SQL Server Performance Assessment and Optimization Techniques

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Emphasis of Presentation

- Interpretation and usage of informative performance counters
- Expand upon PerfMon explanations
- ALL graphs of actual customer data
- Insights acquired from analysis of many customer data sets
- Possible courses of action
- SQL Profiler usage considerations

Overview

- **SQL Server**
  - Measures many activities, but only certain ones can be traced to a **specific** database
  - None can be traced back to a specific query
  - Sometimes need additional tools such as SQL Profiler (SQL Server trace) to complete analyses
- **Must monitor other performance objects**
- **Presentation refers to SQL Server objects unless otherwise noted**

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Overview

- **Many PerfMon explanations useless**
- **Example explanations**
  - SQL Compilations/sec is “Number of SQL compilations”
  - Table Lock Escalations/sec is “The number of times locks on a table were escalated”
  - Bulk Copy Rows/sec is “Number of rows bulk copied per second”

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PerfMon Counter Hierarchy

- **Three-level hierarchy**
- **Objects at top level**
- **Counters**
  - Comprise bottom level
  - Always pertain to a particular object
- **Instance level added between object and counter levels when necessary**

Object Hierarchy Examples

- Processor object → Processor 0 instance → % Processor Time counter
- Memory object → Page writes/sec counter

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SQL Server Objects

- One set per SQL Server instance
- Each set divided into 17 categories
- 4 memory-related
- 2 lock-related

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SQL Server Objects

- **7 measure database backup, replication, and user settable categories**
  - Applicable to database backup and replication performance, as well as specifically defined and maintained user counters
- **Rest involve database transactions, log handling, and database access activities**

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SQL Server Object List

SQL Server Objects	Category
SQL Server: Access Methods	Database access
SQL Server: Backup Device	Database backup
SQL Server: Buffer Manager	Memory management
SQL Server: Buffer Partition	Memory management
SQL Server: Cache Manager	Memory management
SQL Server: Databases	Transactions & log handling
SQL Server: General Statistics	User connections
SQL Server: Latches	Locking
SQL Server: Locks	Locking
SQL Server: Memory Manager	Memory management

SQL Server Object List

SQL Server Objects	Category
SQL Server: Replication Agents	Database replication
SQL Server: Replication Dist.	Database replication
SQL Server: Replication Logreader	Database replication
SQL Server: Replication Merge	Database replication
SQL Server: Replication Snapshot	Database replication
SQL Server: SQL Statistics	SQL command activities
SQL Server: User Settable	User defined

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Buffer Manager and Buffer Partition Objects

- 21 counters
- 5 involve Address Windowing Extensions (AWE)
- AWE covered indirectly

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Buffer Cache Hit Ratio

- Frequency with which database read requests are satisfied from database cache memory instead of disk
- Higher values result in lower disk usage
- Recommended value at least 90%
- Raw performance data can sometimes exceed 100%

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Detecting Insufficient SQL Memory

- Compare Memory Manager object's *Target Server Memory (KB)* with *Total Server Memory (KB)* counters
- If Total less than Target, possibly insufficient memory
- If comparison too small or *Buffer Cache Hit Ratio* is too low, allocate more memory to SQL Server, if possible

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SQL Server Only App and Single Instance

- **If SQL Server only application on system and there is only one instance, decisions may be simpler**
  - Reconfigure to use all of memory automatically, if not already doing so and **not** using AWE
  - Add more memory

AWE and SQL Server Using All Memory Automatically

- **Setting SQL Server to use all memory has often caused problems when AWE used on Windows 2000**
- **Can cause system to**
  - Exhaust Windows memory
  - Page heavily
- **AWE-related tables hard to identify**

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AWE and SQL Server Using All Memory Automatically

- Scalability experts have stated that AWE-related tables consume more Windows memory as more AWE memory locations accessed (at least on Windows 2000)
- Experience has shown this to be true

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AWE User Experiences #1

- **30 GB allocated to SQL Server on 32 GB system**
  - System paged heavily after user activity increased
  - Little or no available memory for Windows
  - Could not attribute Windows memory usage to a process
- **Reduced allocation to 28 GB**
  - Paging ceased
  - Both system and SQL Server ran fine
  - Buffer cache hit ratio hardly affected

AWE User Experiences #2

- **All but 65 MB allocated to SQL Server on 8 GB system**
  - System ran fine for several weeks, but available memory decreased very slowly
- **Full text index creation executed**
  - System cache increased
  - Index creation programs required own non-SQL memory
- **System began to page heavily**
  - Little or no available memory for Windows
  - System basically stopped functioning when available memory dropped below 4 MB
- **SQL memory allocation reduced to insure 678 MB available – problems ceased permanently**

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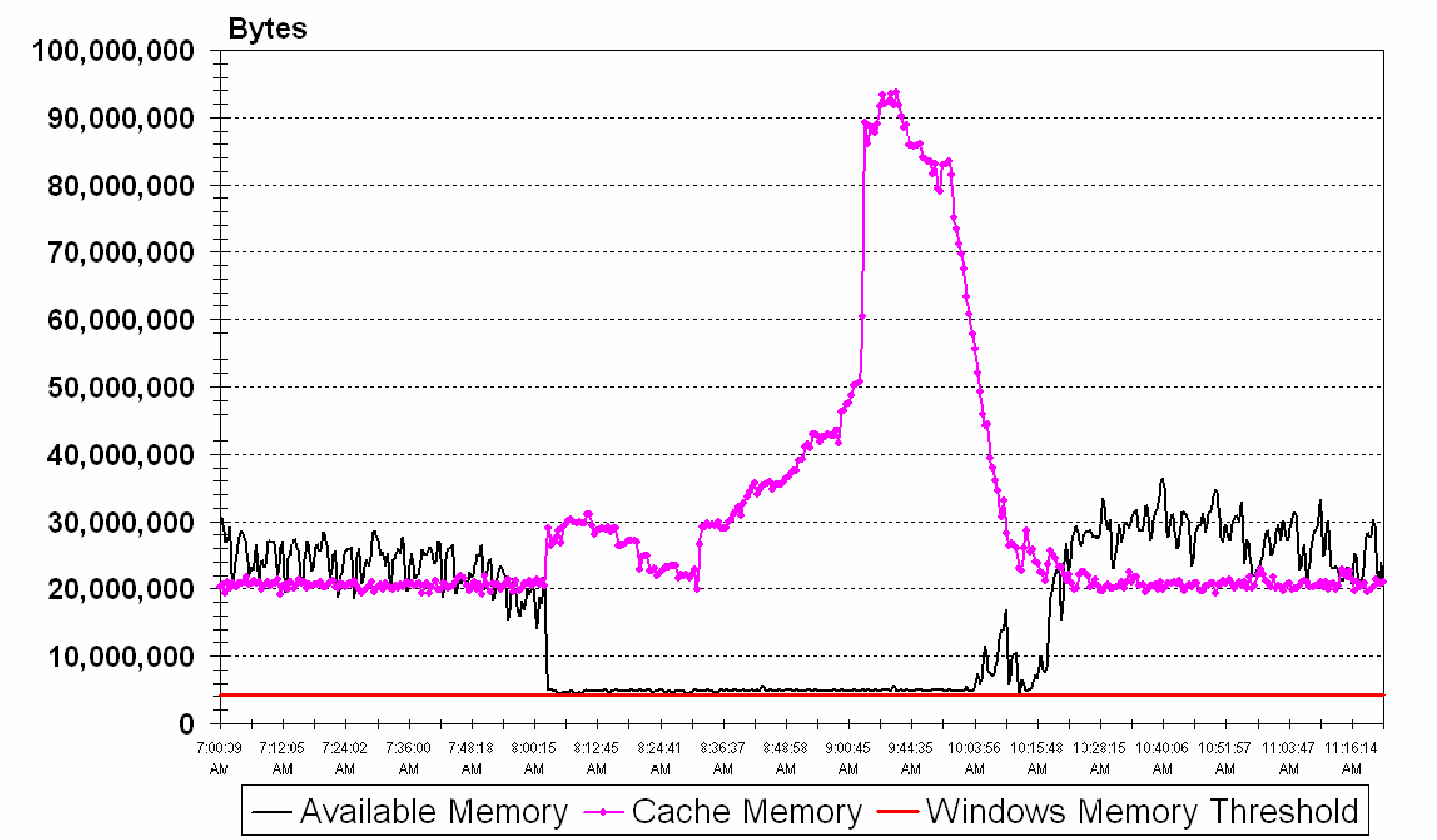
Available & Cache Memory



SQL One of Many Apps

- **Decisions much more complex if SQL Server NOT only major application on computer or multiple instances exist**
- **Classic system versus database conflict**
  - Allocating too much memory to SQL Server can harm other applications, SQL Server instances, or Windows, unless sufficient memory can be added
- **Need to match instance memory with business requirements**

Increasing SQL Memory

- **Make very gradual changes**
- **Monitor system Memory object counters before and after any changes**
  - Page writes/sec
  - Available Bytes
    - Insure Windows 4 MB available memory limit **impossible to reach**, regardless of application activities

Free Pages Counter

- Number of memory buffers available to receive database pages read from disk
- Indicator of insufficient SQL Server memory
- Values consistently close to zero indicate SQL Server memory shortage
- Closely associated with *Free list stalls/sec*

FreeList Stalls Counter

- Frequency with which requests for available database pages are suspended because no buffers are available
- Free list stall rates of 3 or 4 per second indicate too little SQL memory available

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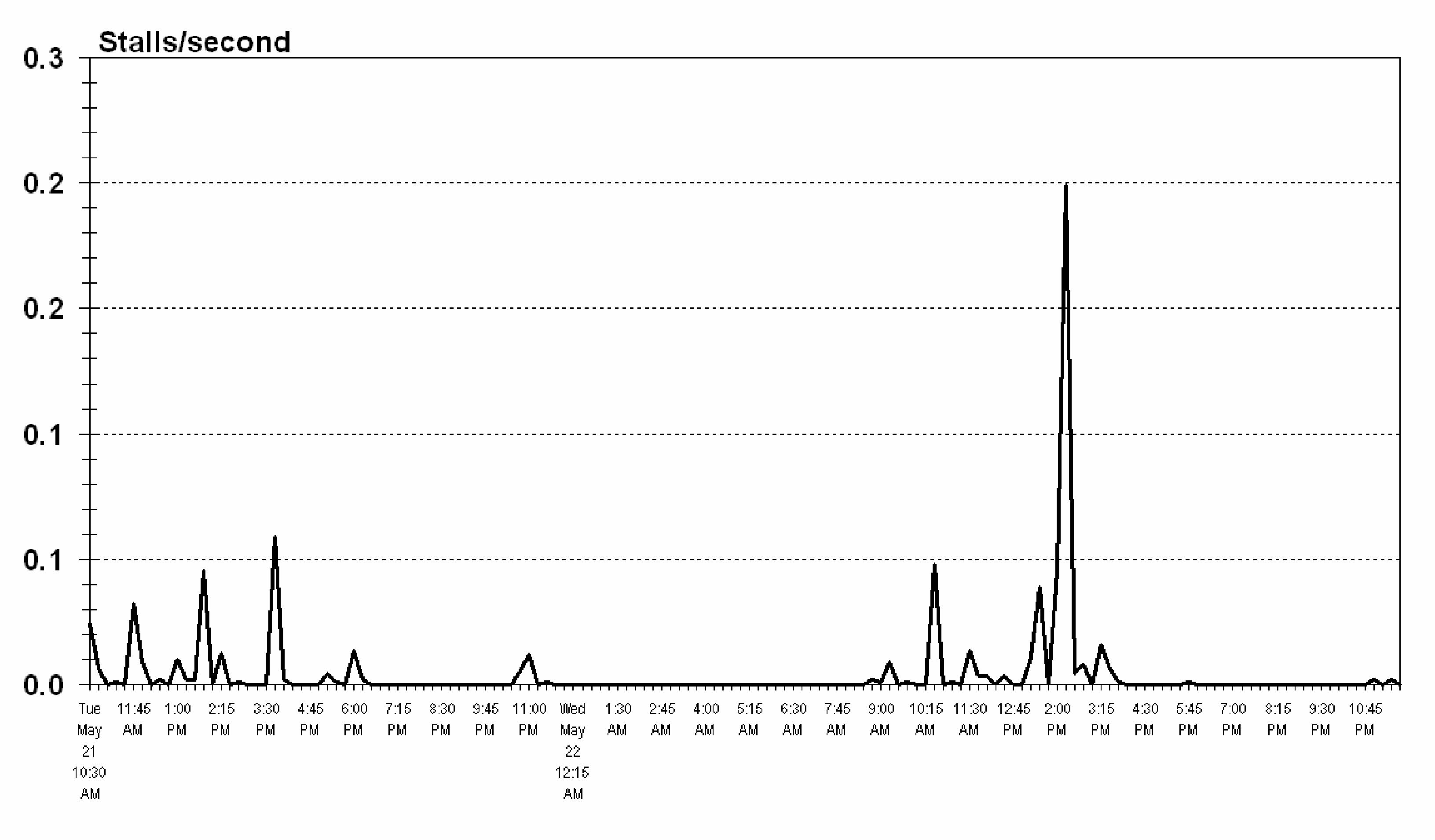
FreeList Stalls Graph



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Stolen Pages Counter

- Pages "stolen" when Windows requires memory for another application
- Useful indicator of overall system memory shortage
- Short periods may be normal
- Example: system backup begins after large database batch run completes

Database I/O Counters

- ***Page Reads/sec*** **and** ***Page Writes/sec*** **counters**
- **Measures physical I/Os, not logical I/Os**
- **May indicate**
  - Insufficient database memory
  - Applications improperly accessing database
  - Improper database table implementation

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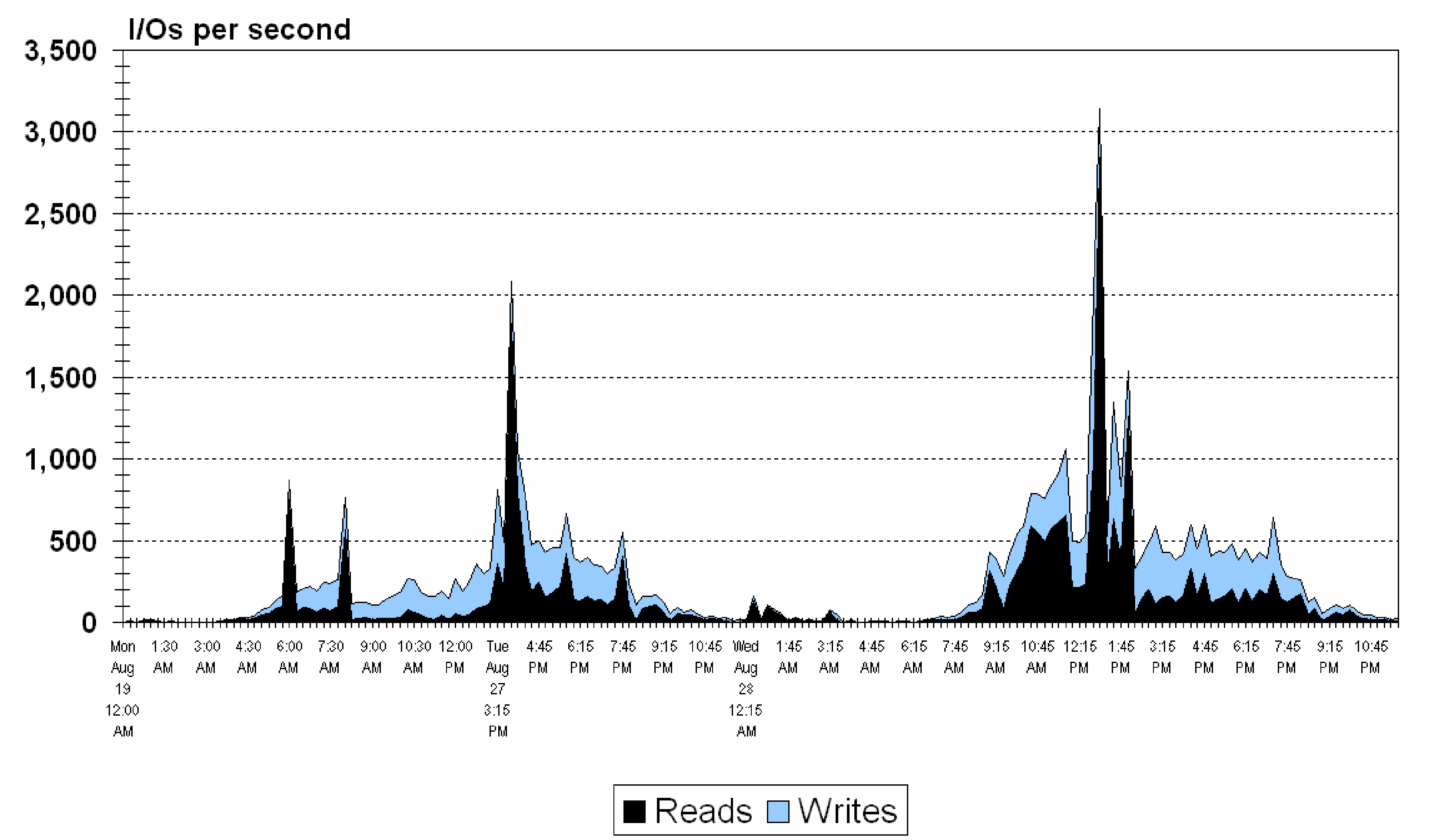
I/O Activity Graph



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Page Lookups/sec Counter

- **Measures number of times database attempted to find a page in buffer pool**
- **Logical read**
- **Useful for corroborating and further quantifying buffer cache hit ratio**
- **Compare *Page Reads/sec* with *Page lookups/sec***

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Buffer Cache Hit Ratio - Revisited

- Can perform computation when more precision necessary, e.g., 30 of 32 GB allocated to SQL
- 1 – (Page reads/sec / Page lookups/sec)

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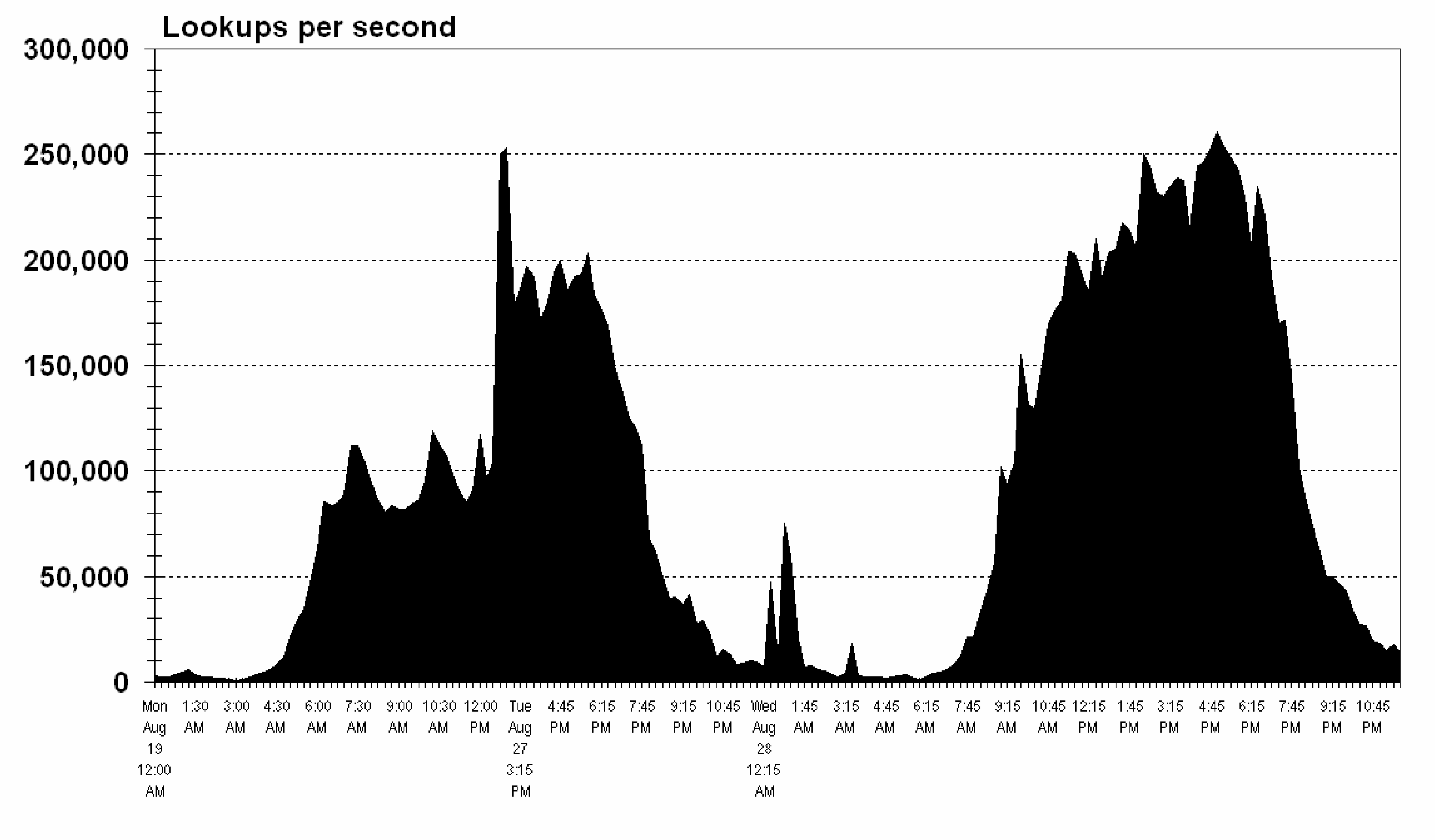
Page Lookups Graph



Memory Manager Object

- **Counters can be used to develop SQL Server memory composition graph**
  - *Connection Memory (KB)*
  - *Granted Workspace Memory (KB)*
  - *Lock Memory (KB)*
  - *Optimizer Memory (KB)*
  - *SQL Cache Memory (KB)*
- **Monitor lock blocks**

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Access Methods Object

- **Most helpful counters**
  - *Forwarded Records/sec*
  - *Full Scans/sec*
  - *Index Searches/sec*
  - *Range Scans/sec*
  - *Table Lock Escalations/sec*

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Forwarded Records

- **Only occur in tables without clustered indices, i.e., heaps**
- **Occur when row/record moved from one database page to another because changed record cannot fit back in original page**
  - Image data, i.e., bitmap data
  - Variable-length string data
- **Most frequently occur in Tempdb**

Forwarded Records

- **Creates de facto physical linear search, which can cause *long* record access times and high page read rates**
- **Adding clustered index is simplest way to eliminate problem**
  - Use as few data columns as possible
- **Otherwise, create records that are large enough to accommodate changes**

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Detecting Forwarded Records

- **Two ways to determine total count of forwarded records in a table**
- **Enable trace flag 2509 and execute DBCC CHECKTABLE command as shown below**
  - DBCC TRACEON (2509)
  - GO
  - DBCC CHECKTABLE (<table name>)

OR

- **Execute DBCC SHOWCONTIG using TABLERESULTS option as shown below**
  - DBCC SHOWCONTIG (<table name>) WITH TABLERESULTS

Forwarded Records/sec

- Measures # of records fetched via forwarded record pointers
- Since forward record "chains" are prevented by SQL Server, counter refers to actual record count, not number of pointer "chases"

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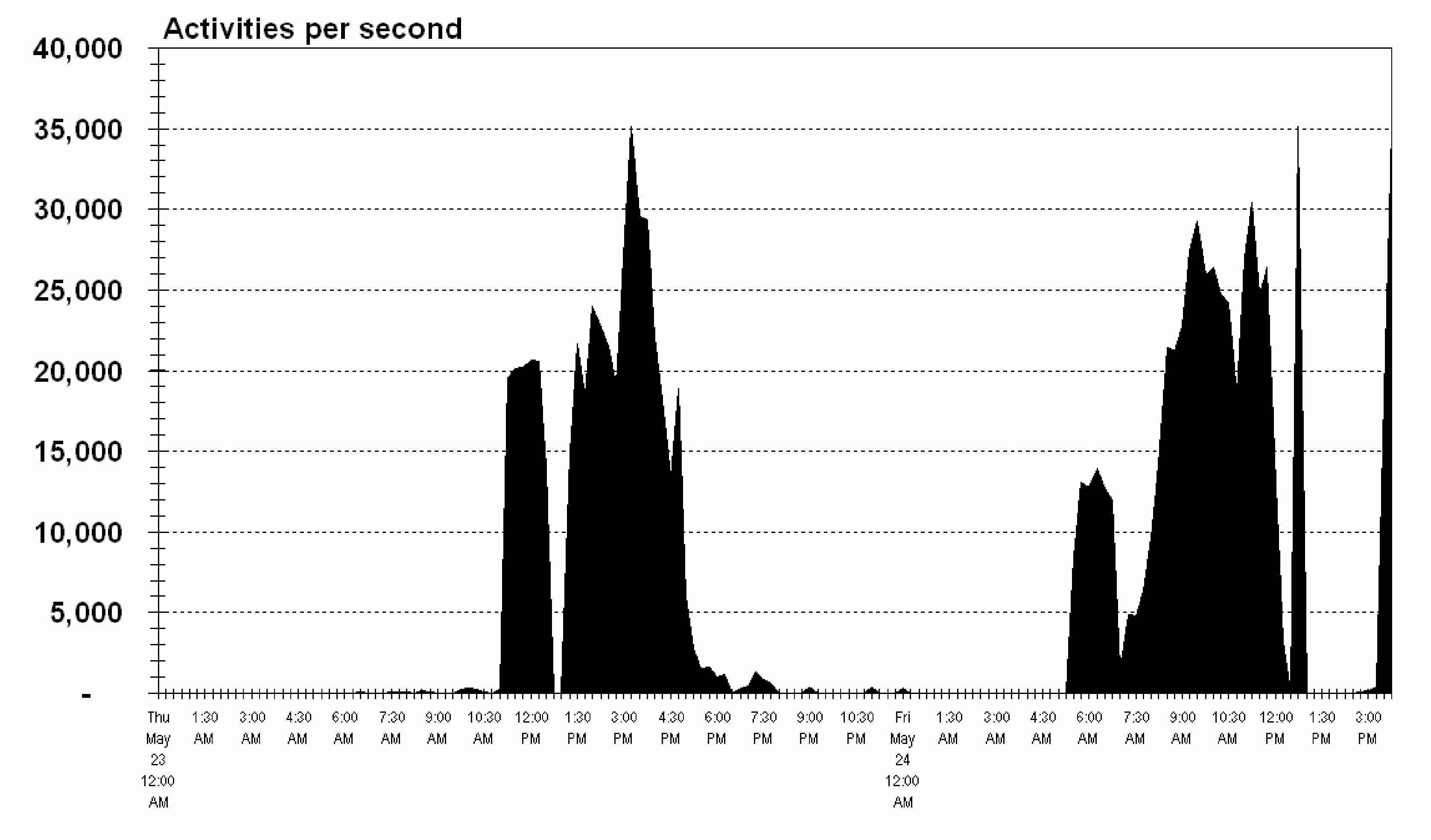
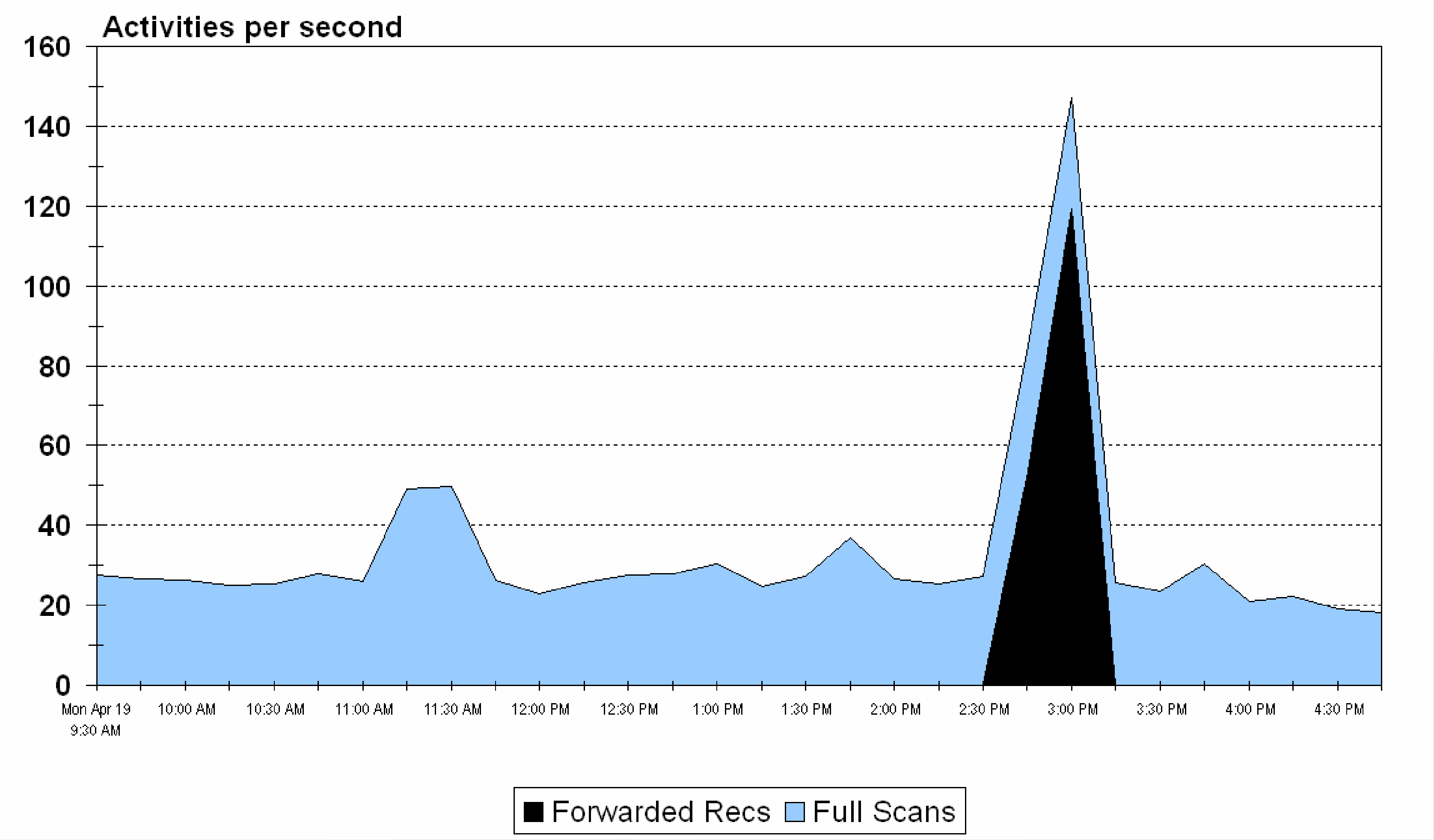
Forwarded Records Graph



Full Scans

- Unrestricted linear searches through table or index
- Example SQL statement
  - SELECT * FROM TABLETHATISAHEAP
- SQL Query **Estimated Execution Plan** can identify them ahead of time
- SQL Query **Actual Execution Plan** and SQL Profiler (trace) can identify them when they occur
- Trace records contain **logical** reads and writes

Access Method Graph



I/O Activity vs. Access Methods

- Direct graphical comparison of these entities is very helpful
- Shows whether physical and logical linear searches, i.e., forwarded records and full scans, result in physical I/Os or are completely satisfied from memory
- Many linear searches can be against very short tables that are always in memory
- Comparison distinguishes relatively harmless ones from those that impact the I/O subsystem

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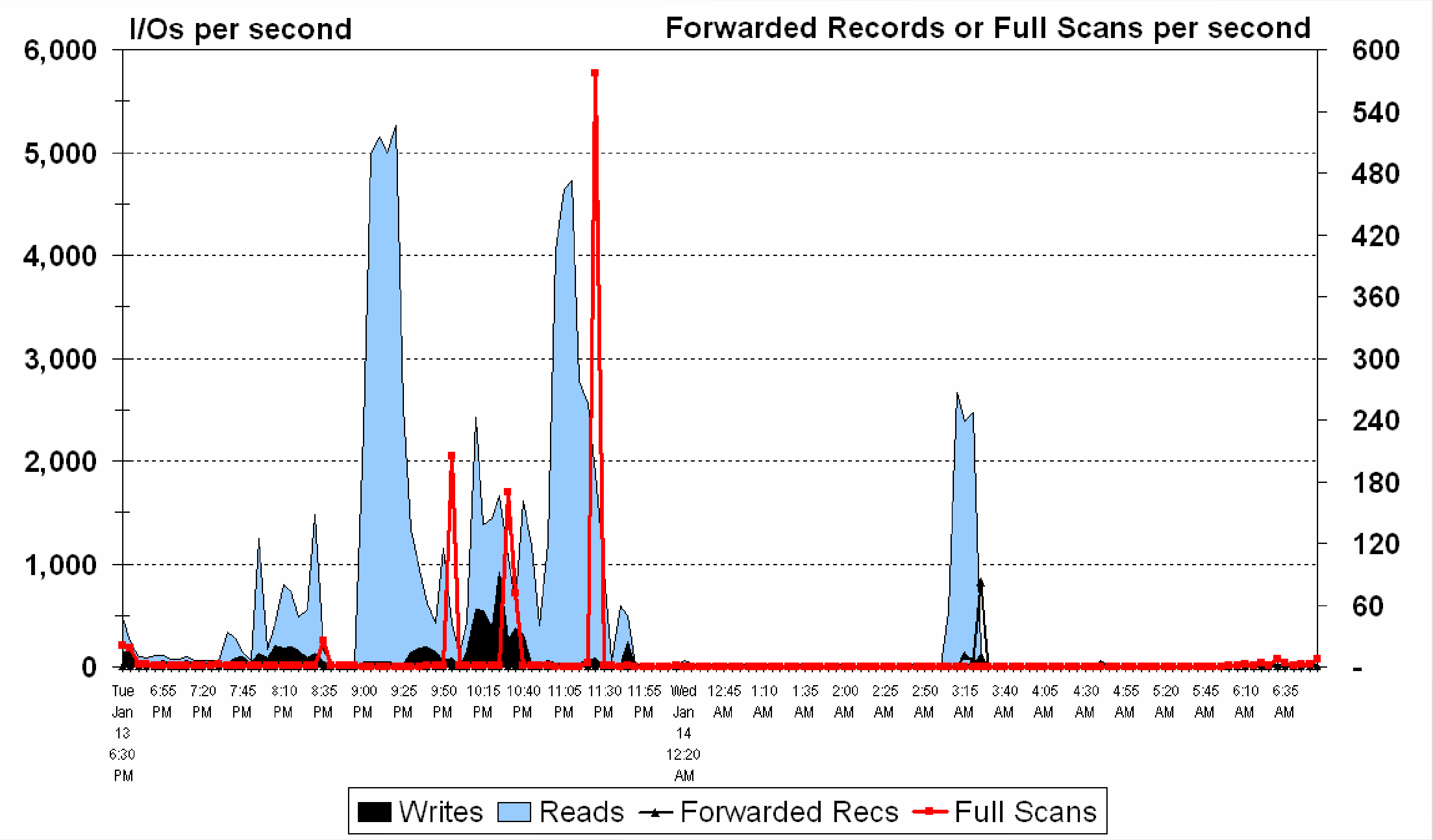
SQL Server I/O, Forwarded Record, & Full Scan Graph



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Locks Object

- **One of the most important objects**
- ***Number of Deadlocks/sec* critical**
- **SQL Profiler can provide information about how deadlock was created**
- ***Lock Timeouts/sec* also critical**
  - # of lock requests that exceed maximum specified wait time
  - Monitors each type of lock

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Lock Types/Instances

Item	Description
Database	Entire database
Extent	Contiguous group of 8 data pages or index pages
Key	Row lock within index
Page	8-kilobyte (KB) data page or index page
RID	Row ID. Used to lock single row within table
Table	Entire table, including all data & indices

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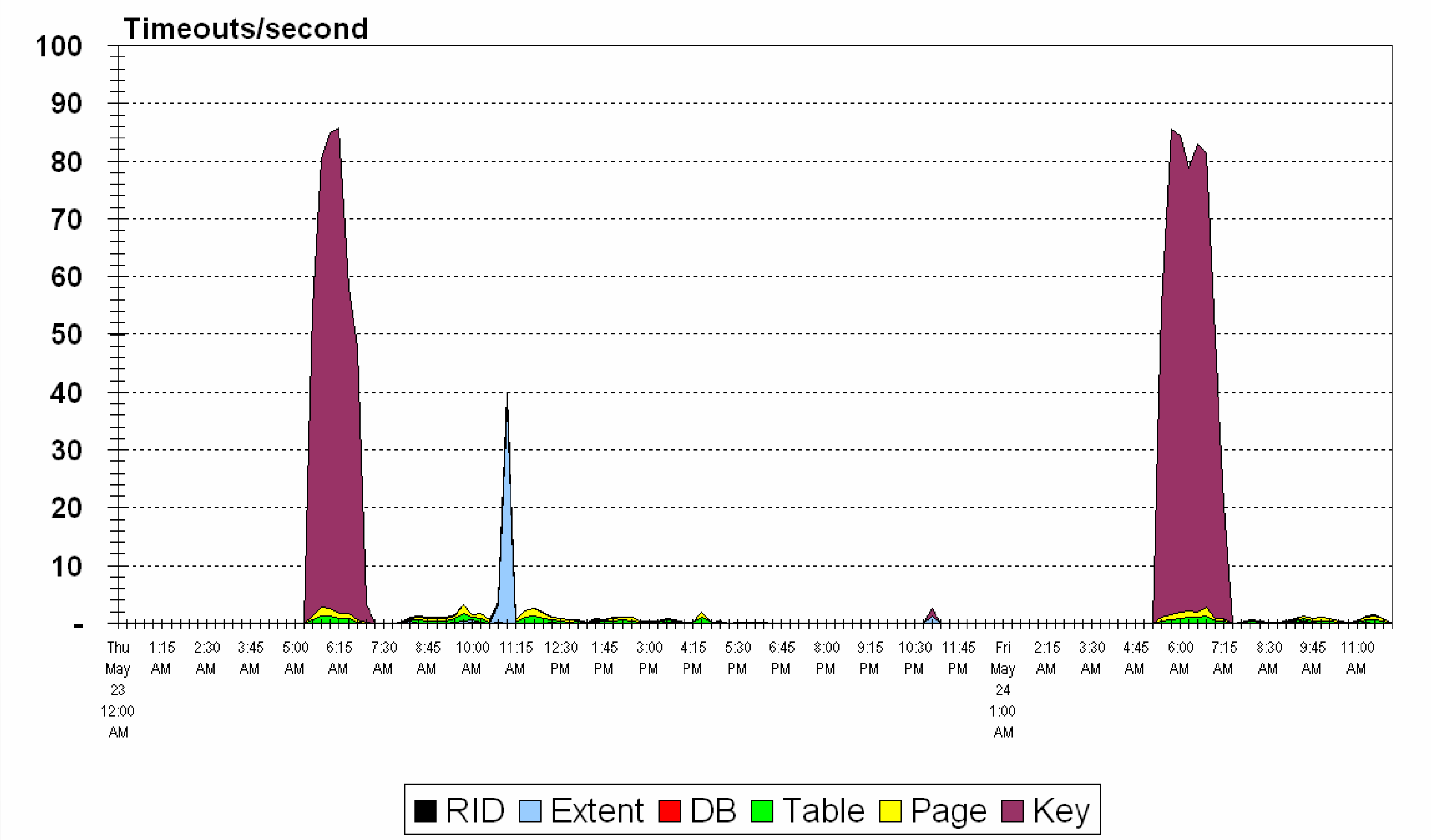
Lock Timeouts Graph



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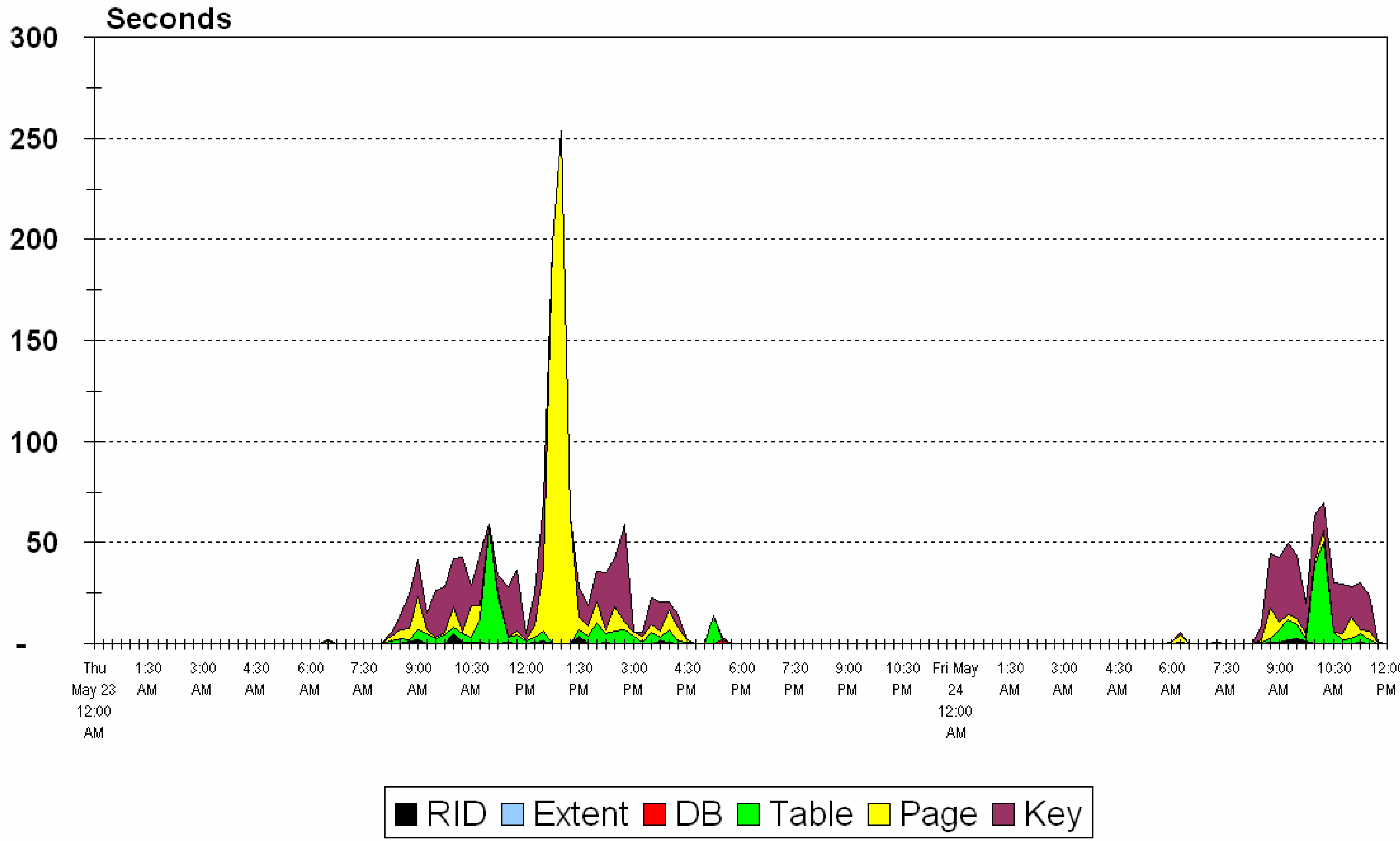
Other Lock Counters

- ***Average Wait Time (ms)***
  - Measures average time each lock request was forced to wait
- **Useful to sum these to prevent averages from disguising problems**
  - Calculate percentage of interval spent waiting
- ***Lock Waits/sec***
  - Records how often lock requests waited
- **Trace duration filter does not apply to lock timeouts**

Total Lock Wait Times



Lock Escalations

- **Row, key, or page locks automatically escalated to coarser table locks as appropriate**
  - Single table lock acquired
  - Many lower level locks released
- **Recorded in *Table Lock Escalations/sec***
- ***Lock Owner Blocks Allocated* and *Lock Blocks Allocated* can be used to validate that applications hold too many locks for too long**

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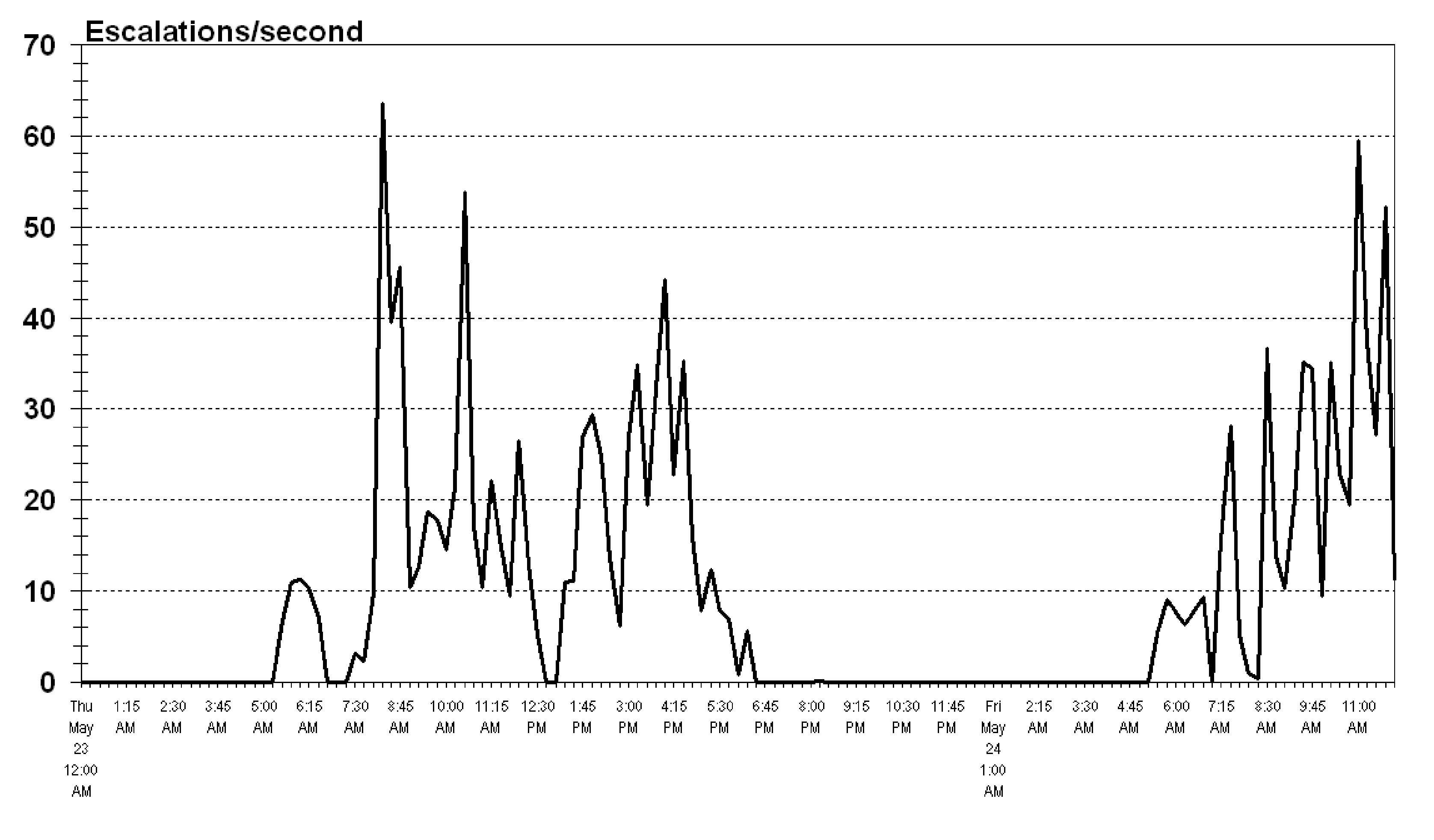
Table Lock Escalations



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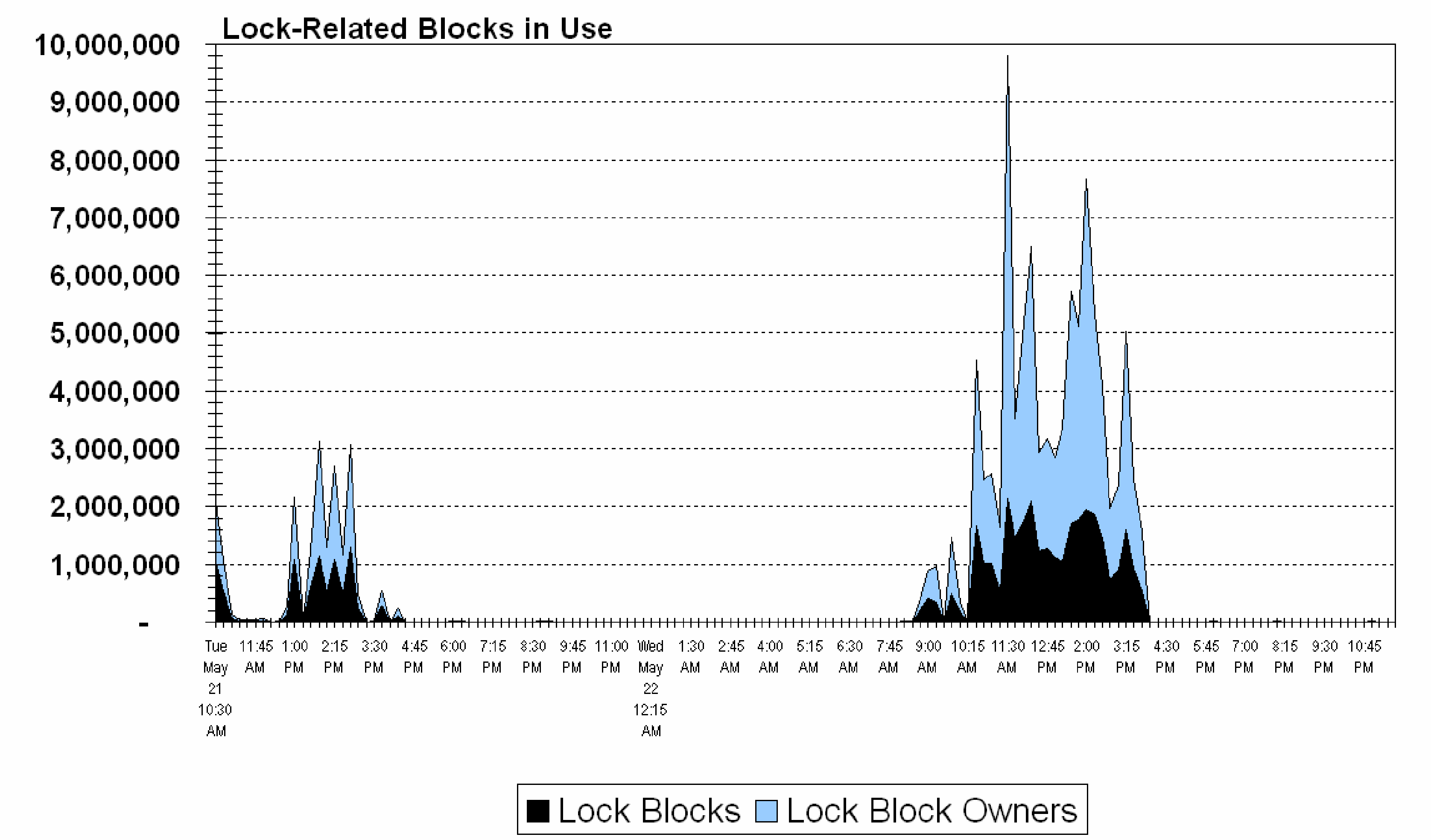
Lock Block & Lock Block Owners Graph



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Latches

- **Latches**
  - Lightweight, short-term synchronization objects
  - Protect action that need not need be locked for life of transaction

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Latch Object Counters

- **Counters**
  - *Average Latch Wait Time (ms)*
  - *Latch Waits/sec*
  - *Total Latch Wait Time (ms)*

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Avg. Latch Wait Time (ms) Counter

- **Large values, e.g., greater than one second**
  - Indicate large number of physical I/Os or long I/O times
  - Check following counters
    - *Page Reads/sec* and *Page Writes/sec*
    - System PhysicalDisk object, especially *Avg. Disk Sec/Transfer*
  - Often coincide with low buffer cache hit ratios

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% Disk Times & Queue Lengths

- *% Disk Times* useless because they are simply restatements of queue lengths using percent format
- Perfmon constrains these to 100%
- Queue lengths can no longer be interpreted as most Windows performance books suggest, i.e., disk is in trouble when queue length > 2
- Queue lengths of 14 or more are common, even on well-performing I/O subsystems

Physical I/O Measurements

- **Only I/O time is measured directly**
- **Disk driver provides I/O times to Windows**
- **Due to driver's location in I/O path**
  - I/O time = service time + queue time
- **May not be possible to improve large service times due to physical or financial constraints**

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Large SQL Server I/Os

- Beginning with Service Pack 3, SQL Server can generate very large I/Os, e.g., larger than 65,535 bytes
- 131,070 byte and larger I/Os have been observed (see Example #3)
- HBAs can be saturated fairly quickly under these conditions
- I/O service times can cause I/O times to be high even if queuing does not occur

I/O Time Calculations

- Important to know whether queuing is causing large I/O times
- Use Little's Law to compute missing statistics

Little's Law

N = X * R

- N => average # customers at a service center
- X => program completion rate
- R => average elapsed time

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Using Little's Law to Compute Missing I/O-Related Times

- **All calculations use PhysicalDisk counters**
- **Disk Utilization = 100 - *% Idle Time***
- **Disk service time = Disk Utilization / *Disk Transfers/sec***
- **Disk queue time = *Avg. Disk sec/Transfer* - Disk service time**

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RAID Example Calculations #1

- Disk Utilization = 36.57%
- Disk Transfers/sec = 0.65
- Avg. Disk sec/Transfer = 2.0095
- Disk service time = .3657 / 0.65 = 0.563 seconds or 563 milliseconds
- Disk queue time = 2.0095 – 0.563 = 1.447 seconds or 1,447 milliseconds
- Bytes/Transfer = 1,307

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RAID Example Calculations #2

- Disk Utilization = 77.67%
- Disk Transfers/sec = 30.89
- Avg. Disk sec/Transfer = 2.4424
- Disk service time = .7767 / 30.89 = 0.025 seconds or 25 milliseconds
- Disk queue time = 2.4424 – 0.025 = 2.4174 seconds or 2,4174 milliseconds
- Bytes/Transfer = 22,437

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RAID Example 1 vs. 2

- I/O times are not that far apart despite being outrageously high
- Queuing being encountered for both disks
- Low I/O rate of Disk #1 appears to contribute to high service times
  - 1,307 bytes should not require 563 ms

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RAID Example 1 vs. 2

- **Disk #2 is doing much more work**
  - Utilization is double
  - I/O size is 17 times larger
  - Service time is much more reasonable @ 25 ms
- **Problems began when faster processor complex attached**
- **Solution was to reconfigure EMC drives**

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RAID Example Calculations #3

- Disk Utilization = 99.59%
- Disk Transfers/sec = 58.2
- Avg. Disk sec/Transfer = 0.7678
- Disk service time = 0.9959 / 58.2 = 0.0171 seconds or 17.1 milliseconds
- Disk queue time = 0.7678 – 0.0171 = 0.7507 seconds or 750.7 milliseconds
- Bytes/Transfer = 168,536

RAID Example #3 Discussion

- **100% utilization is suspicious, but RAID may be functioning well enough**
  - In this case, it obviously is not
- **17 ms service times are good considering average I/O size**
- **Queuing is the problem**
- **Drives comprising disk were clearly saturated**

RAID Example #3 Discussion

- Another disk processed 143.7 I/Os per second @ 7.8 ms per I/O
- Queue time was 2.1 ms
- Service time was 5.7 ms
- 28,786 Bytes/Transfer
- When all disks were combined, HBA was at the limit
- Solution was to add drives and HBAs

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SQL Statement Handling

- **Batch**
  - Group of SQL statements
  - Possibly hundreds or thousands of lines
  - Must be parsed and compiled into an optimized execution plan
- **Compilation and parsing can be**
  - Quite resource intensive
  - Time-consuming

SQL Statistics Object

- **Most important counters**
  - *Batch Requests/sec*
  - *SQL Compilations/sec*
  - *SQL Re-Compilations/sec*
- **Use with Cache Manager object *Cache Hit Ratio* counter**

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Batch Requests/sec

- **Number of select, insert, and delete statements**
- Each **of these statements triggers a batch event, which causes counter to be incremented**
- Note**: This** includes **each of these statement types that are executed within a stored procedure**

SQL Server Connection Affinity

- **Documented in Q299641**
- ***Batch Requests/sec* can be compared with System *Context Switches/sec* counter to highlight need for SQL Server Connection Affinity**
- **Network packet comparison with System *Context Switches/sec* counter also useful**
- **Processor *% DPC Time* counter can also be useful in this endeavor**

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Connection Affinity Example

- *Batch requests/sec* correspond almost exactly with System *Context Switches/sec*
- Network packet traffic also almost perfectly matches System *Context Switches/sec*
- Processor DPC activities correspond closely as well

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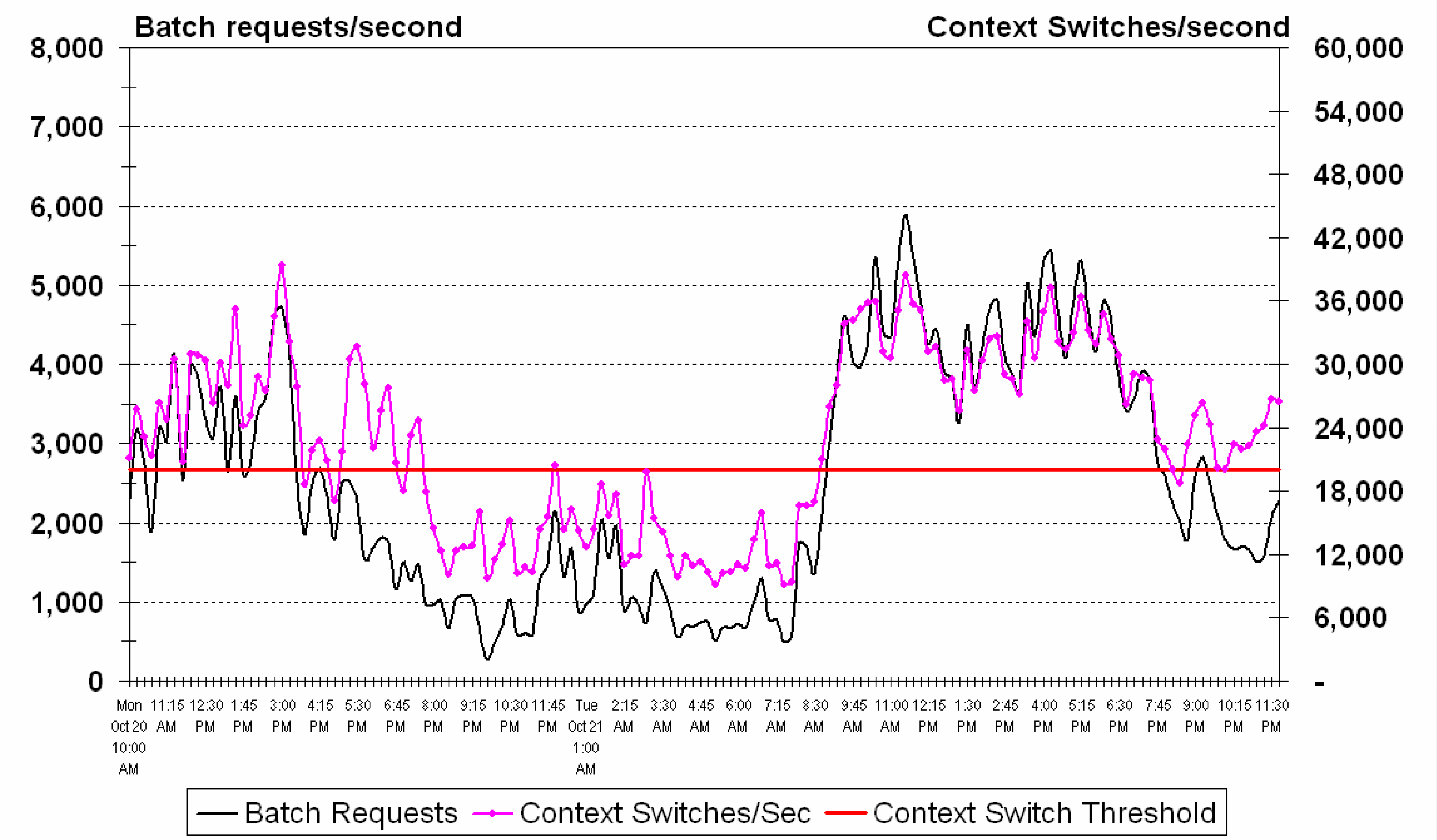
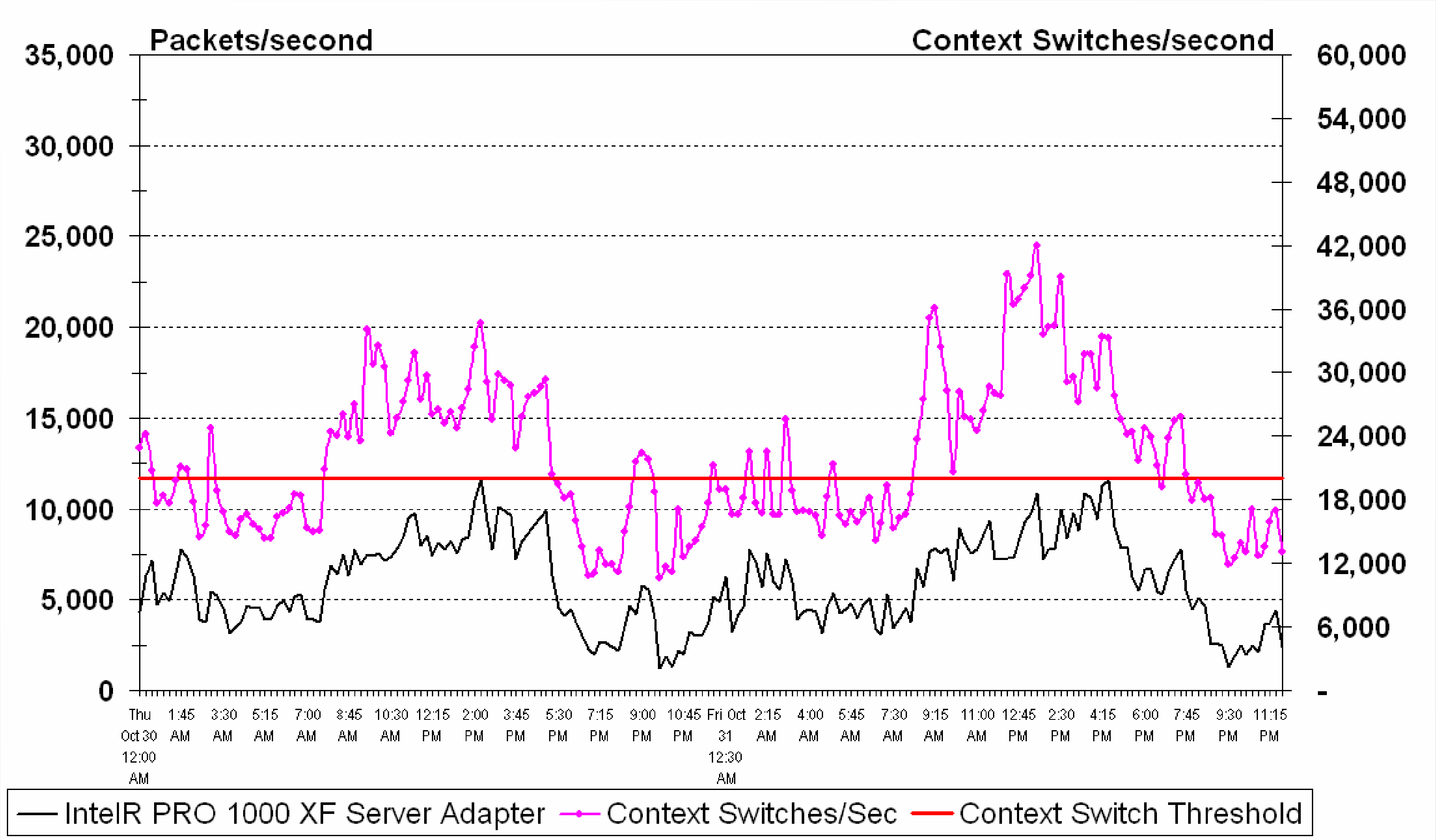
Batch Requests vs. Context Switching Graph



Network Card Packet Traffic & Context Switches Graph



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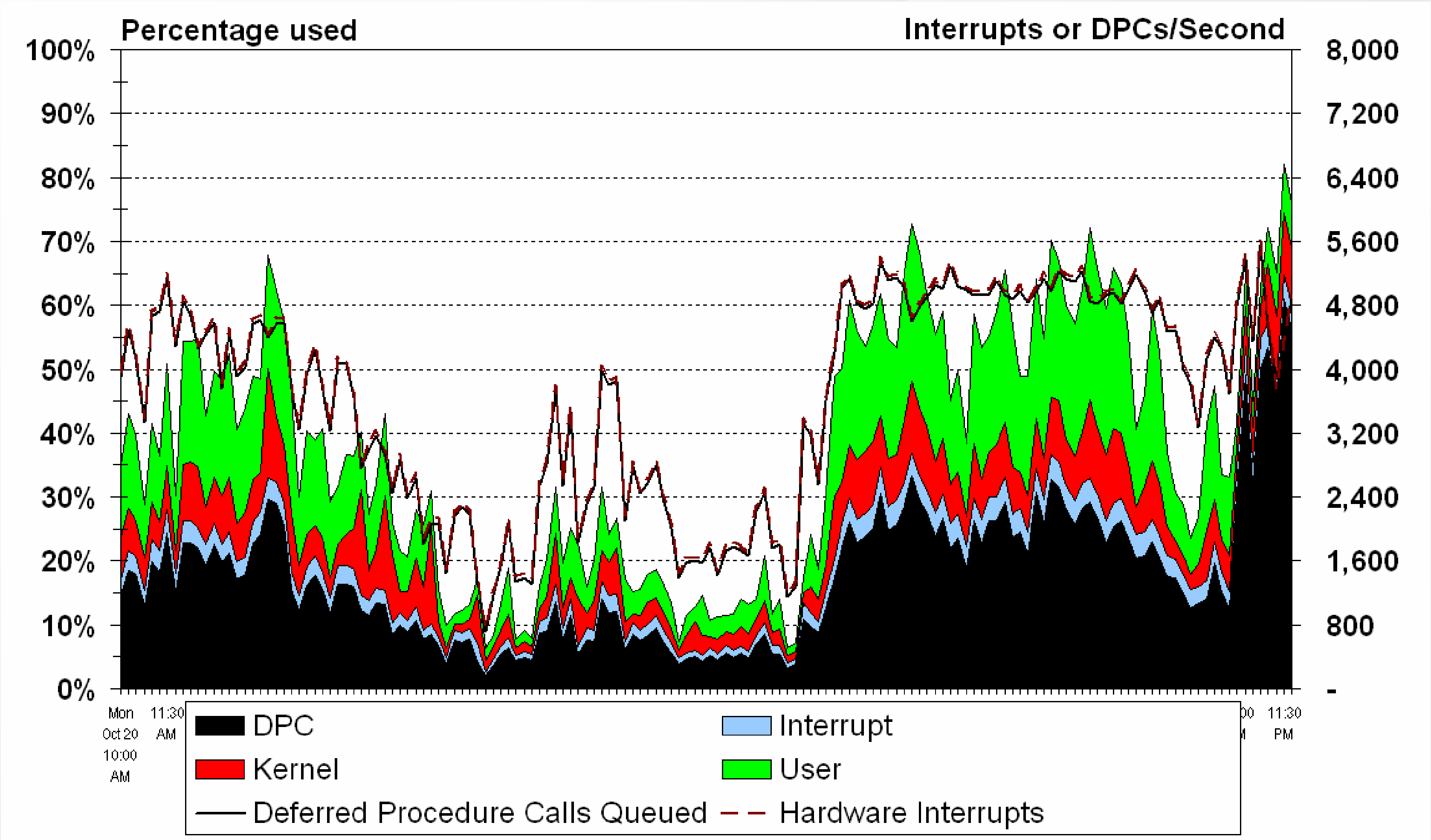
Processor Overview Graph



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Stored Procedure Compilation

- **Allows batch to be parsed and compiled only once (hopefully)**
- **Execution plan cached & re-used unless**
  - Removed from cache
  - Execution plan invalidated because of database changes
- **If stored procedure requested after removal or invalidation, it is recompiled**

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Cache Manager Object

- **Monitors various execution-related entities and their re-use**
  - Prepared SQL plans
  - Procedure plans
  - Trigger plans
  - Normalized trees
- **Used in SQL statement, stored procedure and trigger compilation, optimization, and execution**

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Cache Hit Ratio

- **Most important**
- **Should be 90% or higher**
- **Lower values**
  - Indicate too many ad-hoc queries
  - Often associated with higher values of
    - *SQL Compilations/sec* (SQL Statistics object)
    - *SQL Re-Compilations/sec*

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Guidelines

- ***SQL Compilations/sec*** **should be less than 40% of** ***Batch Requests/sec***
- **High compilation rates frequently**
  - Correspond with lower Cache Manager cache hit ratios
  - Indicate lack of stored procedure usage
  - Indicate possible memory shortage

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General Statistics Object

- **Useful in capacity planning situations**
- ***Logins/sec***
- ***Logouts/sec***
- ***User Connections***
- **Useful in calculating work per user or connection**

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Databases Object

- Each database is a performance counter instance
- Log and transaction counters most important

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Log

- **Database journal**
- **Used for recovery**
- **Changes written here before database**
- **Can dramatically hinder database performance if placed on busy disk**
- **Should be on own disk volume**
  - Minimizes disk head movement

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Log Flush Wait Time Counter

- Measures total time database commits waited for log flushes
- Obviously, should be small

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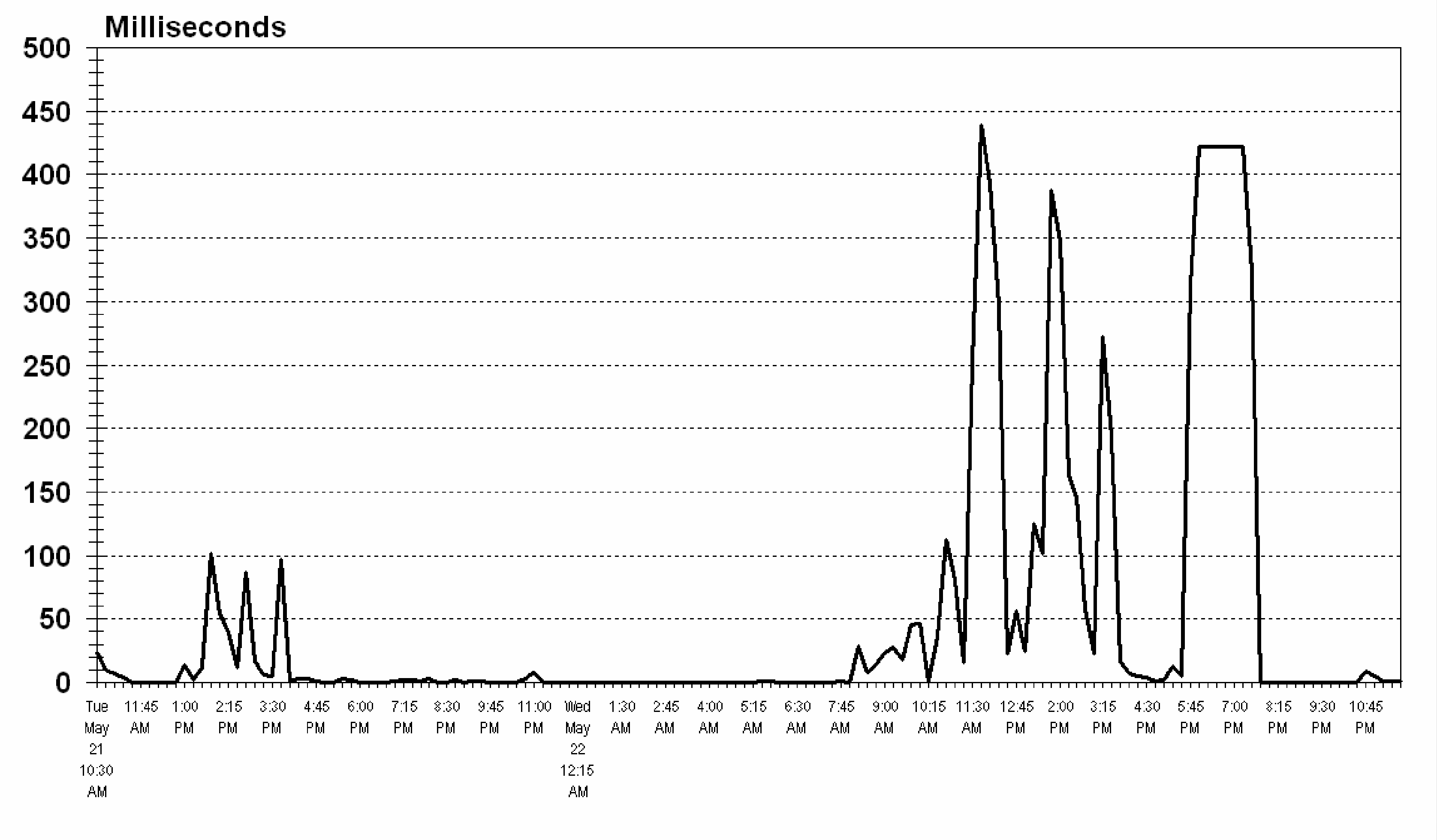
Average Log Write Waiting Times Graph



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Potentially Confusing Log Counters

- ***Log Flushes/sec*** **measures number of log buffers flushed to disk**
- ***Log Flush Waits/sec*** **measures number of flushes that had to wait**
  - Seems like an ideal number
- **Waits should be subset of total?**
  - Unfortunately, only in some cases

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Recovery Models

- **Full Recovery**
  - Every database change logged
  - Recover to last complete transaction
- **Bulk-logged**
  - Bulk operations minimally logged
  - Recover to end of transaction log backup
- **Simple**
  - Recover to last database backup
- **Waits a subset of Total only for Simple model, which is used least in production**

Other Database Counters

- *Transactions/sec* counter indicates which databases updated most frequently
- Particularly important because all Tempdb transactions are monitored

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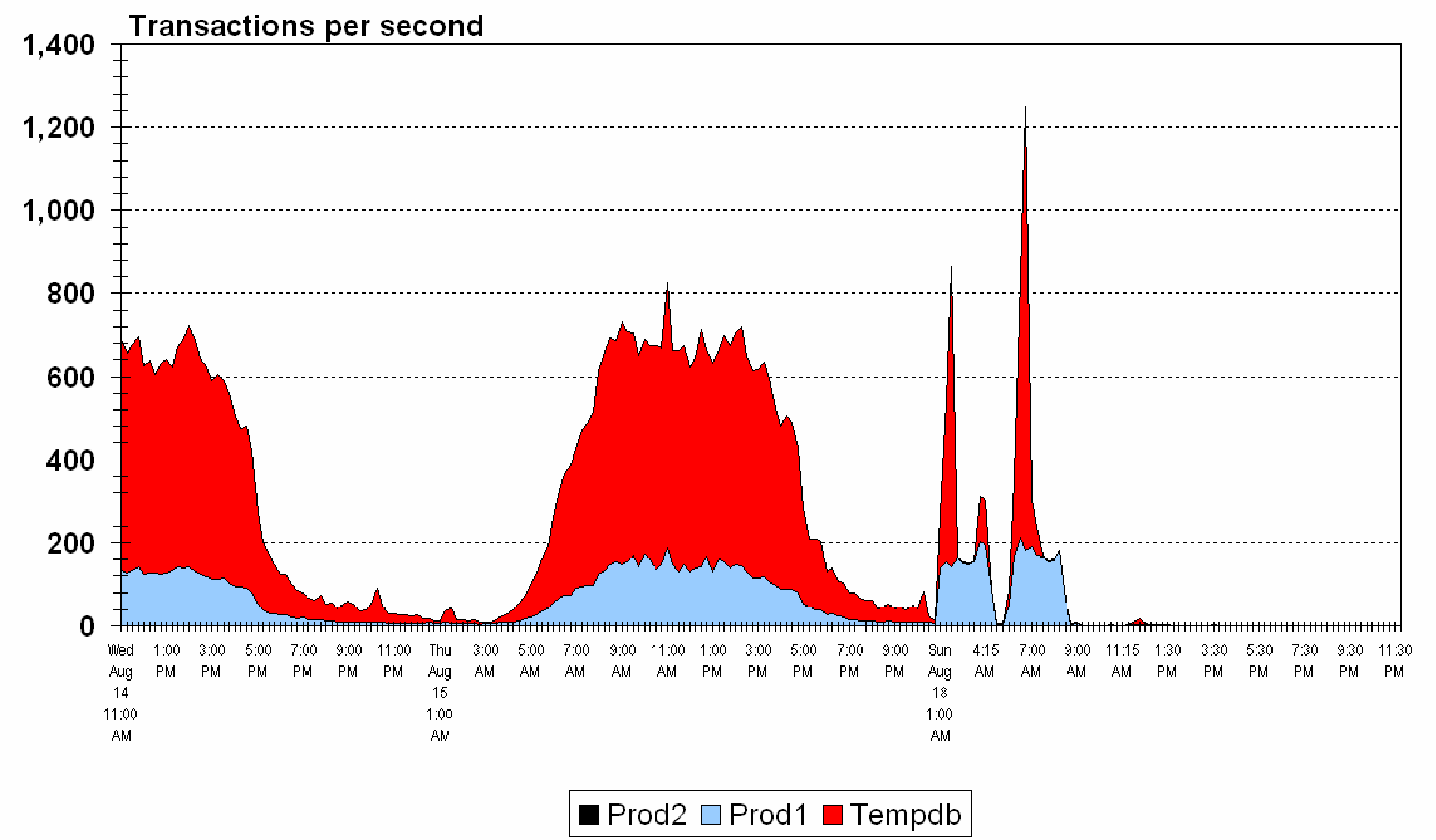
Tempdb

- Contains all temporary disk tables and workspaces
- Overuse can significantly hinder scalability
- Can become major bottleneck
- Use creatively designed queries to reduce Tempdb activity

Table Variables

- More efficient than pure tables
- Unfortunately, still use Tempdb as other temporary tables do
- Obviously, spreading Tempdb across several physical disks helps performance
- Not so obviously, increasing number of physical Tempdb files can reduce file access bottleneck, especially if Tempdb hit very hard

Database Transaction Volumes Graph



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Other Database Counters

- ***Bulk Copy Throughput/sec***
  - Useful for monitoring efficiency and frequency of flat file loads into database tables
- **Bulk copies/inserts can *easily* cause table escalation and locking**
- **Extremely efficient method for mass data loads**
- **Should be infrequent during online day**

Statistics

- Computed for tables and indices
- Enables query optimization
- Can be expensive to create or update depending upon sample size and frequency
- May want to update these manually during off-peak times instead of using automatic defaults
- *DBCC Logical Scan Bytes/sec* useful for detecting when statistics recalculated

Statistics

- **Set on by default in Tempdb**
- **Application Sentinel SQL Optimizer detects this**
- **Various options can be used to control impact of statistics update or recreation**
  - FULLSCAN
  - SAMPLE <n> PERCENT or ROWS
  - RESAMPLE
  - ALL or COLUMNS or INDEX

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Database Size Counters

- Log File(s) Size (KB)
- Data File(s) Size (KB)
- Log File(s) Used Size (KB)
- Percent Log Used
- Log Growths
- Log Truncations
- Log Shrinks

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Database Size Counters

- **Useful for determining**
  - Volatility of log files
  - Frequency of database and log expansion
  - Overall sizes of databases and their logs
- **Minimize frequency of database and log expansions**

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SQL Profiler

- **Bad reputation as a resource hog and performance killer need not be deserved**
- **Excessive resource consumption caused by**
  - Requesting entities that are changed constantly, e.g., locks and scans
  - Not using duration filter
  - Requesting too many entities
- **Updating GUI on monitored machine**

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Events

- **Entities that are monitored**
- **Careful use of templates can** greatly **reduce resource consumption**
- **Unfortunately, duration filter does not control Lock:Timeout event logging**
  - Most records returned will be zero duration
- **Lock:Deadlock and Lock:Deadlock Timeout still valuable events**

Starting Events

- **Following events usually unnecessary because start time can be calculated from ending records using duration**
  - Stored Procedures event class
    - SP:Starting, SP:StmtStarting, RPC:Starting
  - T-SQL event class
    - SQL:BatchStarting, SQL:StmtStarting

Other Events

- **Performance events**
  - Potentially very useful
  - Execution Plan, Show Plan All, Show Plan Statistics, and Show Plan Text difficult to decipher
- **Errors and Warnings events**
  - **Extremely** useful for highlighting inefficient sorts, missing statistics, inefficient joins
  - Low overhead

Warnings Summary

Database ID	Object ID	Event Name	Event SubClass Name	Integer Data	Count
1		**Sort Warnings**	**Single pass**		354
6		**Sort Warnings**	**Single pass**		9,006
6		**Sort Warnings**	**Multiple pass**		1,323
6	3	**Hash Warning**	**Hash recursion**	0	540
6	3	**Hash Warning**	**Hash recursion**	1	6
6	5	**Hash Warning**	**Hash recursion**	0	219
6	7	**Hash Warning**	**Hash recursion**	0	1,062
6	11	**Hash Warning**	**Hash recursion**	0	27,477
8		**Sort Warnings**	**Single pass**		153

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sp_trace Instead of Profiler

- Most efficient to use sp_trace commands to capture trace information because no GUI involved
- Better than using remote Profiler because session does not restart after network interruption

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sp_trace Commands

- sp_trace_create defines a trace, but does not start it
- sp_trace_setevent “adds or removes an event or event column to a trace”
- sp_trace_setfilter “applies a filter to a trace”
- sp_trace_setstatus “modifies the current state of the specified trace,” e.g., starts or stops trace

sp_trace

- **Can be used to “sample” trace data instead of continuously capturing data**
  - Collect for a few minutes and then stop
  - Restart collection at some future point
- **Useful on high-volume systems where any tracing could be noticed**
- **Job can be set up to implement this**

Using SQL Server to Analyze Traces

- **Traces can be imported easily into a SQL Server database using**
  - T-SQL commands
  - SQL Profiler
- **Stored Procedures can be used to**
  - Summarize data
  - Replace numeric IDs with meaningful text
  - Locate offending queries
  - Join trace data with other performance data

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Conclusions

- Many performance counters available with SQL Server
- Several have useful descriptions associated with them, but many do not
- Most objects and counters pertain to SQL Server as an entity without regard to a specific user, query, or database

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Conclusions

- When complex applications access multiple databases under one SQL Server instance, PerfMon counters alone do not provide enough information
- Extremely important to combine SQL Server performance information with system performance information, especially processor, memory, and I/O

Conclusions

- **SQL Query and SQL Profiler both provide extremely useful insights into how specific databases, queries, transactions, batches, and stored procedures perform**

Conclusions

- Many analysts believe that SQL Profiler cannot be run against a production system without severely damaging performance
- This need not be true!
- Lightweight Profiler templates or trace T-SQL routines can be used to gather very specific and inexpensive information regularly

Conclusions

- SQL Trace output can be imported into a SQL Server database for fast and easy analysis
- Once specific queries or stored procedures have been identified as offenders, additional data can be gathered for just those entities

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- Mark Friedman and Odysseas Pentakalos, *Windows 2000 Performance Guide*
- *Microsoft SQL Server 2000 Books Online*

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