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Performance Tuning a SAS Environment with Network Appliance Filers

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TECHNICAL REPORT

Network Appliance, a pioneer and industry leader in data storage technology, helps organizations understand and meet complex technical challenges with advanced storage solutions and global data management strategies.

Abstract

The goal of this document is to help customers maximize SAS application performance while reaping the benefits of network attached storage. Specifically, this is a guide for performance tuning in an enterprise class environment containing the SAS application and using a Network Appliance NAS (network attached storage) subsystem (aka Filer). The recommendations include configuration and parameter changes to the SAS environment, the platform specific UNIX® operating system, NFS (Network File System) client, and the NetApp® filer subsystem. The following UNIX platforms are covered: Solaris™, HP/UX, Tru64. This document is divided into two major sections. Section 1 discusses concepts and issues important to performance in a SAS/NetApp environment. Section 2 contains specific recommendations involving SAS deployment issues as well as operating system specific configuration recommendations. This document is a joint publication of SAS Institute and Network Appliance, Inc.

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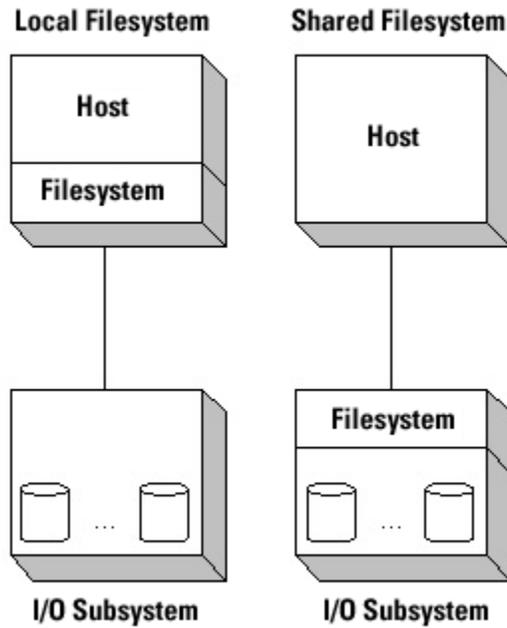
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1. General Issues

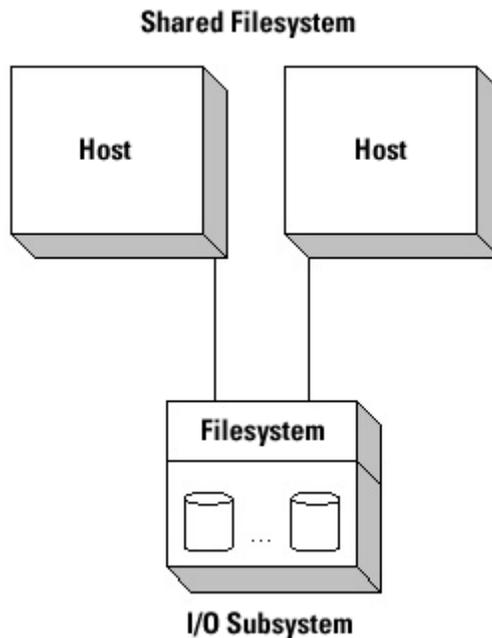
1.1. Local Filesystems versus Shared Filesystems

There are two filesystem paradigms of interest for SAS deployment.

Modern UNIX platforms offer two paradigms for filesystem deployment: local filesystems and shared filesystems.



These options are also referred to as "direct-attach or SAN" (local filesystem) or "network attached storage—NAS" (shared filesystem). Commercially these paradigms lead to very different storage subsystem products with different costs, capabilities, and scalability. Conceptually, they have only a couple of differences. Specifically shared filesystems allow more efficient use of storage resources by enabling multiple hosts to access data while keeping the data management responsibilities (and costs) off the host system.



The shared filesystem solution (NAS) scales to multiple hosts in a simple fashion that introduces very little overhead due to the additional hosts.

Shared filesystems (NAS) provide flexibility and increase storage efficiency for SAS environments.

1.2. SAS Performance

SAS application performance is a complex topic.

SAS is a powerful and diverse application. Specifying a "canonical" workload generated by SAS is impossible. However, at the core, SAS's main function is to load, manipulate, and store data. In any given SAS deployment, the underlying compute platform, operating system, and I/O infrastructure work together to service these data manipulation operations.

SAS performance is typically measured in terms of run time or "wall-clock time". Stated simply, the goal is to complete each SAS job in as little time as possible. There are two main components to performance in a SAS deployment: computational capability and I/O subsystem performance. An optimally tuned deployment requires a balanced consumption of these two resources.

SAS Workloads are different than Database Workloads

SAS performs most operations by doing large block (mostly) sequential I/O. This workload has very different characteristics than a typical Database On-Line Transaction Processing (OLTP) workload. As a result, typical performance tuning techniques that improve performance for OLTP (and other database) workloads are not necessarily applicable (or even positive) in SAS environments.

Exploring computational capabilities is beyond the scope of this document.

The first component in SAS performance is computational speed. Each platform has a CPU and memory subsystem with some level of capability. These capabilities vary among platforms and range from slow, inexpensive, single CPU platforms (e.g. PCs) to large, expensive, multiple CPU systems (e.g. 32 CPU Solaris platforms). Exploring the performance comparison of various computational platforms is beyond the scope of this document.

SAS application performance is very dependent upon I/O subsystem performance.

The second component in SAS performance is I/O subsystem performance. SAS workloads that manipulate large amounts of data are typically constrained more by I/O performance than by computational capabilities. Inspecting SAS I/O performance closely reveals several important performance characteristics.

SAS I/O Model

Modern compute platforms provide two broad classes of I/O interfaces: filesystems and raw devices. The SAS I/O model depends upon the filesystem interface technology. This means that in any deployment, in addition to the raw device or underlying disk platform,

SAS requires a filesystem interface and SAS I/O performance is dependent upon the performance of that interface.

Megabytes per Second

The most obvious characteristic of I/O performance is bandwidth. Bandwidth is typically stated in terms of megabytes per second (MB/s) the I/O subsystem is capable of delivering to the SAS application. Obviously the more MB/s a subsystem can deliver, the faster a SAS job can complete. The MB/s capability of an I/O subsystem is a result of many factors, including: the connection technology and speed (e.g. SCSI or Fibre Channel or Ethernet), the storage hardware platform (e.g. JBOD, small RAID boxes, NetApp filers), and the number and type of disk drives.

CPU Cost of I/O

The next characteristic of I/O performance is the CPU cost of doing I/O. The goal is to achieve high bandwidth levels at very low CPU utilizations. Although the absolute cost of I/O varies among host platforms, there are some general characteristics.

- First, the lowest cost I/O typically comes from a native filesystem implementation (such as Solaris's UFS) running on top of a direct attached JBOD (see next section for comparison of different connection paradigms) or SAN platform. The native filesystem is tightly integrated with the host operating system and is highly tuned to minimize I/O costs. Additionally, the native filesystems provide a single system paradigm (i.e. no shared data among multiple hosts) that minimizes the protocol overhead associated with managing data coherency among multiple consumers (e.g. locks).
- The next lowest cost I/O typically comes from native implementations of Network File System (NFS) implementations. Like native filesystems, NFS implementations are typically tightly integrated with the host operating system. Unlike native filesystems, NFS implementations provide mechanisms for sharing data among multiple host machines. This functionality has protocol overhead not associated with native filesystems.
- The least cost effective I/O typically comes from third party filesystem implementations layered on top of either direct attached JBODs or SAN attached platforms. These filesystems are not as tightly integrated with the operating system as native file systems or NFS implementations. These third party filesystems also provide advanced data sharing features (such as Clustered Filesystems) but ultimately pay a very high CPU cost for this functionality.

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I/O Caching

The final and most subtle characteristic of I/O performance involves I/O buffer caching on the host platform. The highest performing I/O solution is one that minimizes the actual amount of physical I/O traffic. For instance, a SAS job with a dataset that is smaller than the amount of host memory needs to only fetch the data from the storage subsystem once. All subsequent accesses to that data can be serviced from the host buffer cache, therefore minimizing I/O traffic and maximizing performance.

The concepts and techniques associated with I/O buffer caching are well understood. Unfortunately, the specific implementation and algorithm choices made from platform to platform vary widely. Additionally, a single platform may perform different caching techniques depending on which filesystem implementation is being used (e.g. UFS vs NFS). This variance in I/O caching can provide interesting opportunities and challenges to maximizing I/O performance in a SAS environment. Beware of performance issues that are a result of caching techniques.

1.3. SAS Environments

SAS NFS performance tuning techniques depend upon the specific deployment.

SAS NFS deployments have several important characteristics: SAS version, single host versus multiple hosts configuration, number of SAS sessions per host, and host memory size versus SAS data set size. This section outlines each of these characteristics

1.3.1. SAS Versions

SAS currently has three major releases of interest: 6.12, 8.2, and 9.0. Additionally, for some Operating System platforms there are multiple SAS versions based on the underlying compute architecture. From a performance standpoint there are several factors to consider in selecting (or changing) SAS versions.

1.3.2. SAS Work

Most SAS programs depend heavily on the ability to create and access temporary data files quickly and effectively. The location of this temporary data (referred to typically by the directory name "SAS Work") is configurable via the SAS configuration file. The data files created and accessed in SAS Work are not shared among multiple SAS sessions or multiple hosts. Specifically, the data files in SAS Work are specific to a given SAS user session. Given this property of SAS Work, the specifics of where SAS Work is located and which locking and caching options are set strongly impacts overall SAS performance.

For SAS NFS deployments SAS Work CAN be located on the NFS server (as opposed to placing SAS Work on local storage). In general, SAS Work should be accessible via an NFS mount point that is separate from other SAS data. This allows flexibility in specifying the locking and caching behavior of the SAS Work files. (See next section for specific deployment recommendations.)

1.3.3. Single versus Multiple SAS Sessions

On a given host running the SAS application, there can be either a single SAS session (or user) or multiple SAS sessions. The performance and scalability of multiple sessions is dependent upon the underlying platform's capabilities. A full exploration of how many SAS sessions a given platform can support, while important, is beyond the scope of this discussion.

There are however several aspects of multiple SAS sessions that are important for NFS deployments. Specifically, whether or not the multiple sessions share the same or different SAS Work space is an important issue. Additionally, the amount of memory each

SAS session uses and as a result, the amount of memory left for operating system caching is an important issue. The optimal resolution of these issues is specific to the overall deployment architecture and is discussed in a later section.

1.3.4. Single versus Multiple Host Deployments

SAS deployments are sometimes associated with very large data sets. Accessing and processing this data through a single host can be cost prohibitive and sometimes impossible with today's UNIX compute platform technology. As a result, when shared filesystems are used, these deployments often involve multiple host computers processing the data simultaneously. There are several techniques for deploying and accessing/processing the data simultaneously. A full discussion of these techniques is beyond the scope of this discussion.

There are however several aspects of multiple SAS hosts deployments that are important for NFS deployments. The main issue is the applicability of locking and caching techniques that enhance single host performance. A secondary issue is the placement and usage of SAS Work directories for each individual host. The optimal resolution is again specific to the overall deployment architecture.

1.3.5. Memory Configuration

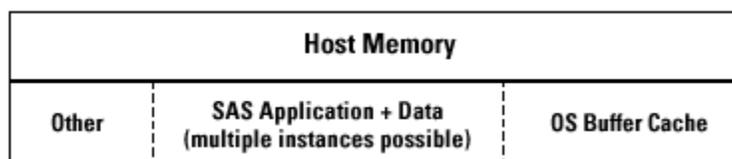
SAS performance can be strongly affected by host memory size, SAS memory configuration settings, and data set size.

Each SAS session specifies (or takes a default) configuration file that specifies several options for the session. Of particular interest for I/O performance are:

- memsize: specifies how much host memory a given SAS session is allowed to use
- sortsize: specifies how much data to sort at one time (each sort is broken into multiple load, sort, store temporary data phases)
- maxmemquery: specifies how much memory a query is allowed to use.

In addition to the SAS settings, performance also depends on the amount of host memory, the amount of memory used by the application, and the amount of memory left for the operating system to allocate to the buffer cache. Note also that multiple SAS sessions can be running on a single host, increasing the total memory used for the SAS application and datasets.

Selecting the optimal setting for memory settings depends on the relationship of the SAS dataset size to the host memory size. Consider a simple, single SAS session host configuration. Host memory, SAS memory, and OS buffer cache have the following relationship:



For purposes of this discussion, host memory is divided into three categories: SAS application memory, OS buffer cache, and "other". The SAS application memory is limited by the configuration variable memsize. In general, the operating system requires some memory for normal OS function, and allocates the rest as buffer cache. The OS buffer cache is used to hold recently read and pre-fetched data as well as recently written data.

This simple memory usage description results in two classes of SAS data sets: data sets that are smaller than host memory and data sets that are larger than host memory. For datasets that are smaller than host memory, increasing the SAS memory variables to values larger than the data set size will result in minimal I/O and maximum performance. For data sets larger than host memory, reducing SAS memory consumption and thereby allowing more memory for the OS buffer cache increases prefetch effectiveness and write caching, maximizing I/O performance and effectiveness.

The same set of variables and considerations apply for host environments with multiple SAS sessions. However, the SAS application and dataset size is computed as the sum of all active sessions.

1.4. General NFS Performance Tuning

Network File System - Overview

NFS can be a "high performance I/O infrastructure".

NFS was originally created as a method for sharing data on a local area network. As network technologies advance NFS becomes more capable. Specifically, many organizations now use Network Attached Storage (NAS) as the primary technology for connecting host computers to storage subsystems. Making the transition from a simple shared environment to a high performance I/O infrastructure requires NFS configuration modifications and tuning beyond typical default or public network settings.

NFS Clients are not all created equal, nor are they configured the same way.

Each UNIX operating system (e.g. Sun's Solaris, HP's HP-UX, IBM's AIX) has an NFS client. The purpose of this client is to translate file operations, such as read and write, into NFS requests over a network. These clients share one very important characteristic: adherence to a standard protocol definition. This means that each OS client will function correctly in conjunction with a standard NFS server platform. For example, NetApp filers provide a standard NFS server that can connect with all flavors of UNIX NFS clients.

Unfortunately, the implementation and parameterization of an NFS client is very platform specific. This means that some NFS clients perform well under some workloads and not others based on various configuration settings. Additionally, which workloads perform optimally varies based on the platform.

Network Appliance Filers are a key component of a high speed NFS I/O infrastructure.

In an NFS deployment there are two components: NFS Clients and NFS Servers. For the

duration of this paper the only NFS Server discussed is the Network Appliance filer family of NFS Servers.

1.4.1. Network Configuration

Network Topologies

Deploying NFS as a high speed storage infrastructure requires either a private network, a dedicated VLAN, or a point-to-point configuration.

There are multiple methods for deploying NFS attached storage.

1. Public network: Storage targets are connected to an internal network, competing for network resources with all other network traffic.
2. Private network: Storage targets are connected to a dedicated network that carries only storage traffic.
3. Virtual LAN (VLAN): Storage targets are connected to the internal network, but "virtual LANs" separate storage traffic from other network traffic. (This requires networking components with VLAN capabilities.)
4. Point-to-Point: A host is connected to its storage through a dedicated, point-to-point, non-switched network.

A public network is not well suited for high-speed storage infrastructure demands. Other, non-performance critical, data traffic consumes bandwidth. Many infrastructures contain older networking components that are not high performance. A high-speed NFS deployment requires either a private network, a dedicated VLAN, or a point-to-point configuration.

Network Speeds

Deploying NFS as a high speed storage infrastructure requires Gigabit Ethernet.

Current IP network technology has several speed alternatives. Common choices are 10 Mbit (mega-bit), 100 Mbit, 1 Gb (or 1000 Mbit.) Many company's public networks (aka intranets) are currently deployed on 100 Mbit (or even 10 Mbit) technology. Deploying Gigabit networks requires upgrading to high speed NICs (Network Interface Cards) and Gigabit capable switching infrastructures. Gigabit deployment continues to become cheaper and easier as the required components become commodities.

Below is a table comparing theoretical bandwidth limits of various connection technologies. Additionally, the table lists average latency (in milliseconds) to transfer 64 KB (kilobytes) of data.

Connection Technology	Theoretical Bandwidth	Latency for 64 Kb transfer
10Mbit Ethernet	1.25 MB/s	50 ms
100 Mbit Ethernet	12.5 MB/s	5 ms

1Gb Ethernet	125 MB/s	0.5 ms (500 us)
1 Gb Fibre Channel	125 MB/s	0.5 ms (500 us)
SCSI-3	160 MB/s	0.4ms (400us)
10 Gb Ethernet (future)	1.25 GB/s	0.05 ms (50 us)

Table 1. Alternative storage connection technologies.

High speed storage infrastructures can also be deployed with such technologies as 1Gb Fibre Channel or SCSI-3. An NFS infrastructure that delivers similar performance requires the bandwidth associated with Gigabit Ethernet.

Gigabit Ethernet technology is available for all UNIX Systems. Enterprise applications that require high performance should always be deployed with gigabit technology. Network Appliance filers support 10 Mbit, 100 Mbit, and 1 Gbit Ethernet infrastructures. The 10/100 Mbit components are standard. Gigabit Ethernet NICs are available as add-on options.

Network Protocols

UDP delivers more performance than TCP in high speed storage infrastructures.

Most UNIX environments provide two protocol options for an NFS to IP transport: TCP (Transmission Control Protocol) and UDP (User Datagram Protocol). In clean networks (e.g. point-to-point) UDP is a higher performance protocol than TCP. In general network infrastructures however TCP provides more predictable (less variable) performance due to the flow control mechanisms employed. In high speed storage infrastructures the benefits of the consistent predictability of TCP must be weighed against the potential performance gains of UDP.

In addition to the TCP/UDP options, network deployments must also select which version of the NFS protocol to use, Version 2 or Version 3. NFS version 3 should be used when available.

Maximum Transfer Unit (MTU) - Jumbo Frames

NFS storage infrastructures gain increased bandwidth and increased efficiency with Jumbo frames.

IP networks can configure the Maximum Transfer Unit (MTU). This value specifies the maximum packet size for each transfer on the IP wire. The default value for this is 1500 bytes. Some network components (switches and NICs) support larger MTU size, specifically, 9000 bytes. An MTU size of 9000 is typically referred to as having "Jumbo frames".

Jumbo frames provide two advantages:

1. More efficient use of the IP wire: larger packets means that transfer overheads are amortized over more data bytes.

2. Fewer host interrupts per data unit transferred which translates to less host CPU consumption per data unit transferred.

Note that Jumbo frames are not always supported. Not all Ethernet NICs support Jumbo frames. Also many Ethernet routers do not route jumbo frames or in some cases will route them only after breaking them into many small transfers, negatively impacting performance. All jumbo frame environments should be in switched or point-to-point configurations.

1.4.2. NFS Configuration

NFS clients require parameterization changes to achieve optimal performance in high-speed deployments.

Typical NFS deployments for applications other than high-speed I/O infrastructures require no changes to the default configuration for basic operation. However, the default settings are insufficient for high-speed deployments. Specifically, each NFS client has a default set of variable settings to control important concurrency and throughput settings. The most common variables control:

1. Maximum threads: concurrent threads performing NFS operations on behalf of the user application
2. Number of read aheads: concurrent, asynchronous read aheads performed on behalf of the user applications.
3. Hiwater transmit and receive values for UDP (`udp_rcv_hiwat`, `udp_xmit_hiwat`)
4. Maximum read and write transfer size (`rsize`, `wsize`)

The technique for setting these variables and the specific names vary among platforms.

1.4.3. Operating System Parameters

Autonegotiation

Ensure transfer speeds and flow control settings are enabled and configured correctly.

Between every NFS Client and NFS Server there are three important network components: Host NIC, Switch, Server NIC. These three components (or in a point to point configuration, the two NICs) must agree on and equally support two important parameters: transfer speed and flowcontrol settings.

Kernel Patches

High performance NFS clients are still evolving. Aggressively follow OS vendor provided NFS client patches.

Each platform vendor periodically delivers patches for various OS related issues (aka bugs). A high-performance I/O infrastructure often requires the very latest patch levels.

1.5. Caches and Locks

A high performance SAS NFS deployment must carefully scope sharing, locking, and caching to maximize performance.

A primary feature of NFS is the ability to share data coherently across multiple host platforms. The NFS file server provides a centralized location for managing data sharing, locking, and coherency. Each individual host can have high-speed, cacheable, coherent access to the data. This key feature of NFS also provides a challenging environment for implementing a high-performance infrastructure.

NFS Client Caching

Caching, with respect to the NFS client, has several aspects:

1. **Data read once can be cached in the host buffer cache.** Subsequent accesses to the same data can be satisfied from the host cache without fetching the data from the NFS server on each read. This property also enables prefetching: the host senses a sequential access pattern and asynchronously prefetches data on behalf of the application. When the application actually requests the data, the data is found in the host buffer cache—a performance benefit.
2. **Data written to the host buffer cache is first written to the NFS Server (cleaned).** Subsequent reads to that data can be satisfied from the host OS buffer cache. So data that is written and then read sees a performance benefit from the buffer cache.
3. **Data set size plays a role in host buffer caching.** Data set sizes that are smaller than the available OS buffer cache (which is a subset of total host memory) can benefit from caching. Data sets that are larger than the OS buffer cache and have a non-predictable I/O pattern are difficult to cache. Although the host attempts to cache the data, the probability of accessing data in the cache decreases as a function of the ratio of data set size to buffer cache size. The end result is that most data is fetched from the NFS server on most accesses.

The NFS client depends on the NFS server to maintain cache coherency across multiple platforms, typically by the management of "attributes". Attributes and attribute caching are beyond the scope of this discussion.

Force Caching Off

Under certain applications performance may be enhanced by purposely setting up the NFS client to NOT cache any data. This technique of forcing the NFS client to not cache is often referred to as "forcedirectio". On some platforms "forcedirectio" is available for both NFS and the native filesystem. However, some platforms do not have the "forcedirectio" option at all. **SAS NFS deployments do not benefit from this feature.**

Locks

Applications accessing data via NFS can maintain data coherency with file and region locks. The application can choose to lock a file, guaranteeing that all accesses to the data from multiple hosts find the correct data. This technique is used by SAS to ensure multiple SAS sessions can access data files coherently.

Unfortunately, some NFS clients take a brute-force approach to maintaining coherency of locked data. Specifically, on some platforms, locking a file or data region results in all data associated with the file being invalidated from cache when the file is closed. This creates a performance degradation, especially when comparing performance with a native filesystem that maintains the data in cache for subsequent opens and reads.

Local Locking

As an antidote to the "locks == invalidate cache on close" issue, some platforms provide the concept of "local locking". NFS filesystems mounted with a "local locking" option enabled have two properties:

1. **Locks are scoped only to the local host.** Applications sharing data on that host and using locks to provide coherency are safe. However, any other host accessing that data DOES NOT obey the locking/coherency semantics. This is acceptable for some deployments, and not others.
2. **Host buffer caching IS enabled.** Since all locking and data activity (of interest) happens locally on the host, caching and coherency work the same as with a native filesystem. Specifically, data is maintained in cache across close/open.

Each SAS NFS deployment can maximize performance by understanding and applying the most appropriate locking and caching options. The next two sections discuss how to apply these settings in different deployments.

Weak Cache Consistency

Beware poor implementations of NFS "Weak Cache Consistency" algorithms. NFS Version 3 provides for implementation of a "Weak Cache Consistency" algorithm. This basically allows two or more clients to write-share a file while maintaining some level of consistency. Unfortunately, some implementations cause "false invalidations". Basically, even in a single host environment, a recently written set of data may be invalidated, even though no other hosts are accessing the data.

A scenario where this behavior decreases performance is quite common in SAS. Consider for example a common "data sort". The data sort has two phases:

- (1) read the original data, perform a partial sort and write the partially sorted data to a "temporary file"
- (2) read the temporary file, perform a merge, and write the result to the final data destination

An important factor in this operation is the relationship of temporary data size to OS buffer cache size. If the temporary data set is too large to fit in the OS buffer cache, then the false invalidates do not decrease performance. However, if the temporary data set fits in the OS buffer cache, then the invalidates are precisely the wrong behavior.

Determining whether a specific platform suffers from the weak cache consistency issue is simple. Here is a set of steps for examining this behavior on a Solaris system:

(1) Create a 10M "temporary file" using dd. Monitor the I/O using iostat

- iostat -xz 1 (in a window separate from the dd window)
- dd if=/dev/zero of=temporary.file bs=4096 count=2500
- Note on the iostat output that 10M is written

(2) Read the 10M "temporary file" using dd. Continue the iostat monitor.

- dd if=temporary.file of=/dev/null bs=4096 count=2500
- Note on the iostat output the 10M is read from disk or not

If the false invalidates happen, then step (2) will cause data to be read from disk (as viewed in iostat). If the false invalidates do not happen, then step (2) will result in NO actual disk traffic (as viewed by iostat). This comparison can be performed against native filesystems and against any NFS filesystems.

Note: This issue does not exist in NFS Version 2. However, V2 is limited to accessing a maximum of 2G sized files. This is a limiting factor for many modern applications.

2. Specific Tuning Recommendations

2.1. Performance Tuning SAS Configuration

This section discusses specific steps necessary to tune different SAS configurations for optimal I/O performance in an NFS environment.

2.1.1. Infrastructure and Operating System Settings

Infrastructure configuration

- Deploy a gigabit Ethernet infrastructure
- Enable Jumbo frames at the Ethernet level
- Evaluate transport protocol (UDP or TCP)

Operating System Tuning

- Install latest kernel patches
- Disable auto-negotiation for Ethernet connections
- Increase maximum NFS threads, hi and low water marks, and streams settings

Network Appliance Filer Configuration

- For maximum performance in a single filer environment:
 - create one (1) volume using all disks (except for spares). This configuration assures maximum performance from the disks.

- Store SAS Work in same volume as data files, but mount SAS Work through a separate mount point

2.1.2. Single Host Configurations

Single Host Environments

- If multiple SAS sessions, all sessions share same SAS Work mount point
- SAS Work mount point is mounted with "local locking" option if available. In the absence of "local locking" option, enable SAS with "filelocks=none" option.
- Mount all other data mount points with "local locking" if available. However, do NOT disable filelocks as a substitute for "local locking".

2.1.3. Multiple Host Configurations

Multiple Host Environments

- If multiple SAS sessions on a host, all sessions share same SAS Work mount point
- SAS Work mount point is mounted with "local locking" option if available. In the absence of "local locking" option, enable "filelocks=none" option to turn off file locking. Then use the LIBNAME command to selectively enable locks for all non-SAS Work directories.
- Mount all other data mount points WITHOUT "local locking" option.

Summary Matrix

This is a matrix summarizing the recommendations for:

- where to place SAS Work and which mount options to use
- where to place SAS data files and which mount options to use

The decision criteria are:

- which operating system is in use
- the availability of the "llock" mount option
- which SAS version is in use
- whether or not data files are "write-shared" by multiple hosts

Solaris	SAS® 8.2	SAS® 9.0
SAS Work Files	If Solaris "Weak Cache Consistency" bug #(4407669) patch is available, then: Place SAS Work on filer (according to above guidelines) Mount SAS Work with "llock" option.	If Solaris "Weak Cache Consistency" bug #(4407669) patch is available, then: Place SAS Work on filer (according to above guidelines) Mount SAS Work with "llock" option.
	If Solaris "WCC" patch is NOT available.	If Solaris "WCC" patch is NOT available.

	<p>then: Use SAS "filelocks=none" option (as described above.) Re-enable filelocks for all data other than SAS Work (as described above).</p>	<p>then: Place SAS work files on non-NFS filesystem. Watch for Solaris patch availability.</p>
SAS Data Files	<p>Place all Data Files on the filer (according to above guidelines) Enable Prefetch settings (as outlined above) If data files are NOT write shared among multiple hosts, then mount with "llock" option. If data files ARE write shared among multiple hosts, then do NOT mount with "llock" option. Consider creating separate mount points for write shared and non-write shared data files.</p>	

HP-UX	SAS® 8.2	SAS® 9.0
SAS Work Files	<p>If "llock" option is available, then: Place SAS Work on filer (according to above guidelines) Mount SAS Work with "llock" option.</p> <p>If "llock" option is NOT available, then: Use SAS "filelocks=none" option (as described above.) Re-enable filelocks for all data other than SAS Work (as described above).</p>	<p>If "llock" option is available, then: Place SAS Work on filer (according to above guidelines) Mount SAS Work with "llock" option.</p> <p>If "llock" option is NOT available, then: Place SAS work files on non-NFS filesystem. Watch for "llock" option availability on HP-UX.</p>
SAS Data Files	<p>Place all Data Files on the filer (according to above guidelines) If "llock" option is available, then: If data files are NOT write shared among multiple hosts, then mount with "llock" option. If data files ARE write shared among multiple hosts, then do NOT mount with "llock" option. Consider creating separate mount points for write shared and non-write shared data files.</p> <p>If "llock" option is NOT available, then: No action required. Watch for "llock" option availability on HP-UX.</p>	

2.2. Solaris Configurations

This section specifies commands and options for tuning a Sun Solaris configuration.

Operating System Version

Optimal performance is gained by using Solaris 2.9 or Solaris 2.8.

Gigabit Ethernet Configuration

On the Solaris Platform

- Sun provides Gigabit Ethernet cards in both PCI and SBUS configurations. The PCI cards deliver higher performance than the SBUS versions.
- Syskonnect is one third party NIC vendor that provides Gigabit Ethernet cards. The PCI versions have proven to be high performance NICs.

On the NetApp filer

- NetApp filers provide Gigabit Ethernet NIC's as an optional connection technology.

Enabling Jumbo Frames

On the Solaris Platform

- Sun Gigabit Ethernet cards do NOT support jumbo frames.
- Syskonnect (third party NIC vendor) provides SK-98xx cards which do support jumbo frames.

To enable jumbo frames execute the following steps:

- Edit /kernel/drv/skge.conf
- uncomment the line JumboFrames_Inst0="On";
- Edit /etc/rcS.d/S50skge
- add line: ifconfig skge0 mtu 9000
- Reboot

On the NetApp filer

- Verify the correct MTU setting
 - On the filer issue the command: ifconfig <interface>
 - Verify the mtu value is 9000
- Change MTU to 9000
 - Change the value with the command: ifconfig <interface> mtusize 9000
 - Make this permanent by adding to /etc/rc on the filer

NFS Protocol Configuration

On the Solaris Platform

- Edit the /etc/vfstab
- For each NFS mount participating in the high speed I/O infrastructure make sure the mount options specify UDP version 3 with transfer sizes of 32K:
 - ...,vers=3,proto=udp, rsize=32768, wsize=32768,...

On the NetApp filer

- Ensure NFS v3 is enabled by entering the command
 - `options nfs.v3.enable on`

Kernel Patches

On the Solaris Platform

- List of desired Solaris 8 patches
 - 108528-15 - KJP
 - 108727-17 - NFS
 - 109783-01 - NFSD
 - 111197-02 - MOUNTD
 - 111958-02 - STATD
 - 111393-02 - AUTOMOUNTD
 - 110700-01 - AUTOFS
 - 110710-01 - NSCD
- List of desired Solaris 9 patches
 - 113184-01 - KJP
 - 112955-01 - AUTOFS
 - 112975-01 - KAIO

Autonegotiation

On the Solaris Platform

Solaris GigE cards need to have auto-negotiation forced off and transmit flow control forced on.

This can be done by

- Edit `/etc/system` and add the following lines
- `set ge:ge_adv_1000autoneg_cap=0 # force auto-negotiation off`
- `set ge:ge_adv_pauseTX=1 # force transmit flow control on`

With Sysconnect Gigabit Ethernet cards for Solaris systems

- Edit `/kernel/drv/skge.conf` and verify the following lines exist

- AutoNegotiation_A_Inst0="Off";
- DuplexCapabilities_A_Inst0="Full";

On the NetApp filer

- Verify the filer flow control setting is set to "full"
 - On the filer command line issue the command: `ifconfig <interface>`
 - Verify that the flowcontrol setting is "full"
 - If not, issue the command: `ifconfig <interface> flowcontrol full`

NFS Tuning

In Solaris, the most common method for setting NFS config variables so they remain persistent across system reboots is to edit the file `/etc/system` to include the following entries

```
set nfs:nfs3_max_threads=64
set nfs:nfs3_nra=64
set sq_max_size=VALUE
```

VALUE is calculated as 400 units for each Gigabyte of RAM (e.g. 2G RAM = 800 units). Hiwater settings are typically added to the `/etc/rc/init.d` script by adding the following lines:

```
nnd -set /dev/udp udp_rcv_hiwat 65535
nnd -set /dev/udp udp_xmit_hiwat 65535
```

Note that a system reboot is required for these variable changes to take affect.

Local Locking

On the Solaris Platform

- Edit the `/etc/vfstab`
- For each NFS mount qualified for "local locking" add the `llock` option
 - `...,vers=3,proto=udp, llock, ...`

2.3. HP/UX Configurations

This section specifies commands and options for tuning an HP-UX configuration.

Operating System Version

Optimal performance is gained by using Version 11i and later.

Gigabit Ethernet Configuration

On the HP-UX Platform

- HP-UX supports Gigabit Ethernet NIC's

On the NetApp filer

- NetApp filers provide Gigabit Ethernet NIC's as an optional connection technology.

Enabling Jumbo Frames

On the HP-UX Platform

- Issue the command: `lanadmin -M 9000 1`
- Add this change to `/etc/rc` to maintain settings across boots
- For each Gigabit Ethernet interface (IFACE) issue the command:
 - `ifconfig IFACE mtusize 9000 up`
- Add these changes to `/etc/rc.config.d/hpgelanconf` to maintain settings across boot:
 - `HP_GELAN_MTU[0]=9000`

On the NetApp filer

- Verify the correct MTU setting
 - On the filer issue the command: `ifconfig <interface>`
 - Verify the mtu value is 9000
- Change MTU to 9000
 - Change the value with the command: `ifconfig <interface> mtusize 9000`
 - Make this permanent by adding to `/etc/rc` on the filer

NFS Protocol Configuration

On the HP-UX Platform

- Edit the `/etc/checklist`
- For each NFS mount participating in the high speed I/O infrastructure make sure the mount options specify UDP version 3 with transfer sizes of 32K:
 - `...,vers=3,proto=udp, rsize=32768, wsize=32768,...`

On the NetApp filer

- Ensure NFS v3 is enabled by entering the command
 - `options nfs.v3.enable on`

Kernel Patches

On the HP-UX 11i Platform

- Latest patches can be found at <http://itrc.hp.com>

Autonegotiation

On the HP-UX Platform

- No auto-negotiation changes required. In /etc/rc.config.d/hpgelanconf, HP_GELAN_AUTONEG must be set to "1" for proper operation.

On the NetApp filer

- Verify the filer flow control setting is set to "full"
 - On the filer command line issue the command: ifconfig <interface>
 - Verify that the flowcontrol setting is "full"
 - If not, issue the command: ifconfig <interface> flowcontrol full

NFS Tuning

In HP-UX, the most common NFS tuning variable is located in /etc/rc.config.d/nfsconf:

```
NUM_NFSIOD=32
```

Note that a system reboot is required for these variable changes to take affect.

Local Locking On the HP-UX Platform

- HP-UX does invalidate cache when a file is closed IF the file was locked.
- Local locking may be supported in upcoming HP-UX releases.

Weak Cache Consistency

HP-UX does NOT perform false invalidates due to the weak cache consistency algorithm.

2.4. Tru-64 Configurations

This section specifies commands and options for tuning a Compaq/HP Tru64 configuration.

Operating System Version

Optimal performance is gained by using Version 5.1 (revision 732).

Gigabit Ethernet Configuration

On the Tru64 Platform

- Tru64 supports Gigabit Ethernet NIC's

On the NetApp filer

- NetApp filers provide Gigabit Ethernet NIC's as an optional connection technology.

Enabling Jumbo Frames

On the Tru64 Platform

- For each Gigabit Ethernet interface (IFACE) issue the command:
 - ifconfig IFACE ipmtu 9000

On the NetApp filer

- Verify the correct MTU setting
 - On the filer issue the command: `ifconfig <interface>`
 - Verify the mtu value is 9000
- Change MTU to 9000
 - Change the value with the command: `ifconfig <interface> mtusize 9000`
 - Make this permanent by adding to `/etc/rc` on the filer NFS Protocol Configuration

On the Tru64 Platform

- Edit the `/etc/fstab`
- For each NFS mount participating in the high speed I/O infrastructure make sure the mount options specify TCP version 3 with transfer sizes of 32K:
 - `...,vers=3,proto=tcp, rsize=32768, wsize=32768,...`

On the NetApp filer

- Ensure TCP is enabled by entering the command
 - `options nfs.tcp.enable on`
 - `options nfs.v3.enable on`

Kernel Patches

On the Tru64 Platform

- Version 5.1 (revision 732)
- Apply BL17 or BL18 (PK3 or PK4)
- Apply customer specific patch 547 manually
- Apply patch 547 included in BL19 and 5.1A

Autonegotiation

On the Tru64 Platform

- No Autonegotiation changes required

On the NetApp filer

- Verify the filer flow control setting is set to "full"
 - On the filer command line issue the command: `ifconfig <interface>`

- Verify that the flowcontrol setting is "full"
- If not, issue the command: `ifconfig <interface> flowcontrol full`

NFS Tuning

In Tru64 there are currently no recommended configuration changes for NFS Tuning.

Local Locking

On the Tru64 Platform

- Local locking is not a supported mount option