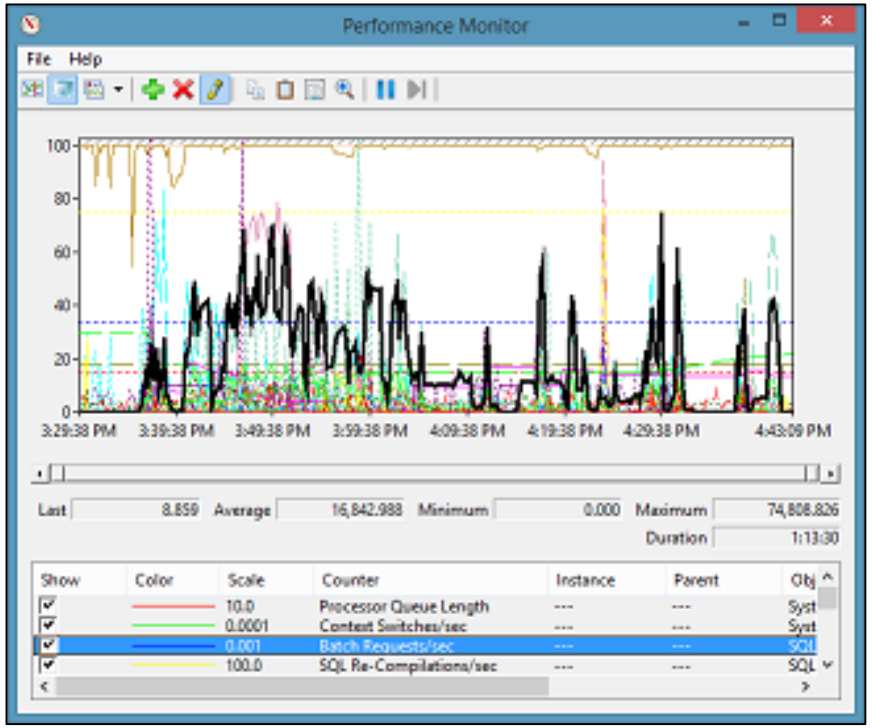
- Batch Requests > 1000 indicates busy server.

SQL Statistics\SQL Compilations/sec

- A high number can be an indicator of ad hoc queries, this must be cross referenced with ad hoc plans in the plan cache.

SQL Statistics\SQL Recompilations/sec

- If high determine recompilation reason with Xevent session. Usually stale statistics, Temp table usage and option WITH Recompile.



Demonstration

Examining SQL Server Scheduling

Waits and queues

- Using waits and queues troubleshooting methodology

Questions?

Knowledge Check

While troubleshooting a resource bottleneck what two objects should you examine?

What are the three components that make up query execution time?

What is the difference between a PAGELATCH wait and a PAGEIOLATCH wait?

Which DMV should you examine to view historical wait information?

Which DMV should you examine to view current wait information?