

Thread and Task Architecture Guide

Operating system task scheduling

Threads are the smallest units of processing that can be executed by an operating system, and allow the application logic to be separated into several concurrent execution paths. Threads are useful when complex applications have many tasks that can be performed at the same time.

When an operating system executes an instance of an application, it creates a unit called a process to manage the instance. The process has a thread of execution. This is the series of programming instructions performed by the application code. For example, if a simple application has a single set of instructions that can be performed serially, that set of instructions is handled as a single **task**, and there is just one execution path (or **thread**) through the application. More complex applications may have several **tasks** that can be performed concurrently instead of serially. An application can do this by starting separate processes for each task, which is a resource-intensive operation, or start separate threads, which are relatively less resource-intensive. Additionally, each thread can be scheduled for execution independently from the other threads associated with a process.

Threads allow complex applications to make more effective use of a processor (CPU), even on computers that have a single CPU. With one CPU, only one thread can execute at a time. If one thread executes a long-running operation that does not use the CPU, such as a disk read or write, another one of the threads can execute until the first operation is completed. By being able to execute threads while other threads are waiting for an operation to be completed, an application can maximize its use of the CPU. This is especially true for multi-user, disk I/O intensive applications such as a database server. Computers that have multiple CPUs can execute one thread per CPU at the same time. For example, if a computer has eight CPUs, it can execute eight threads at the same time.

SQL Server task scheduling

In the scope of SQL Server, a **request** is the logical representation of a query or batch. A request also represents operations required by system threads, such as checkpoint or log writer. Requests exist in various states throughout their lifetime and can accumulate waits when resources required to execute the request are not available, such as locks or latches. For more information about request states, see `sys.dm_exec_requests`.

A **task** represents the unit of work that needs to be completed to fulfill the request. One or more tasks can be assigned to a single request.

- Parallel requests will have several active tasks that are executed concurrently instead of serially, with one **parent task** (or coordinating task) and multiple **child tasks**. An execution plan for a parallel request may have serial

branches - areas of the plan with operators that don't execute in parallel. The parent task is also responsible for executing those serial operators.

- Serial requests will only have one active task at any given point in time during execution. Tasks exist in various states throughout their lifetime. For more information about task states, see `sys.dm_os_tasks`. Tasks in `SUSPENDED` state are waiting on resources required to execute the task to become available. For more information about waiting tasks, see `sys.dm_os_waiting_tasks`.

A SQL Server **worker thread**, also known as worker or thread, is a logical representation of an operating system thread. When executing **serial requests**, the SQL Server Database Engine will spawn a worker to execute the active task (1:1). When executing **parallel requests** in row mode, the SQL Server Database Engine assigns a worker to coordinate the child workers responsible for completing tasks assigned to them (also 1:1), called the **parent thread** (or coordinating thread). The parent thread has a parent task associated with it. The parent thread is the point of entry of the request and exists even before engine parses a query. The main responsibilities of the parent thread are:

- Coordinate a parallel scan.
- Start child parallel workers.
- Collect rows from parallel threads and send to the client.
- Perform local and global aggregations.

Note

If a query plan has serial and parallel branches, one of the parallel tasks will be responsible for executing the serial branch.

The number of worker threads spawned for each task depends on:

- Whether the request was eligible for parallelism as determined by the Query Optimizer.
- What is the actual available degree of parallelism (DOP) in the system based on current load. This may differ from estimated DOP, which is based on the server configuration for max degree of parallelism (MAXDOP). For example, the server configuration for MAXDOP may be 8 but the available DOP at runtime can be only 2, which affects query performance.

Note

The **max degree of parallelism (MAXDOP)** limit is set per task, not per request. This means that during a parallel query execution, a single request can spawn multiple tasks up to the MAXDOP limit, and each task will use one worker. For more information about MAXDOP, see **Configure the max degree of parallelism Server Configuration Option**.

A **scheduler**, also known as SOS scheduler, manages worker threads that require processing time to carry out work on behalf of tasks. Each scheduler is mapped to an individual processor (CPU). The time a worker can remain active in a scheduler is called the OS quantum, with a maximum of 4 ms. After its quantum time expires, a worker yields its time to other workers that need to access CPU resources, and changes its state. This cooperation between workers to maximize access to CPU resources is

called **cooperative scheduling**, also known as non-preemptive scheduling. In turn, the change in worker state is propagated to the task associated with that worker, and to the request associated with the task. For more information about worker states, see `sys.dm_os_workers`. For more information about schedulers, see `sys.dm_os_schedulers`.

In summary, a **request** may spawn one or more **tasks** to carry out units of work. Each task is assigned to a **worker thread** who is responsible for completing the task. Each worker thread must be scheduled (placed on a **scheduler**) for active execution of the task.

Note

Consider the following scenario:

- Worker 1 is a long-running task, for example a read query using read-ahead over in-memory based tables. Worker 1 finds its required data pages are already in Buffer Pool, so it doesn't have to yield to wait for I/O operations, and can consume its full quantum before yielding.
- Worker 2 is doing shorter sub-millisecond tasks and therefore is required to yield before its full quantum is exhausted.

In this scenario and up to SQL Server 2014 (12.x), Worker 1 is allowed to basically monopolize the scheduler by having more overall quantum time.

Starting with SQL Server 2016 (13.x), cooperative scheduling includes Large Deficit First (LDF) scheduling. With LDF scheduling, quantum usage patterns are monitored and one worker thread doesn't monopolize a scheduler. In the same scenario, Worker 2 is allowed to consume repeated quantum's before Worker 1 is allowed more quantum, therefore preventing Worker 1 from monopolizing the scheduler in an unfriendly pattern.

Scheduling parallel tasks

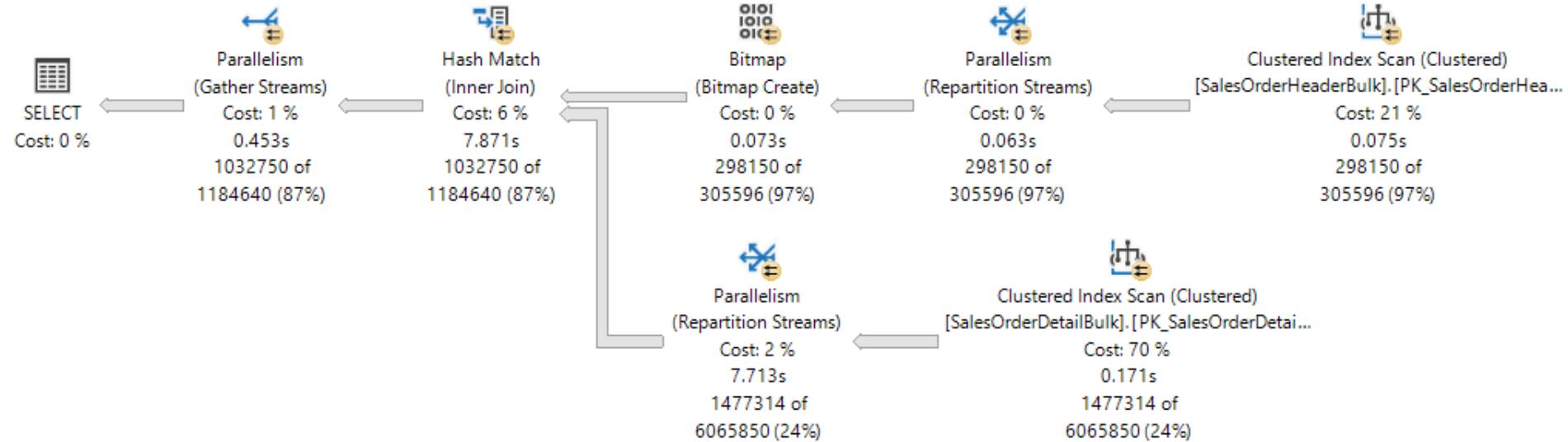
Imagine a SQL Server configured with MaxDOP 8, and CPU Affinity is configured for 24 CPUs (schedulers) across NUMA nodes 0 and 1. Schedulers 0 through 11 belong to NUMA node 0, schedulers 12 through 23 belong to NUMA node 1. An application sends the following query (request) to the Database Engine:

```
SQLCopy
SELECT h.SalesOrderID, h.OrderDate, h.DueDate, h.ShipDate
FROM Sales.SalesOrderHeaderBulk AS h
INNER JOIN Sales.SalesOrderDetailBulk AS d ON h.SalesOrderID = d.SalesOrderID
WHERE (h.OrderDate >= '2014-3-28 00:00:00');
```

Tip

The example query can be executed using the **AdventureWorks2016_EXT sample database** database. The tables Sales.SalesOrderHeader and Sales.SalesOrderDetail were enlarged 50 times and renamed to Sales.SalesOrderHeaderBulk and Sales.SalesOrderDetailBulk.

The execution plan shows a Hash Join between two tables, and each of the operators executed in parallel, as indicated by the yellow circle with two arrows. Each Parallelism operator is a different branch in the plan. Therefore, there are three branches in the execution plan below.



Note

If you think of an execution plan as a tree, a **branch** is an area of the plan that groups one or more operators between Parallelism operators, also called Exchange Iterators. For more information about plan operators, see **Showplan Logical and Physical Operators Reference**.

While there are three branches in the execution plan, at any point during execution only two branches can execute concurrently in this execution plan:

1. The branch where a *Clustering Index Scan* is used on the Sales.SalesOrderHeaderBulk (build input of the join) executes alone.
2. Then, the branch where a *Clustering Index Scan* is used on the Sales.SalesOrderDetailBulk (probe input of the join) executes concurrently with the branch where the *Bitmap* was created and currently the *Hash Match* is executing.

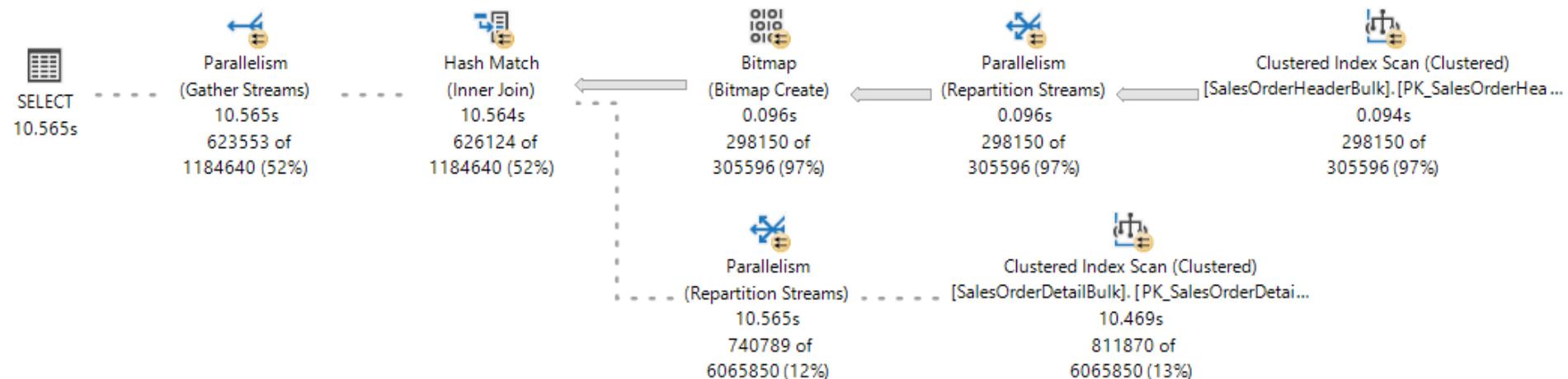
The Showplan XML shows that 16 worker threads were reserved and used on NUMA node 0:

XMLCopy

```
<ThreadStat Branches="2" UsedThreads="16">
  <ThreadReservation NodeId="0" ReservedThreads="16" />
</ThreadStat>
```

Thread reservation ensures the Database Engine has enough worker threads to carry out all the tasks that will be needed for the request. Threads can be reserved across several NUMA nodes, or be reserved in just one NUMA node. Thread reservation is done at runtime before execution starts, and is dependent on scheduler load. The number of reserved worker threads is generically derived from the formula **concurrent branches * runtime DOP** and excludes the parent worker thread. Each branch is limited to a number of worker threads that's equal to MaxDOP. In this example there are two concurrent branches and MaxDOP is set to 8, therefore **2 * 8 = 16**.

For reference, observe the live execution plan from Live Query Statistics, where one branch has completed and two branches are executing concurrently.



The SQL Server Database Engine will assign a worker thread to execute an active task (1:1), which can be observed during query execution by querying the sys.dm_os_tasks DMV, as seen in the following example:

SQLCopy

```
SELECT parent_task_address, task_address,
       task_state, scheduler_id, worker_address
FROM sys.dm_os_tasks
```

WHERE session_id = <insert_session_id>
ORDER BY parent_task_address, scheduler_id;

Tip

The column parent_task_address is always NULL for the parent task.

Tip

On a very busy SQL Server Database Engine, it's possible to see a number of active tasks that's over the limit set by reserved threads. These tasks can belong to a branch that is not being used anymore and are in a transient state, waiting for cleanup.

Here is the result set. Notice there are 17 active tasks for the branches that are currently executing: 16 child tasks corresponding to the reserved threads, plus the parent task, or coordinating task.

TABLE 1

parent_task_address	task_address	task_state	scheduler_id	worker_address
NULL	0x000001EF4758ACA8	SUSPENDED	3	0x000001EFE6CB6160
0x000001EF4758ACA8	0x000001EFE43F3468	SUSPENDED	0	0x000001EF6DB70160
0x000001EF4758ACA8	0x000001EEB243A4E8	SUSPENDED	0	0x000001EF6DB7A160
0x000001EF4758ACA8	0x000001EC86251468	SUSPENDED	5	0x000001EEC05E8160
0x000001EF4758ACA8	0x000001EFE3023468	SUSPENDED	5	0x000001EF6B46A160
0x000001EF4758ACA8	0x000001EFE3AF1468	SUSPENDED	6	0x000001EF6BD38160
0x000001EF4758ACA8	0x000001EFE4AFCCA8	SUSPENDED	6	0x000001EF6ACB4160
0x000001EF4758ACA8	0x000001EFDE043848	SUSPENDED	7	0x000001EEA18C2160
0x000001EF4758ACA8	0x000001EF69038108	SUSPENDED	7	0x000001EF6AEBA160
0x000001EF4758ACA8	0x000001EFCFDD8CA8	SUSPENDED	8	0x000001EFCB6F0160
0x000001EF4758ACA8	0x000001EFCFDD88C8	SUSPENDED	8	0x000001EF6DC46160
0x000001EF4758ACA8	0x000001EFBCC54108	SUSPENDED	9	0x000001EFCB886160
0x000001EF4758ACA8	0x000001EC86279468	SUSPENDED	9	0x000001EF6DE08160
0x000001EF4758ACA8	0x000001EFDE901848	SUSPENDED	10	0x000001EFF56E0160
0x000001EF4758ACA8	0x000001EF6DB32108	SUSPENDED	10	0x000001EFCC3D0160
0x000001EF4758ACA8	0x000001EC8628D468	SUSPENDED	11	0x000001EFBFA4A160
0x000001EF4758ACA8	0x000001EFBD3A1C28	SUSPENDED	11	0x000001EF6BD72160

Observe that each of the 16 child tasks has a different worker thread assigned (seen in the `worker_address` column), but all the workers are assigned to the same pool of eight schedulers (0,5,6,7,8,9,10,11), and that the parent task is assigned to a scheduler outside this pool (3).

Important

Once the first set of parallel tasks on a given branch is scheduled, the Database Engine will use that same pool of schedulers for any additional tasks on other branches. This means the same set of schedulers will be used for all the parallel tasks in the entire execution plan, only limited by MaxDOP.

The SQL Server Database Engine will always try to assign schedulers from the same NUMA node for task execution, and assign them sequentially (in round-robin fashion) if schedulers are available. However, the worker thread assigned to the parent task may be placed in a different NUMA node from other tasks.

A worker thread can only remain active in the scheduler for the duration of its quantum (4 ms) and must yield its scheduler after that quantum has elapsed, so that a worker thread assigned to another task may become active. When a worker's quantum expires and is no longer active, the respective task is placed in a FIFO queue in a `RUNNABLE` state, until it moves to a `RUNNING` state again, assuming the task won't require access to resources that are not available at the moment, such as a latch or lock, in which case the task would be placed in a `SUSPENDED` state instead of `RUNNABLE`, until such time those resources are available.

Tip

For the output of the DMV seen above, all active tasks are in `SUSPENDED` state. More detail on waiting tasks is available by querying the `sys.dm_os_waiting_tasks` DMV.

In summary, a parallel request will spawn multiple tasks. Each task must be assigned to a single worker thread. Each worker thread must be assigned to a single scheduler. Therefore, the number of schedulers in use cannot exceed the number of parallel tasks per branch, which is set by the MaxDOP configuration or query hint. The coordinating thread does not contribute to the MaxDOP limit.

Allocating threads to a CPU

By default, each instance of SQL Server starts each thread, and the operating system distributes threads from instances of SQL Server among the processors (CPUs) on a computer, based on load. If process affinity has been enabled at the operating system level, then the operating system assigns each thread to a specific CPU. In contrast, the SQL Server Database Engine assigns SQL Server **worker threads** to **schedulers** that distribute the threads evenly among the CPUs, in a round-robin fashion.

To carry out multitasking, for example when multiple applications access the same set of CPUs, the operating system sometimes moves worker threads among different CPUs. Although efficient from an operating system point of view, this activity can reduce SQL Server performance under heavy system loads, as each processor cache is repeatedly reloaded with data. Assigning CPUs to specific threads can improve performance under these conditions by eliminating processor reloads and reducing thread migration across CPUs (thereby reducing context switching); such an association between a thread and a processor is called processor affinity. If affinity has been enabled, the operating system assigns each thread to a specific CPU.

The affinity mask option is set by using ALTER SERVER CONFIGURATION. When the affinity mask is not set, the instance of SQL Server allocates worker threads evenly among the schedulers that have not been masked off.

Caution

Do not configure CPU affinity in the operating system and also configure the affinity mask in SQL Server. These settings are attempting to achieve the same result, and if the configurations are inconsistent, you may have unpredictable results. For more information, see **affinity mask option**.

Thread pooling helps optimize performance when large numbers of clients are connected to the server. Usually, a separate operating system thread is created for each query request. However, with hundreds of connections to the server, using one thread per query request can consume large amounts of system resources. The max worker threads option enables SQL Server to create a pool of worker threads to service a larger number of query requests, which improves performance.

Using the lightweight pooling Option

The overhead involved in switching thread contexts may not be very large. Most instances of SQL Server will not see any performance differences between setting the lightweight pooling option to 0 or 1. The only instances of SQL Server that might benefit from lightweight pooling are those that run on a computer having the following characteristics:

- A large multi-CPU server
- All the CPUs are running near maximum capacity
- There is a high level of context switching

These systems may see a small increase in performance if the lightweight pooling value is set to 1.

Important

Do not use fiber mode scheduling for routine operation. This can decrease performance by inhibiting the regular benefits of context switching, and because some components of SQL Server cannot function correctly in fiber mode. For more information, see **lightweight pooling**.

Thread and Fiber Execution

Microsoft Windows uses a numeric priority system that ranges from 1 through 31 to schedule threads for execution. Zero is reserved for operating system use. When several threads are waiting to execute, Windows dispatches the thread with the highest priority.

By default, each instance of SQL Server is a priority of 7, which is referred to as the normal priority. This default gives SQL Server threads a high enough priority to obtain sufficient CPU resources without adversely affecting other applications.

Important

This feature will be removed in a future version of Microsoft SQL Server. Avoid using this feature in new development work, and plan to modify applications that currently use this feature.

The priority boost configuration option can be used to increase the priority of the threads from an instance of SQL Server to 13. This is referred to as high priority. This setting gives SQL Server threads a higher priority than most other applications. Thus, SQL Server threads will generally be dispatched whenever they are ready to run and will not be preempted by threads from other applications. This can improve performance when a server is running only instances of SQL Server and no other applications. However, if a memory-intensive operation occurs in SQL Server, however, other applications are not likely to have a high-enough priority to preempt the SQL Server thread.

If you are running multiple instances of SQL Server on a computer, and turn on priority boost for only some of the instances, the performance of any instances running at normal priority can be adversely affected. Also, the performance of other applications and components on the server can decline if priority boost is turned on. Therefore, it should only be used under tightly controlled conditions.

Hot add CPU

Hot add CPU is the ability to dynamically add CPUs to a running system. Adding CPUs can occur physically by adding new hardware, logically by online hardware partitioning, or virtually through a virtualization layer. Starting with SQL Server 2008, SQL Server supports hot add CPU.

Requirements for hot add CPU:

- Requires hardware that supports hot add CPU.
- Requires the 64-bit edition of Windows Server 2008 Datacenter or the Windows Server 2008 Enterprise Edition for Itanium-Based Systems operating system.
- Requires SQL Server Enterprise.

- SQL Server cannot be configured to use soft NUMA. For more information about soft NUMA, see [Soft-NUMA \(SQL Server\)](#).

SQL Server does not automatically start to use CPUs after they are added. This prevents SQL Server from using CPUs that might be added for some other purpose. After adding CPUs, execute the RECONFIGURE statement, so that SQL Server will recognize the new CPUs as available resources.

Note

If the **affinity64 mask** is configured, the affinity64 mask must be modified to use the new CPUs.

Best Practices for running SQL Server on computers that have more than 64 CPUs

Assigning Hardware Threads with CPUs

Do not use the affinity mask and affinity64 mask server configuration options to bind processors to specific threads. These options are limited to 64 CPUs. Use the SET PROCESS AFFINITY option of ALTER SERVER CONFIGURATION instead.

Managing the Transaction Log file size

Do not rely on autogrow to increase the size of the transaction log file. Increasing the transaction log must be a serial process. Extending the log can prevent transaction write operations from proceeding until the log extension is finished. Instead, preallocate space for the log files by setting the file size to a value large enough to support the typical workload in the environment.

Setting Max Degree of Parallelism for index operations

The performance of index operations such as creating or rebuilding indexes can be improved on computers that have many CPUs by temporarily setting the recovery model of the database to either the bulk-logged or simple recovery model. These index operations can generate significant log activity and log contention can affect the best degree of parallelism (DOP) choice made by SQL Server.

In addition to adjusting the **max degree of parallelism (MAXDOP)** server configuration option, consider adjusting the parallelism for index operations using the MAXDOP option. For more information, see [Configure Parallel Index Operations](#). For more information and guidelines about adjusting the max degree of parallelism server configuration option, see [Configure the max degree of parallelism Server Configuration Option](#).

Setting the Maximum Number of Worker Threads

SQL Server will dynamically configure the **max worker threads** server configuration option at startup. SQL Server uses the number of available CPUs and the system architecture to determine this server configuration during startup, using a documented formula.

This option is an advanced option and should be changed only by an experienced database administrator or certified SQL Server professional. If you suspect that there is a performance problem, it is probably not the availability of worker threads. The cause is more likely something like I/O that is causing the worker threads to wait. It is best to find the root cause of a performance issue before you change the max worker threads setting. However, if you need to manually set the maximum number of worker threads, this configuration value must always be set to a value of at least seven times the number of CPUs that are present on the system. For more information, see [Configure the max worker threads](#).

Using SQL Trace and SQL Server Profiler

We recommend that you do not use SQL Trace and SQL Profiler in a production environment. The overhead for running these tools also increases as the number of CPUs increases. If you must use SQL Trace in a production environment, limit the number of trace events to a minimum. Carefully profile and test each trace event under load, and avoid using combinations of events that significantly affect performance.

Important

SQL Trace and SQL Server Profiler are deprecated. The *Microsoft.SqlServer.Management.Trace* namespace that contains the Microsoft SQL Server Trace and Replay objects are also deprecated.

This feature will be removed in a future version of Microsoft SQL Server. Avoid using this feature in new development work, and plan to modify applications that currently use this feature.

Use Extended Events instead. For more information on **Extended Events**, see **Quick Start: Extended events in SQL Server** and **SSMS XEvent Profiler**.

Note

SQL Server Profiler for Analysis Services workloads is NOT deprecated, and will continue to be supported.

Setting the number of tempdb data files

The number of files depends on the number of (logical) processors on the machine. As a general rule, if the number of logical processors is less than or equal to eight, use the same number of data files as logical processors. If the number of logical processors is greater than eight, use eight data files and then if contention continues, increase the number of data files by

multiples of 4 until the contention is reduced to acceptable levels or make changes to the workload/code. Also keep in mind other recommendations for tempdb, available in Optimizing tempdb performance in SQL Server.

However, by carefully considering the concurrency needs of tempdb, you can reduce database management overhead. For example, if a system has 64 CPUs and usually only 32 queries use tempdb, increasing the number of tempdb files to 64 will not improve performance.

SQL Server components that can use more than 64 CPUs

The following table lists SQL Server components and indicates whether they can use more than 64 CPUs.

SQL SERVER COMPONENTS THAT CAN USE MORE THAN 64 CPUS		
Process name	Executable program	Use more than 64 CPUs
SQL Server Database Engine	Sqlserver.exe	Yes
Reporting Services	Rs.exe	No
Analysis Services	As.exe	No
Integration Services	Is.exe	No
Service Broker	Sb.exe	No
Full-Text Search	Fts.exe	No
SQL Server Agent	Sqlagent.exe	No
SQL Server Management Studio	Ssms.exe	No
SQL Server Setup	Setup.exe	No