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Evaluation of Different SAN Technologies for Virtual Machine Hosting

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Abstract

This thesis covers a problem which companies faces every day: Finding a Storage Area Network(SAN) solution that tackles the rising demands from users and their software and when working with virtualization environments. In this paper it will be showed a way to investigate and identify, from a selection of SAN technologies, which is the most efficient and optimal based on scenarios that fits real life experiences. The approach taken was to create an experimental setup in a controlled environment that fits real life experience. The benchmark tool bonnie++ was used to simulate activity and interpreted by an analysis script tool developed by the author. Distributed Replicated Block Device(DRBD), Network File System(NFS), Parallel Virtual File System(PVFS), Internet SCSI(ISCSI) and ATA over Ethernet(AoE) are the SAN technologies which will be evaluated and discussed. The optimal SAN technologies will be chosen based on a certain criterias such as raw performance and stability.

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Chapter 1

Introduction

1.1 Motivation

Companies today need storage possibilities like Storage Area Network(SAN). There is a rising demands from stakeholders in major corporations to smaller businesses that have both system administrators and a large network of employees/clients. This technology adds some degree of certainty of their work not being lost when computers crash due to hardware or software failure, and for system administrators to gain a better way of handling backup situations.

Finding one SAN solution that is the best in correspondence to the setup of the company is not easy. Obstacles like what type of operating system they are using, how much money they would like to invest and how the technology they are interested in, fits in with the other type of software they are using.

There is a large variety of SAN technologies to choose from in the market today. This is a many-to-many problem which will require testing to figure out what type of SAN that is needed. Setup of the companies computer system would respond differently for each of the technologies we can choose from.

A common way of testing out whether the SAN technology is a good pick for the system of a company is to combine SAN with Virtualization. This way we can perform some stress testing and find out its strengths and weaknesses. Several scenarios should be made since the technology itself might respond differently depending on the setup of the system.

Companies needs their workplace to operate efficiently and have a secure way of backing up so that there is a way to restore when important data is lost. Therefore, the descision on what SAN that is suited for their systems, should be determined based on a number of dimensions.

In stress testing the SAN technology there are different terms that are important. Two factors that distinguishes themselves from the others are performance and stability. These factors are fundamental for checking how well the SAN technology works.

The combination with SAN technology and Virtualization is a good way to use these kind of pressures tests. Since we can scale up several clients which will take use of the SAN technology. Moreover, adding this to valid scenarios could help in finding the best SAN solution for a company.

1.2 Problem Statement

The following problem statement was chosen for this project after going through motivational pointers and formulate it in such a way that it could be possible to find a solution.

How to investigate and identify a combination with SAN technologies and Virtualization that is efficient and optimal?

Investigate and identify means here experimenting in an controlled environment and perform analysis based on these results. SAN technologies Storage Area Network, a different set of technologies used for storing and backing up files on a system. Virtualization - Enterprise level software that is commonly known and used for setting up larger networking systems. Efficient and optimal draws it meaning from a benchmarking point of view. From data gathered from experiments that are analysed there should be possible to find whether the solution is better or worse.[2]

1.3 Approach

There are several ways to approach the problem for this project. In this section we will look at some of the most used ways to handle these kind of problems, and why this approach was chosen for this problem.

1.3.1 Survey

Studying previous work done with SAN technology and benchmark testing could provide with enough data to calculate some predicaments and conclude whether one of the SAN solutions is better than the other. On the other hand this could give a wrong picture of actual performance for the SAN since not all combinations would be analysed by each other.

1.3.2 Comparative study

This approach that requires cooperation with several companies to gain access to their production environment. Furthermore, we need to be allowed to use their equipment in order to perform measurements, so that there is possible to compare results. A problem might occur with this approach since it can not be done in an controlled environment. Companies have different set ups and hardware solutions. In terms of newer technology it would also be hard to run and test them on the current system of the company. Since we will not be able to alter their current configurations on the system and have no other option than to use what they already have. Realistic speaking, time would be a problem for this type of approach, since it would be problems visiting enough companies to conduct the project.Especially considering that they should be within the boundaries of a controlled experiment.

The chosen approach is interesting for system administrators in view of newer technology, reading about the results could also encourage them to test this technology at their own company. They could also be interested in the different scenarios that will be used in this approach as well as the analysis in terms of saleability Since it will require a large number of clients to give enough pressure on the technology itself to determine its performance.

1.4 Thesis Outline

This chapter contains the motivational pointers for this project and how the problem statement got formulated. Chapter 2.1 explains in detail the different technologies used during this project, the SAN technologies that are to be tested and the tools used for measuring and fully test them out. The methodology of this project, what kind of experimental setup and lab equipment used during this project is mentioned in chapter 3. Results will be displayed in chapter 4 with a brief overview and fully explained descriptive statistics for the data that was measured. Chapter 5 will discuss these results and based on these discussions find out which technology that performs better or worse which we will conclude in the last chapter.

Chapter 2

Background

The previous chapter contained the motivation and formulated the problem statement. Furthermore, some different approaches were mentioned for giving solutions or answers to this statement. In this chapter we will review the background literature for the different technologies used in this project and briefly describe different factors that could affect the results in the end.

2.1 Storage Area Network technologies

Demands for storage solutions has increased in recent years. Companies used to have data on servers that were connected to the Local Area Network(LAN) or Wide Area Network depending on the set-up of their system. On this server canalization of traffic such as data transfers and backing up the data would take place. Today SANs have taken over as a solution.[9]SANs create a pool of storage devices, where they are linked together, so that users can connect and access the data directly over the network. In addition to reducing bandwidth load, it has better storage management and more fault tolerance. Moreover, SANs have the ability to transmit data at high speeds over great distance when used in combination with fibre channel technology.

However, there are complications integrating the fibre channel technology with hardware technologies, which is often upgraded. Hence, there have been vendors working on ways to link SAN technologies over Ethernet and other networking technologies. The solution vendors have found has evolved SAN and made it possible for this technology to work together with other protocols, and has become multi protocol capable. Furthermore, towards the simplification of the SAN infrastructure, technologies that were competing with SAN for floor space can now work together in a single machine.

2.1.1 Network-attached storage

Network-attached storage(NAS) is also a commonly used storage technology. The way this technology works is that it is a computer connected to the network, with installed NAS software on it. This unit can provide with file-based storage services for clients connected to the network. A NAS storage contains an engine that implements file services which is possible when using access protocols such as NFS or CIFS. When more hard disk storage space is needed on a network that already utilize servers, NAS is allowed to add this without having to shut the servers down for maintenance and upgrades.

NAS is not an integral part of the server, but a device that delivers data to the user while the server handles all processing of data. This device does not need to be located within the server but can be placed anywhere in the LAN. It is also possible to make them up of multiple networked NAS devices. These units uses Ethernet and file-based protocols to communicate, which differs from SANs use of Fibre Channel and block-based protocols for communicating. This type of storage gives acceptable performance and security, and provides with less expenses when being implemented to the servers because of the usage of Ethernet adapters instead of Fibre Channel adapters. [7]

2.1.2 Network File System

The Network File System(NFS) is a technology that operates on a client to server level. It is designed to let users(clients) view and optionally store and update files on a remote computer. However, for allowing this the user needs to have an NFS client and the remote computer needs the NFS server. These applications allows for the NFS to work over the TCP/IP protocol.

Moreover, NFS server provides the possibility of organizing important files on a centralized location, allowing authorized users continuous access. NFS has currently two versions that are used. NFS version 2(NFSv2), which is supported by many operating systems and has been around for several years. NFS version 3(NFSv3) is the second version. It has more features than NFSv2 like including a variable file handle size and better error reporting.

2.1.3 NAS vs SAN

We have looked through two popular choices when it comes to storage technology. Both have different strengths and weaknesses which makes none of them the "best" choice. Compared to SAN, NAS provides with a storage and file system SAN, on the other hand, only provides with storage technology and let the matter of the file system go to the clients side. Both work with virtualization like Xen, because Xen can access the virtual machines disk either like a file or a block device. Example below is a line from a Xen configuration file, where you can specify the location of the image you want to use.

```
disk = [ 'file://home/christian/disk.img,hda1,w' ]
```

2.2 iSCSI

Internet SCSI, or iSCSI has emerged as a protocol and looked upon as a solution for the increased demands in the industry. Compared to Fibre Channel usage within SANs, iSCSI has a few advantages that gives them a growth in the market.

2.2.1 Architecture

The iSCSI protocol has the ability to map over TCP/IP and enable access to TCP/IP networks over Ethernet.[11] In the mapping process SCSI block oriented storage data will be transfered which will enable the storage devices to work over Ethernet. There are many reasons for its popularity, reduced cost and the possibility to achieve a uniformed network infrastructure when deploying iSCSI protocol over a Gigabit Ethernet. This allows for the storage to be reached over a larger area, since there is usually a physically restriction to a limited environment in a

traditional storage system like Fibre Channel for instance.

Another positive point is the availability of inexpensive software implementations of the iSCSI protocol, which could allow use of compelling platforms in a iSCSI deployment. On the other hand, the iSCSI-based storage is not without challenges. One of the main challenges that faces iSCSI is the issues in the network traffic between an initiator and a target that are far apart from each other[12]. An initiator serves the same purpose as a SCSI bus adapter would, except instead of being physically attached it uses SCSI commands over the network. The target, on the other hand, represents the location for the iSCSI server, where storage resources are made available for the users. If compared to other existing technologies such as Fibre Channel, there are improvements to be made in terms of efficiency and performance. Moreover, networking technology between initiator and target can be diverse and heterogeneous. This could cause changes so that packets suffers from long delay, loss and retransmission.

2.3 DRBD

DRBD which stands for Distributed Replicated Block Device is an implementation in form of a Linux kernel module providing a two-node high availability(HA) cluster. It was developed by Philipp Reisner and Lars Ellenberg and their team at LINBIT. The purpose of this technology is to keep a high data availability up for a company which also includes when a system breaks completely down. [6].

Architecture

As already mentioned DRBD works as an Linux kernel module. This technology provides a block device driver for the kernel. For each of these cluster nodes, this driver will be in control of a "real" block device that holds a replication of the systems data. Operations concerning read will be run locally while writing will be transmitted to the other nodes in the HA cluster.

The transport layer chosen for this technology is TCP, mostly because of it is available for kernel modules. Furthermore, the choice of this layer was based on its solution to two basic problems, the packet recording and the flow control. This has simplified the development, however, it has also brought limitations for the DRBD-based clusters to two-nodes.

Moreover, the design of the technology at its current state, allows for only one node to modify the replicated storage. However, it is possible to change roles of the nodes but not data at a concurrent rate on both of the nodes. There are two roles which is possible for each of the nodes in this DRBD architecture, primary or secondary state.

Write access is only granted to applications in the primary state of a given device. This only applies for one device in a connected device pair, if you try to apply it for both they will break up the connection and form their independent degraded clusters. Assigning these roles are usually managed by a cluster management software, Heartbeat and Failsafe.

```
#/etc/drbd.conf
global {
  usage-count yes;
```

```
}
common {
  protocol C;
}
resource r0 {
  on atlantis {
    device    /dev/drbd1;
    disk      /dev/sda7;
    address   10.1.1.31:7789;
    meta-disk internal;
  }
  on nexus {
    device    /dev/drbd1;
    disk      /dev/sda7;
    address   10.1.1.32:7789;
    meta-disk internal;
  }
}
```

Explanation of the config file

DRBD uses the file drbd.conf to be configured and set up to work on your system. In the first line we see a global section, this section contains a few option that are only allowed once. However, it is only usage-count that is relevant for this project and most of the users of this technology. This option, if enabled, allows for DRBD to contact a http-server of the DRBD project which keeps various statistics of all the versions and will then also inform you of updates. Furthermore, we have the common section, every configuration made in this section will be inherited by all of the resources you set up. Although, it is not required but keeps the file more systematic avoid repeating yourself. In the example above we see a line with protocol C, which will be count for every resource including r0. This is also possible to change explicitly for one resource if you wish it.

The resource section contains every DRBD resource you will use for your setup. It is possible to name these resources what you want, however, it can not contain any characters other than the ones we find in US-ASCII or whitespaces. Each of this resources will have a host sub-section, where it will be needed to have two as seen on the example above, one for each cluster node. Moreover, if you want to have a more detailed explanation of the configuration you can look in [10] and find much more information.

2.4 Pvfs

Parallel Virtual File System(PVFS) is a parallel file system for Linux clusters. This technology is intended to work as a high-performance parallel file system which everyone can download and use. Especially in research concerning parallel Input/Output(I/O) and parallel file systems for Linux clusters.

2.4.1 Architecture

Primary goal of the PVFS is to provide high-speed access to file data for parallel applications. Furthermore, PVFS provides with features like user controlled striping of data across disks on different I/O nodes, allowing existing data to operate on PVFS without recompiling and consistent name space.

The PVFS design is a client-server system with multiple servers, which are called I/O daemons. I/O daemons are on separate nodes in the cluster. These I/O nodes have disks attached to them, which the PVFS files will be striped across over. Moreover, PVFS also has a manager daemon which handles metadata operations like permissions in creating, open, close and remove of files. The manager itself does not involve in read/write operations, the client and I/O daemons handles all file operations. The different kind of operators such as the clients, I/O daemons and manager do not have to be on separate machines. Although, it might prove to be better in terms of performance to keep them apart.[8]

PVFS has no kernel modifications or modules are needed to install or operate this system, which makes it primarily a user-level implementation. Furthermore, PVFS uses TCP for the communication that goes on internally, which makes it not dependent on any specific message-passing library.

2.5 ATA over Ethernet

The ATA over Ethernet(AoE) is an open standard based protocol which allows for clients to access disk drives directly over the network that are attached to a client host. This could either be a web, mail or cluster server. This protocol has simple implementation that can make the cost of AoE server to be very low.

2.5.1 Architecture

In this protocol there are two classes of messaging, ATA and Config/Query, which we will discuss a bit more in detail as well as the shared common header they have. The common header works in such a way that it is possible to send messages between client hosts and AoE servers. It consists of four functions which we will mention now in order. First, it grants the possibility to correlate responses with requests. Providing a way to to discover the Ethernet address of an AoE server when it is placed in rack storage blades, is the second function. Third, is that the common header can identify requests from responses. The last function of the common header is that it contains error information.

The Advanced Technology Attachment(ATA) is a standard that evolved since the early 1980‘s from both the ST506 interface and the Western Digital 1010 disk controller chip. These chips had a set of registers which held the information of cylinder, track and sector. Furthermore, there was a also a command register that used to initiate data transfers by writing operational codes to it. A status and error register reported if it was a successful or unsuccessful completion of the command. Todays ATA standard covers both the physical connections to the drive and the logical interface. Its messages contain requests and responses which will perform ATA transactions. In these transactions, there are three possibilities: no transfer of data, data is being written to disk, or data is read from disk. This mechanism with ATA messages simply exports ATA interface on AoE servers to the client hosts. For more detailed information on the header of these messages you can read more in [4].

The Config/Query messages is the second class of AoE messages. There are two ways to set the config data. One way is to set the config memory to a value only if the current config data is zero length, which can be done by a set request. However, if the config memory already has non-zero length data, the set request fails. Another option is to force the AoE server to set the config memory. Config values intended for the data can be zero length, allowing the config data to be reset. The contents in Query messages can be used to optionally match against the stored config information. There are three different ways of querying for the data. First approach is that the config data can be unconditionally read. Another way is that the config data can be returned. Although, this is only possible if the query data matches the prefix of the config on the AoE server. What is meant by this is that the query has a number of bytes, that is less than or equal to the length of the data in the server. Furthermore, the number of bytes in the query must match the bytes in server, so that the AoE server can respond with the complete config information. Lastly, there is a query that requires an exact match of the stored information. Both the data in the request and server must match in content and length. In broadcast queries this is useful when one is looking for a specific AoE server.

2.6 Virtualization

Ever since the Virutalization was introduced in the 1960s on IBMs platforms the uses for this technology has grown. The possibility to create an exact image of the contents of a operating systems file system and then reproduce it up to as many times as you like, depending on the hardware resources your machine have, showed great promise. Although, it was not before powerful hardware and improvements to the Virtualization in terms of effectiveness was made that the technology really made an impression. Larger companies started to look upon this technology and its ability to save both cost and space. Furthermore, the copy and duplication of VMs highlights another dimension, namely time. With this option the installation time could be reduced considerable. The community have been encouraged by this and experimented forth solutions which are open source.

Nowadays bigger and more challenging tasks is given for VMs and its abilities. An example is the use of VMs at Høgskolen in Oslo, where system administration courses uses this technology so that the students can have the chance to investigate solutions themselves on larger networks. When studying about how networking and connecting larger Local Area Networks(LAN) together, it would be impossible for a school to provide with enough hardware for all the students to fully experience this. Instead, one or two machines can run several VMs which could work as a LAN and give enough challenges that could be found in a real life scenario. Another example of the uses this technology have is the ability to move old legacy servers into virtual machines and then put all of these servers on one machine. It saves time by avoiding the change of newer hardware and installing from scratch. Process of this action is called P2V(physical to virtual) which is performed by certain virtualiazation companies which has the tools for this kind of task.

2.6.1 Virtualization and networked storage

In addition to the growing usage of virtualization comes the need of other technologies. Especially, the possibility to store and backup sensitive data which can be done by SAN technologies. Although, providing all the VMs with high performance and stability storage has been a challenge, the improvements have made VMs a more popular choice for companies. By studying and performing more benchmark testing on this combination, VMs would be an obvious choice

in different scenarios as a service provider. Most important is the need to have a SAN or NAS in for live migration of virtual machines to work. It is therefore that deploying a SAN or NAS is very common as soon as the size of the total setup grows beyond a few servers.

2.6.2 Xen

Xen is an open source x86 virtual machine monitor(VMM) which grants the possibility for creating instances of operating systems(OS) running simultaneously on a single physical machine.

Architecture

In the beginning of Xen, the Linux Xen-aware kernel was called XenoLinux. It is not a name that is used nowadays, instead we use the term as Xen-kernel or a xenified Linux kernel. Xen platform supports several OS, especially GNU/Linux distributions that have packages for the Xen hypervisor and built-in support in the kernel making it xenified. Other popular OS such as NetBSD,FreeBSD and Windows XP have also been made supportive for Xen.

The Xen hypervisor handles the IO, memory and VM creation[3]. It is the underlying layer that allows for resource virtualization and abstraction. A well known term within virtualization is called Paravirtualization. Paravirtualization drives the VMM to expose a virtual machine abstraction which is slightly different from the underlying hardware. The terminology that Xen uses is domains. On top of the hypervisor where the main OS that is running also has the privileges to manage all of the other domain. This OS is referred to as domain0 or dom0 for short while the other domains are referred to as domU or user domains. Furthermore, a hypercall mechanism is exposed from Xen which VMs are forced to use for performing privileged operations. An event notification mechanism is also used so that it can deliver virtual interrupts and other kinds of notifications to VMs. Lastly, there is an shared memory based device channel that transfers I/O messages between the VMs.

The privileged domain (dom0) has additional software for basic virtual machine manipulation. Providing an Application programming interface(API) to software tools like xm is the xend daemon. Only administrators have access to dom0 for creating, modifying and destroying domUs. These domUs can be configured as you see fit by writing a configuration file. This file can describe location of the file system, amount of memory, how many network cards and what type of network parameters. An example is shown below.

```
atlantis:/var/www# cat small_xen.cfg

#  -*- mode: python; -*-
kernel = "/boot/vmlinuz-2.6.18-6-xen-686"
ramdisk = "/boot/initrd.img-2.6.18-6-xen-686"
memory = 64
disk = [ 'file://home/christian/disk.img,hda1,w' ]
root = '/dev/hda1'
extra = '2'
name = 'first'
vif = [ 'bridge=eth1' ]
```

In runtime there is possible to do alterations to the configuration of the VMs. Actions such as increasing and decreasing memory, adding disks as well as pin down the virtual machine to a specific CPU, are possible when it is running. When it comes to networking, Xen VMs can connect to each other by using bridge devices on the physical server, this will either provide isolated networks on the server or bridge the physical network.

2.6.3 Factors that could affect performance

Setting up and installing virtual machines is not without problems, there are several factors that are to be considered. It is not only the virtual software itself that could provide with some difficulties but the software as well as the hardware it builds upon. Furthermore, we will look more into network bounding, the Linux kernel and memory, as some of the factors this project that could affect performance and influence the outcome of the results.

Network bonding

Connectivity when it comes to virtual machines is predefined in configurations files. Unfortunately, there is complications with configurations if there is network bonding present. Companies and their system administrators use this technique to boost the performance and availability of the servers by combining two or more Ethernet interfaces to work as one. Thus, causing conflicts when configuring the right name for the interface since Xen does not discover network bonding.

Linux kernel

The importance of choosing a kernel is crucial if you want to avoid a lot of patching which will also involve a lot of configuring and re installations of the file system As we mentioned earlier, Xen requires a xenified kernel to work as intended. However, this is more complicated than it sounds. Although, over recent years of development most kernels have in-built Xen packages with needed software to "xenify" a kernel.

Memory

Memory effects the file system performance both physically and on a virtual based platform like Xen. Especially, the virtual machines can decrease the performance ,if the memory is allocated in such a way that they go out memory and start compensating by drawing memory from other sources like other VMs. It is therefore important to allocate memory usage on each VM and calculate how much it will need in order to get optimal performance when doing operations with the file system. Moreover, the amount of physical memory as well as the specifications of it has great effect upon performance.

2.7 bonnie++

In this study, there are different tools that could be used. Especially, when it comes to collecting data, there is one tool in particular that is interesting. The benchmarking tool bonnie++ has the ability to perform Input/Output(I/O) tests, which concludes transfers and other time consuming events, and collect these results. Data collected can determine how well the file system performs on different tasks. Although, there has been a growing usage of benchmarking tools over the years, storage system researchers and other practitioners find these tools to contain too little scientific methodology or statistical strictness. In an attempt to respond to

these issues, a workshop was held [1] where problems where discussed and solutions proposed. At this workshop there were also a brief overview of different tools that is used for benchmarking file systems FileBench, IOzone and SPECsfs were highly recommended in addition to bonnie++ as a tool for measuring I/O data on file systems.

Bonnie++ has several flags for adjusting how many times the it should run the test, number of files as well the size of the file itself. Moreover, there are options for stating where these files should be stored and written from, and how the output should be delivered. Default output is given directly to the console which can be difficult to interpret if you have little experience with this tool.[5]

```
Atlantis:/home/christian# bonnie++ -d /xen/client/data/ -u root
Using uid:0, gid:0.
Writing with putc()...done
Writing intelligently...done
Rewriting...done
Reading with getc()...done
Reading intelligently...done
start 'em...done...done...done...
Create files in sequential order...done.
Stat files in sequential order...done.
Delete files in sequential order...done.
Create files in random order...done.
Stat files in random order...done.
Delete files in random order...done.
Version  1.03       ------Sequential Output------ --Sequential Input- --Random-
                    -Per Chr- --Block-- -Rewrite- -Per Chr- --Block-- --Seeks--
Machine        Size K/sec %CP K/sec %CP K/sec %CP K/sec %CP K/sec %CP  /sec %CP
Atlantis         7G 39785  69 46401  10 17419   3 42279  66 41921   3 151.4   0
                    ------Sequential Create------ --------Random Create--------
                    -Create-- --Read--- -Delete-- -Create-- --Read--- -Delete--
                files  /sec %CP  /sec %CP  /sec %CP  /sec %CP  /sec %CP  /sec %CP
                   16 +++++ +++ +++++ +++ +++++ +++ +++++ +++ +++++ +++ +++++ +++
Atlantis,7G,39785,69,46401,10,17419,3,42279,66,41921,3,151.4,0,16,+++++,+++,+++++,+++,
+++++,+++,+++++,+++,+++++,+++,+++++,+++
```

The output of bonnie++ is also possible to run in an quiet mode which will cut out the status messages on the different processes and only return the output. Interpreting the output data you will also see plus symbols(+++) instead of data. In every test two numbers are reported, one is the amount of work done (higher numbers are better) and the other is percentage of CPU time taken to perform the work (lower numbers are better). If one of the tests completes in less than 500ms the output will be displayed as "++++". Reason for this is because such a test result can't be calculated accurately due to rounding errors and the author of the program would rather display no result than a wrong result.

There is a second type of output named CSV(Comma Separated Values). It has the ability to be imported into any spread-sheet or database program. Furthermore, possibilities to convert the CSV data to Hyper Text Markup Language(HTML) and plain-ascii exists, by using the included programs bon_csv2html and bon_csv2txt that follows this package.

Bonnie++ has been used in several scientific studies when it comes to I/O data. In [11] they did an analysis of the iSCSI protocol, where iSCSI were compared against the fibre channel in an commercial environment. Different set-ups of the iSCSI protocol, both software and hardware implementations, were investigated by its performance and evaluated based on these results. In on of these set ups bonnie++ was used to measure the performance of an ext3 file system on a raid array that was remotely using iSCSI.

Explanation of Bonnie++ outputs		
Sequential Output	Per Character(Per Chr)	The method putc() is used to write the file. The CPU overhead is needed here in order to do the stdio code as well as the Operating System(OS) space allocation.
	Block	For doing these calculations, the method write(2) is being used to write the file. However, the CPU overhead should in this section only be the OS file space allocation.
	Rewrite	In this operation every BUFSIZ of the file will be read by using read(2), then tampered with for so to rewrite it with write(2). Furthermore, no space allocation will take place, and the I/O is well localized which should test the effectiveness of the filesystem cache and speed in the data transfer.
Sequential Input	Per Character(Per Chr)	Read the file using getc(). This operation should only use stdio and sequential input.
	Block	Using write(2) for creating the file and should act as a pure test of sequential input performance.
	Seeks	This operation search for the files that is being written. It runs SeekProcCount processes (default 3) in parallel for achieving a reliable number for the benchmark tool.
Sequential Create	These file creations tests uses filnames that contains 7 digit number (0 - 12). In the sequential create phase files are being created in numeric order. Then they will be stored in the readdir you provide with -d flag and be removed in the same order they were stored.	
Random Create	Creates files that will fool the filesystem and appear random. Furthermore, the files will be stored and removed in a random order. By specifying some other value than the default for maximum size, Bonnie++ will during the creation of files provide with random amount of data to each file.	

Chapter 3

Methodology

In the start of this project there were a few matters to consider. For measuring and collecting data we decided to use the benchmarking tool bonnie++. Furthermore, we needed to analyse the data we received from these benchmarking tests. Since there was no tool available to perform the necessary operations, one had to be made. The analys tool what was developed is a Perl script which will calculate average, median and variance on the data. That can be used on a later point to compare the different technologies.

3.1 Analysis Tool

In research where benchmark testing is being conducted, there is a necessity for analysis tools that can compress the outcome and make it representative for further studies. There are already a sourceforge project called bonnie-to-chart that performs different actions with the output data from bonnie++. Although there is a lot of interest for bonnie++ when it comes to analysis of the data and a tool like bonnie-to-chart is available, creating new framework tool seemed like the best option. This way I could decide what type of data that is important and how the output would look like.

3.1.1 Input

The analysis tool is based upon a Perl script which handles a single output file at a time from a bonnie++ session. It collects the data by using the file handler option in Perl and splits up all the columns by using the split() feature. By reading the output files from bonnie++ sessions you will see a lot of data where "+++" occurs. Every test will report two numbers, amount of work done and the percentage of CPU time taken when performing the test. The Author of this program implemented the "+++" function to prevent wrong results[5]. Basically he thinks that tests that completes in less than 500ms can not be calculated in an accurately way due to rounding errors. Hence, displaying no result is better than displaying a wrong result. Therefore, when the scripts comes across a field that contains similar data it uses a regular expression to exchange the "+++" to 0. Since the data, as mentioned above, is considered to be unreliable when the "+++" symbols occur.

When done with the splitting up and sorting of the columns of data it goes into arrays for easing the operation for doing descriptive statistics on the data. This make it possible for the use of Perl modules. Math:NumberCruncher is the module that is being used for performing the statistics on the data and simplify the operations for performing the calculations like Median, Mean, Average, Min/Max and Variation which will be described later on.

3.1.2 Usage

Describing the usage of this tool is simple. The users needs some basic understanding of computers and know how operations are done in the Linux operating system. First of all a bonnie++ session needs to be run in order to get data for the analysis tool to work with. Following line is an example of a session.

```
bonnie++ -d /tmp/ -x 100 -q -u root > /home/user/100x_nfs_1of3
```

The flag "-d" indicates where the tests will be performed on the VM. Important thing to remember when deciding upon where the tests should be run is to check if you have enough free space. Default value for the files will be 1 Gigabyte which was sufficient for these experiments. Although, if you would like to change the size you can use the "-s" flag to change this. The number of times the test is conducted is decided by the "-x". Without any value it will run as default only one time. For the analysis tool it would not matter whether it is 1 or 100, but for the sake of having reliable data it would be best with 100 or more. The "-q" is for quiet mode which means that it will drop unnecessary output lines that is being produced while performing these tests. The user performing these tests should be presented by the "-u" flag. Files that will be created and contain the data should be named in a fashion that it is easy to identify so that there will be no misunderstanding. Especially since there will be lot of tests if you scale up the number of VMs and bonnie++ is only able to write out which machine it is and not the type of test that is taken. Furthermore, the name should contain the technology you are testing and will be useful when several technologies are being tested at once. After a successful bonnie++ session where you write the output to a file as shown above, it is then possible to use this file as input for the analysis tool. Following line is an example of how to use the analysis tool.

```
bonperl.pl 100x_nfs_1of3 > /home/user/bonniedata/100x_nfs_1of3.tex
```

The file which is "100x_nfs_1of3" here will be analysed by the tool. Output from this operation will be printed out in a table format as well as a graph for each of the operations in latex code. Reasons for this is to both save time and present the data in a manner so that it is easy to read. Although, first, it will be necessary to save the output to another file of your choosing. This file will then need to be compiled to a pdf file for making the data readable. Enter the folder where you put it and write the following command. It will depend on whether you have the latex packages installed for your operating system for a successful compilation.

```
pdflatex 100x_nfs_1of3.tex
```

3.2 Experimental Setup

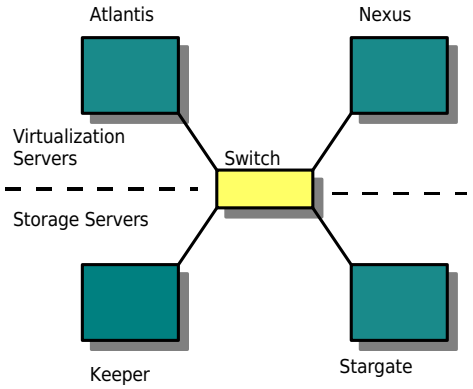

Figure 3.1: Figure of the lab setup

The lab setup of this project is seen on 3.1. These machines are members of an IBM Bladserver. Atlantis and Nexus will be acting as the virtualization servers, where we expand with more vms if the tests requires more clients. All of the machines have bounded network cards, both with a 1GB capacity, making it a total of 2GB for each of the machine. The storage servers will be Keeper and Stargate through the testing of the technologies and are meant to variate the SAN software. Keeper will be the main machine for this, since most of the technologies only need one machine as server. Hence, Stargate will be a backup when two machines are required for setting up the specific SAN technology.

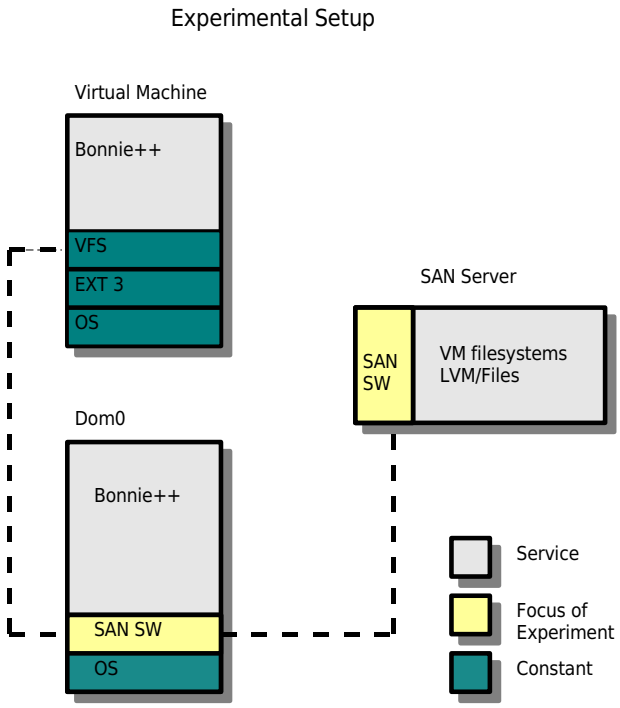

Figure 3.2: experimental setup

Keeper has a variation of SAN software during these experimental tests as you can see on 3.2. Dom0, that will be on the two machines atlantis and nexus which are connected to the SAN server, serves as an hypervisor for VMs. These machines also have SAN client software. Furthermore, in order for the VMs to act as clients for the SAN technology, a variation on the SAN client software is also required. Since the VMs themselves can not interpret that they are connected to a SAN with current design. Moreover, the Dom0 has a constant Debian distribution as a operating system that is used under every test of SAN technologies. The VM image I use for these VMs only contains necessary file system with bonnie++ and does not contain any network configuration. Each of these VMs has kernel(2.6.18-6-xen-686), running ext 3, and same operating system when they are booted up for testing.

3.2.1 Base tests

Comparative studies requires data that we can compare with, this is why these base tests are taken. They give an indication on what is the optimal result you can get by running a test directly on the base of the system itself. By doing so we can then compare the results we get from these tests with the data from the actual experimental data, and then determine its strengths or weaknesses.

Base tests that are to be run during this project:

- Keeper which is the SAN server
- Virtualization server with no VMs up

- Virtualization server with one VM up
- Virtualization server with ISCSI installation
- Virtualization server with NFS installation
- Virtualization server with DRBD installation
- Virtualization server with AoE installation
- Virtualization server with Pvfs installation

3.2.2 non-Base tests

These tests are the actual experimental data. Where the variation of the SAN technology is in focus and the scaling of clients is the main process for identifying the best one based on the comparison of the data.

3.3 Output

Under these experimental benchmark tests there is an expectation that a random SAN technology test should have the same performance as a base test on keeper or worse. Hence, we can then expect that a virtual machine placed on top with a random SAN technology should perform just as well or worse as the base test. As mentioned earlier an output file should be named accordingly to the test that is taken. In doing so scaling of the VMs will be more systematic and thorough. Each technology will require a considerable increase of clients in each scenario which will generate a lot of files. Keeping a system is then crucial when compiling these files to an appropriate format, especially when using pdflatex on the generated latex tables that are generated from the analyse tool.

3.4 Analysis

In this section the different measurements will be listed and explained in detail. It will also explain what kind of meaning they have for the investigation and how it helps in identifying the best SAN technology.

- **Median**
  Median will be one of the two ways to find the average. It does it by arranging the values in order and selecting the one number in the middle. However, if the values from a series of tests or a sample is even, the median will be the mean of the two middle numbers.

- **Mean**
  Mean is the second way to find the average and will be the sum of these measurements that is taken during the test of each technology divided by the amount of measurements taken.

- **Min**
  Finding the minimum value that is recorded during a test could determine how low the performance of the technology went during an experiment. Hence, be an important factor when deciding what the best technology is, and how it adds up with variation number.

- **Max**
  Maximum value determines the highest performance score of the technology which will alongside the minimum value help us gain the whole picture of how the technology works. Furthermore, the maximum and minimum of the measured results will give a performance point of view were for the given technology.

- **Variation**
  Variation is of great importance for finding the most stable SAN technology. Seeing as the greater the number, the greater the performance of the technology variates which makes it difficult to rely on. System administrators wants a reliable technology that has the same performance most of the time and not take chances on one that might perform much better in a certain amount of time. Although, it would be better for me if I had a mathematical distribution as well in order to fully understand the variation results.

Chapter 4

Results

The results from these base tests is what can be called the optimal performance from the operations of the benchmark tool bonnie++. These results will be an important factor in deciding the best SAN technology when comparing scores.

4.1 Explanation of output in tables

In the first block session we can see the name of the machine and what file size this bonnie++ session used to perform the different operations with. File size can be changed but the default value is used for all of the bonnie++ sessions. Next block contains putc which produces output and writes in two modes, by character and by block. The output results from putc and putc_block are measured in kilobytes per second(KB/s) while putc_cpu and put_block_cpu contains the percentage of the cpu used during these operations.

After the writing process, bonnie++ will do a rewrite operation of the current files which will also be measured in KB/s. Then we reach the reading section which is organized by the getc and getc_block operations. Both of these operations are also measured in KB/s while the getc_cpu and get_block_cpu are the percentage of cpu used during these operations. Measuring seeks is the next section where seeks are files found per second and seeks_cpu is the percentage used during the search for files. The amount of files is mentioned in num_files, if you want you can specify yourself how many files that should be in this test and also how the size should be divided between them with the bonnie++ flags. Although, 16 files is the default value and was used when testing all of the SAN technologies.

When it comes to the sequential operations, only seq_create and seq_create_cpu will be interesting in terms of data. The other operations will finish up to quickly to be a reliable result and not worth mentioning. However, for the random operations, only ran_stat and ran_stat_cpu will be unreliable data. ran_create will show how many files that are created in a random order per second while the ran_create_cpu will show the percentage of cpu usage during this time. ran_del show how many files that are deleted in a random order per second.

4.2 Keeper basetest

Results from the base test of keeper with no SAN technologies installed. It runs a basic Debian installation with a few alterations from the ABC startsidens security systems. Although, this

should not affect the outcome in any way, when it comes to disk activity during these benchmarking tests.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0	0	0	nan	keeper	keeper	0
file_size	7	7	0	nan	7G	7G	0
putc	45871.808	45853	18.808	59109.751	45403	46607	1204
putc_cpu	95.515	95	0.515	0.290	95	97	2
put_block	70315.303	70885	569.697	2073288.373	65950	72880	6930
put_block_cpu	24.333	24	0.333	0.424	23	25	2
rewrite	29713.081	30009	295.919	318502.943	28480	30459	1979
rewrite_cpu	7	7	0	nan	7	7	0
getc	49877.535	50453	575.465	1830404.491	45300	51507	6207
getc_cpu	91.141	92	0.859	5.637	83	94	11
get_block	72161.899	72627	465.101	1819859.364	65732	73967	8235
get_block_cpu	5.020	5	0.020	0.020	5	6	1
seeks	537.737	546.300	8.563	2953.941	344.6	617.0	272.4
seeks_cpu	0.354	0	0.354	0.229	0	1	1
num_files	16	16	0	nan	16	16	0
seq_create	3658.535	3658	0.535	1816.835	3464	3721	257
seq_create_cpu	97.929	98	0.071	1.217	93	99	6
seq_stat	0	0	0	nan	0	0	0
seq__cpu	0	0	0	nan	0	0	0
seq_del	0	0	0	nan	0	0	0
seq_del_cpu	0	0	0	nan	0	0	0
ran_create	3746.556	3747	0.444	1354.186	3592	3795	203
ran_create_cpu	98.152	98	0.152	0.977	94	99	5
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	11893.172	12085	191.828	115392.162	11091	12277	1186

Table 4.1: Table of keeper basetest

Overall results

The operation putc shows less to no difference between its mean and median value by only 18 KB/s. Seeing as this is the base test which should be the best optimal result that we are going to compare with, 45 MB/s is not such a bad performance. By a quick overview we can also see that putc_block performs better than putc and uses less cpu load to accomplish that. Although, a bit higher difference we can see but not really alarming.

The rewrite operation is lowered to 30 MB/s which is still good performance if you think about the buffering refreshing itself all the time it is running. Furthermore, reading operations score slightly higher than writing. The getc with 50 MB/s and get_block with 72 MB/s are good results. Seeks has also quite similar numbers in mean and median, 537 to 546 files per second.

Moreover, the seq_create creates 3658 files in an average per second, and the cpu load is high which also is normal. The other functions does not show which is normal, since they finish up to fast for it to be any reliable data according to the author of the program. ran_create gets a bit higher performance on mean and median compared to the seq_create. It also uses a lot of cpu during this operation. Last operation, the ran_del, shows good performance by deleting 12000 files per second.

Descriptive statistics

putc has a a range of 1,2 MB/s between the max and min value which indicates a stable work rate. Furthermore, this could also make it easier to predict the time span of how long it would take to finish writing over files for instance when it comes to backup. putc_block gets higher speed and has much higher max than min. Seeing as mean and median is around 70 MB/s, the min value seems to be very poor performance for this operation and it gives a greater range with 6,9 MB/s which indicates much more unstable results. Moreover, the percentage of cpu used between putc and putc_cpu is significant, reasons for this could be that the cache is more present in the putc operation.

Rewrite operations goes around 30 MB/s which is around 15 MB/s slower than putc performed, this could be that is has to take into account the order of the files when it rewrites, making it drop some performance on the way. The reading operations performs slightly higher than the writing. Both getc and get_block have a larger range between max and min than the in the writing operations. Furthermore, if we look at get_block we can see that average performance measured by mean and median are close to the max value, which makes it interesting to see if it was a slight irregularity or if it actually will be noticeable in the other experiments.

seq_create performs a bit lower than the ran_create, where seq_create has a total of 3658 files per second while ran_create has 3746 files per second. Both seems to be working at a stable rate as well according to the range of the min and max values. Same with the cpu usage during these two operations with a 98 percent usage. The deletion of the files goes at a much higher performance, ran_del has an average of 12000 files deleted per second. Although, it has a larger range between the max and min values which tells us that it is not as stable as during the creation of the files.

Graphs of interest

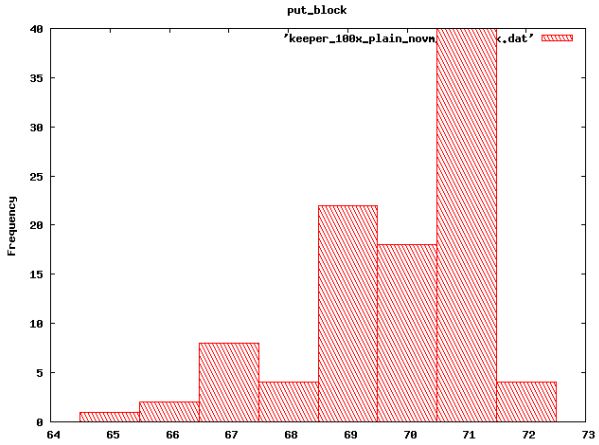

Figure 4.1: keeper put block

As we can see from figure 4.1 the mean values of put_block seems to match the average measurements for this operation. With most hits in the area between 69 MB/s to 71 MB/s which corresponds well with the value of 70 MB/s in the mean. From figure 4.2 we can clearly

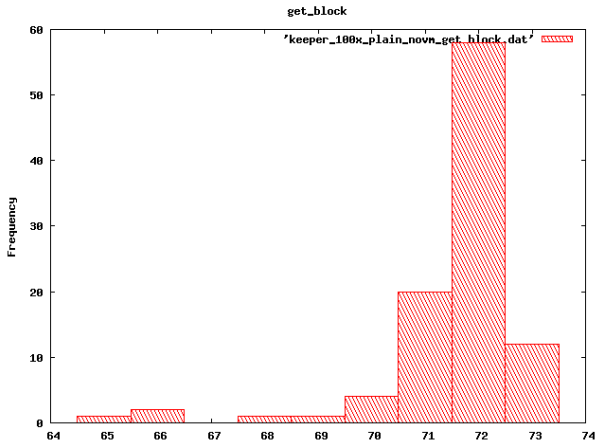

Figure 4.2: keeper get block

see that the mean value of 72 MB/s is accurate according to where the most hits were recorded. Seeing as there is close to 60 hits at 72 MB/s for the get_block operation. By looking at the seeks operations for keeper in 4.3 we can see that the mean value of 537 is valid according to the hits recorded. The graph shows that most of the hits were around 550 files per second.

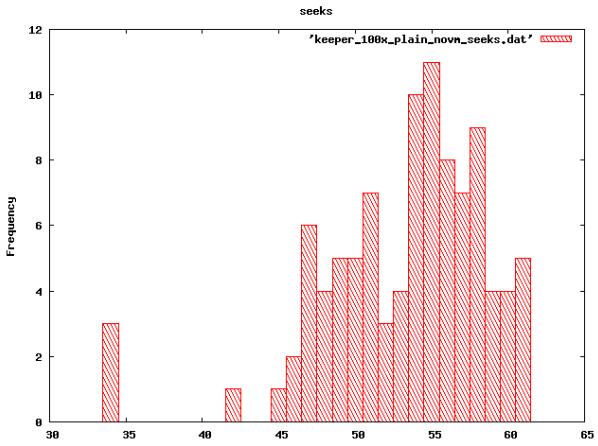

Figure 4.3: keeper seeks

Summary

Looking through the results of the benchmark test, some results were more interesting than the others. Reading performs higher than writing, while rewriting goes even lower. In both of these operations we can also see how the difference between the by char and block transfer is high. When performing the put_block and get_block the cpu resources used are low and they use most of the time to wait for the hard drive during their operations. In the reading operations the maximum values are closer to the median and mean values than the minimum value that could be explain by some slight irregularities during the benchmark test.

4.3 Nexus basetest

This section will display the results measured from the benchmark test run on nexus, which is one of the virtualization servers, with no VMs up and running.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	42277.101	42338	60.899	124824.454	41292	42961	1669
putc_cpu	94.990	95	0.010	0.677	93	96	3
put_block	66632.576	66897	264.424	2759297.557	62611	69596	6985
put_block_cpu	32.263	32	0.263	0.658	30	34	4
rewrite	28845.606	29132	286.394	428861.794	27614	29599	1985
rewrite_cpu	3	3	0	nan	3	3	0
getc	47166.556	47548	381.444	2035148.449	41837	49144	7307
getc_cpu	84.909	86	1.091	7.941	75	88	13
get_block	70311.222	70641	329.778	939812.112	66732	71550	4818
get_block_cpu	0	0	0	nan	0	0	0
seeks	486.417	497.200	10.783	3614.723	321.6	595.2	273.6
seeks_cpu	0	0	0	nan	0	0	0

Table 4.2: Table of nexus basetest

Overall Results

In the writing section we see a good performance on the putc operation with 42 MB/s in mean and median. It also has a min value of 41 MB/s and close to 43 MB/s in max. put_block performance is acceptable, with 66 MB/s in mean and median, and a min value of 62 MB/s and max value of 69 MB/s. rewrite does more than half of the putc operation with a 28 MB/s in mean and 29 MB/s in median. The min and max values have a bit more gap between than putc with 27 MB/s and 29 MB/s.

The reading operations performs better than writing. getc has a mean and median value of 47 MB/s and get_block has a mean and median value of 70 MB/s. Looking at their min and max values, we can see that getc has 41 MB/s min and 49 MB/s max while get_block has 66 MB/s min and 71 MB/s max.

The seek operation has a good performance with 486 files per second in mean and 497 files per second in median. It also has a min value of 321 files per second and a max value of 595 files per second. The rest of the operations during this benchmark were to fast to measure any credible data.

Descriptive statistics

During this benchmark test reading operations have performed better than writing. Although, getc performed better if we look at the mean and compare it with putc, we can see that getc has a much wider range between its min and max values. This suggest that this operations work rate is unstable. However, for the put_block and get_block the situation has changed. Seeing how get_block both performs better if we look at mean and median, and has a lower range with 4,8 MB/s versus put_block with 6,9 MB/s.

The rewrite operation only has half of the performance putc has in mean and median, but seems to be waiting a lot for the disk to complete because of a very low cpu usage of 3 percent. Irregularities of some kind could be causing this like for instance caching. seeks performances well but has a wide range with 273 files per second, which would strongly suggest an unstable work rhythm.

Graphs of interest

These are the graphs of operations that are most interesting when it comes to these benchmark tests.

Figure 4.4 show that most of the measured results are resided in the area between 64 MB/s to 69 MB/s which seems to in balance with the calculated mean value in table 4.3. Same goes for the data we see in figure 4.5 with most of the measured results in between 69 to 71 MB/s and a value of 70 MB/s in mean in table 4.3.

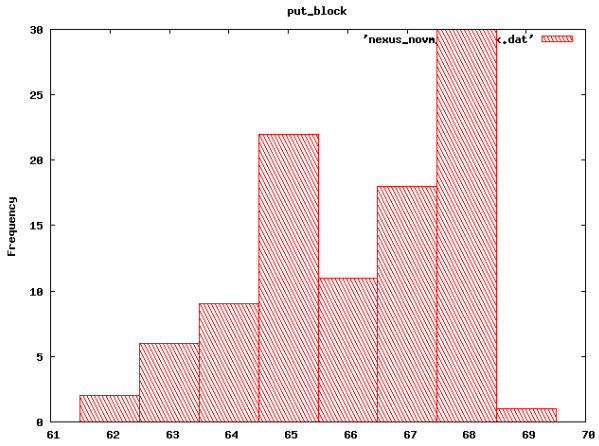

Figure 4.4: Nexus novm putblock

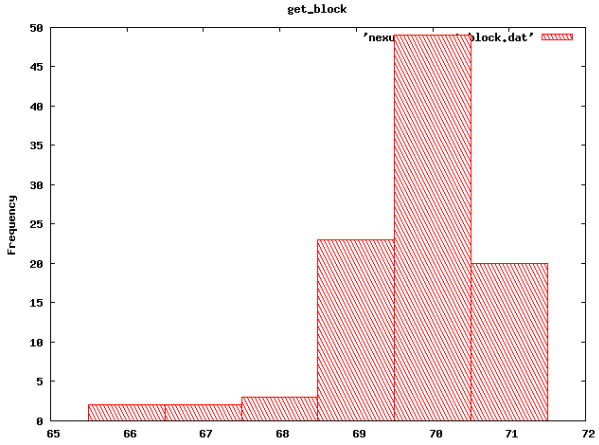

Figure 4.5: Nexus novm getblock

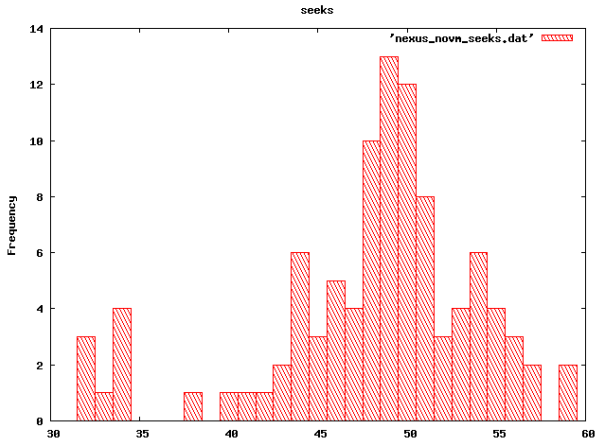

Figure 4.6: Nexus novm seeks

In figure 4.6 we can see that most of the data are measured in the area between 45 to 55 files per second. It makes the number of 486 files per second in mean valid from table 4.3.

Summary

In this base test we have seen how reading operations perform better overall. However, both writing and reading have some instability if we look at their ranges. This also applies for seeks that has close to half of the max value in range with 273 files per second. Furthermore, the creation and deletion tests from this benchmark operated at such a fast rate that there could not be measured any valid data.

4.4 Nexus with one VM

This data set contains the measurements collected from the test performed locally on the virtualization server Nexus with one VM running.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	48393.960	48634	240.040	363248.402	46306	48872	2566
putc_cpu	96.869	97	0.131	0.114	96	97	1
put_block	278673.899	281531	2857.101	213690989.465	233369	307593	74224
put_block_cpu	76.283	77	0.717	5.031	71	81	10
rewrite	77605.869	77633	27.131	25588185.508	67363	91479	24116
rewrite_cpu	12.444	12	0.444	1.116	10	15	5
getc	51685.818	51909	223.182	482574.694	49109	52450	3341
getc_cpu	93.758	94	0.242	0.992	91	95	4
get_block	447152.869	450941	3788.131	559635801.952	355290	471783	116493
get_block_cpu	7.616	7	0.616	10.014	2	19	17
seeks	0	0	0	nan	0	0	0
seeks_cpu	0	0	0	nan	0	0	0
seq_create	4136.919	4147	10.081	1011.973	4002	4160	158
seq_create_cpu	99.313	99	0.313	0.215	99	100	1
seq_stat	0	0	0	nan	0	0	0
seq_stat_cpu	0	0	0	nan	0	0	0
seq_del	0	0	0	nan	0	0	0
seq_del_cpu	0	0	0	nan	0	0	0
ran_create	4276.253	4289	12.747	1487.441	4107	4307	200
ran_create_cpu	99.091	99	0.091	0.083	99	100	1
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	16213.616	16237	23.384	58919.166	15187	17719	2532

Table 4.3: Table from Nexus onevm

Overall Results

In the writing operations we can see that the putc has a good performance of 48 MB/s by looking at the mean and median values. These numbers seems to be close up to the max value of this operation. put_block has a very good performance with a mean of 278 MB/s and median of 281 MB/s, and a max performance of 307 MB/s. Cpu usage of the two operations are quite high, 96 percent with putc and 76 percent with put_block. The rewrite operation has 77 MB/s in mean and median, and a min value of 67 MB/s and a max value of 91 MB/s. Its cpu usage is lower compared to the writing operations putc and put_block with only 12 percent usage.

getc and get_block in the reading section also performs well on this benchmark test. getc has a measured and calculated value of 51 MB/s in mean and median while get_block gets 447 MB/s in mean and 450MB/s in median. This operation scores very high at these tests which we can see even more clearly from the min and max values, seeing as its min value is 355 MB/s which is even higher than the max value of put_block. Furthermore, the max value for get_block

is 471 MB/s which is over two times as much as the min value of put_block.

In the last two sections we can see similar results for the seq_create and the ran_create. seq_create has a value of 4136 files per second while ran_create has 4147 files per second. They both have the same amount of cpu usage during these operations with a 99 percent usage. Last is the ran_del operation which has a measured mean and median value of 16 MB/s.

Descriptive Statistics

The two first sections have some very good results from these tests but unstable. If we look at the put_block values we can see a big difference in the mean and median values as well as a wide range. A range of 74 MB/s would suggest an unreliable rhythm of its operation. The big difference of the mean and median only strengthens this assumption. Same goes for the rewrite and get_block operation, rewrite with 24 MB/s and get_block with 116 MB/s wide range.

However, in the last two sections we can see a more stable work rate and good results. Both seq_create and ran_create having a less to no difference between the mean and median. Only 10 KB/s for seq_create and 12 KB/s for ran_create. ran_del as well with a 23 KB/s difference, although, it shows a slight instability if we look at the range of its min and max values.

Graphs of interest

The seek operation did not contain any credible data during this test. However, the graphs for put_block and get_block have valid data and will be presented. Figure 4.7 shows that the mean

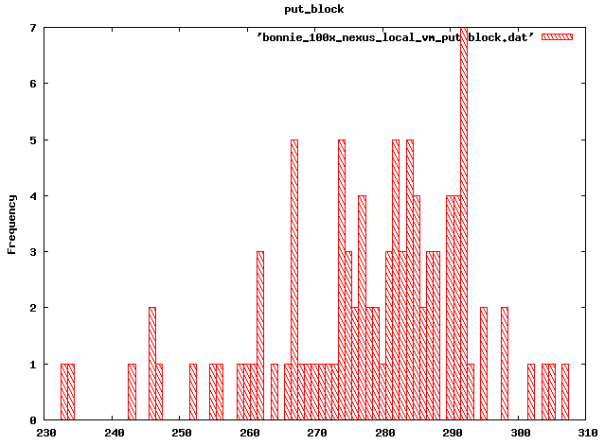

Figure 4.7: Nexus onevm put block

value calculated for the put_block operation seems to be coordinating well with the values in the graph. Seeing as the area between 260 MB/s to 290 MB/s has the most hits.

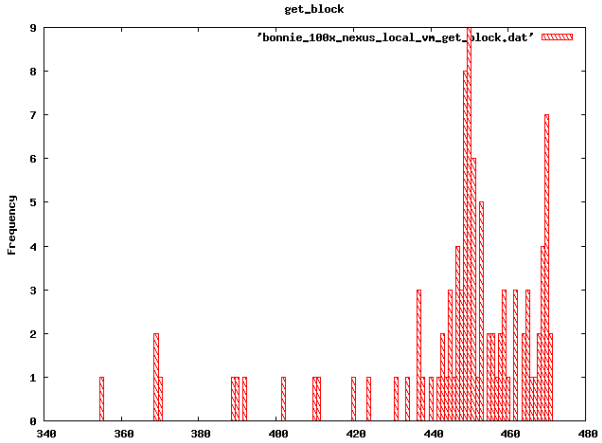

Figure 4.8: nexus onevm get block

Furthermore, we can see from figure 4.8 that the most hits are around the area between 440 MB/s and 470 MB/s. Hence, making the calculated mean value credible and giving a correct picture of how the performance was during the process.

Summary

This benchmark test of the virtual server running with one VM shows good performance, although, it has some unstable results in the writing and reading section. Especially the put_block, rewrite and get_block were the ones that seemed to be the most affected by this. However, the

rest of the results of this benchmark test shows good and stable results with no alarming numbers.

4.5 Iscsi basetest

These are the results for the iscsi base test. The virtualization server runs with one VM and the server itself has a basic iscsi configuration which establishes contact with the iSCSI technology on the SAN server.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	42653.101	42781	127.899	738863.323	37996	44117	6121
putc_cpu	84.848	85	0.152	2.553	75	88	13
put_block	45046.192	45216	169.808	482467.145	40918	46096	5178
put_block_cpu	6.697	7	0.303	0.312	6	8	2
rewrite	11346.717	11235	111.717	77779.880	10858	12216	1358
rewrite_cpu	0	0	0	nan	0	0	0
getc	14439.909	14465	25.091	76518.891	13491	15209	1718
getc_cpu	6.596	7	0.404	0.483	4	8	4
get_block	18294.232	18291	3.232	132275.875	17223	19437	2214
get_block_cpu	0	0	0	nan	0	0	0
seeks	478.597	477.800	0.797	266.913	404.3	570.1	165.8
seeks_cpu	0	0	0	nan	0	0	0
seq_create	4041.636	4037	4.636	3856.231	3838	4212	374
seq_create_cpu	96.929	97	0.071	1.379	94	101	7
seq_stat	0	0	0	nan	0	0	0
seq_stat_cpu	0	0	0	nan	0	0	0
seq_del	0	0	0	nan	0	0	0
seq_del_cpu	0	0	0	nan	0	0	0
ran_create	4242.646	4278	35.354	5385.319	3884	4469	585
ran_create_cpu	98.525	99	0.475	1.987	96	104	8
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	15243.495	14859	384.495	685322.775	13981	16433	2452

Table 4.4: Table of iscsi basetest

Overall Results

In the writing section one can see that both putc and putc_block have a very small difference between their mean and median. We can also see that the cpu usage is very low on the put_block compared to the putc. Rewriting seems perform at a much lower rate than putc and put_block with a difference of 30 MB/s or more. Although, the speed of the operation is very low it has a stable work rate looking at the max and min values.

Reading section of this benchmark test operates on a much lower performance than when it comes to writing. Results from mean and median show 14 MB/s which is under half of what writing section performs The cpu performance of the getc and getc_block are very low, especially

the getc_block which does not report any number even. Seeks seems to be working fine with a number of 478 files found per second. In seq_create 4000 files is created per second from what we can see in the mean and media which is a good performance. Same goes for the ran_create with 4200 files and ran_del with 15000 files created per second. All of the creation operations work with little difference in both average and the range between the max and min values.

Descriptive statistics

Iscsi performance varies a lot during the writing operations putc and put_block. If we look at the max and min values they get, we see the range being large. This could indicate that the iscsi performs on an unstable rate but by looking at the mean and median, it would be more reasonable to assume that some irregularities could have caused this during the measurements. Rewriting has a very low performance as we can see compared to the putc and putc_block processes. Although, is shows a more stable work rate if we look at the range between max and min. putc and put_block with 6 MB/s and 5 MB/s while rewrite performs with a range of 1,3 MB/s.

Reading operations also performs at a more stable rate than the putc and put_block. getc and get_block have ranges of 1,7 MB/s and 2,2 MB/s. Furthermore, getc and get_block have a much lower performance on the mean and median with 14 MB/s and 18 MB/s, that is really low if we think about what I/O measurement would look like for a normal hard drive. Seeks operations does good performance with 478 hits per second and has less to no difference with its mean and median values. Same goes for the max and min values with a range of 374 files per second.

In the last two sections where files are created and deleted, both seq_create and ran_create have similar results in mean and median. The difference on their mean and median is very small and not alarming. Furthermore, we can also see that the range indicates a stable performance based on their max and min values. Although, ran_del has a much higher performance in the mean and median, the operation gains a bit more instability Seeing as the number in the difference and range of its operations rises.

Graphs of interest

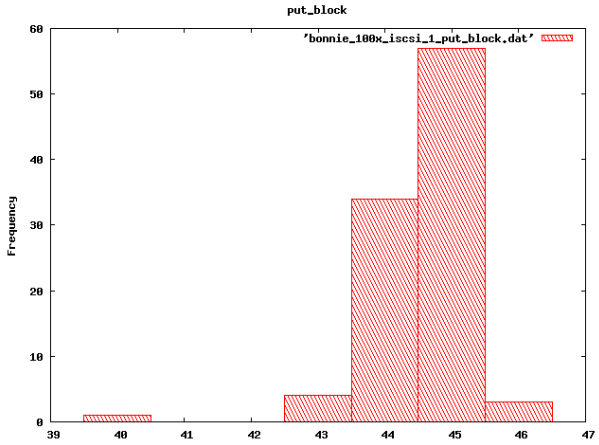

Figure 4.9: iscsi putblock

The graph in figure 4.9 shows good argumentation for the calculated mean value from table 4.5, seeing as most of the measurements recorded were found around 43 and 46 MB/s. Figure

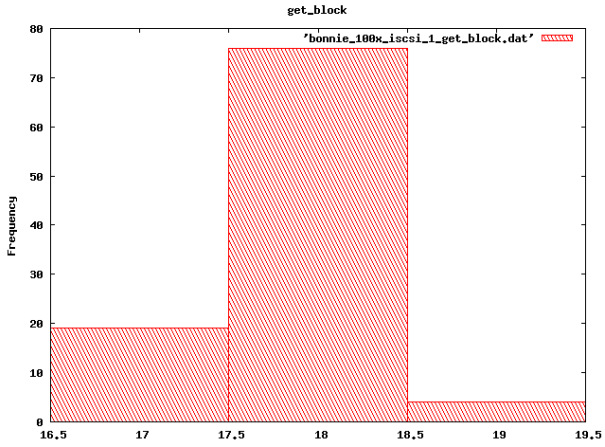

Figure 4.10: iscsi getblock

4.10 shows that most of the measured values are found in the area from 16,5 MB/s to 19 MB/s. This makes the mean value from table 4.5 valid which has a value of 18 MB/s. By studying the graphs in figure 4.11 we see that most of the measurements were recorded in the area between 430 to 460 files per second. This suggest that the mean value from table 4.5 is affected by unstable work rate during the benchmark test.

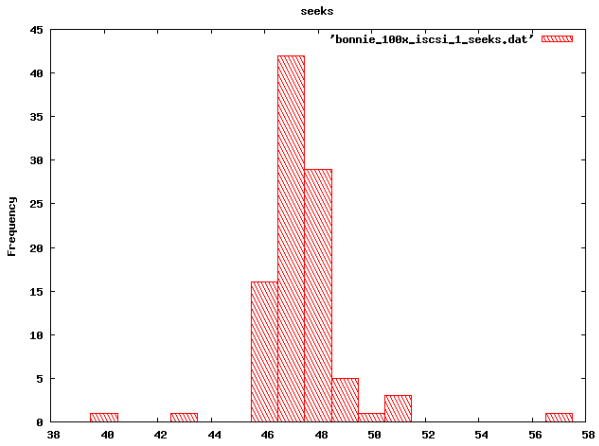

Figure 4.11: iscsi seeks

Summary

One thing in particular that really is abnormal in these measurements is the difference between the writing and reading operations. We can assume that there should be a slight difference when it comes to reading and writing, although, the difference we see here is really interesting. The number of getc is performing on less than half of what putc manages to produce per second according to the mean and median values. Normally, the reading operations usually perform on the same work rate as the writing operations do or better. Furthermore, we can see some lower cpu usage from some of the operations which indicates that they are waiting for the hard drive to finish up before they can start on their next operation.

4.6 Iscsi 3of3 test

These are the results for iscsi where three VMs are run upon Atlantis. Atlantis has iscsi client software installed and is connected to keeper that runs as the iscsi server with the proper software. This table is the representative data from all the three VMs that were running bonnie++ and gives an indication on how VMs are affected when more than one are operating on the shared iscsi device.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	16258.444	16021	237.444	11392432.166	12011	28651	16640
putc_cpu	34.626	35	0.374	42.820	25	59	34
put_block	15246.657	13532	1714.657	8762264.286	12583	21367	8784
put_block_cpu	2.323	2	0.323	0.239	2	4	2
rewrite	4440.919	4329	111.919	172536.923	3675	5821	2146
rewrite_cpu	0	0	0	nan	0	0	0
getc	7730.374	7994	263.626	599217.668	5974	11023	5049
getc_cpu	3.283	3	0.283	0.607	2	5	3
get_block	8996.253	9353	356.747	2426084.492	6444	18603	12159
get_block_cpu	0	0	0	nan	0	0	0
seeks	231.807	235	3.193	7046.147	85.5	482.3	396.8
seeks_cpu	0	0	0	nan	0	0	0
num_files	16	16	0	nan	16	16	0
seq_create	3648.152	3816	167.848	168373.785	2434	4102	1668
seq_create_cpu	95.172	96	0.828	7.496	86	99	13
seq_stat	0	0	0	nan	0	0	0
seq_stat_cpu	0	0	0	nan	0	0	0
seq_del	0	0	0	nan	0	0	0
seq_del_cpu	0	0	0	nan	0	0	0
ran_create	3683.465	3866	182.535	221465.461	2476	4303	1827
ran_create_cpu	95.556	96	0.444	7.277	84	100	16
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	13978.010	14799	820.990	4517906.879	8749	16253	7504

Table 4.5: Table of iscsi 3of3 test

Overall Results

By a quick overview of the writing section we can see a greater gap between the put_block an putc when it comes to the difference of mean and median. Furthermore, we can see that it is the other way around in the range between max and min for these two operations. putc with a 16 MB/s range and put_block with a 8 MB/s. Both of these operations have a very low cpu usage, especially put_block with only 2 percent. Rewriting has lower performance as we can see of the mean and median but has a smaller range between its max and min with 2 MB/s. The reading section also has a large range in the getc and get_block operations between the max and min values. getc has a 5 MB/s while get_block has 12 MB/s. The Seeks operation appears to get a low performance by looking at the mean and median.

seq_create has good performance if we look at the mean and median values. Although, it does not have the range of the other operations, it is still considerable if we look at the max and min values. Same goes for the ran_create, shows good performance in the mean and median values but also has a big range if we look at the max and min values. Cpu usage of these operations is high which is to be expected with 95 to 96 percent usage. ran_del performs 13,9 MB/s in mean and 14,7 MB/s in median which leads to a bigger difference if we compare to the values for seq_create and ran_create. Moreover, the range for ran_del is high compared to the range for seq_create and ran_create.

Descriptive statistics

Both writing and reading operations for the iscsi benchmark test are showing unstable working rate if we look upon the max and min values. putc has a min value of 12 MB/s and a max value of 28 MB/s which ends up in a range of 16 MB/s. This strongly suggest that it works in an unstable manner. Especially if we compare the mean and median values and see how the max value is so much higher, assumptions could be made to describe it as unreliable as well. Although, the range is half on the put_block operation, the difference in the mean and median values is 1,7 MB/s. A very high number compared to the putc operation which strongly indicates an unreliable work rate. rewrite has very low performance as we already covered in the last section, but the range of the max and min values shows a more stable work rate for this operation.

Furthermore, both getc and get_block have a shorter range compared to putc and put_block, they are still too high to be seen as reliable. Although, the unstable results shown in range, we can see that the difference between the mean and median are acceptable with only 0,26 MB/s for getc and 0,35 MB/s for get_block. In the searching section looking at the seek operation we see a very low min value of 85,5 files per second. The range is also very high compared the number we have in max with a range of 396 files per second and a max value of 482 files per second. This low min value could be explained by some irregularities during these benchmark tests like for instance the cache of the cpu on the VM server acting up.

In the section where creating files are being measured we can see from both seq_create and ran_create a stable work rate. seq_create has a a difference of 167 files per second which indicates a reliable work rate and a range of 1,6 MB/s that is acceptable compared to the values we see from the writing and reading operations. Lastly we see the ran_del performs at a much higher rate than both seq_create and ran_create by looking at the mean and median values of these operations. Moreover, the difference is higher but not really affecting the stability as much as the range. The range between its max and min is are much higher than the max and min of seq_create and ran_create, indicating an unstable rhythm in its working rate.

Graphs of interest

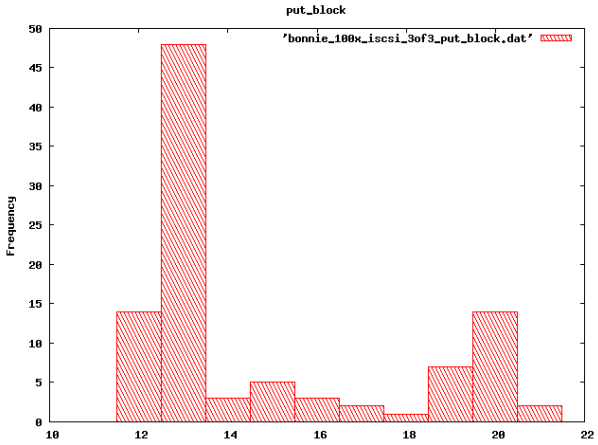

Figure 4.12: iscsi 3of3 putbl

Figure 4.12 shows the measurements recorded for the put_block operation. As we can see the results are widely spread and there are many counts both at the start and at the end. This could indicate that the mean value from table 4.6 is unbalanced based on the data we see in the graph. However, figure 4.13 shows that the get_block operation data from the table 4.6 and

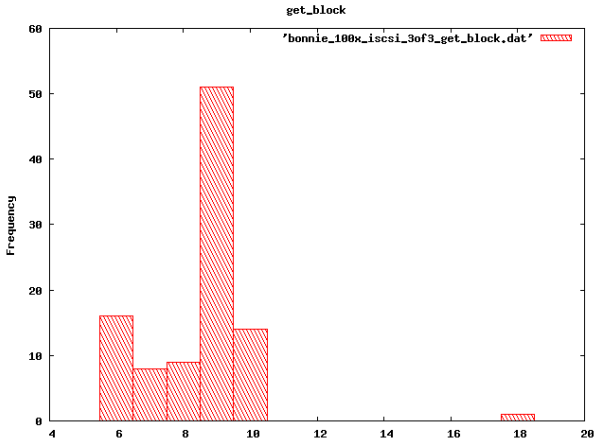

Figure 4.13: iscsi 3of3 getblock

the graph works in harmony.

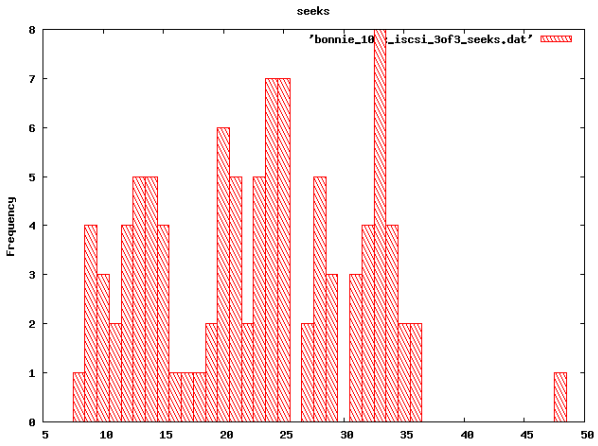

Figure 4.14: iscsi 3of3 seeks

Same situation can be seen in figure 4.14 since most of the measurements are recorded between 100 to 350 files per second and the mean value for the seek operation in table 4.6 is on 230 files per second.

Summary

By looking through what we have observed, one thing in particular should be mentioned. The difference in the performance between the writing and reading section was really the most interesting. Seeing as the reading performance is measured to be half of what the performance in the writing got but still they are operating at the same unstable work rate. Despite of the bad performance in these two sections the ways of testing creating and deleting files scored high. Both the difference and the range were at an acceptable number and indicating a more stable work rate.

4.7 NFS basetest

This table shows the results from a NFS base test that was conducted on the virtualization server Atlantis It was run without any VMs and Atlantis used the benchmark tool directly on the environment shared by NFS.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	28534.444	28419	115.444	611578.954	27089	31697	4608
putc_cpu	60.212	60	0.212	3.238	57	67	10
put_block	27021.515	26818	203.515	1616586.290	24888	30831	5943
put_block_cpu	9.525	9	0.525	0.330	9	12	3
rewrite	13358.869	13337	21.869	47389.791	12861	13942	1081
rewrite_cpu	2.212	2	0.212	0.167	2	3	1
getc	23866.505	23721	145.505	647568.452	22146	26212	4066
getc_cpu	44.576	45	0.424	24.608	33	55	22
get_block	25155.343	25202	46.657	334903.781	23635	26436	2801
get_block_cpu	5.475	6	0.525	0.977	4	8	4
seeks	1049.258	1068.800	19.542	6178.578	615.0	1177.2	562.2
seeks_cpu	1.788	1	0.788	8.329	0	13	13
seq_create	38.697	39	0.303	0.433	38	40	2
seq_create_cpu	0	0	0	nan	0	0	0
seq_stat	4472.424	3714	758.424	1549846.850	3600	6756	3156
seq_stat_cpu	1.333	1	0.333	2.485	0	9	9
seq_del	77.657	78	0.343	2.407	74	79	5
seq_del_cpu	0	0	0	nan	0	0	0
ran_create	39.101	39	0.101	0.273	37	40	3
ran_create_cpu	0	0	0	nan	0	0	0
ran_stat	4939.737	4005	934.737	2523425.547	3916	7943	4027
ran_stat_cpu	0.465	0	0.465	1.239	0	9	9
ran_del	78.404	79	0.596	0.726	77	79	2

Table 4.6: Table of NFS basetest

Overall Results

In the writing section of the NFS base test we can see that there is a very small difference between the mean and median of putc with a 115 KB/s. However, its range between the min and max shows a larger difference with a number of 4,6 MB/s. put_block seems also to have the same phenomena with a difference for the mean and median of 203 KB/s and a range between the min and max values of 5,9 MB/s. We can see that the cpu usage is much lower for the put_block with a 9 percent usage compared to the putc operation that uses 60 percent during its run.

rewrite operation performs at 13 MB/s which is a bit under half of the performance the writing section produces during the benchmark tests. Furthermore, the difference of its mean and median values is only 21 KB/s. Moreover, the range of the min and max values is 1 MB/s. Both of these values are much smaller than the writing sections values. Same goes for the cpu

usage as well with only 2 percent usage as we can see from looking at the mean and median values

The reading section has similar results as in the writing section. getc has 23 MB/s while get_block has 25 MB/s in mean and median. They have the same phenomena as in the reading section with little difference between the mean and median and bigger range when it comes to the max and min values. We can also see that the cpu usage for the getc and get_block is lower with 44 percent and 5 percent usage. seeks seems to be performing quite well with a strong mean of 1049 files and a median of 1068 files per second. Although, the min value 615 files per second is only half of the maximum number of 1177 files per second.

By looking at the file operations like creating and deleting we clearly see bad performance for being I/O benchmark tests. seq_create produces only between 38 to 39 files per second according to the mean and median values. The performance of this NFS base test is so low that we can get a number from the seq_stat. This operation reads through the file and sends back the information about it like for instance permissions. In the mean we see that is stats 4472 files per second while in median it is 3714 files per second. This gives a higher difference than the previous operations for this base test. seq_del also has a low performance by looking at the mean value of 77 files per second and median of 78 files per second. The range of these operations is very low and seems to be stable.

Next section which creates files in a different order seems also to perform low. ran_create has a mean and median at 39 files per second which corresponds well with the min and max values. ran_stat performs a bit higher compared to the seq_stat but this is also goes for the difference of its mean and median values. Both seq_stat and ran_stat produces a very high range and seem to have had problems during the benchmark test. ran_del performs on the same level as seq_del.

Descriptive statistics

Writing and reading section have similar results produced from this benchmark test. There is less to no difference in the mean and median values of the putc,put_block,getc and get_block operations. However, we can see that putc and put_block have a larger range than the getc and get_block, indicating a much more unstable work rate when it comes to writing. Moreover, the rewriting operation performs with a lower mean and median but at a more stable work rate with a range of 1 MB/s.

seeks is performing very well if we look at the mean and median values, up to 1000 files per second. Although, if we look closer at the min and max values, 615 and 1177 files per second, there is a wide range between them. Seeing as the mean and median values are much closer to the max value than the min value, we could assume that some irregularities during its operation occurred, causing bad results.

In the next sections we see operations with poor performance operating at stable work rate. seq_stat and ran_stat stands out as the more unstable ones. Especially if we look at their max and min values. They both have quite wide ranges, seq_stat with 3156 files per second and ran_stat with 4027 files per second. The max value from both of them is also twice as big as the mean and median values, which strongly suggests a very unstable and unreliable work rate for these operations. Furthermore, seq_create, ran_create and ran_del have low performance but a very stable work rate with a range of 2 to 5 files per second.

Graphs of interest

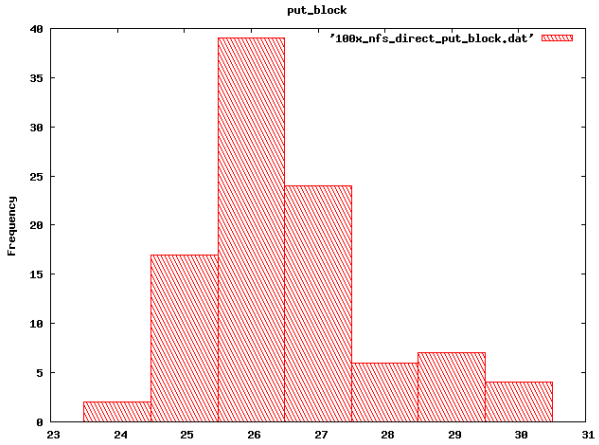

Figure 4.15: NFS base putblock

Figure 4.15 shows that the mean value from table 4.7 for the put_block operation seems to be accurate according to the graphs. In figure 4.16 we see that most of the values are resided

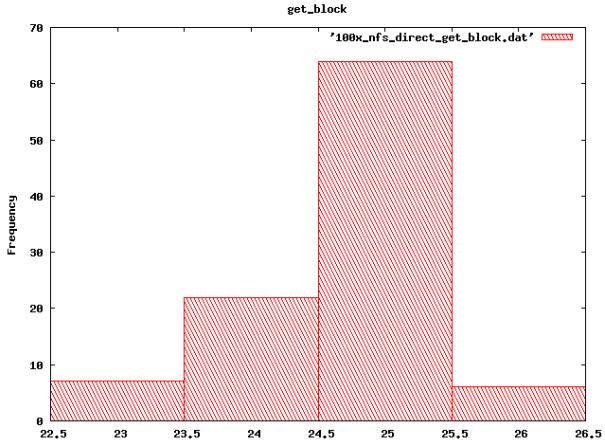

Figure 4.16: NFS base getblock

in the area between 22,5 MB/s to 26,5 MB/s. This validates the mean value of 25 MB/s from table 4.7

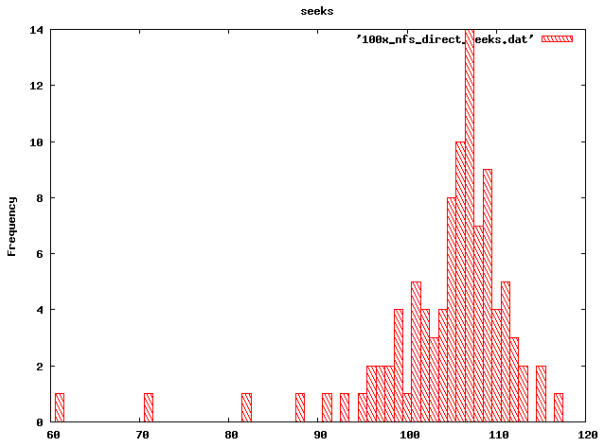

Figure 4.17: NFS base seeks

From figure 4.17 we can see that the measurements recorded are heavily populated in the area between 900 to 1150 files per second. These values corresponds well with the mean value from table 4.7.

Summary

The overall results for this base test shows a very poor performance. Especially in the two sections that handles and tests the creation and deletion of files. seq_create and ran_create going as low as 38 to 39 files per second when we look at their mean and median values. This also affects the outcome of the seq_stat and ran_stat that usually performs to fast to get a valid measurement, because of the slow performance we can do some descriptive statistics of the data coming from those operations as well. Seeks is the only operation under this base test that performs well from what we have seen earlier.

4.8 NFS 3of3 test

From this table of data we can see the results from three VMs running a bonnie++ benchmark test on one of the virtualization servers, in this case Atlantis, which is connected to a shared and mounted folder.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	25321.253	28261	2939.747	97671354.229	5540	40616	35076
putc_cpu	73.343	94	20.657	827.700	15	97	82
put_block	104609.697	111786	7176.303	6174875548.393	5495	289875	284380
put_block_cpu	35.444	38	2.556	715.863	1	85	84
rewrite	53472.293	51444	2028.293	1705559591.035	4035	180698	176663
rewrite_cpu	9.293	8	1.293	76.268	0	33	33
getc	21595.960	24070	2474.040	139606583.554	106	47859	47753
getc_cpu	54.051	58	3.949	935.725	0	95	95
get_block	141666.374	143731	2064.626	13727079249.163	6287	430634	424347
get_block_cpu	4.980	2	2.980	37.111	0	23	23
seeks	3005.201	306.200	2699.001	23392375.841	0	16365.1	16365.1
seeks_cpu	2	0	2	17.455	0	17	17
seq_create	2715.535	2929	213.465	1122266.734	355	4151	3796
seq_create_cpu	84	99	15	898.929	9	102	93
seq_stat	0	0	0	nan	0	0	0
seq_stat_cpu	0	0	0	nan	0	0	0
seq_del	35.293	0	35.293	122067.904	0	3494	3494
seq_del_cpu	0.020	0	0.020	0.040	0	2	2
ran_create	3010.030	3037	26.970	830162.595	342	4280	3938
ran_create_cpu	90.667	99	8.333	512.303	10	100	90
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	11903.657	12049	145.343	14317081.256	680	16409	15729

Table 4.7: Table of NFS 3of3 test

Overall Results

By a quick view in the writing section we can see that the putc performs much lower than put_block, putc has a mean of 25 MB/s and a median of 28 MB/s while put_block has 104 MB/s and 117 MB/s. Both of the operations have a high difference between the mean and median, same conditions can be stated for the ranges. putc has a range of 35 MB/s and put_block with a 284 MB/s which seems to be very high. rewrite has twice the performance in mean with 53 MB/s and almost the same in median which looks a bit suspicious compared to what we have seen before. Its range is also very high with a number of 176 MB/s.

In the reading section we have the same phenomena where getc operates with a mean value of 21 MB/s and median of 24 MB/s while get_block has the mean value of 141 MB/s and 143 MB/s in median. Furthermore, we can see wide ranges according to their min and max values as well. getc with a 47 MB/s and get_block with a very high range of 424 MB/s. Moreover,

the seeks operation has a very big gap between its mean and median, seeing as its mean is 3005 files per second and median only 306 files per second. This could be affected by the range as we can see that min is 0 and max is 16 MB/s.

However, if we look at the operations of creating and deleting files, we see little difference with their mean and median. seq_create has a difference of 213 files per second while ran_create has 26 files per second. Same goes for the ran_del that has 145 files per second. Despite the good results in their difference between mean and median, they all have wide ranges if we look at their min and max values. Especially ran_del that has a number of 15 MB/s compared to seq_create with 3,7 MB/s and ran_create with 3,9 MB/s.

Descriptive statistics

As we mentioned earlier we can see some differences that really strikes out. The first two operations tells us more than enough to see that the NFS has a very unstable work rate. putc with a difference of 2,9 MB/s and put_block with 7 MB/s indicates an unreliable mean as well as median. These two operations have also a very unstable work rate, with 35 MB/s and 284 MB/s. seeks has the most outstanding difference from these benchmark tests with a value of 2,6 MB/s, especially if we look at its mean of 3 MB/s and median of 306 KB/s. This operation has a very unstable work rate as well by looking at its min and max values, seeing as the max value of 16000 files per second is also its range.

Although, in the sections where files are being created and deleted in different order, the mean and median were acceptable according to the values they have in difference. Only exception is the seq_del which usually have no credible measurements taken during these benchmark tests, which seems to have had severe problems during this test. Its mean value of only 35 files per second and no median indicates the likelihood of irregularities causing these strange numbers. However, it could simply be that its work rate is very unstable, and by looking at its min and max values we can clearly see the wide range of 3494 files per second which is the same as the max value.

ran_create and ran_del have also problems with unstable min and max values. Both of them have a very wide range which is very easy to see by studying their max values. ran_create with a 3,9 MB/s range and a max value of 4,2 MB/s, while ran_del has a 15,7 MB/s range and a max value of 16,4 MB/s. These results puts a question mark on the mean and median on how reliable they are.

Graphs of interest

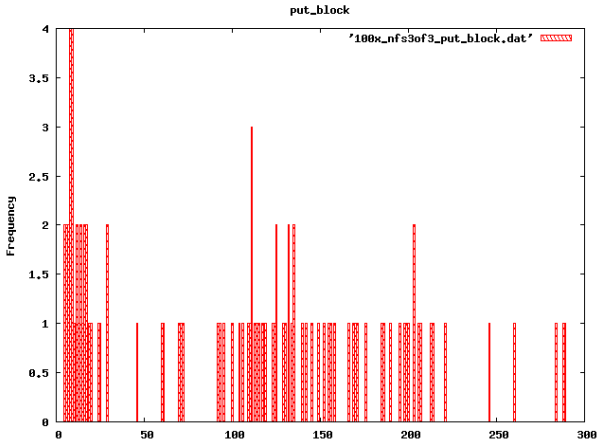

Figure 4.18: NFS 3of3 putblock

From figure 4.18 we see that most of the measurements were taken in the area between 10 MB/s to 60 MB/s. However, there is many measurements taken in the higher regions of this graph, suggesting a long tailed distribution. Table 4.8 seems to have a valid mean number with 25 MB/s when compared to the graphs recordings. It also seems to be a long tailed distribution

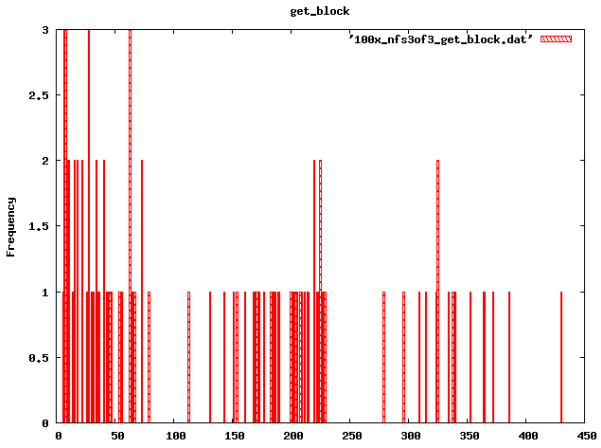

Figure 4.19: NFS 3of3 getblock

in figure 4.19, with most of the measurement taken in the area between 10 to 60 MB/s and also in the area between 170 to 220 MB/s. This could be justified by the mean value of 141 MB/s in table 4.8, however, this graph shows great unpredictability for this type of technology.

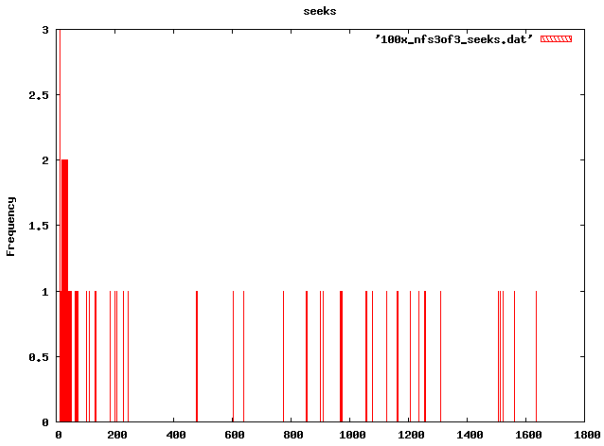

Figure 4.20: NFS 3of3 seeks

Same goes for the graphs in figure 4.20 when we look how most of the measurements taken resides in the area between 200 to 600 files per second and how the highest measurement taken is over 16000 files per second. Suggests a clearly unstable work rate for this technology when more are using it at the same time.

Summary

There were several of the operations that had a high difference between their mean and median values. However, all of the operations had a wide range that made it even clearer for the ones with high difference, that they were working at an unstable work rate. One surprise in this table of data was the seq_del operation with a mean and a max value. This would suggest that the performance was either very low or some irregularities occurred since normally this operation measures no valid data while working properly.

4.9 DRBD basetest

These measurements are taken from a simple DRBD setup without any VMs up and running on either Altantis or Nexus.

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	45244.414	45694	449.586	3458184.626	33992	47396	13404
putc_cpu	91.929	92	0.071	13.157	67	97	30
put_block	45408.515	45478	69.485	3271730.573	34123	49404	15281
put_block_cpu	7.434	7	0.434	0.407	5	9	4
rewrite	23021.475	23226	204.525	1158997.199	18143	24865	6722
rewrite_cpu	0	0	0	nan	0	0	0
getc	38075.253	38237	161.747	631781.967	33203	40033	6830
getc_cpu	49.414	49	0.414	2.121	41	53	12
get_block	70576.859	70806	229.141	1895523.435	60562	72337	11775
get_block_cpu	0	0	0	nan	0	0	0
seeks	356.824	358	1.176	125.870	299.1	378.7	79.6
seeks_cpu	0	0	0	nan	0	0	0
seq_create	4071.556	4079	7.444	2333.297	3872	4185	313
seq_create_cpu	97.404	97	0.404	0.604	95	99	4
seq_stat	0	0	0	nan	0	0	0
seq_stat_cpu	0	0	0	nan	0	0	0
seq_del	0	0	0	nan	0	0	0
seq_del_cpu	0	0	0	nan	0	0	0
ran_create	4262.859	4245	17.859	3088.586	4047	4336	289
ran_create_cpu	98.222	98	0.222	1.345	96	100	4
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	15802.121	16274	471.879	467742.753	14436	16673	2237

Table 4.8: Table of DRBD basetest

Overall Results

First glance over the results we can see that putc and put_block have the same results in mean and median. Both of them have 45 MB/s as a mean and median, and a low difference between them. Furthermore, we see that the min and max range of both of them are high. putc with a 13 MB/s and put_block with a 15 MB/s. rewrite seems to be performing close to half of what putc and put_block have with 23 MB/s in mean and median. This operation has a lower range of 6,7 MB/s between its min and max values.

In the reading section we have a lower result on getc with 38 MB/s in mean and median compared to the putc. However, get_block has a much higher performance with 70 MB/s compared to put_block and a lower range as well. seeks is performing stable with 356 files per second in mean and 358 files per second in median, and have a range of 79 files per second between its min and max values.

When it comes to the creation and deletion testing, we see a less to no difference for both seq_create and ran_create by looking at the mean and median values. There is a slightly higher difference for ran_del but that could be that the performance is higher as well. Seeing as it has 15 MB/s in mean and 16 MB/s in median. The range values repeat the same trend we saw with the difference numbers. seq_create has 313 files per second and ran_create has 289 while ran_del has 2237 files per second.

Descriptive statistics

In the writing section we can see that the putc and put_block have high ranges, suggesting an unstable work rate. Especially since the value of their difference from mean and median is less to none. Seeing that both putc and put_block have 13 and 15 MB/s in range which is almost half of the minimum value.

rewrite and getc performs on a much more stable rate as we see their ranges are half of putc and put_block with 6,7 MB/s and 6,8 MB/s. Although, with the get_block we can see that the range goes up again with 11 MB/s , but that could be that the performance in mean and median is much higher as well.

seeks and the operations from the creation and deletion sections all seem to be in harmony with their mean and median if we look at their difference which is very low. ran_del has the highest numbers in difference and range in this section. However, if we compare the values from ran_del with operations like seeks, seq_create and ran_create we can see that they are much higher. This would suggest that it performs just as stable as the other operations but better seeing as the numbers are higher.

Graphs of interest

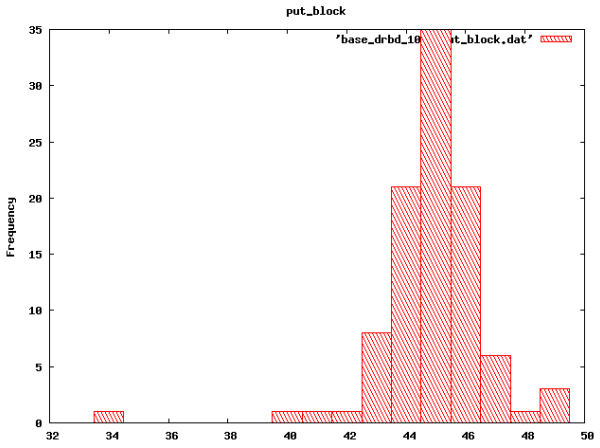

Figure 4.21: DRBD basetest putblock

From figure 4.21 we can see that most of the measured results for put_block are located around 42 MB/s to 48 MB/s which corresponds well with the mean value from given in table 4.9. Figure 4.22 show that most of the data is in the area between 58 MB/s to 72 MB/s which suggests that the mean value from table 4.9 of 70 MB/s is valid. As we can see in figure 4.23 most of the measurements are concentrated around 340 to 370 files per second. The mean value

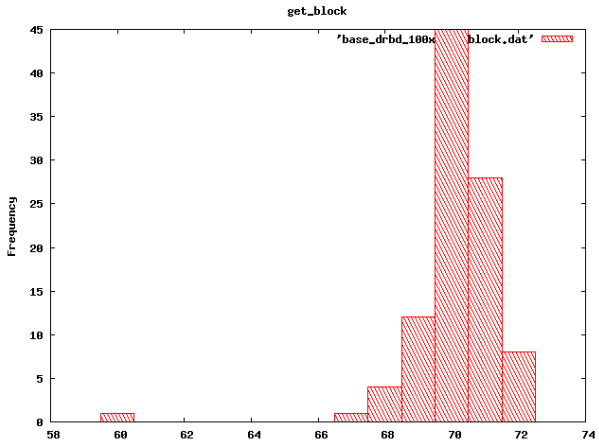

Figure 4.22: DRBD basetest getblock

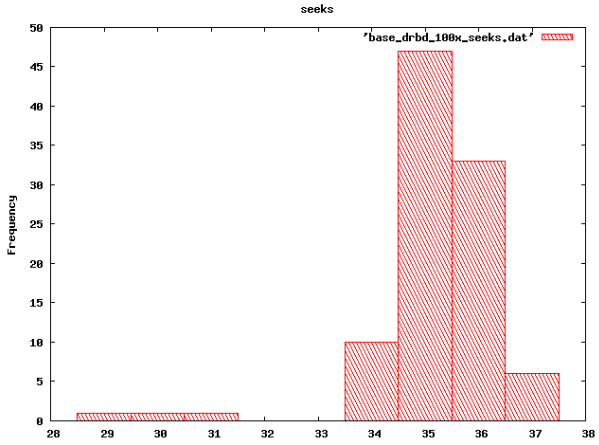

Figure 4.23: DRBD basetest seeks

of 356 files per second from table 4.9 strongly suggests a balanced relation between the table data and the graph.

Summary

DRBD seems to perform a bit lower on writing to blocks as one can see from put_block compared to the reading operation get_block. There were also some instability for both writing and reading during this benchmark test if we look at the ranges calculated from the measured min and max values. The last two section with the creation and deletion of files seemed to be having better performance and a much more stable work rate compared to the first operations.

4.10 DRBD 3of3 test

This table of results contains the data measured from three VMs running the benchmark tool bonnie++ on top of the virtualization server Atlantis

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
putc	10024.525	9206	818.525	3988750.613	8181	16904	8723
putc_cpu	21.141	19	2.141	22.950	17	36	19
put_block	10918.495	10976	57.505	745612.129	8558	12888	4330
put_block_cpu	1.657	2	0.343	0.225	1	2	1
rewrite	7033.495	6891	142.495	439018.311	5794	9071	3277
rewrite_cpu	0	0	0	nan	0	0	0
getc	11255.434	11279	23.566	604215.599	8971	13099	4128
getc_cpu	12.121	12	0.121	1.157	9	15	6
get_block	38747.242	36494	2253.242	62389843.840	26706	66601	39895
get_block_cpu	0	0	0	nan	0	0	0
seeks	147.859	148.500	0.641	70.800	123.4	166.2	42.8
seeks_cpu	0	0	0	nan	0	0	0
seq_create	3134.626	2996	138.626	205190.214	2502	4009	1507
seq_create_cpu	95.455	96	0.545	5.056	88	99	11
seq_stat	0	0	0	nan	0	0	0
seq_stat_cpu	0	0	0	nan	0	0	0
seq_del	299.283	0	299.283	8777880.708	0	29629	29629
seq_del_cpu	0.343	0	0.343	11.559	0	34	34
ran_create	3139.636	2958	181.636	202127.565	2509	4216	1707
ran_create_cpu	95.253	95	0.253	3.623	89	100	11
ran_stat	0	0	0	nan	0	0	0
ran_stat_cpu	0	0	0	nan	0	0	0
ran_del	12651.162	12275	376.162	2870622.237	8715	16349	7634

Table 4.9: Table of DRBD 3of3 test

Overall Results

The writing operations does not perform good during the benchmark test. putc has 10 MB/s in mean and 9 MB/s in median. It also has a min value of 8 MB/s and twice as much in max with 16,9 MB/s. put_block has the similar results in mean and median with 10 MB/s in each. However, the gap between min and max is not that high for this operation, with a min value of

8,5 MB/s and a max value of 12,8 MB/s.

rewrite operations performs lower than putc and put_block with a value of 7 and 6,8 MB/s in mean and median. Its min and max values has a lower gap than the previous operations. Seeing as its min value is 5,7 MB/s and the max value is 9 MB/s.

In the reading section we can see that the performance is better. getc has 11 MB/s in mean and median. Although, the max value is lower than for putc it has a smaller gap between min and max which we can see by looking at its min value of 8,9 MB/s and max value of 13 MB/s. get_put has a much higher performance with 38 MB/s in mean and 36 MB/s in median. This seems to cause a much larger gap between its min and max values, as we can see with a min value of 26 MB/s and a max value of 66 MB/s.

Operations when creating files are performing at a similar rate. seq_create and ran_create have the same values in mean and median. Same goes for the min and max values, since both of them have a min value of 2500 files per second and max value of 4000 files per second. Moreover, the deletion operations are really unbalanced. Looking at the seq_del we have a mean value of 299 files per second and no median which gives the impression that this operation was struggling From what we see from the min value of 0 and max value of 29629 files per second, we can really back this up. As for ran_del we see a better performance and more stable as well. It has a mean value of 12651 files per second and median of 12275 files per second , and a smaller gap with a min value of 8715 files per second and a max value of 16349 files per second.

Descriptive statistics

The writing operation putc has a wider range than the reading operation getc with value of 8,7 MB/s. This indicates that writing with this technology is much more unstable than reading. It is much easier to see the difference when it comes to put_block and get_block, seeing as put_block has a range of 4 MB/s and get_block 39 MB/s. get_block has a much higher performance but this seems to be affecting the stability of this operation.

In the creation of files operations we see nothing out of the ordinary, however, the deletion operations are having problems if we look at seq_del. seq_del has a mean of 299 files per second while its median is equal to 0. This would suggest that some irregularities is causing these strange numbers. A path towards that direction only gets stronger when we look at the min value of 0 and max which is 29629 files. By these measured results we could assume that there is an unbalance when comparing the mean and median with the max value.

Graphs of interest

Seeing how the data measured lies within 8 to 12 MB/s in figure 4.24 the mean value of 10 MB/s is easily justified from table 4.10 Figure 4.25 shows that most of the measurements taken for the get_block operation for DRBD with 3 VMs are found around 30MB/s to 40 MB/s. This means that the mean value from table 4.10 is a bit unbalanced according to the graph. It is, however, much better balance the mean value of 147 files per second for the seeks operation in table 4.10 when we look at the graphs in figure 4.26. Since most of the measurements collected are in the area between 120 to 160 files per second.

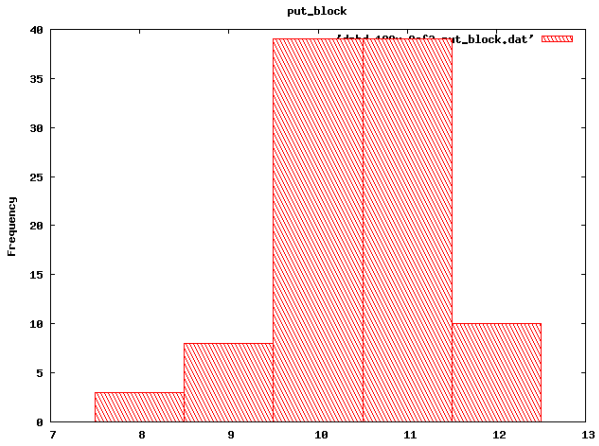

Figure 4.24: DRBD 3of3 putblock

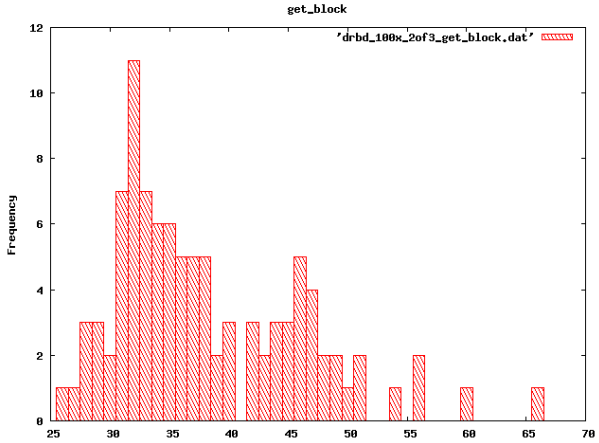

Figure 4.25: DRBD 3of3 getblock

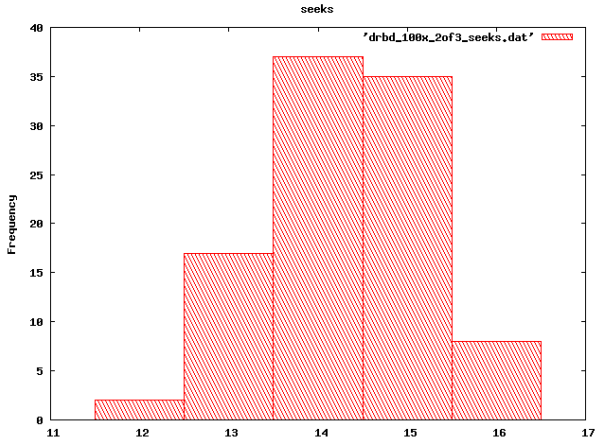

Figure 4.26: DRBD 3of3 seeks

Summary

What we have seen of these results is low performance from both the writing and the reading sections and all of their operations. It also was a high range for most of the operation, especially the get_block operation. Although, creation of files seemed to be working rather well for this technology, there were some strange results from the deletion tests. Seeing as seq_del seem to be struggling a lot with very low performance and high difference in both its mean and median as well as the min and max values.

4.11 Summary

We have so far covered every technology that have been tested during this project. In this section we will summarize the results and make an easy viewable comparison of these technologies with their base tests, where the mean and range value will be in focus when going through all of the different operations.

Operation	Keeper	iscsi	nfs	drbd	nexus
putc	45871	42653	28534	45244	42277
put_block	70315	45046	27021	45408	66632
getc	49877	14439	23866	38075	47166
get_block	72161	18294	25155	70576	70311
rewrite	29713	11346	13358	23021	28845
seeks	537	478	1049	356	486
seq_create	3658	4037	38	4071	0
ran_create	3746	4242	39	4262	0
ran_de	11898	15243	78	15802	0

Table 4.10: Table of Summary Results Mean Basetest

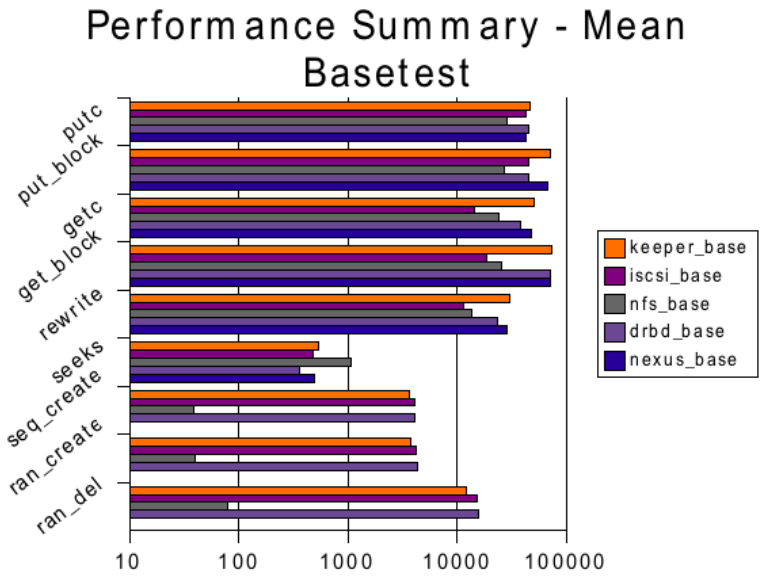

Figure 4.27: Performance Summary Mean

Performance summary basetests Mean

From figure 4.27 we see the best results for each of the technologies by viewing their mean values and comparing them. These results are based on the criterias and the type of environment I used during this project. By looking close at this picture we can see that the basetests from DRBD and keeper have even results in the reading operations. However, we can see that DRBD performs better in the writing operations putc and put_block. NFS performs better if we look at the seeks operation and iscsi does it slightly better during the file operations. Although, overall it seems to be DRBD that performs best under the criterias chosen.

Operation	Keeper	iscsi	nfs	drbd	nexus
putc	1024	6121	4608	13404	1669
put_block	6930	5178	5943	15281	6985
getc	6207	1718	4066	6830	7307
get_block	8235	2214	2801	11775	4818
rewrite	29713	1358	1081	6722	1985
seeks	272	165	562	79	273
seq_create	257	374	2	313	0
ran_create	203	585	3	289	0
ran_del	1186	2452	2	2237	0

Table 4.11: Table of Summary Results Range Basetest

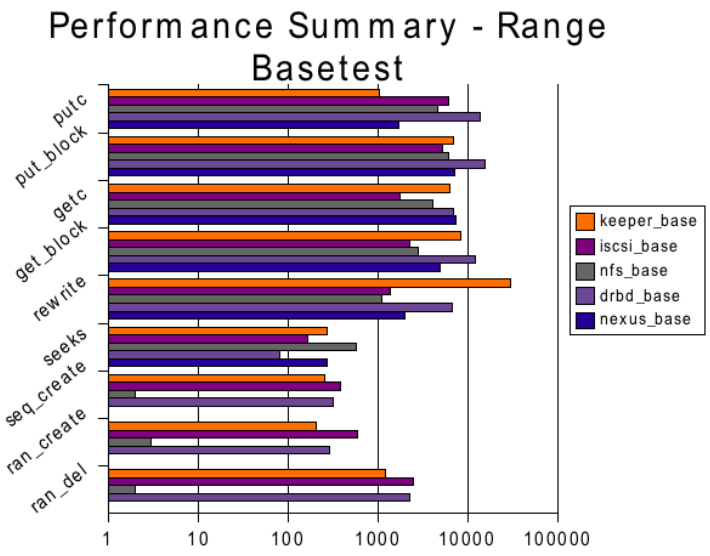

Figure 4.28: Performance Summary Range

Performance summary basetests Range

In figure 4.28 the range values of all of the operations are gathered so that we can easily compare them. Seeing that a high range value is unfortunate for the technologies, making them appear unpredictable and have a certain amount of time it performs very low for instance, so that a lower score is better in this figure. From the writing operations putc and put_block we can see that keeper has a slightly lower range than nexus. Furthermore, in the reading operations we can see that the iscsi technology has a lower range compared to the other technologies. Moreover, we see that DRBD has the lowest range for the seeks operation. However, in the final operations seq_create, ran_create and ran_del NFS has a much lower range than all of the other technologies. This also tell us it performs best overall from a range point of view based on the criterias and the experimental setup chosen.

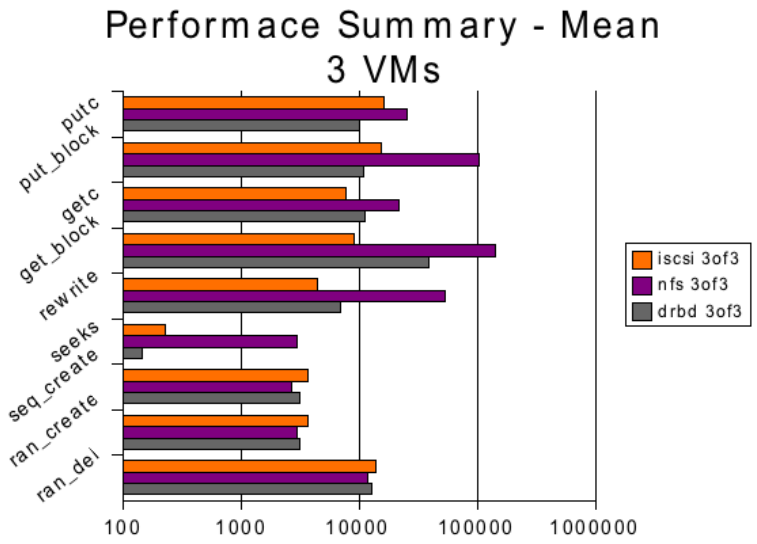

Figure 4.29: Performance Summary Mean 3VMs

operation	iscsi	nfs	DRBD
putc	16258	25321	10024
put_block	15246	104609	10918
getc	7730	21595	11255
get_block	8996	141666	38747
rewrite	4440	53472	7033
seeks	231	3005	147
seq_create	3648	2715	3134
ran_create	3683	3010	3139
ran_del	13978	11903	12651

Table 4.12: Table of Summary Results Mean 3VMs test

Performance summary 3VMs Mean

By looking at figure 4.29 we see the mean results for all of the operations for the different technologies running 3 VMs. In the writing and the reading operations we see that NFS has a much better performance compared to the other technologies DRBD and iscsi. NFS has no competition at all when it comes to the seeks operation. Furthermore, in the other file operations seq_create, ran_create and ran_del NFS is passed by both DRBD and iscsi on all of them. However, overall it seems to be NFS is the technology that performs best with 3 VMs according to the criterias and the experimental setup I have chosen for this project.

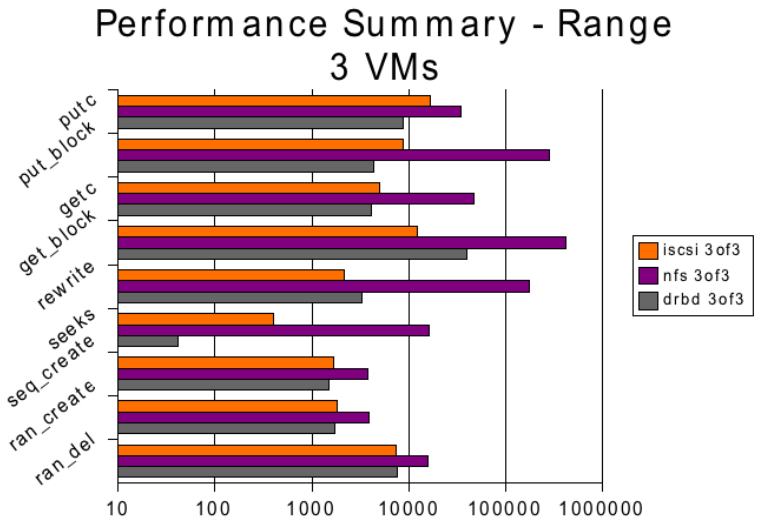

Figure 4.30: Performance Summary Range 3VMs

Operation	iscsi	nfs	DRBD
putc	16640	35076	8723
put_block	8784	284380	4330
getc	5049	47753	4128
get_block	12159	424347	39895
rewrite	2146	176663	3277
seeks	396	16365	42
seq_create	1668	3796	1507
ran_create	1827	3938	1707
ran_del	7504	15729	7634

Table 4.13: Table of Summary Results Range 3VMs test

Performance summary for 3 VMs Range

Figure Performance Summary Range 3VMs shows what the technologies running with 3 VMs have of range for the different operations. Seeing how NFS performed so well according to figure 4.29 it has much wider range for all of the operations. DRBD and iscsi have more or less the same values for range in the file operations seq_create, ran_create and ran_del. However, if we look closer upon the writing and reading operations we can see that DRBD has a lower range compared to the iscsi. The rewrite operation is the only encounter we see that DRBD performs worse than iscsi. Based upon the results gathered from the experimental setup used for this project and its criterias it is DRDB that performs best overall from a range point of view.

Best overall

Determine what technology that is best overall is not easy based on these criterias and experimental chosen for this project. It depends more on what you or your company are looking for and how many clients that will take use of this technology. DRBD and NFS are the ones that

shows themselves as the better technology based on these scenarios.

Based on these tests we can see that the more VMs added as clients, NFS is the one that performs the best on an average. However, if you want to have a more predictable and stable work rate DRBD is a better choice. Same relation is to be found for the base tests, seeing that DRBD performs best on an average when standalone and NFS has a lower performance but a much more stable work rate.

Chapter 5

Discussion

In this chapter we will go through and discuss some of the choices that were made during the process that affected the outcome. Furthermore, it contains a retrospective view of the entire process and the experimental setup, to see and explain what could have been done or should have been done for the different choices made during the process.

5.0.1 The Process

From the very beginning of the process and the experimental testing started I had a open mind of which SAN technology that would perform best. Seeing that all of the technologies I tested are popular choices in smaller to larger companies. However, before the testing could start a benchmark tool had to be found. The choice ended up with bonnie++ which is very popular and used by both private and corporate people that are testing out different storage devices and technologies. Although, there are many other benchmark tools out there that are highly recommended[1], I have no regret of choosing bonnie++. It has a lot of documentation and been in use for quite some time, making it easier to find answers to problems that may occur when used. However, in spite of it being so popular there was no analysis tool that I could use for my project. Thus, the decision to make my own tool was made. It did take me some time to fully comprehend how I was going be able to gather the data from the bonnie++ output with this tool, so that I could make the necessary statistics on the data and print it out in an understandable format like tables and graphs. In the long run this saved me time since I now could see and compare much easier by looking at tables and graphs.

By having both the benchmark tool chosen and analysis tool created, setting up the experimental environment was left. If we look at the the figure 3.1 we see how we have two machines that act as virtualization servers and two as SAN servers. The reason for having two SAN servers was that DRBD would require them to serve as two nodes. Furthermore, I had variations on the machines concerning the SAN software and the amount of VMs running as users. One thing that did not vary during these tests was the file system This could also have been possible to vary and would have perhaps affected or changed some of the relations in the results. In hindsight, it would have been interesting too see if it would affect the results and contribute evidence to conduct a more thorough investigation when trying to identify the most optimal SAN technology. In addition there could have been applied more VMs to further stress test the SAN technologies to see if the relations would differ from the results I have ended up with three VMs. I had intentions of testing with six and twelve VMs as well, however, time constraints and the results from running three VMs seemed to be sufficient in order to receive interesting results.

The blade servers used during this project were located at another facility, which made it time consuming to get the system back up and running again when problems occurred Both travel distance and the steps to be allowed to go there made each problem of this magnitude cost several hours of work.

The results from the benchmark tests that were performed with criterias I had chosen showed that DRBD performed best overall according to the mean values from figure 4.27.Although, this could have been affected by some technical issues which we will discuss later on. NFS, which had a low performance according to the mean values had a much better outcome for its range value in figure 4.28 with a very low value on some of the operations. Surprisingly, when adding more VMs we see that NFS performed better overall on an average in figure 4.29. The reason for using a word like surprising is because of some technological issues that happened during the experiment which we will mention later.

5.0.2 The Results

When one takes a look at the results in general, one usually questions them, if they are valid or to be dependent upon. These results, however, are according to the experimental setup and the criterias sat for the bonnie++ benchmarking tool, valid. The decisions made for what type of operations that should be more interesting for identifying and finding the best technology I made based on the fact that SAN technologies use block devices to read and write. It is of course possible to argument for other operations that could be more interesting in terms of identifying and find the best SAN technology. The credibility of the data is also improved by the feature in bonnie++, as mentioned in the background chapter, which does not take into account the results from the operations that is being completed to fast. This lead to a few operations not getting any data for each of the tested technologies.

The values chosen to compare the different technologies with was mean and range. With the use of mean we can easily see how well each technology perform on an average while range will showed us the difference between its highest and lowest measured performance during an operation. Retrospectively, the two choices of measured values were enough to gain knowledge which I could base a conclusion on. As long as the median would not be too different from the mean value it would be credible to use as a measurement for performance. However, it turned out to quite similar results overall in some cases which lead to some difficulties identifying the optimal SAN technology. So I regret I did not take into consideration even more values when summarizing and evaluating the final results.

The AoE and Pvfs technologies are not present in the result chapter or summary. Basically I believe I aimed too high with collecting data for 5 technologies with the kind of experimental setup chosen for this project and scenarios. Especially considering how it took me much more time getting the necessary knowledge to configure and install DRBD. The reason for this is that it is a very new technology and has compatibility issues with certain software which I should have studied more so that I could have foreseen this in my time management schedule. This set-back affected the time schedule for the whole process and forced me to do adjustments in the end.

This experiment is possible to repeat by anyone who read and understand the process of this project. However, do not expect to get the exact same results as I have, but you should be able to see the same relationships between the different technologies during basetesting and testing

with 3 VMs. The script used for analyzing the data and print out the tables and graphs of data is fully accessible for those who wishes to use it. Same goes for the bonnie++ benchmarking tool, it should be available for those who want to test it out.

Technological issues

During this project a few things did not work out as planned. When I started with the virtual software such as Xen, it was a problem to configure and setup a combination of operating system and kernel versions that would be xenified and work well with the systems at ABC Startsiden. Seeing that they had some network configurations that would not cooperate well with the Xen software. They way I solved this was to make the virtual server itself be connected to the network and have a connection to the SAN server while the the VMs that would run the benchmark test would have no awareness of the network. However, the VMs traffic would go through to the virtual server and then further to the SAN server by sharing these images over SAN that were used for creating these SANs. In hindsight, an attempt to work out the networking configurations of the company could have been done, although, it was still a good choice if we look at the fact that the VMs would create traffic on the devices shared from the SAN technology. DRBD had some compatibility issues with the kernel version on the SAN servers. It was also dependent on another SAN technology if it was to be tested with the same experimental setup as explained in the methodology chapter. For obtaining results I had to configure and install the DRBD resources on both of the virtualization servers which would give it an advantage in form of caching for the VMs running on top with bonnie++. In retrospect, I would have used more time on finding a way to solve these compatibilities issues. However, it would have taken too much time to patch the kernel and to gain enough experience to solve this within the few weeks I had sat aside for this technology. That is why I decided on a scenario for this technology that would most likely affect its results and overall picture of the three SAN technologies tested. NFS which had very good performance when testing with three VMs had to be run several times for achieving results. Bonnie++ stopped running after 20 repetitions on all of the VMs each time it crashed which took a lot of time to redo and run again. Especially since the benchmark tests was set to a 100 repetitions and it took about seven hours to finish one benchmark test.

Chapter 6

Conclusion

As introduced in the first chapter: Companies need SAN technolgies for having a better way of securing and backing up their data. However, there are many types which needs to be evaluated. This thesis‘ aim was to investigate different technologies and based on these results answer this question. Virtualization was used to simulate real ”users” within a company and bonnie++ created traffic to test the SAN technology. Although, some technical issues were present during this process, it did not seem to affect the results too much. After having calculated and analyzed the results for the SAN technologies that were tested. It was not possible to determine one technology to be the most optimal and efficient among the chosen. Thus, DRBD and NFS were pointing themselves out and performed best based on analyzes from the mean and range values, saying that DRDB had the highest performance in mean while NFS worked more predictable and had a more stable work rate. However, they changed places when adding more users, which showed that NFS performed best on an average and DRBD had a more stable work rate.

Future work

There are many SAN technologies which you can choose for both smaller and larger companies. In this thesis five SAN technologies were supposed to be tested but only three were fully tested as explained in the discussion chapter. By using the scenarios and way of testing presented in the methodology chapter one can potentially test out every SAN technology that is interesting. Although, it will be a challenge when experimenting with technologies that are not a typical SAN solution like DRBD, so further work on improving the lab setup would be beneficial in terms of time. Furthermore, the analysis script can be further developed to gain more in depth knowledge on how well a technology perform and more automation for the different steps taken in order to receive results.

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Appendices

Appendix A

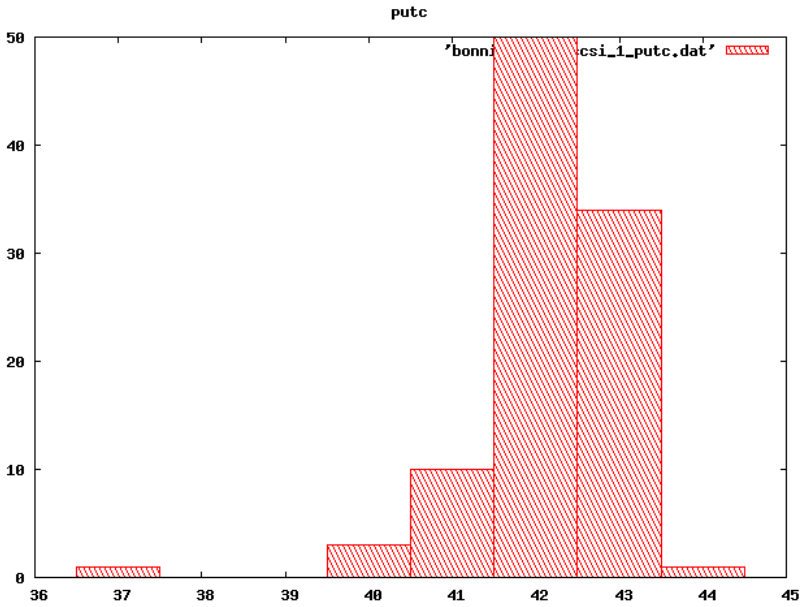
Selected bonnie++ output files

- Iscsi basetest
- NFS basetest
- DRBD basetest
- Iscsi representative data for 3 VMs
- NFS representative data for 3 VMs
- DRBD representative data for 3 VMs

bonnie 100x iscsi 1

May 8, 2009

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0.000	0.000	0.000	nan	etch	etch	0
file_size	1.000	1.000	0.000	nan	1G	1G	0
putc	42653.101	42781.000	127.899	738863.323	37996	44117	6121
putc_cpu	84.848	85.000	0.152	2.553	75	88	13
put_block	45046.192	45216.000	169.808	482467.145	40918	46096	5178
put_block_cpu	6.697	7.000	0.303	0.312	6	8	2
rewrite	11346.717	11235.000	111.717	77779.880	10858	12216	1358
rewrite_cpu	0.000	0.000	0.000	nan	0	0	0
getc	14439.909	14465.000	25.091	76518.891	13491	15209	1718
getc_cpu	6.596	7.000	0.404	0.483	4	8	4
get_block	18294.232	18291.000	3.232	132275.875	17223	19437	2214
get_block_cpu	0.000	0.000	0.000	nan	0	0	0
seeks	478.597	477.800	0.797	266.913	404.3	570.1	165.8
seeks_cpu	0.000	0.000	0.000	nan	0	0	0
num_files	16.000	16.000	0.000	nan	16	16	0
seq_create	4041.636	4037.000	4.636	3856.231	3838	4212	374
seq_create_cpu	96.929	97.000	0.071	1.379	94	101	7
seq_stat	0.000	0.000	0.000	nan	0	0	0
seq_stat_cpu	0.000	0.000	0.000	nan	0	0	0
seq_del	0.000	0.000	0.000	nan	0	0	0
seq_del_cpu	0.000	0.000	0.000	nan	0	0	0
ran_create	4242.646	4278.000	35.354	5385.319	3884	4469	585
ran_create_cpu	98.525	99.000	0.475	1.987	96	104	8
ran_stat	0.000	0.000	0.000	nan	0	0	0
ran_stat_cpu	0.000	0.000	0.000	nan	0	0	0
ran_del	15243.495	14859.000	384.495	685322.775	13981	16433	2452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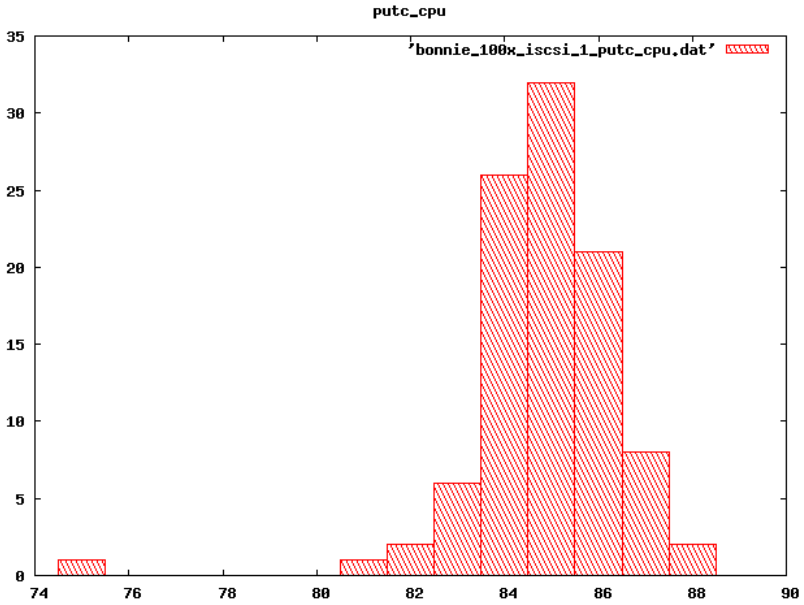
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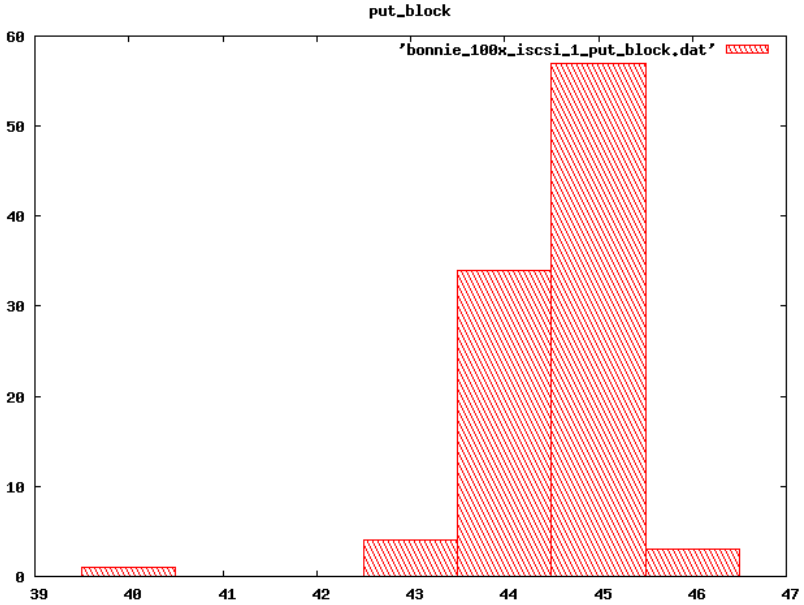
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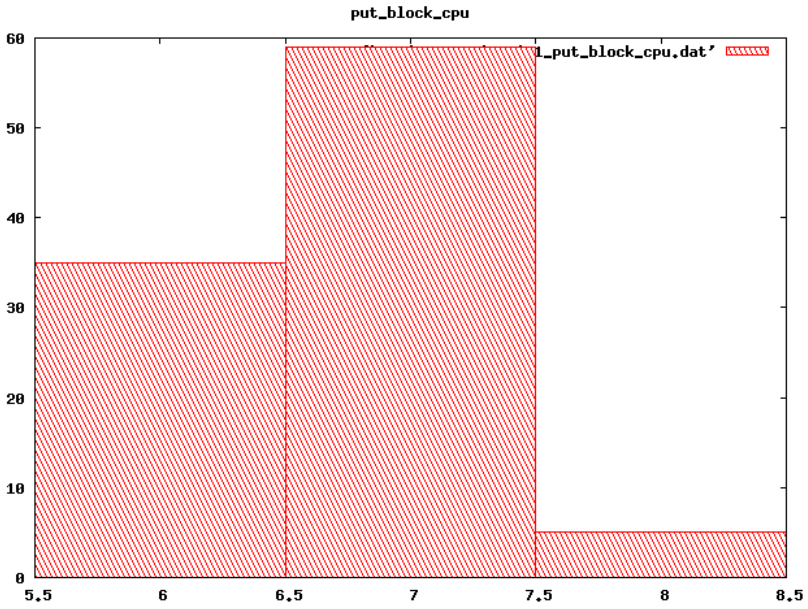
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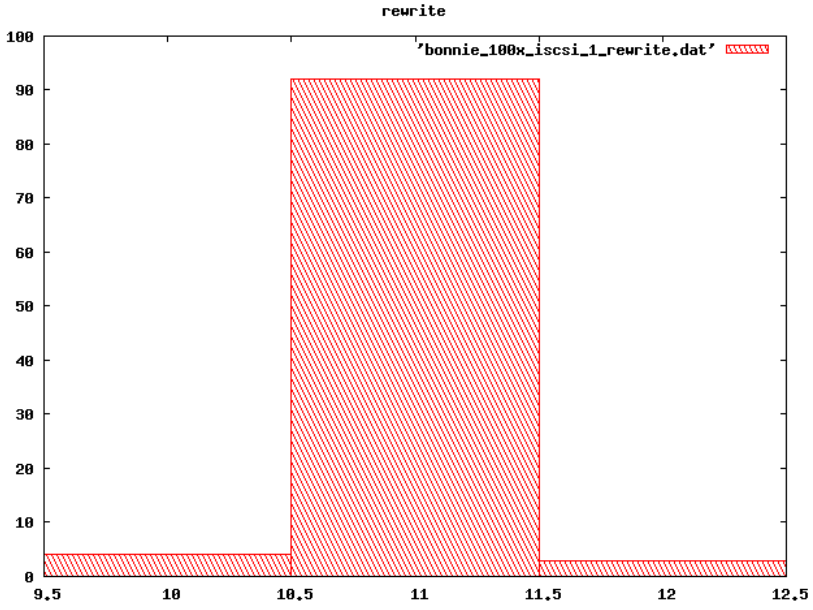
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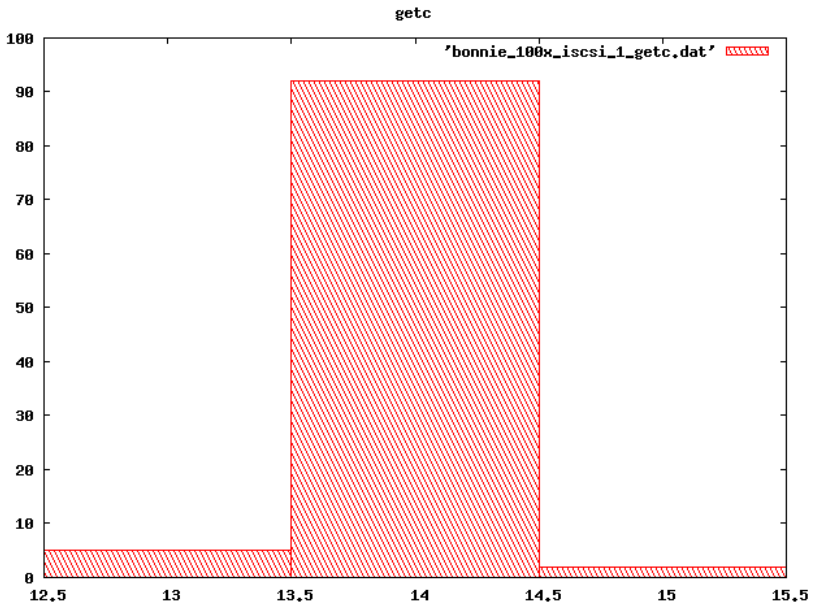
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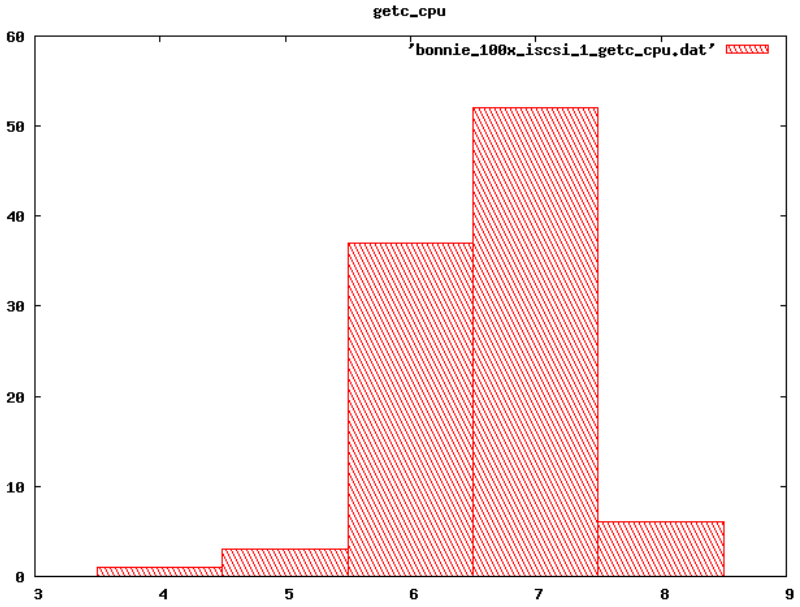
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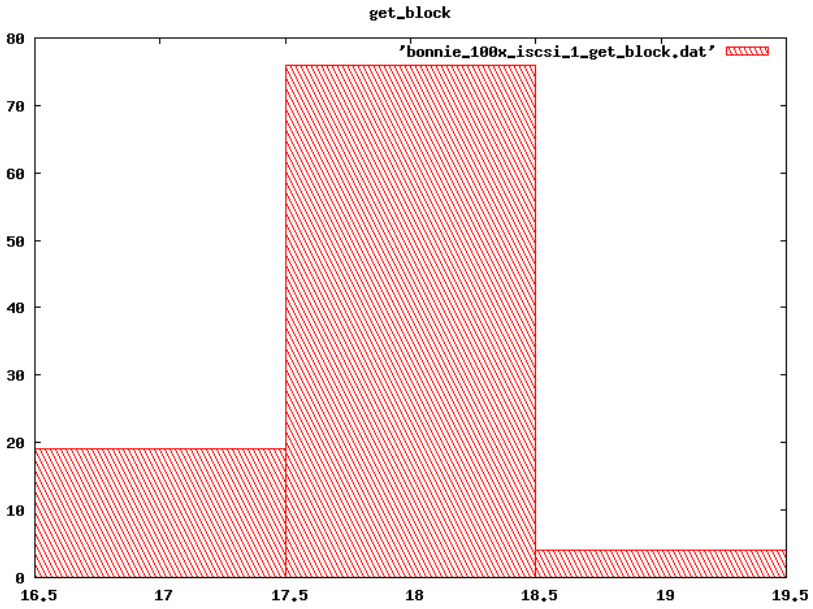
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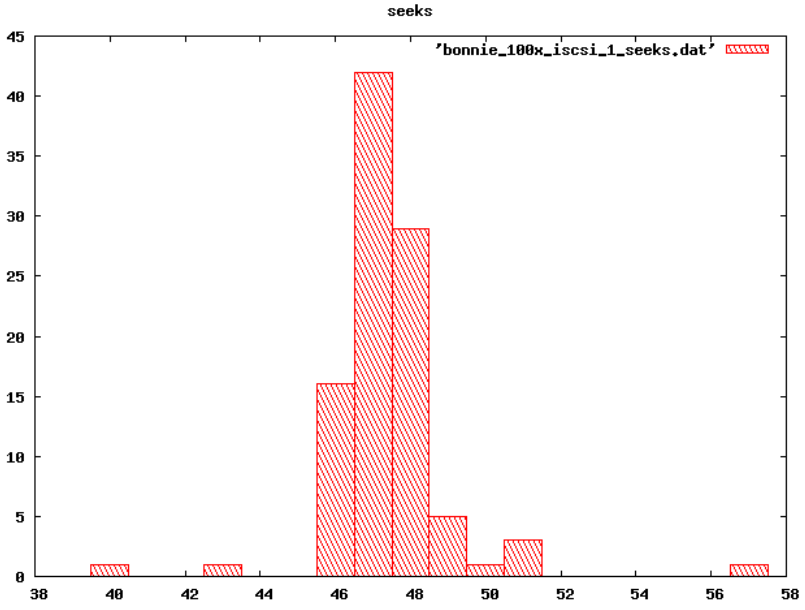
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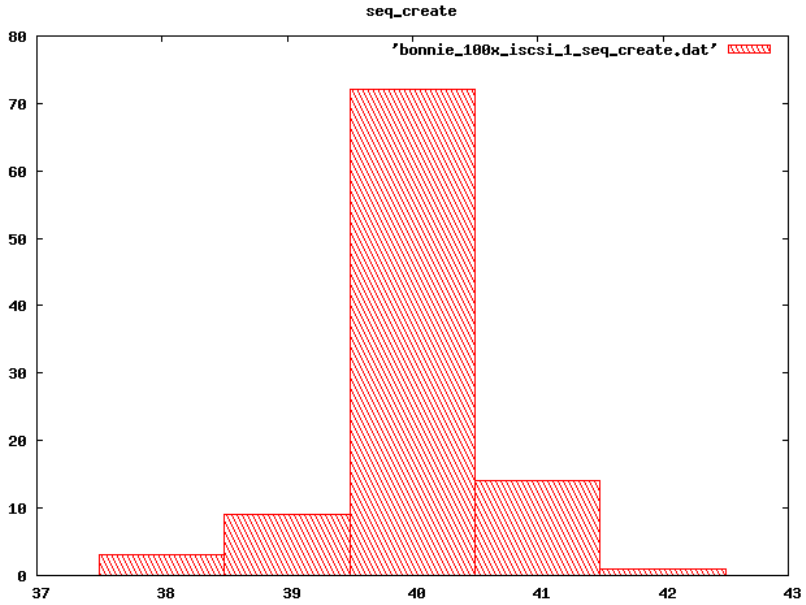
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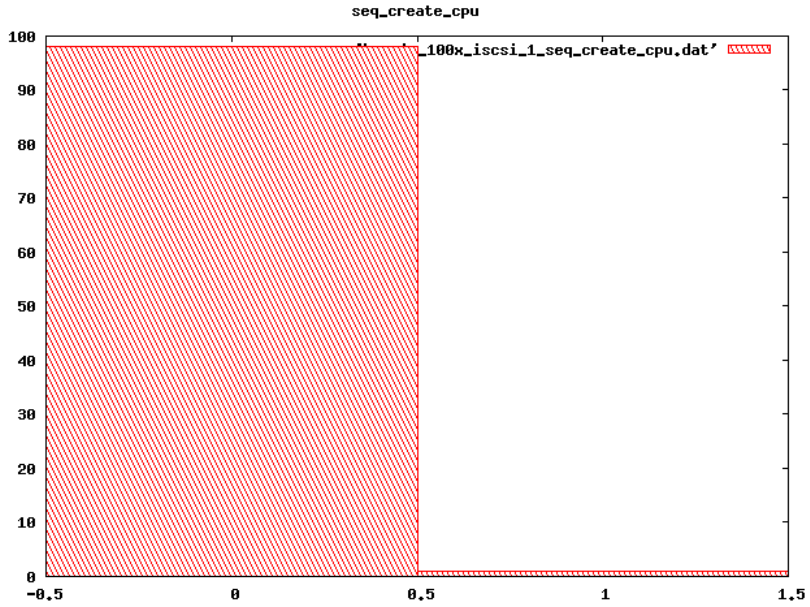
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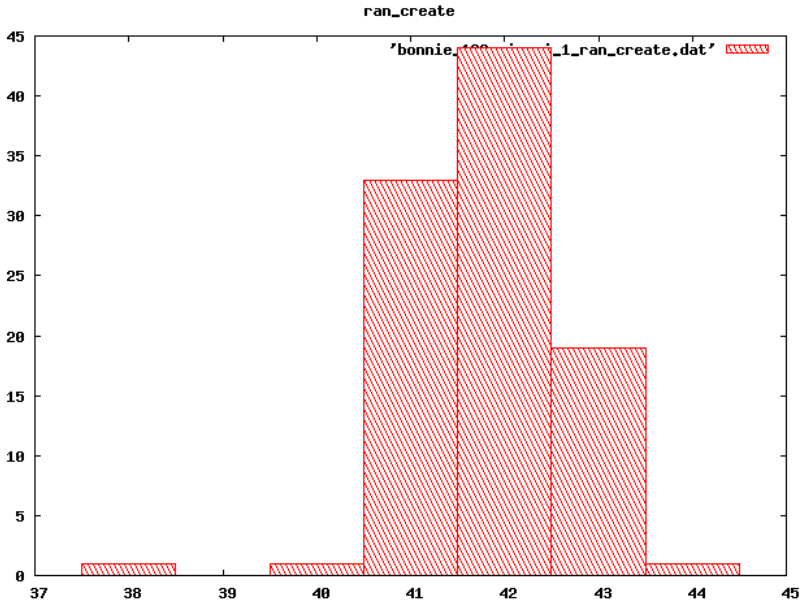
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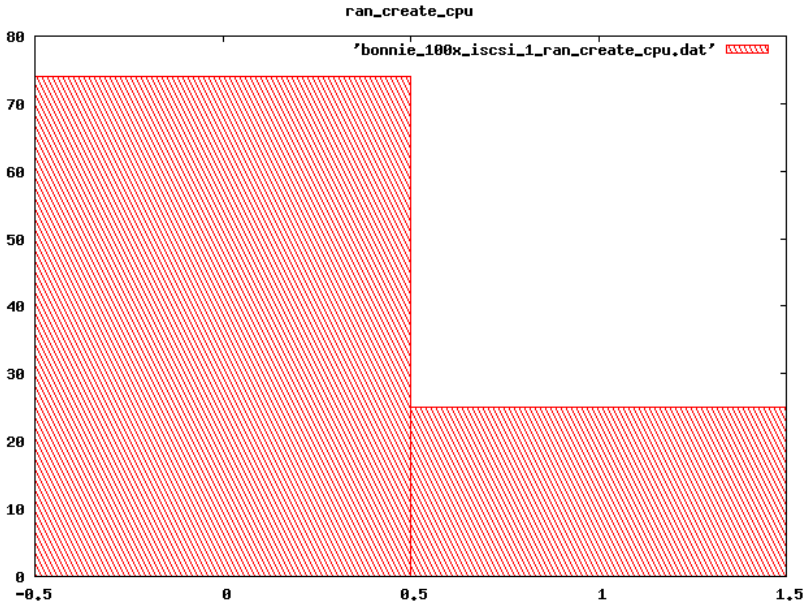
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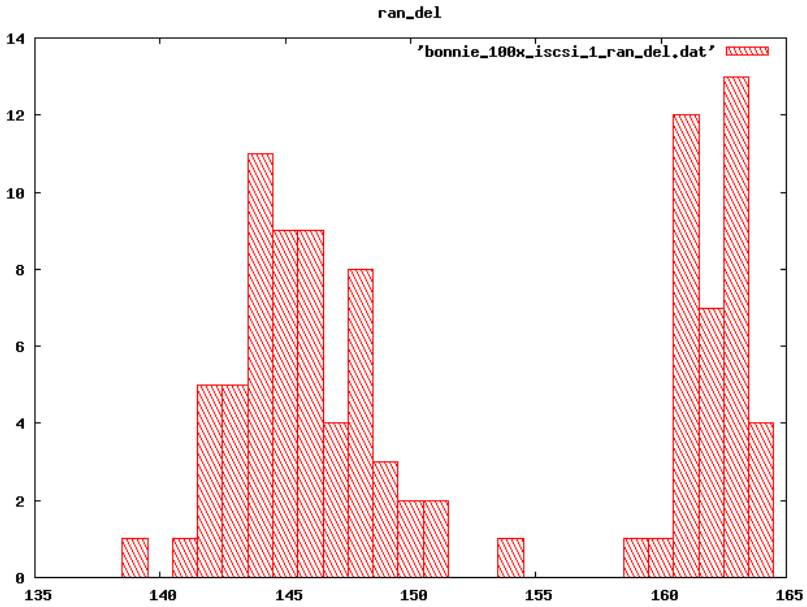
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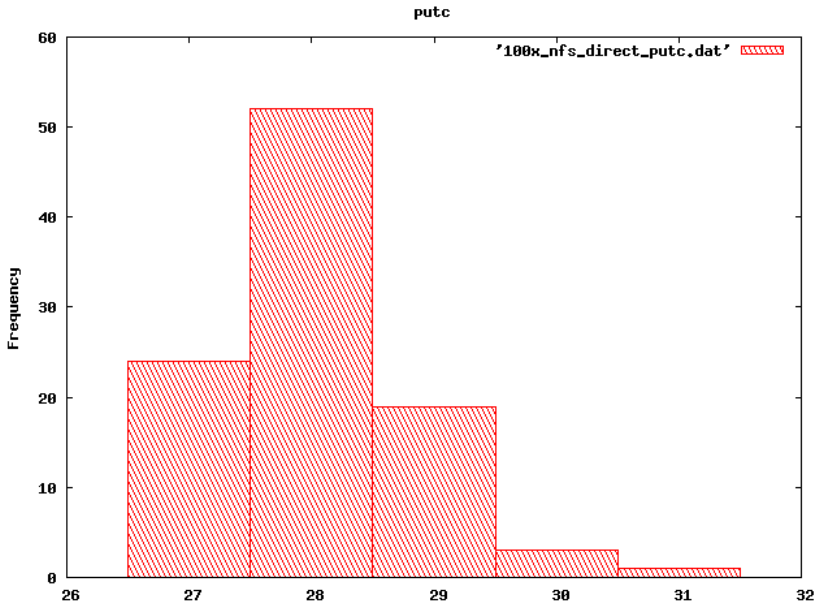
12
10
8
6
4
2
0
135
140
145
150
155
160
165

100x nfs direct

May 19, 2009

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0.000	0.000	0.000	nan	atlantis	atlantis	0
file_size	4.000	4.000	0.000	nan	4G	4G	0
putc	28534.444	28419.000	115.444	611578.954	27089	31697	4608
putc_cpu	60.212	60.000	0.212	3.238	57	67	10
put_block	27021.515	26818.000	203.515	1616586.290	24888	30831	5943
put_block_cpu	9.525	9.000	0.525	0.330	9	12	3
rewrite	13358.869	13337.000	21.869	47389.791	12861	13942	1081
rewrite_cpu	2.212	2.000	0.212	0.167	2	3	1
getc	23866.505	23721.000	145.505	647568.452	22146	26212	4066
getc_cpu	44.576	45.000	0.424	24.608	33	55	22
get_block	25155.343	25202.000	46.657	334903.781	23635	26436	2801
get_block_cpu	5.475	6.000	0.525	0.977	4	8	4
seeks	1049.258	1068.800	19.542	6178.578	615.0	1177.2	562.2
seeks_cpu	1.788	1.000	0.788	8.329	0	13	13
num_files	16.000	16.000	0.000	nan	16	16	0
seq_create	38.697	39.000	0.303	0.433	38	40	2
seq_create_cpu	0.000	0.000	0.000	nan	0	0	0
seq_stat	4472.424	3714.000	758.424	1549846.850	3600	6756	3156
seq_stat_cpu	1.333	1.000	0.333	2.485	0	9	9
seq_del	77.657	78.000	0.343	2.407	74	79	5
seq_del_cpu	0.000	0.000	0.000	nan	0	0	0
ran_create	39.101	39.000	0.101	0.273	37	40	3
ran_create_cpu	0.000	0.000	0.000	nan	0	0	0
ran_stat	4939.737	4005.000	934.737	2523425.547	3916	7943	4027
ran_stat_cpu	0.465	0.000	0.465	1.239	0	9	9
ran_del	78.404	79.000	0.596	0.726	77	79	2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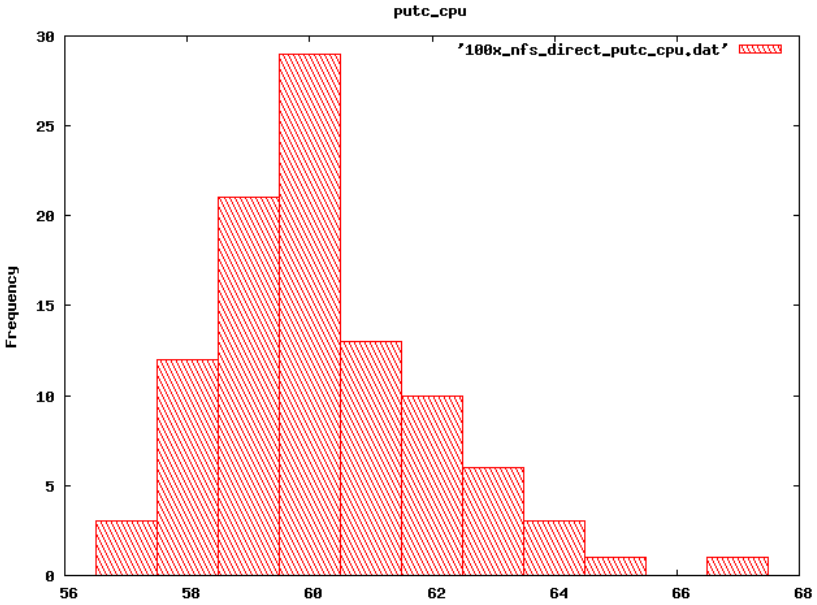
putc_cpu
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Frequency
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10
15
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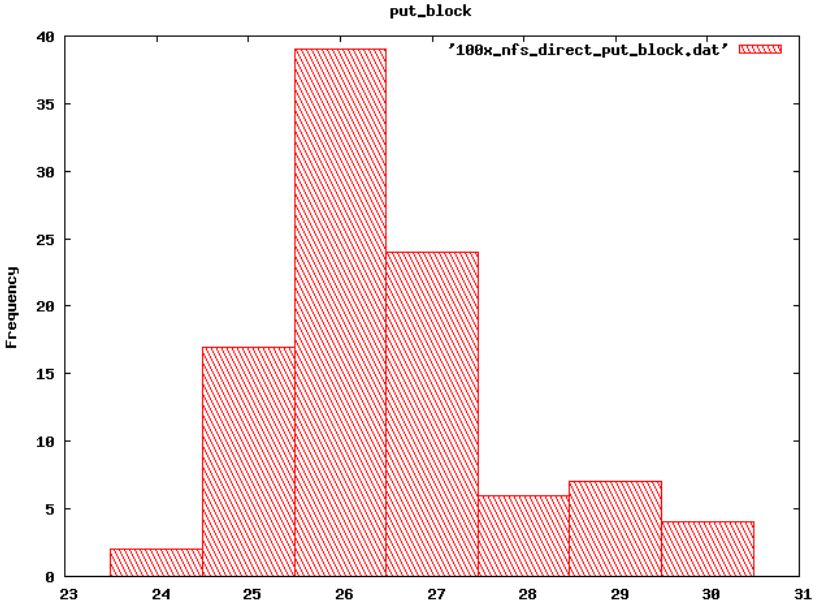
30
56
58
60
62
64
66
68


put_block
'100x_nfs_direct_put_block.dat'
Frequency
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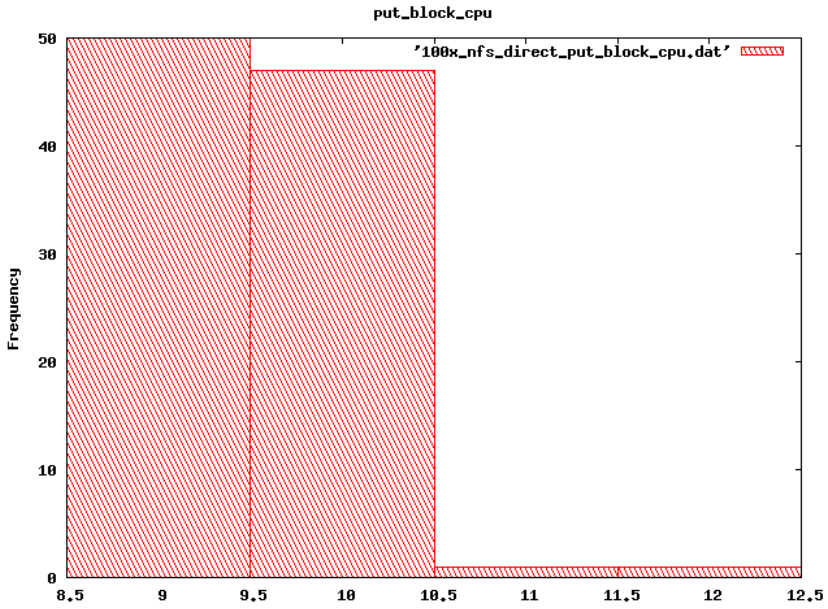
30
31


put_block_cpu
'100x_nfs_direct_put_block_cpu.dat'
Frequency
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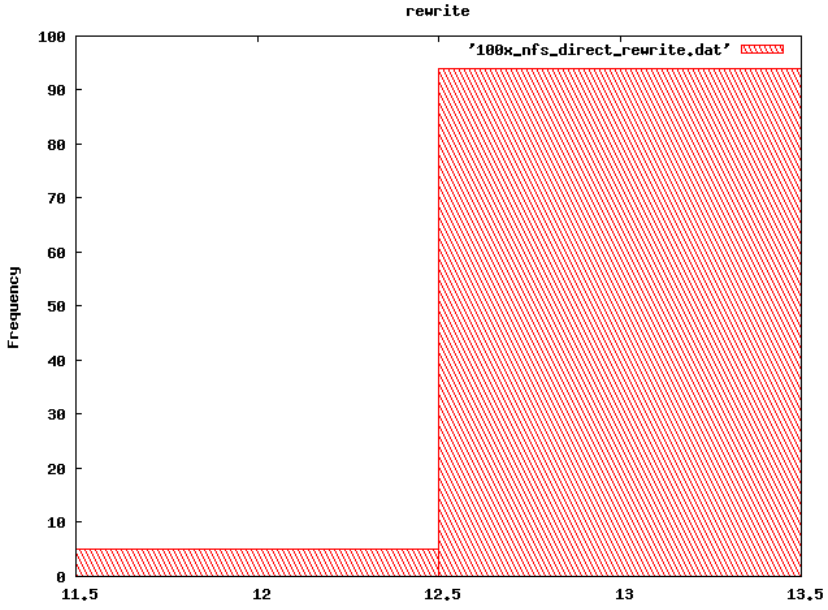
9.5
10
10.5
11
11.5
12
12.5


rewrite
'100x_nfs_direct_rewrite.dat'
Frequency
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20
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80
90
100
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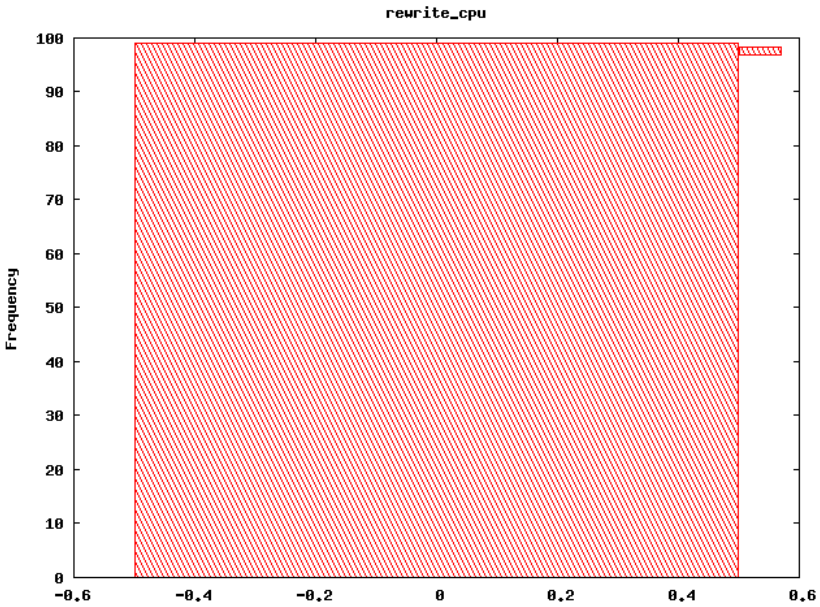
12.5
13
13.5


rewrite_cpu
Frequency
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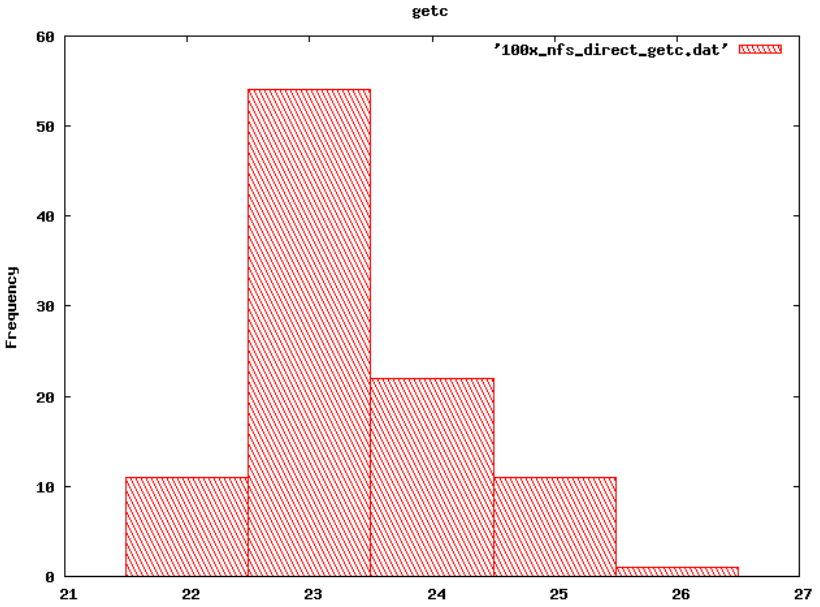
0.2
0.4
0.6


getc
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Frequency
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24
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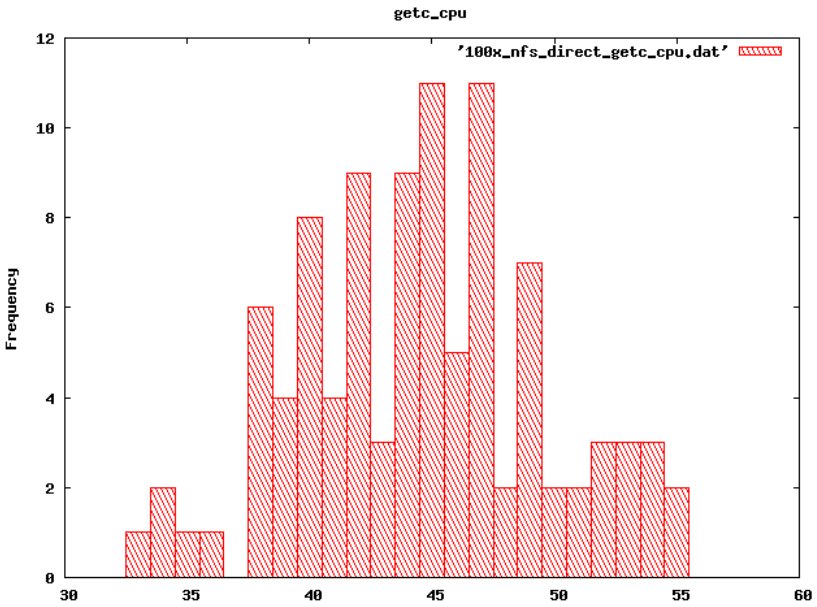
27


getc_cpu
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Frequency
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2
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6
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12
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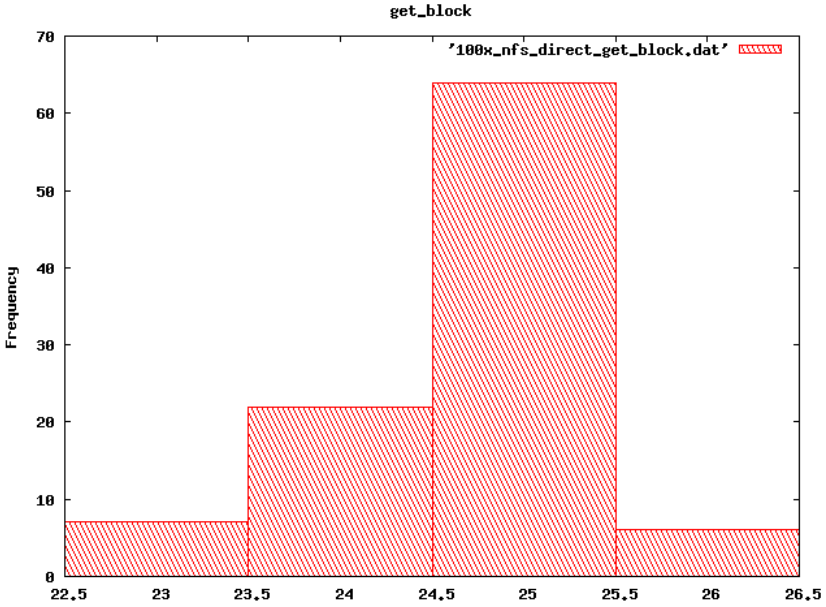
40
45
50
55
60


get_block
'100x_nfs_direct_get_block.dat'
Frequency
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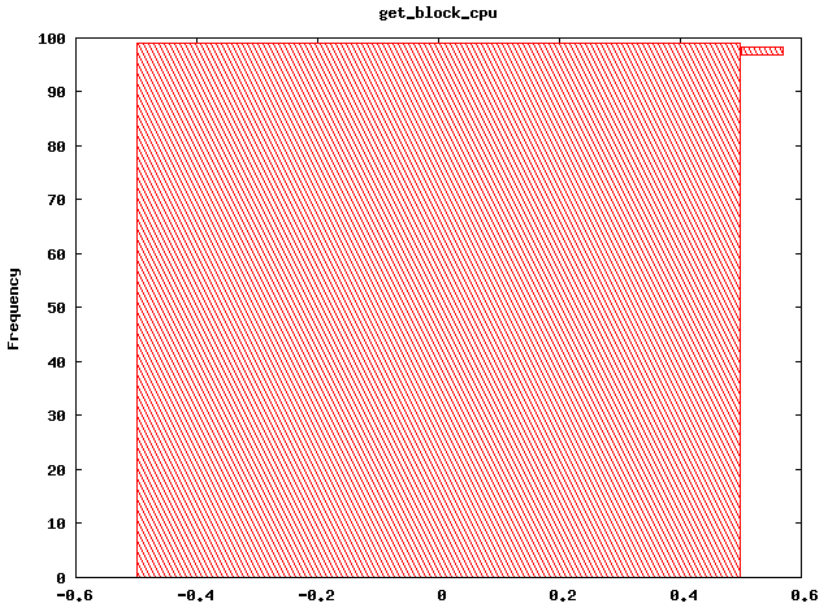
22.5
23
23.5
24
24.5
25
25.5
26
26.5


get_block_cpu
Frequency
100
90
80
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60
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30
20
10
0
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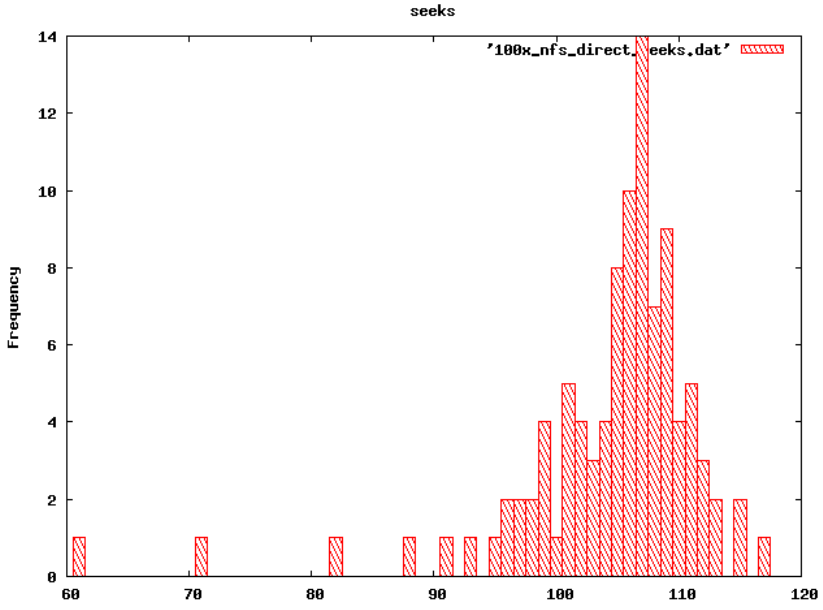
-0.4
-0.2
0
0.2
0.4
0.6


seeks
'100x_nfs_direct_seeks.dat'
Frequency
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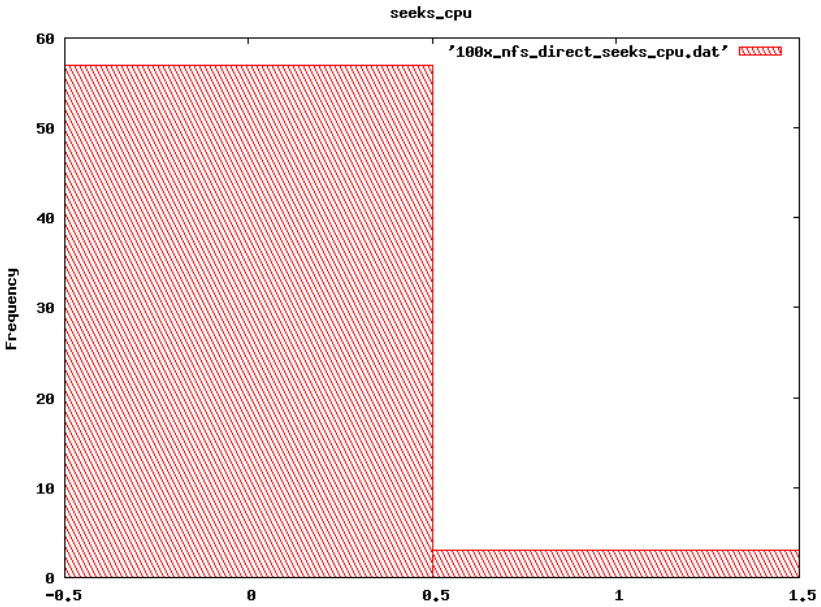
12
10
8
6
4
2
0
60
70
80
90
100
110
120


seeks_cpu
'100x_nfs_direct_seeks_cpu.dat'
Frequency
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20
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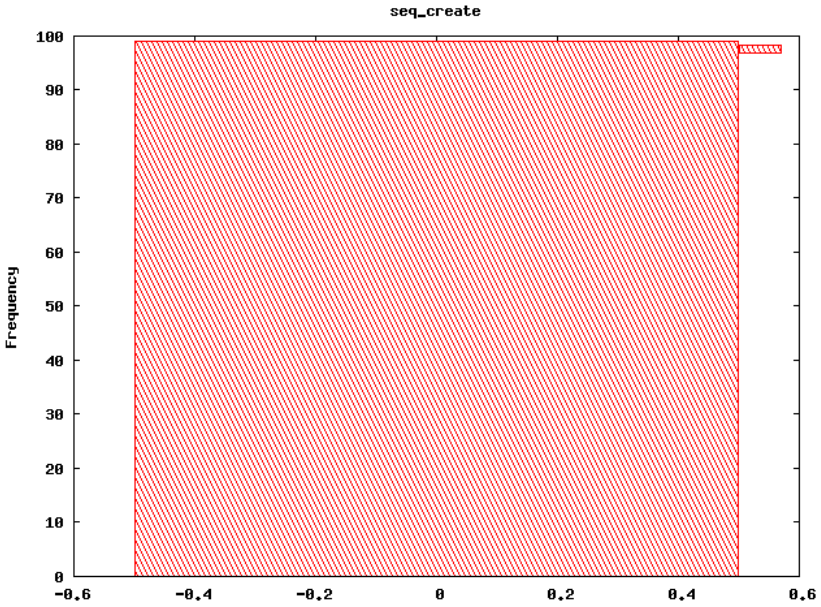
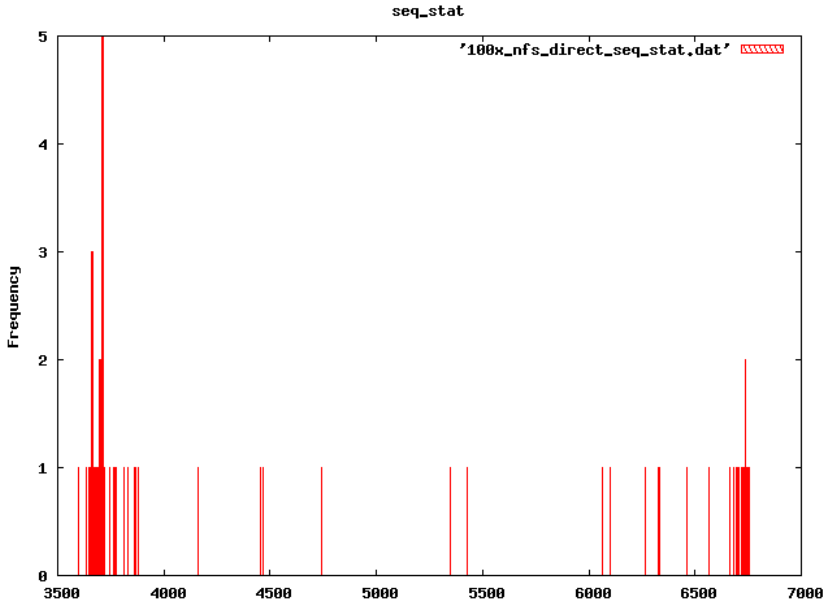
0
-0.5
0
0.5
1
1.5


seq_create
Frequency
100
90
80
70
60
50
40
30
20
10
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


seq_stat
'100x_nfs_direct_seq_stat.dat'
Frequency
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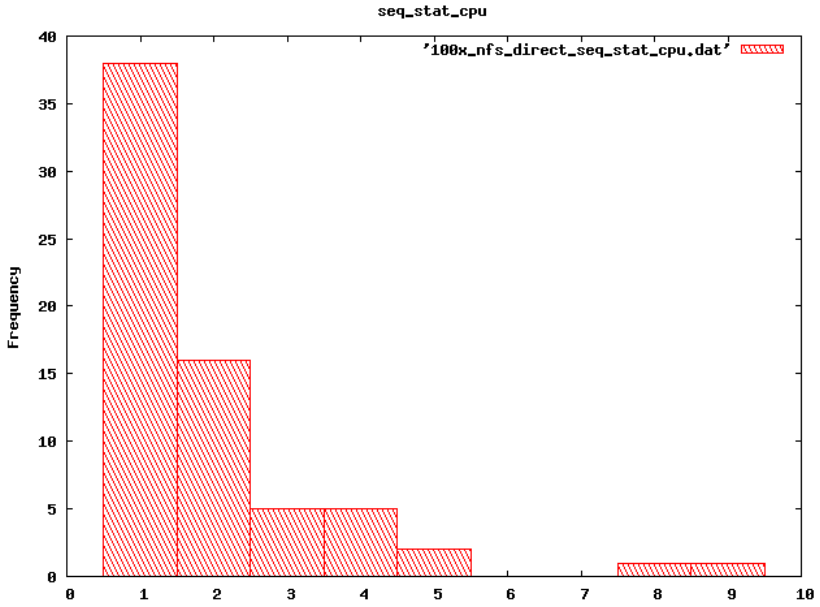
1
2
3
4
5
3500
4000
4500
5000
5500
6000
6500
7000


seq_stat_cpu
'100x_nfs_direct_seq_stat_cpu.dat'
Frequency
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20
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30
35
40
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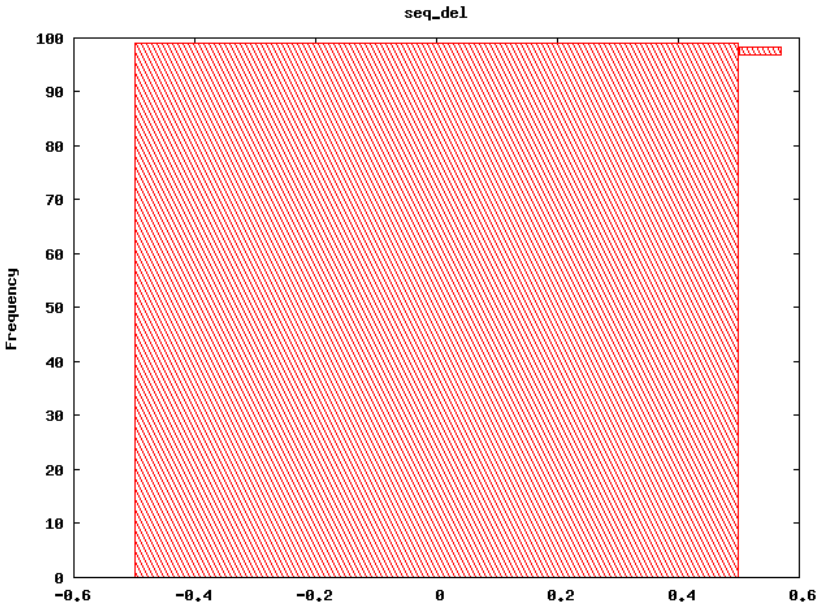
1
2
3
4
5
6
7
8
9
10


seq_del
Frequency
100
90
80
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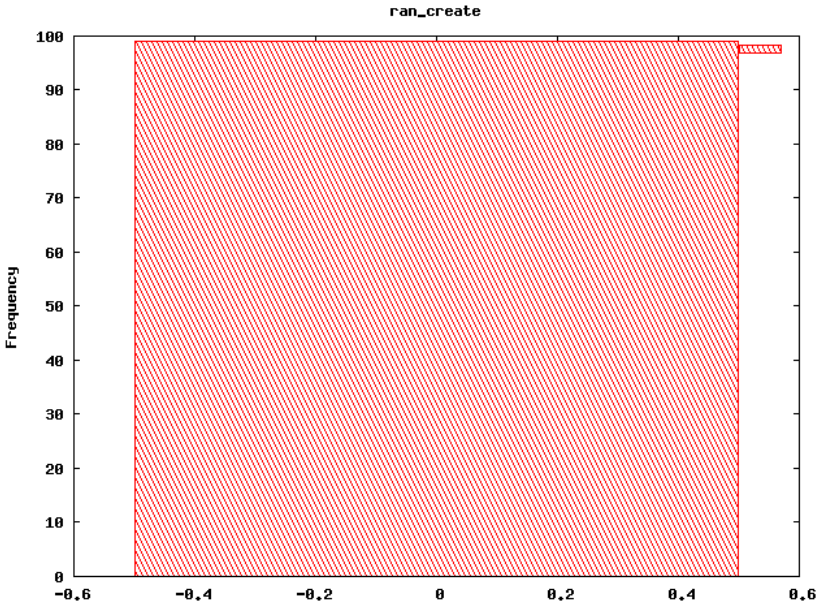
50
40
30
20
10
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


ran_create
Frequency
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90
80
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20
10
0
-0.6
-0.4
-0.2
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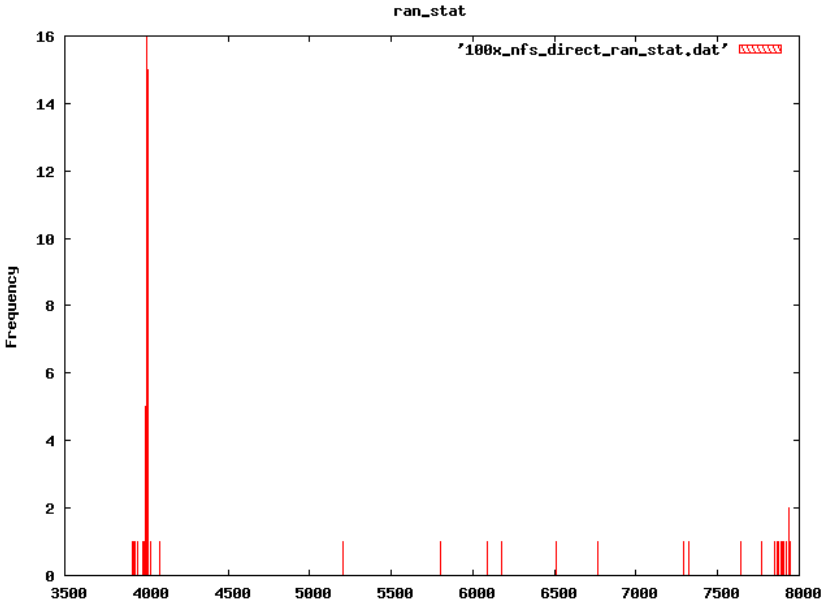
0.2
0.4
0.6


ran_stat
'100x_nfs_direct_ran_stat.dat'
Frequency
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6
4
2
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5000
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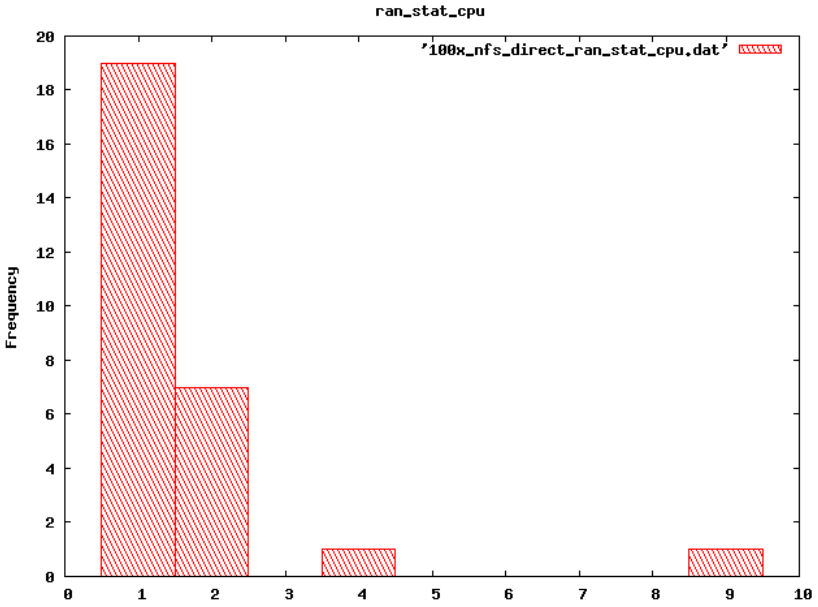
6000
6500
7000
7500
8000


ran_stat_cpu
'100x_nfs_direct_ran_stat_cpu.dat'
Frequency
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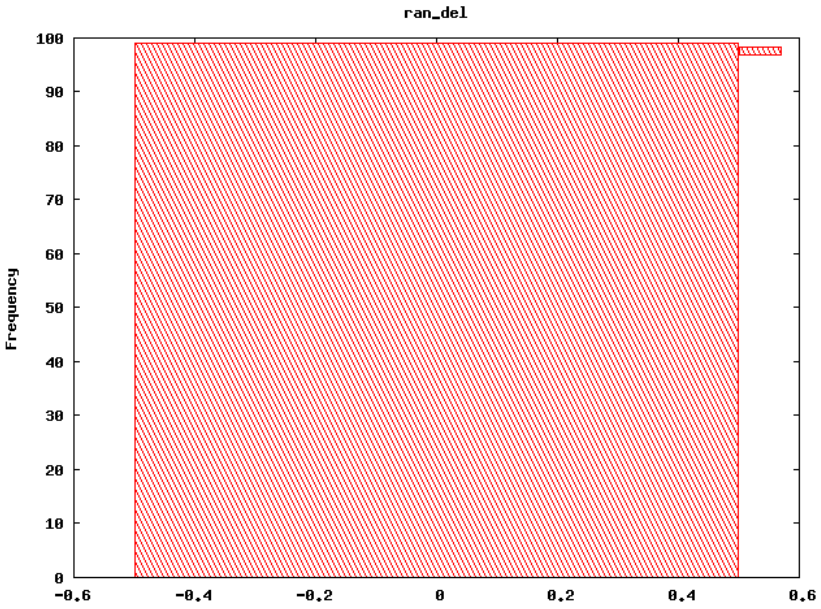
7
8
9
10


ran_del
Frequency
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80
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60
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20
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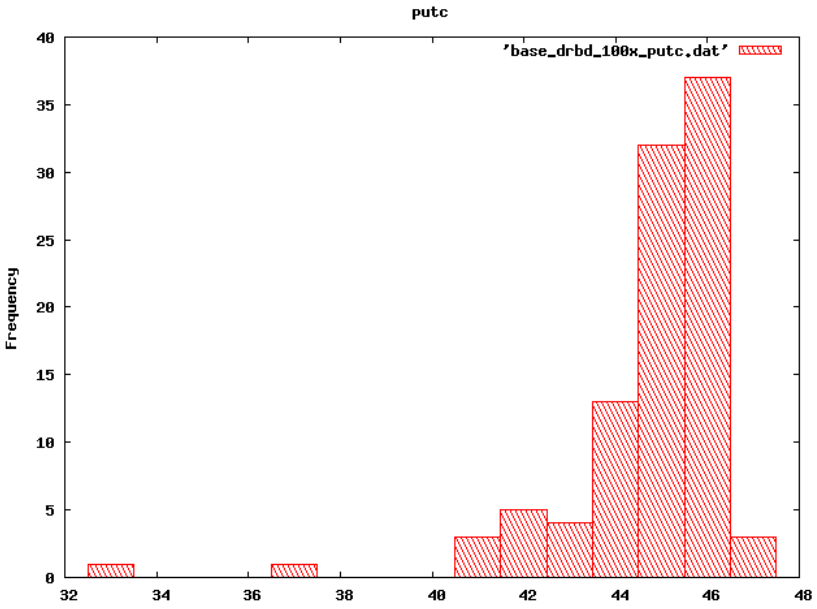
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

base drbd 100x

May 19, 2009

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0.000	0.000	0.000	nan	etch	etch	0
file_size	300.000	300.000	0.000	nan	300M	300M	0
putc	45244.414	45694.000	449.586	3458184.626	33992	47396	13404
putc_cpu	91.929	92.000	0.071	13.157	67	97	30
put_block	45408.515	45478.000	69.485	3271730.573	34123	49404	15281
put_block_cpu	7.434	7.000	0.434	0.407	5	9	4
rewrite	23021.475	23226.000	204.525	1158997.199	18143	24865	6722
rewrite_cpu	0.000	0.000	0.000	nan	0	0	0
getc	38075.253	38237.000	161.747	631781.967	33203	40033	6830
getc_cpu	49.414	49.000	0.414	2.121	41	53	12
get_block	70576.859	70806.000	229.141	1895523.435	60562	72337	11775
get_block_cpu	0.000	0.000	0.000	nan	0	0	0
seeks	356.824	358.000	1.176	125.870	299.1	378.7	79.6
seeks_cpu	0.000	0.000	0.000	nan	0	0	0
num_files	16.000	16.000	0.000	nan	16	16	0
seq_create	4071.556	4079.000	7.444	2333.297	3872	4185	313
seq_create_cpu	97.404	97.000	0.404	0.604	95	99	4
seq_stat	0.000	0.000	0.000	nan	0	0	0
seq_stat_cpu	0.000	0.000	0.000	nan	0	0	0
seq_del	0.000	0.000	0.000	nan	0	0	0
seq_del_cpu	0.000	0.000	0.000	nan	0	0	0
ran_create	4262.859	4245.000	17.859	3088.586	4047	4336	289
ran_create_cpu	98.222	98.000	0.222	1.345	96	100	4
ran_stat	0.000	0.000	0.000	nan	0	0	0
ran_stat_cpu	0.000	0.000	0.000	nan	0	0	0
ran_del	15802.121	16274.000	471.879	467742.753	14436	16673	2237


putc
'base_drbd_100x_putc.dat'
Frequency
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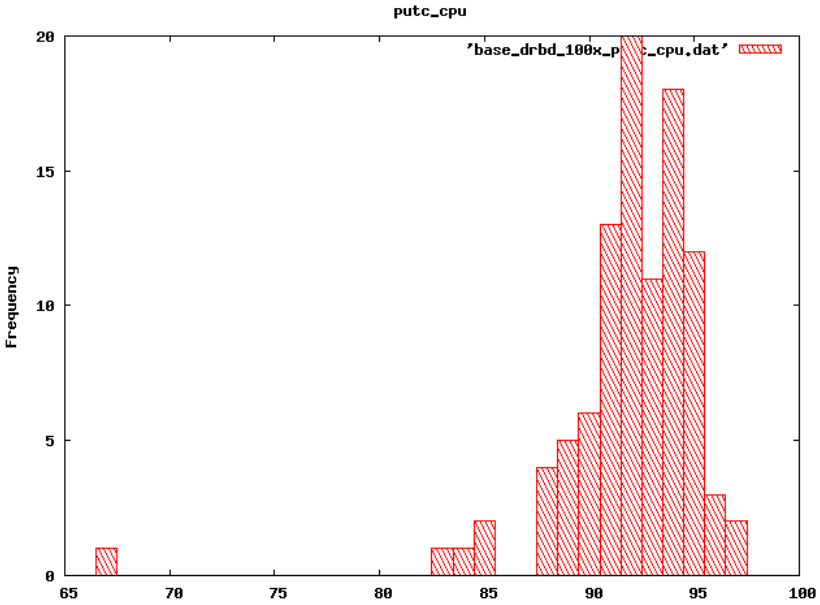
44
46
48


putc_cpu
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c_cpu.dat'
Frequency
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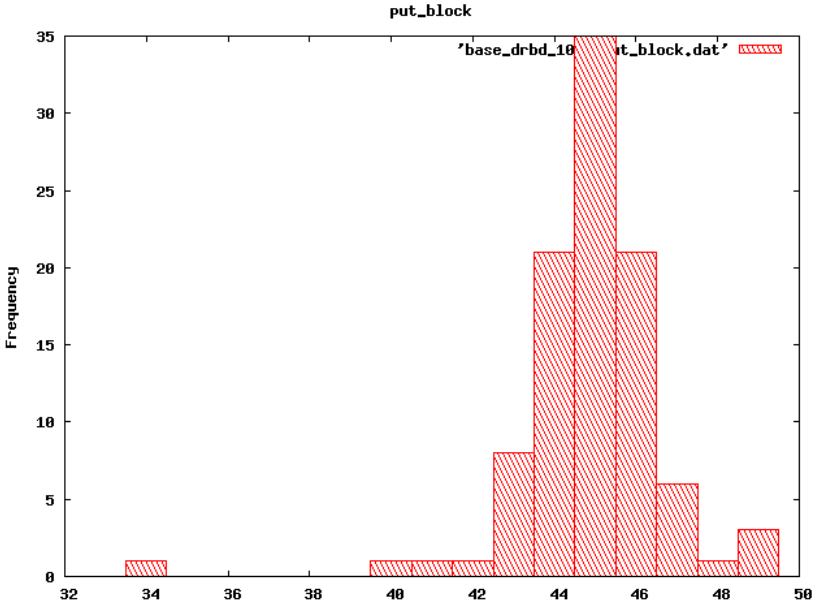
90
95
100


put_block
'base_drbd_10
t_block.dat'
Frequency
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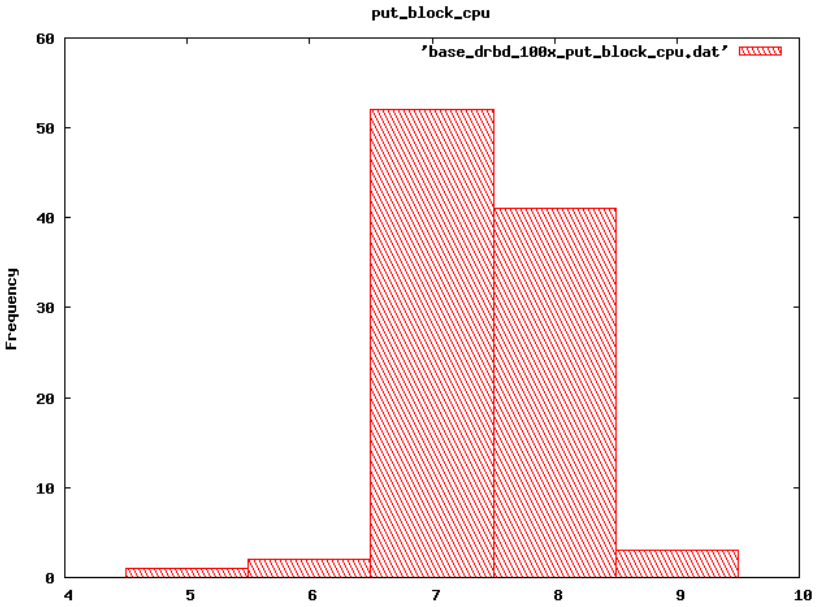
44
46
48
50


put_block_cpu
'base_drbd_100x_put_block_cpu.dat'
Frequency
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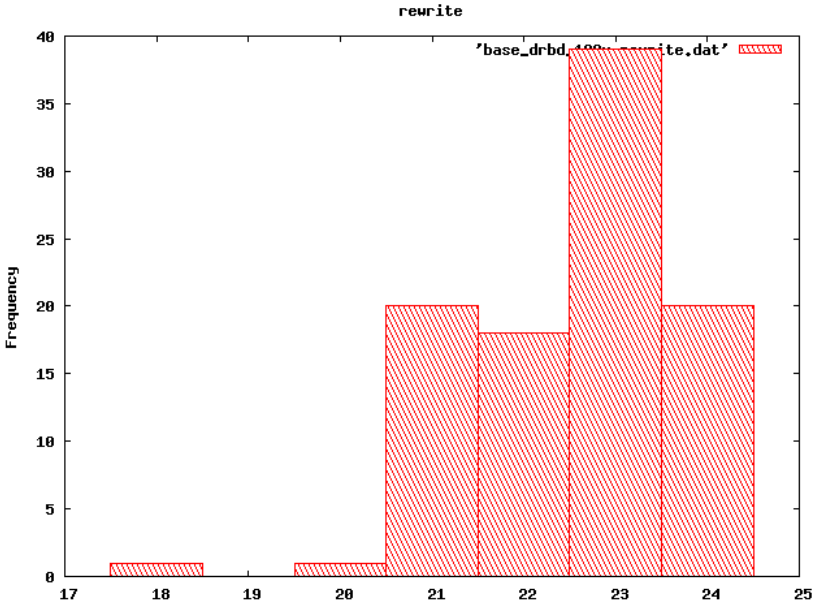
7
8
9
10


rewrite
'base_drbd_100x_rewrite.dat'
Frequency
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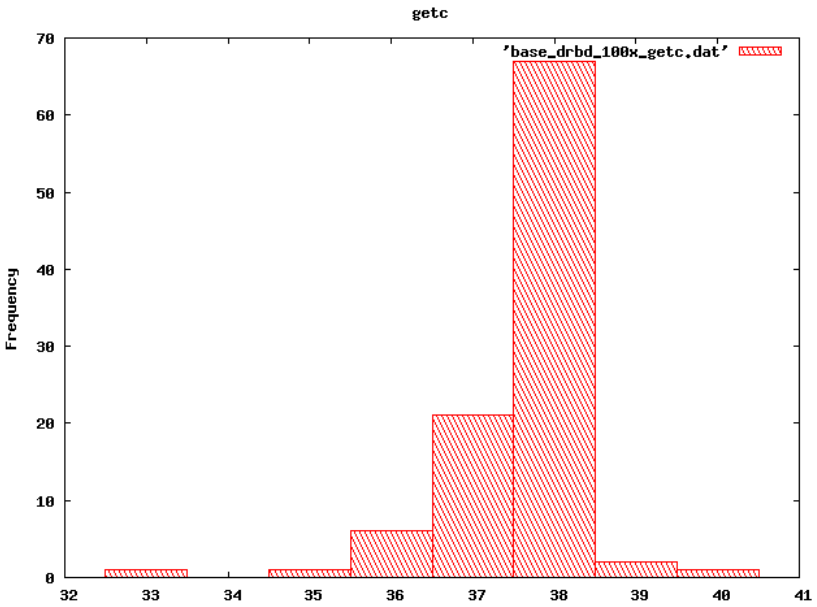
22
23
24
25


getc
'base_drbd_100x_getc.dat'
Frequency
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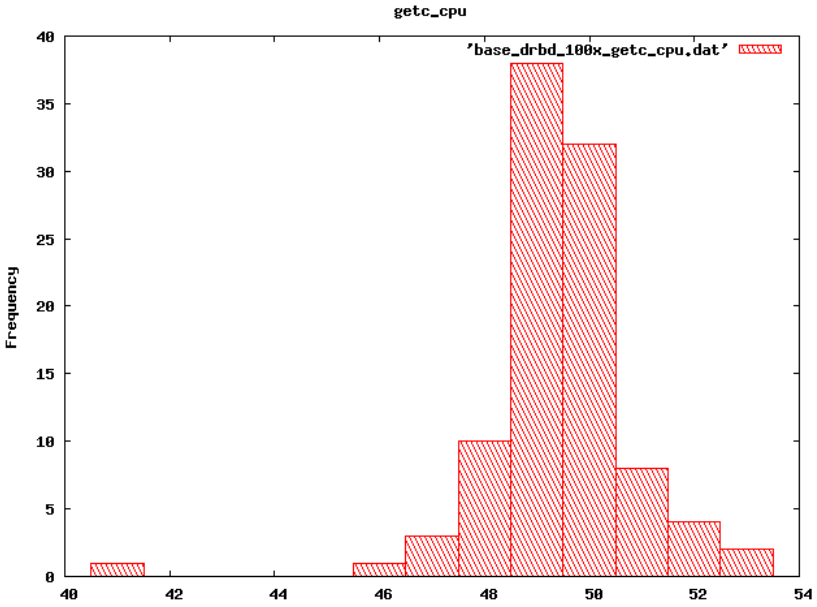
38
39
40
41


getc_cpu
'base_drbd_100x_getc_cpu.dat'
Frequency
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44
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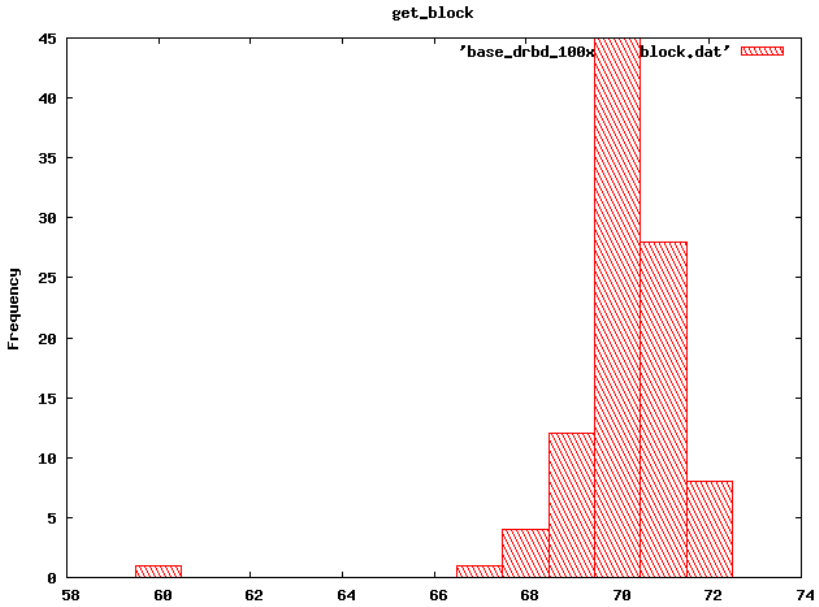
48
50
52
54


get_block
'base_drbd_100x_block.dat'
Frequency
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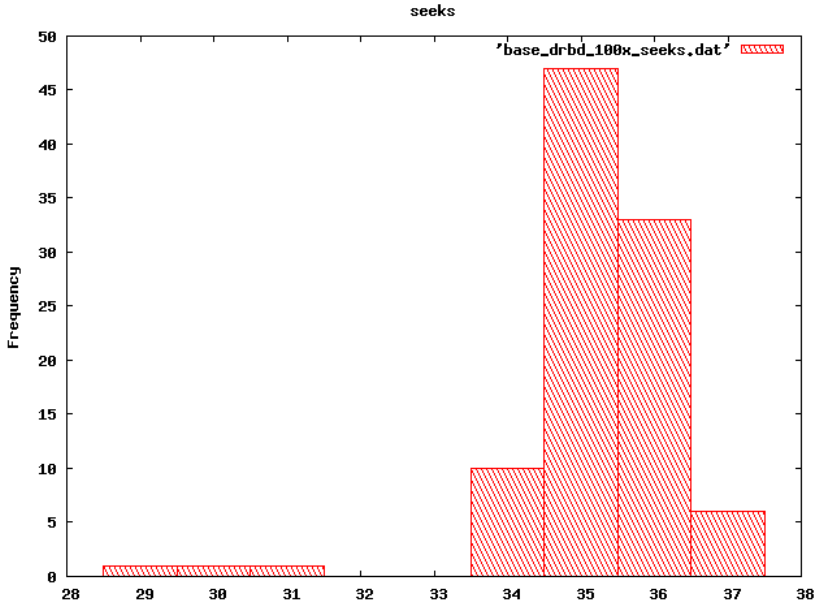
72
74


seeks
'base_drbd_100x_seeks.dat'
Frequency
0
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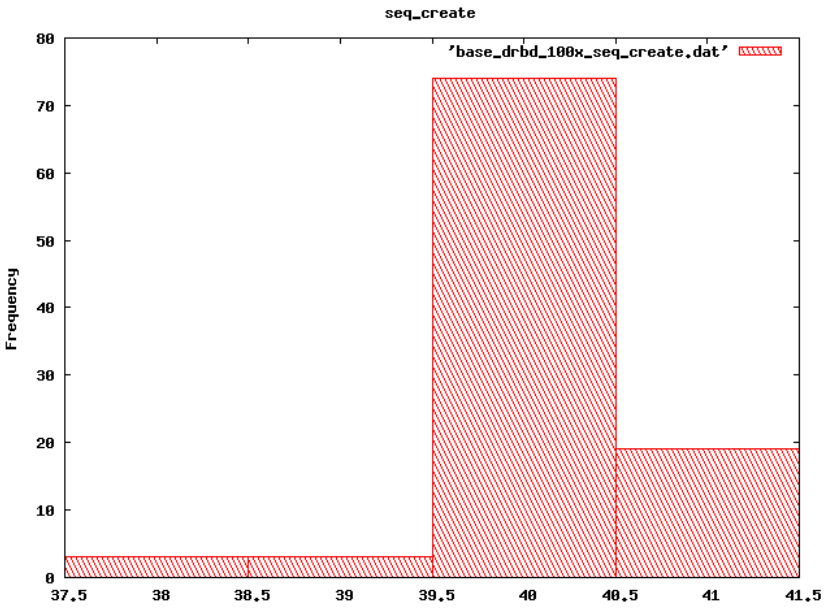
37
38


seq_create
'base_drbd_100x_seq_create.dat'
Frequency
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39.5
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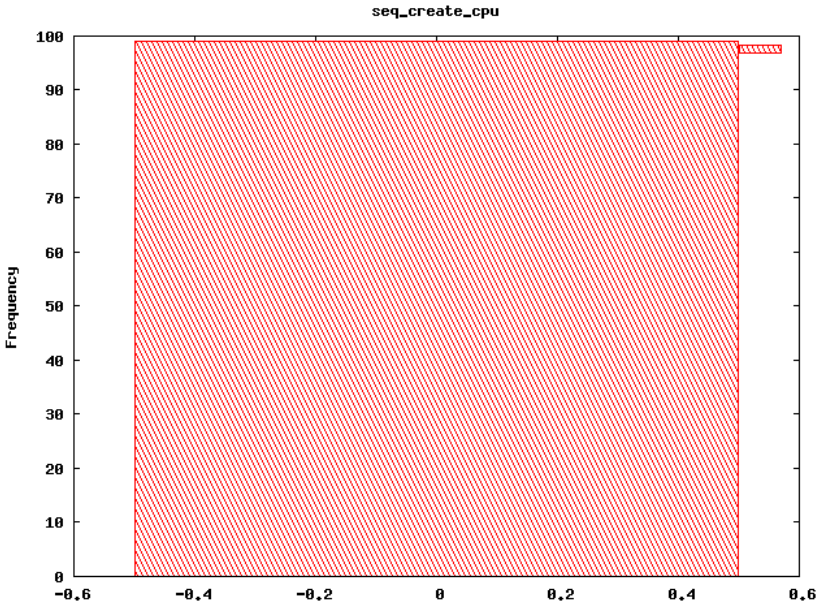
40.5
41
41.5


seq_create_cpu
Frequency
100
90
80
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60
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10
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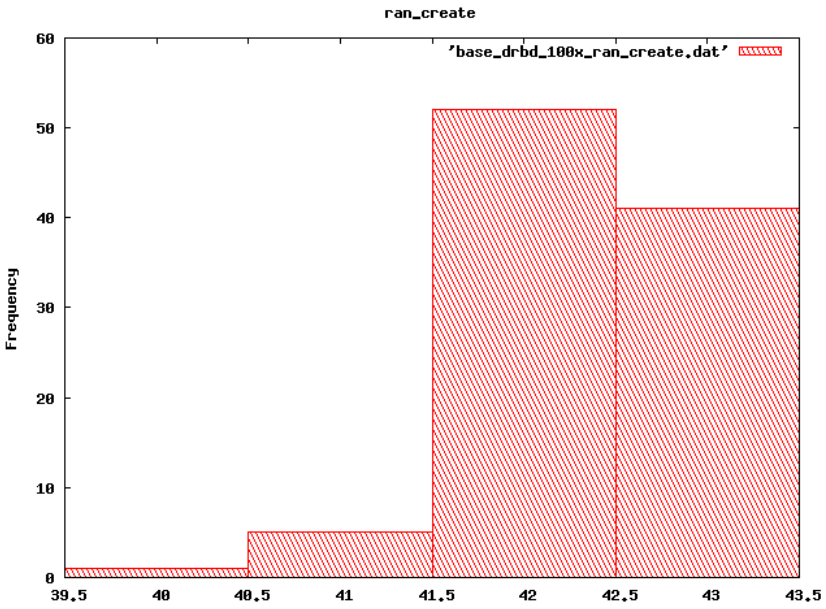
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


ran_create
'base_drbd_100x_ran_create.dat'
Frequency
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10
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39.5
40
40.5
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41.5
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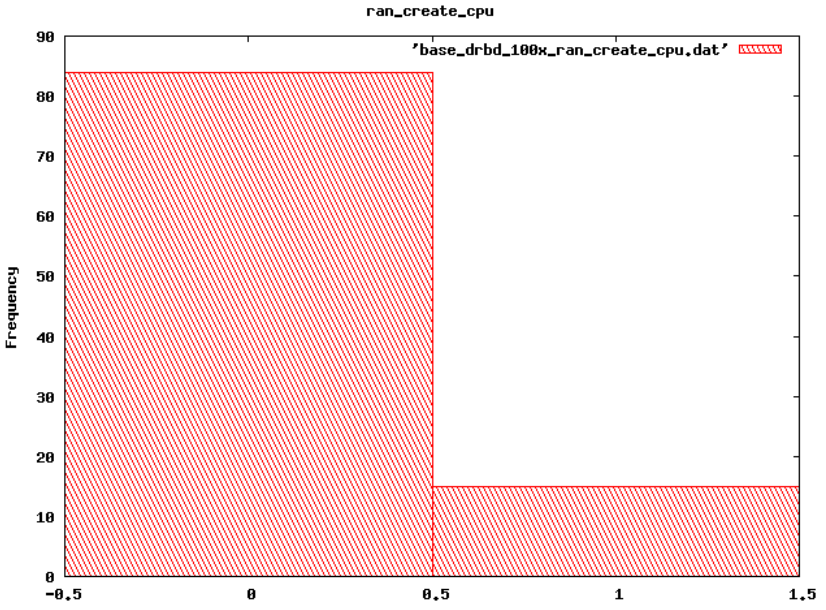
42.5
43
43.5


ran_create_cpu
'base_drbd_100x_ran_create_cpu.dat'
Frequency
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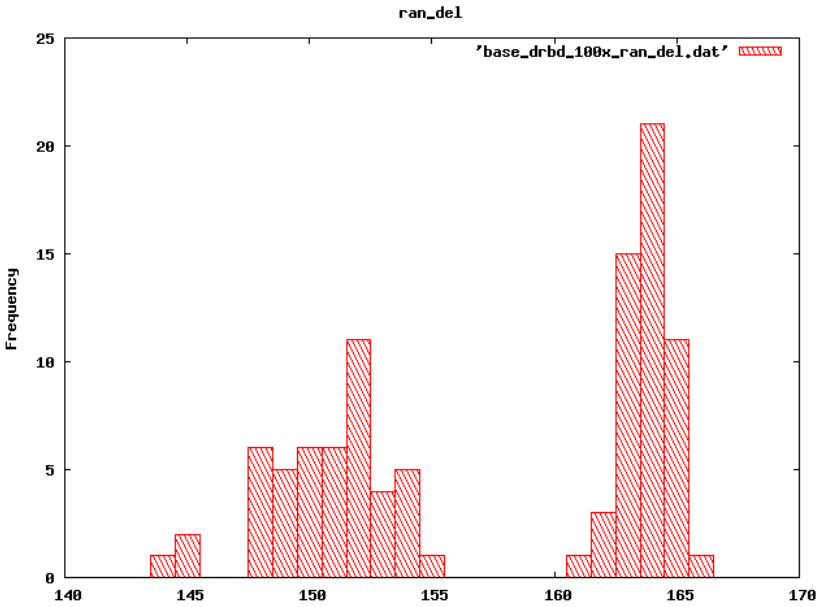
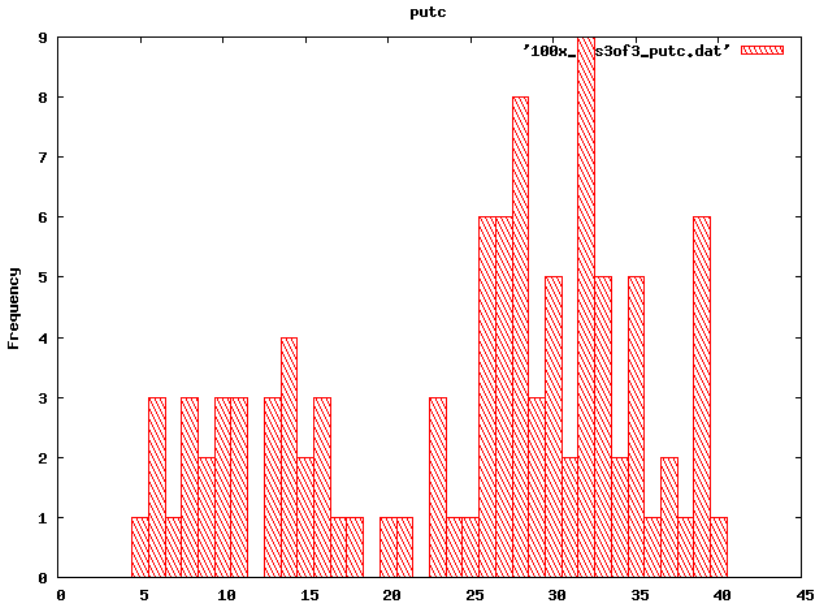
0.5
1
1.5

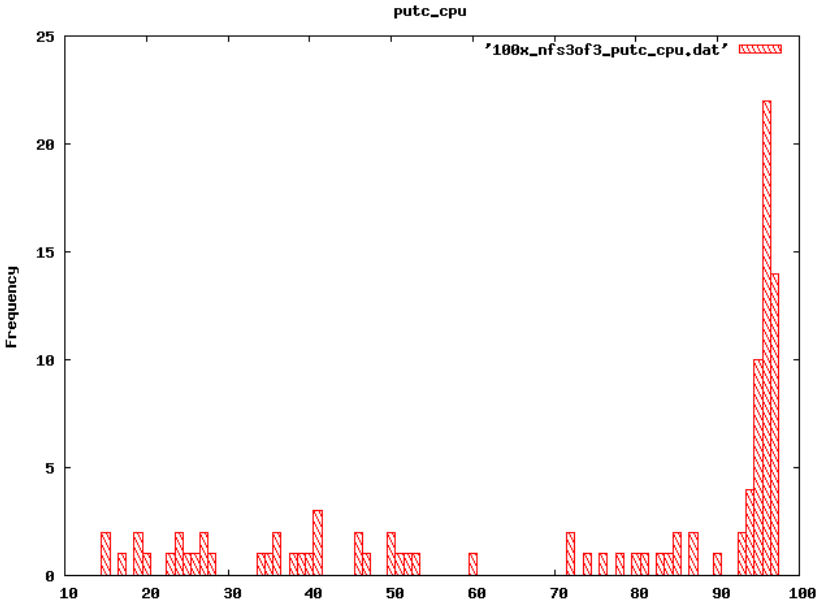

ran_del
'base_drbd_100x_ran_del.dat'
Frequency
25
20
15
10
5
0
140
145
150
155
160
165
170

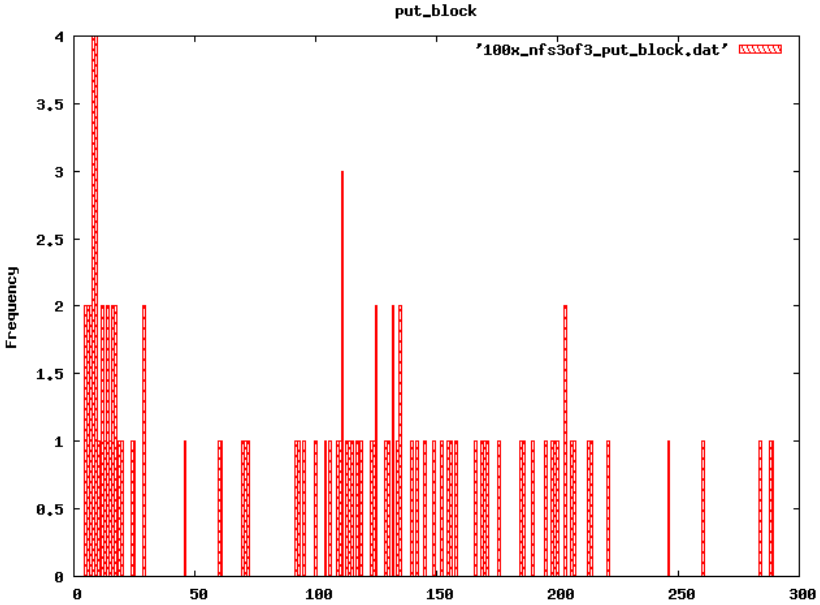
100x nfs3of3

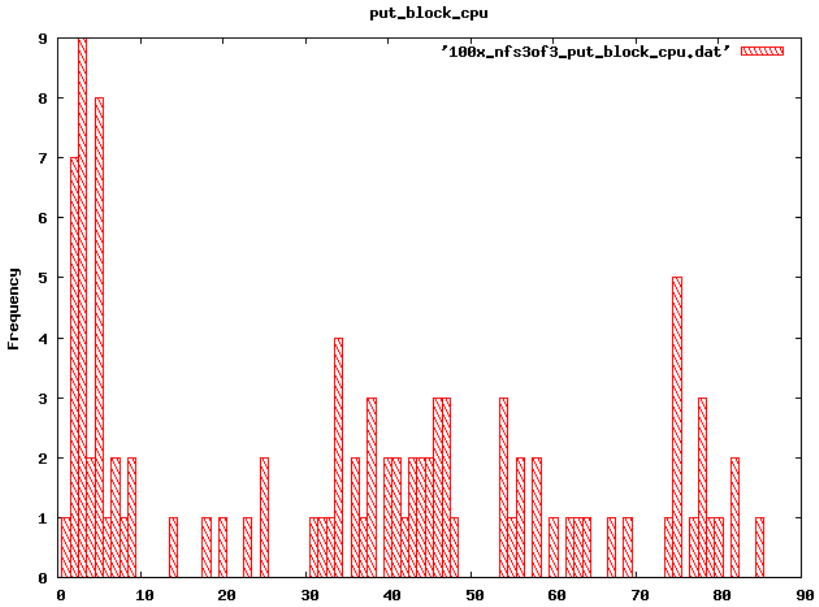
May 19, 2009

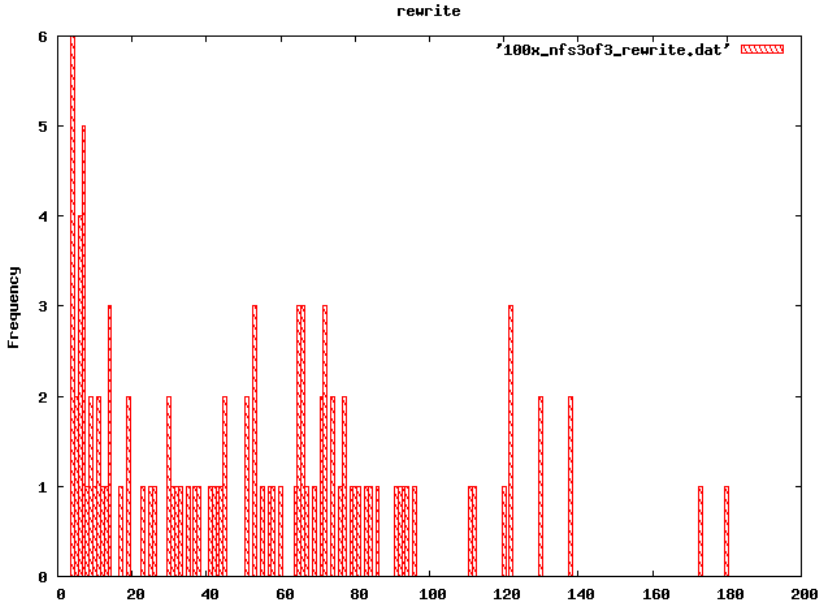
Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0.000	0.000	0.000	nan	etch	etch	0
file_size	300.000	300.000	0.000	nan	300M	300M	0
putc	25321.253	28261.000	2939.747	97671354.229	5540	40616	35076
putc_cpu	73.343	94.000	20.657	827.700	15	97	82
put_block	104609.697	111786.000	7176.303	6174875548.393	5495	289875	284380
put_block_cpu	35.444	38.000	2.556	715.863	1	85	84
rewrite	53472.293	51444.000	2028.293	1705559591.035	4035	180698	176663
rewrite_cpu	9.293	8.000	1.293	76.268	0	33	33
getc	21595.960	24070.000	2474.040	139606583.554	106	47859	47753
getc_cpu	54.051	58.000	3.949	935.725	0	95	95
get_block	141666.374	143731.000	2064.626	13727079249.163	6287	430634	424347
get_block_cpu	4.980	2.000	2.980	37.111	0	23	23
seeks	3005.201	306.200	2699.001	23392375.841	0	16365.1	16365.1
seeks_cpu	2.000	0.000	2.000	17.455	0	17	17
num_files	16.000	16.000	0.000	nan	16	16	0
seq_create	2715.535	2929.000	213.465	1122266.734	355	4151	3796
seq_create_cpu	84.000	99.000	15.000	898.929	9	102	93
seq_stat	0.000	0.000	0.000	nan	0	0	0
seq_stat_cpu	0.000	0.000	0.000	nan	0	0	0
seq_del	35.293	0.000	35.293	122067.904	0	3494	3494
seq_del_cpu	0.020	0.000	0.020	0.040	0	2	2
ran_create	3010.030	3037.000	26.970	830162.595	342	4280	3938
ran_create_cpu	90.667	99.000	8.333	512.303	10	100	90
ran_stat	0.000	0.000	0.000	nan	0	0	0
ran_stat_cpu	0.000	0.000	0.000	nan	0	0	0
ran_del	11903.657	12049.000	145.343	14317081.256	680	16409	15729

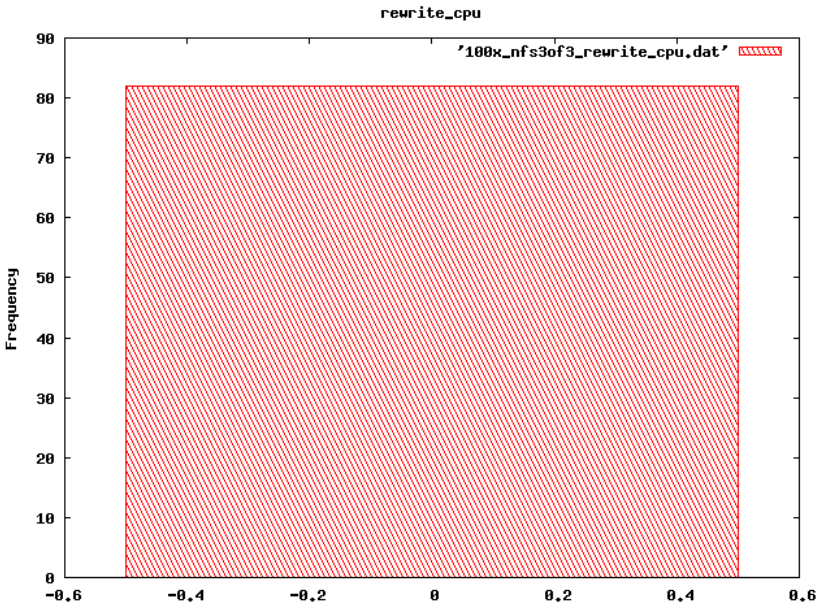

putc
'100x_s3of3_putc.dat'
Frequency
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
35
40
45

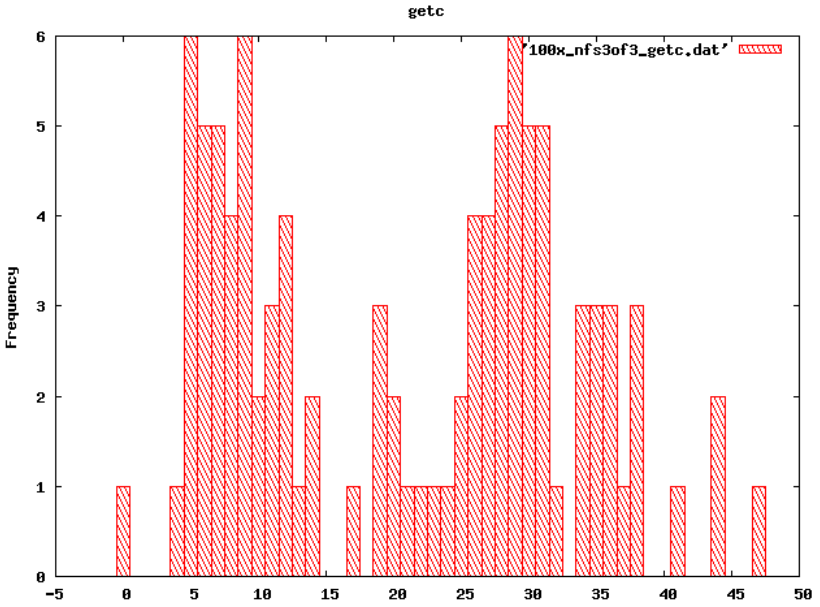

putc_cpu
'100x_nfs3of3_putc_cpu.dat'
Frequency
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100

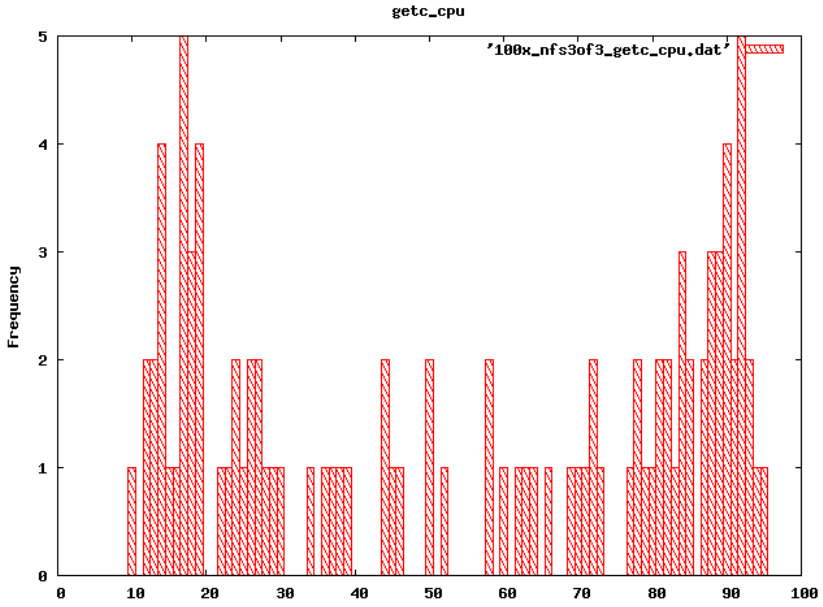

put_block
'100x_nfs3of3_put_block.dat'
Frequency
4
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300

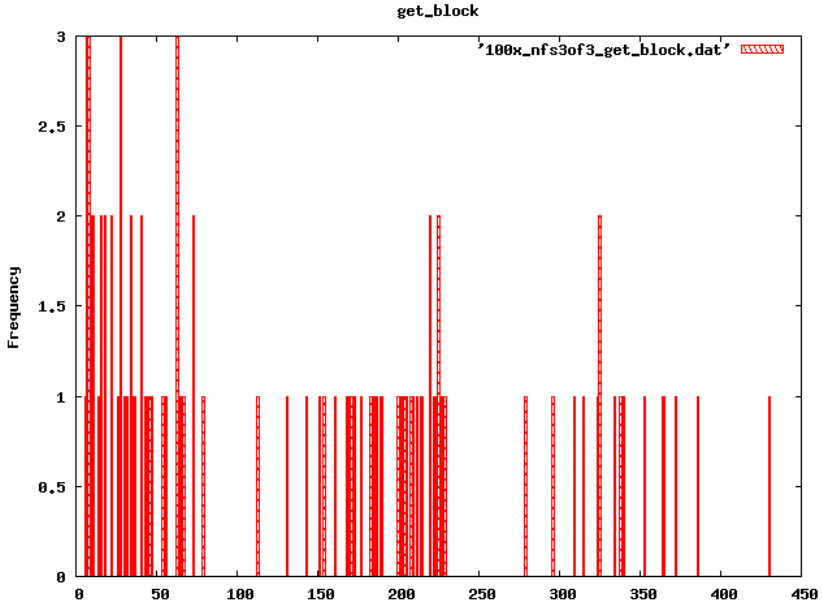

put_block_cpu
'100x_nfs3of3_put_block_cpu.dat'
Frequency
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
90

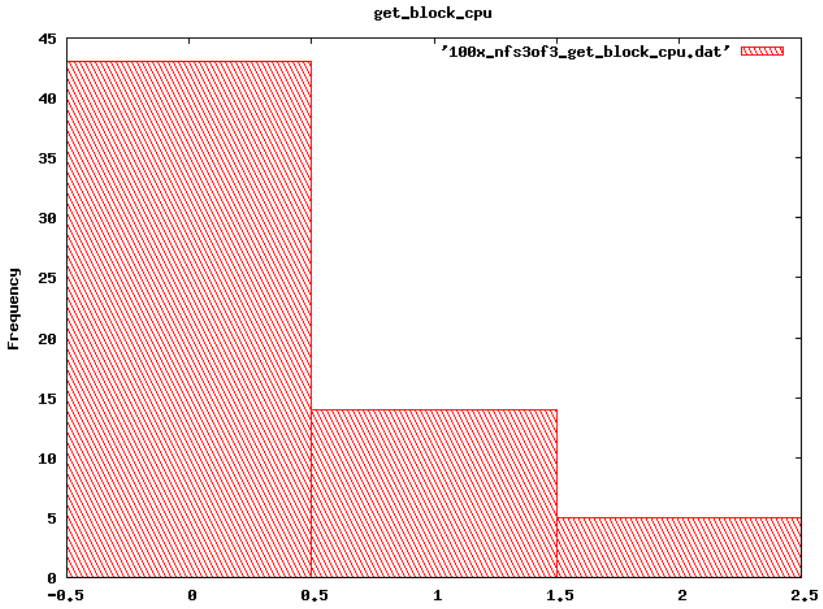

rewrite
'100x_nfs3of3_rewrite.dat'
Frequency
0
1
2
3
4
5
6
0
20
40
60
80
100
120
140
160
180
200

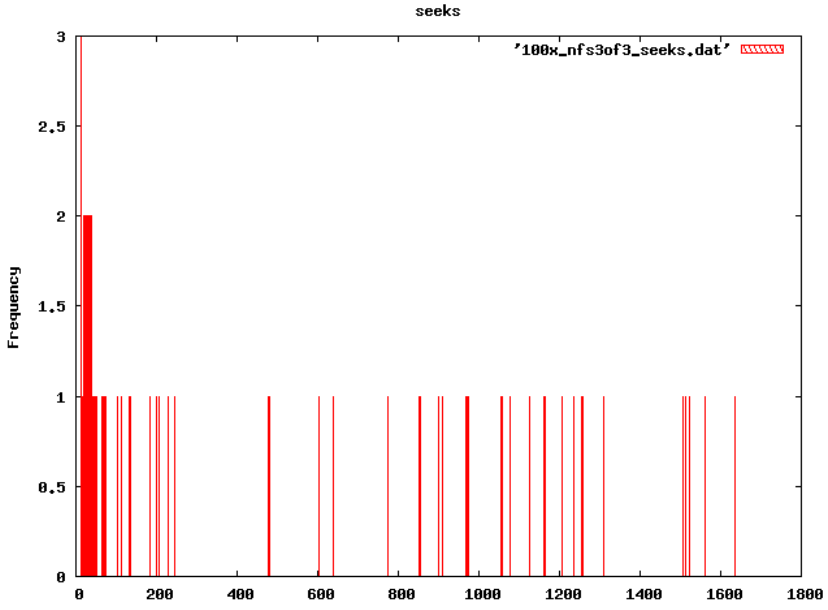

rewrite_cpu
'100x_nfs3of3_rewrite_cpu.dat'
Frequency
90
80
70
60
50
40
30
20
10
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6

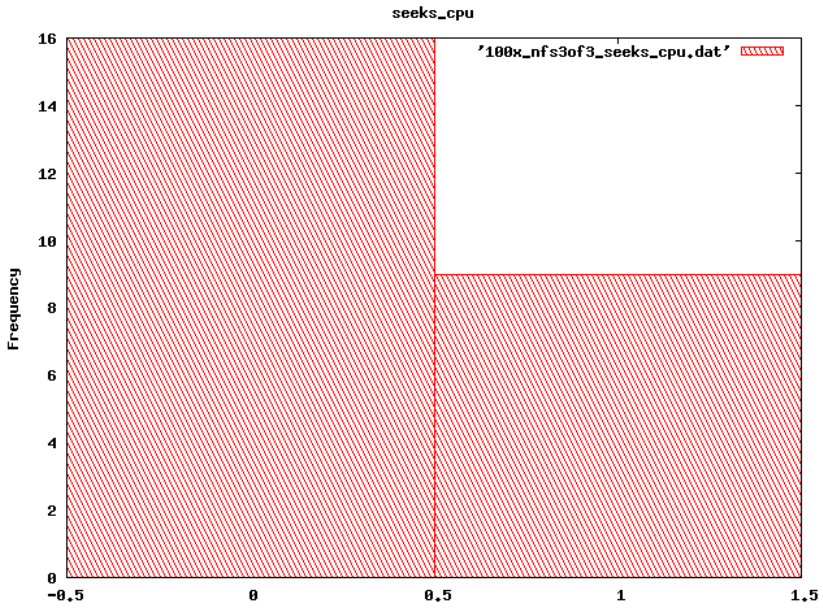

getc
'100x_nfs3of3_getc.dat'
Frequency
6
5
4
3
2
1
0
-5
0
5
10
15
20
25
30
35
40
45
50

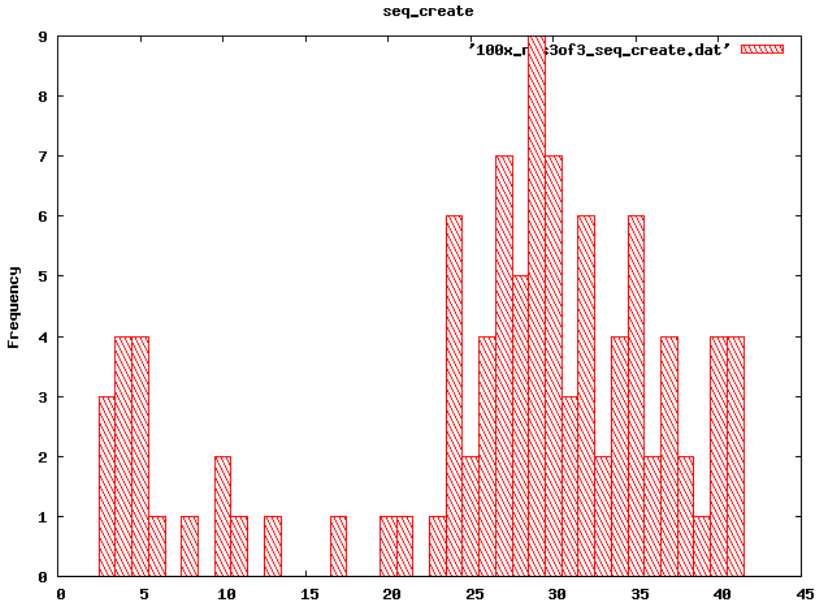

getc_cpu
'100x_nfs3of3_getc_cpu.dat'
Frequency
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90
100

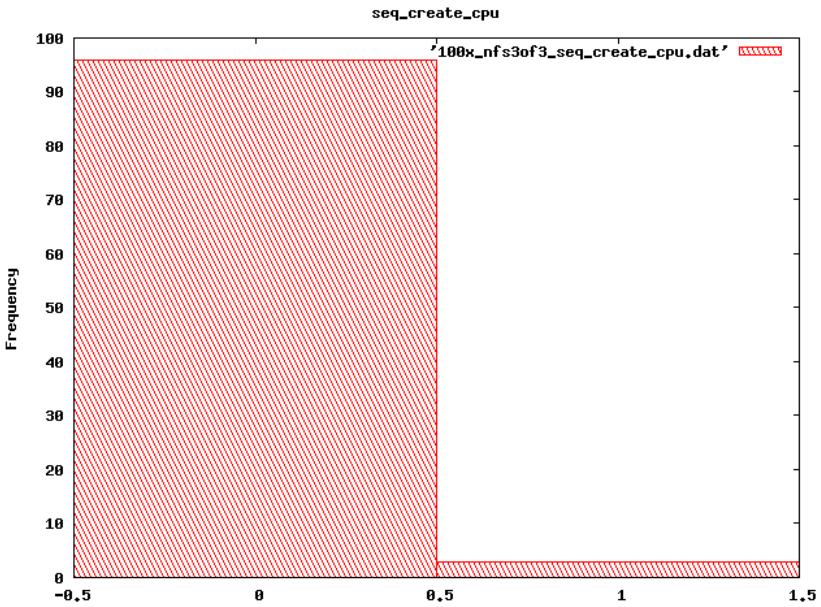

get_block
'100x_nfs3of3_get_block.dat'
Frequency
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250
300
350
400
450

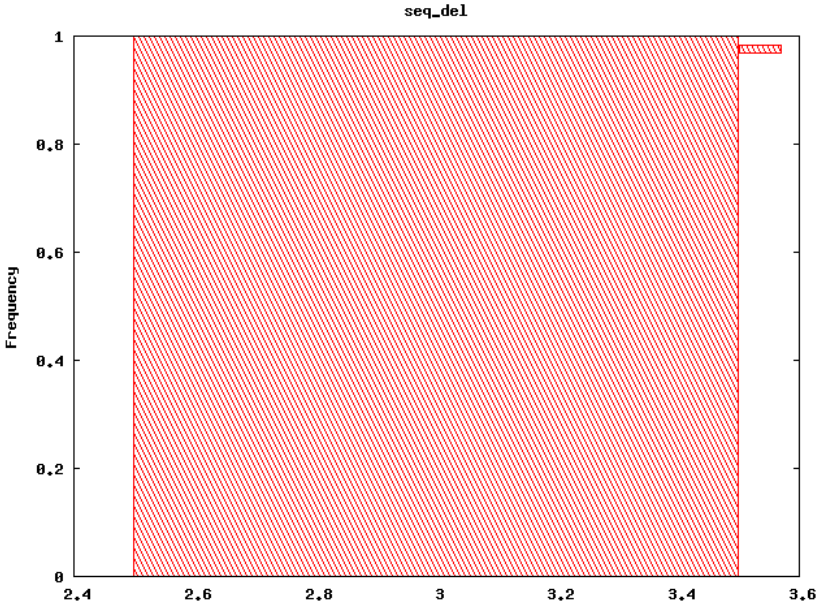

get_block_cpu
'100x_nfs3of3_get_block_cpu.dat'
Frequency
45
40
35
30
25
20
15
10
5
0
-0.5
0
0.5
1
1.5
2
2.5

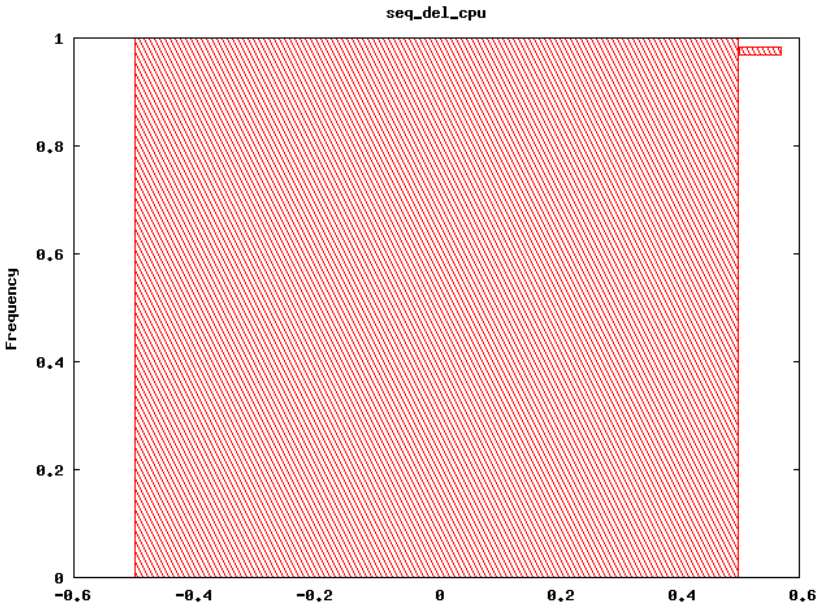

seeks
'100x_nfs3of3_seeks.dat'
Frequency
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000
1200
1400
1600
1800

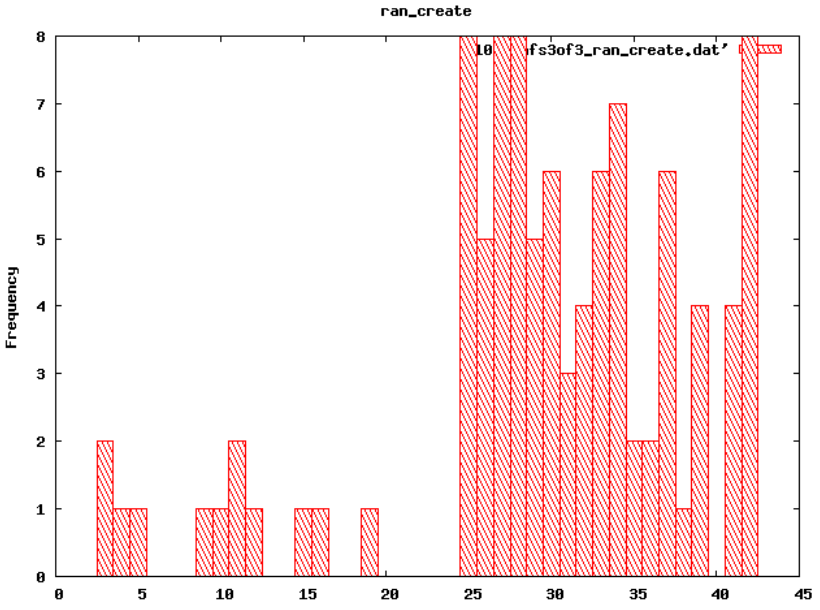

seeks_cpu
'100x_nfs3of3_seeks_cpu.dat'
Frequency
16
14
12
10
8
6
4
2
0
-0.5
0
0.5
1
1.5

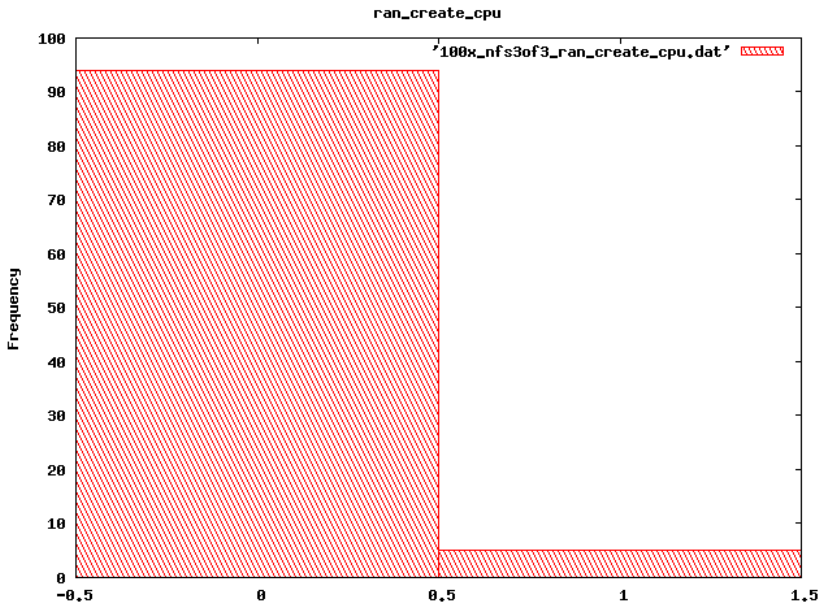

seq_create
'100x_r 3of3_seq_create.dat'
Frequency
9
8
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45

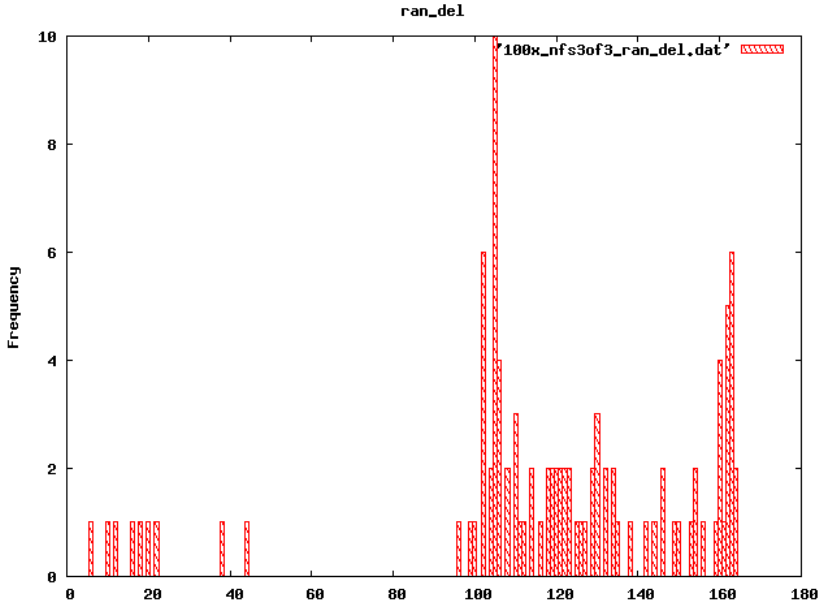

seq_create_cpu
'100x_nfs3of3_seq_create_cpu.dat'
Frequency
100
90
80
70
60
50
40
30
20
10
0
-0.5
0
0.5
1
1.5


seq_del
Frequency
1
0.8
0.6
0.4
0.2
0
2.4
2.6
2.8
3
3.2
3.4
3.6


seq_del_cpu
Frequency
1
0.8
0.6
0.4
0.2
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


ran_create
'fs3of3_ran_create.dat'
Frequency
8
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45

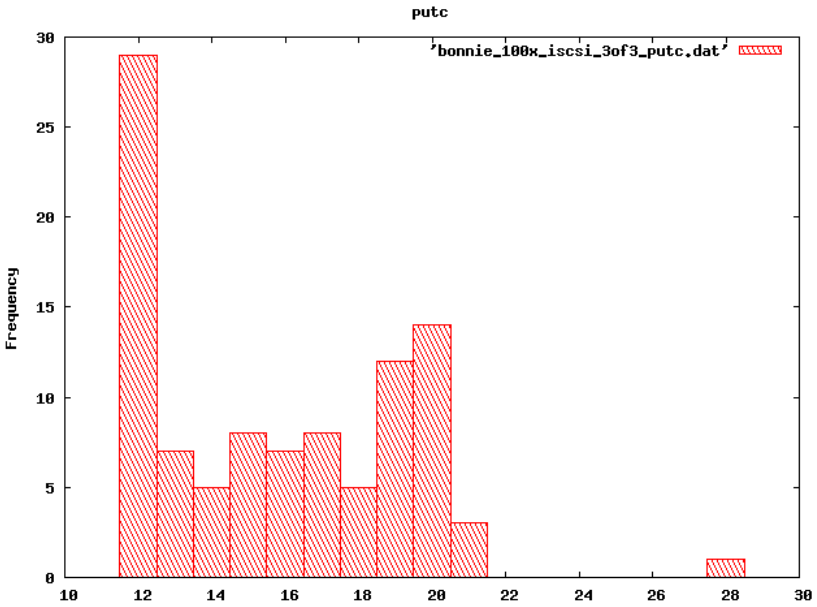

ran_create_cpu
'100x_nfs3of3_ran_create_cpu.dat'
Frequency
100
90
80
70
60
50
40
30
20
10
0
-0.5
0
0.5
1
1.5

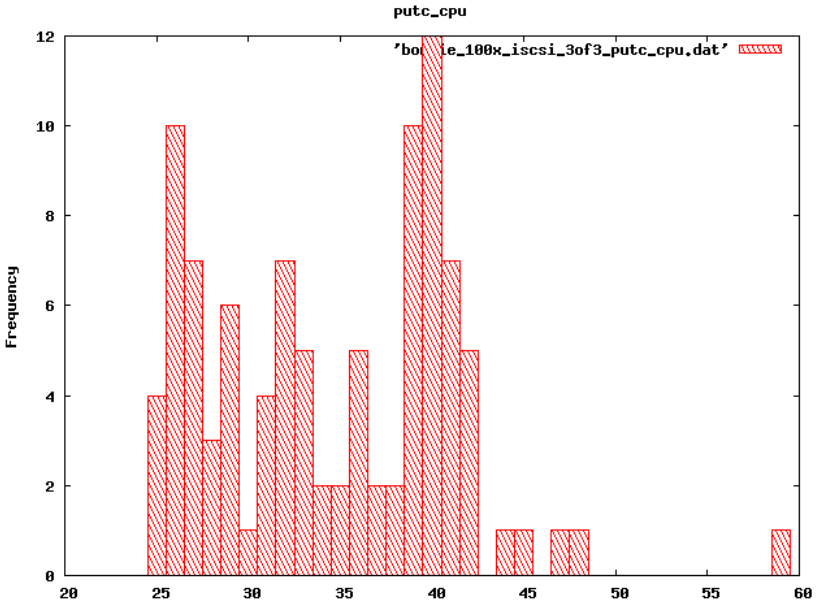

ran_del
'100x_nfs3of3_ran_del.dat'
Frequency
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
180

bonnie 100x iscsi 3of3

May 19, 2009

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0.000	0.000	0.000	nan	etch3	etch3	0
file_size	1.000	1.000	0.000	nan	1G	1G	0
putc	16258.444	16021.000	237.444	11392432.166	12011	28651	16640
putc_cpu	34.626	35.000	0.374	42.820	25	59	34
put_block	15246.657	13532.000	1714.657	8762264.286	12583	21367	8784
put_block_cpu	2.323	2.000	0.323	0.239	2	4	2
rewrite	4440.919	4329.000	111.919	172536.923	3675	5821	2146
rewrite_cpu	0.000	0.000	0.000	nan	0	0	0
getc	7730.374	7994.000	263.626	599217.668	5974	11023	5049
getc_cpu	3.283	3.000	0.283	0.607	2	5	3
get_block	8996.253	9353.000	356.747	2426084.492	6444	18603	12159
get_block_cpu	0.000	0.000	0.000	nan	0	0	0
seeks	231.807	235.000	3.193	7046.147	85.5	482.3	396.8
seeks_cpu	0.000	0.000	0.000	nan	0	0	0
num_files	16.000	16.000	0.000	nan	16	16	0
seq_create	3648.152	3816.000	167.848	168373.785	2434	4102	1668
seq_create_cpu	95.172	96.000	0.828	7.496	86	99	13
seq_stat	0.000	0.000	0.000	nan	0	0	0
seq_stat_cpu	0.000	0.000	0.000	nan	0	0	0
seq_del	0.000	0.000	0.000	nan	0	0	0
seq_del_cpu	0.000	0.000	0.000	nan	0	0	0
ran_create	3683.465	3866.000	182.535	221465.461	2476	4303	1827
ran_create_cpu	95.556	96.000	0.444	7.277	84	100	16
ran_stat	0.000	0.000	0.000	nan	0	0	0
ran_stat_cpu	0.000	0.000	0.000	nan	0	0	0
ran_del	13978.010	14799.000	820.990	4517906.879	8749	16253	7504


putc
'bonnie_100x_iscsi_3of3_putc.dat'
Frequency
0
5
10
15
20
25
30
10
12
14
16
18
20
22
24
26
28
30


putc_cpu
'bo ie_100x_iscsi_3of3_putc_cpu.dat'
Frequency
0
2
4
6
8
10
12
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25
30
35
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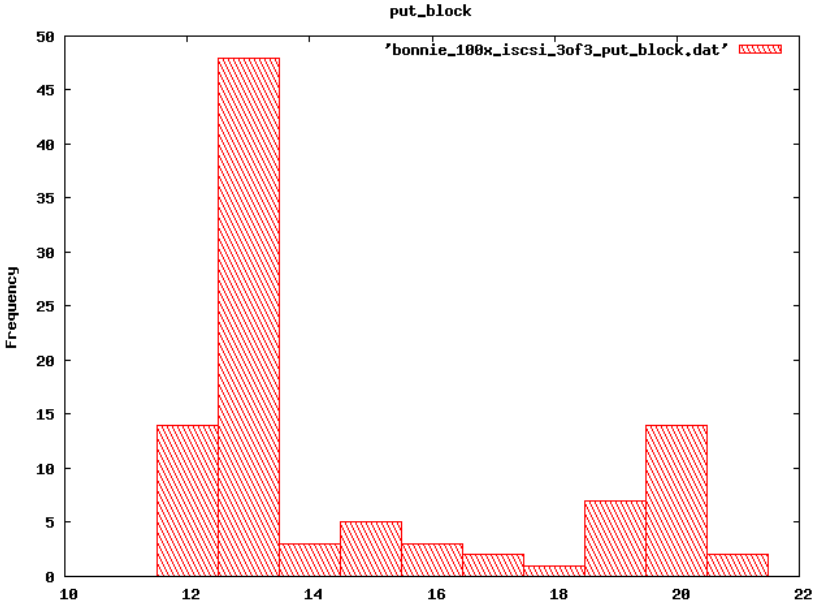
50
55
60


put_block
'bonnie_100x_iscsi_3of3_put_block.dat'
Frequency
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10
15
20
25
30
35
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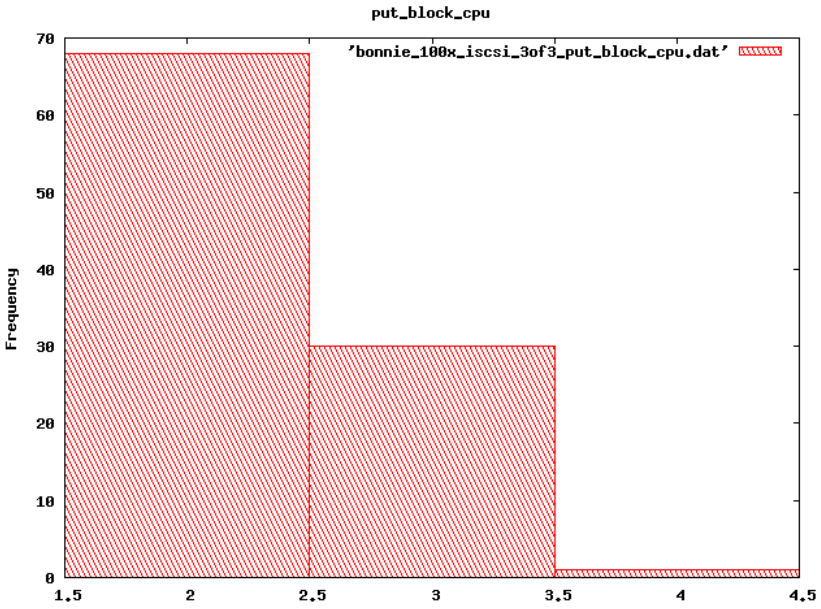
45
50
10
12
14
16
18
20
22


put_block_cpu
'bonnie_100x_iscsi_3of3_put_block_cpu.dat'
Frequency
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60
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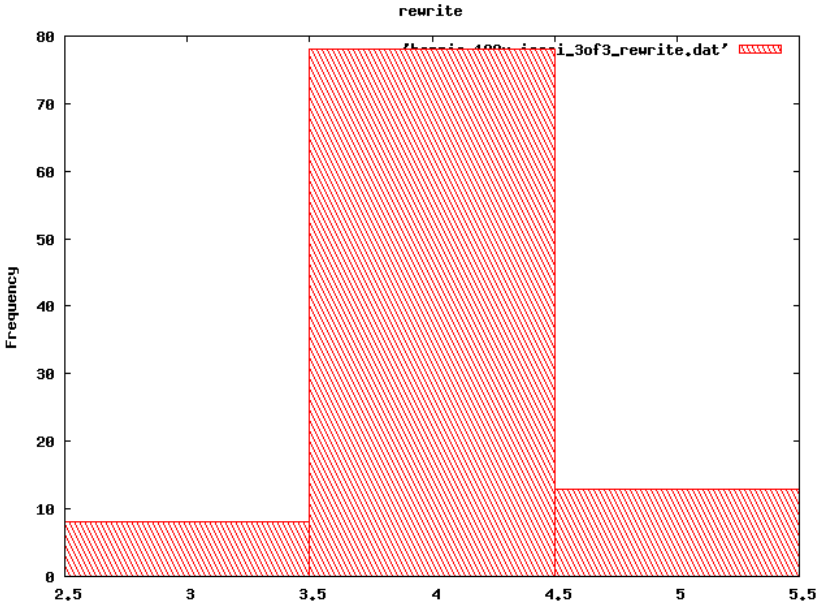
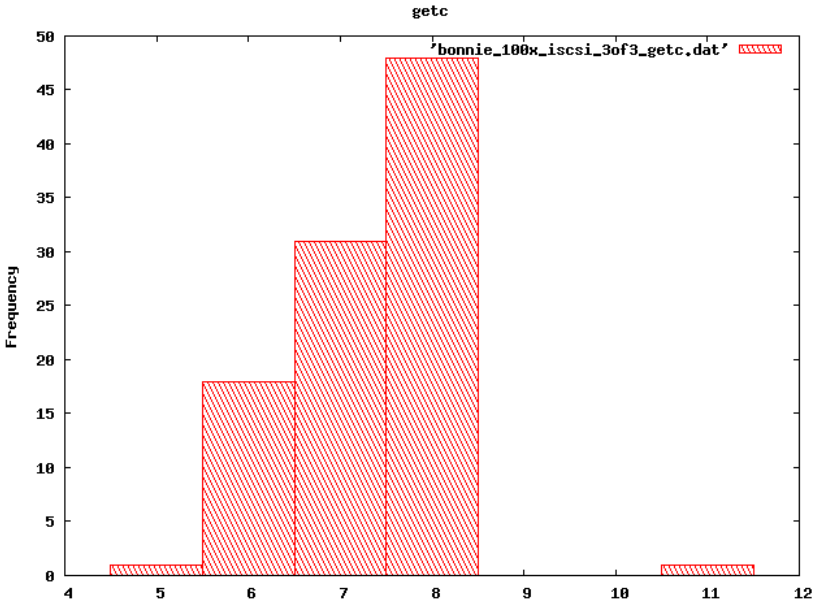
40
30
20
10
0
1.5
2
2.5
3
3.5
4
4.5


rewrite
i_3of3_rewrite.dat'
Frequency
80
70
60
50
40
30
20
10
0
2.5
3
3.5
4
4.5
5
5.5


getc
'bonnie_100x_iscsi_3of3_getc.dat'
Frequency
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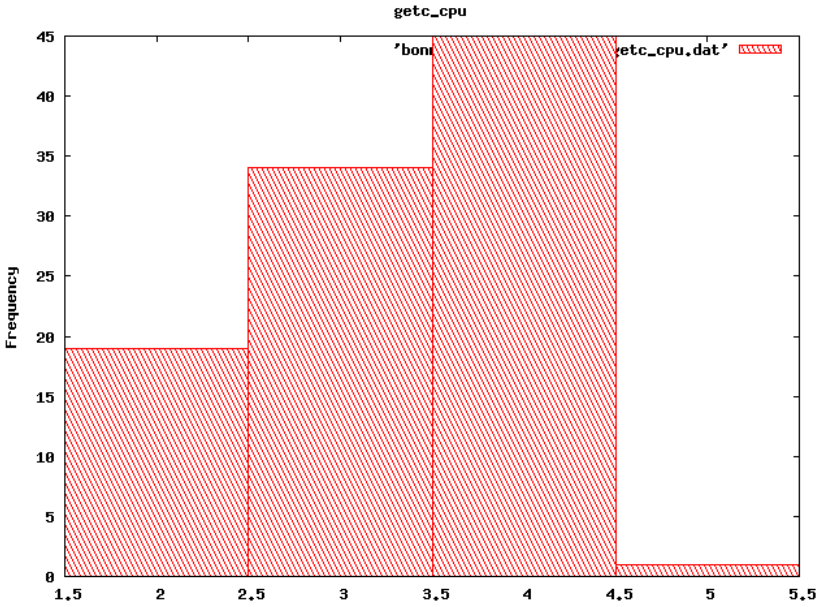
5
10
15
20
25
30
35
40
45
50
4
5
6
7
8
9
10
11
12


getc_cpu
'bon
etc_cpu.dat'
Frequency
0
5
10
15
20
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30
35
40
45
1.5
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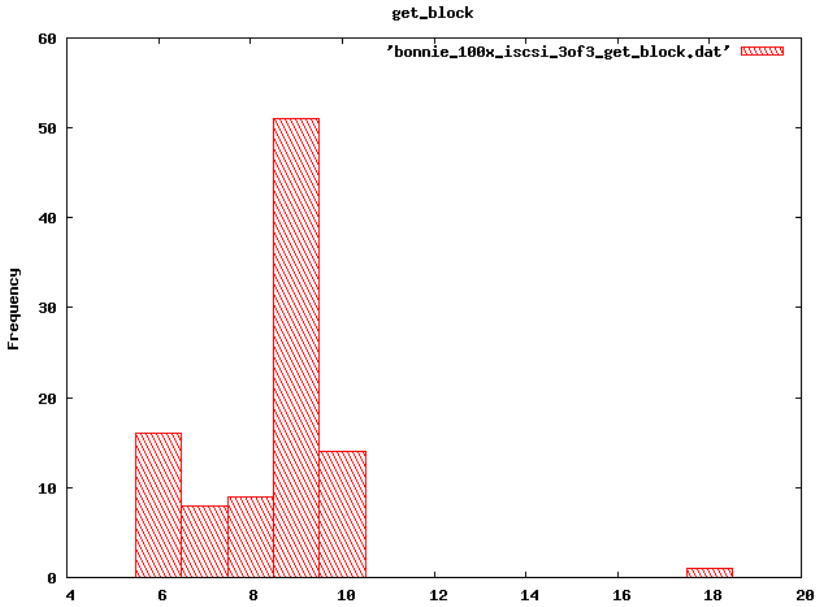
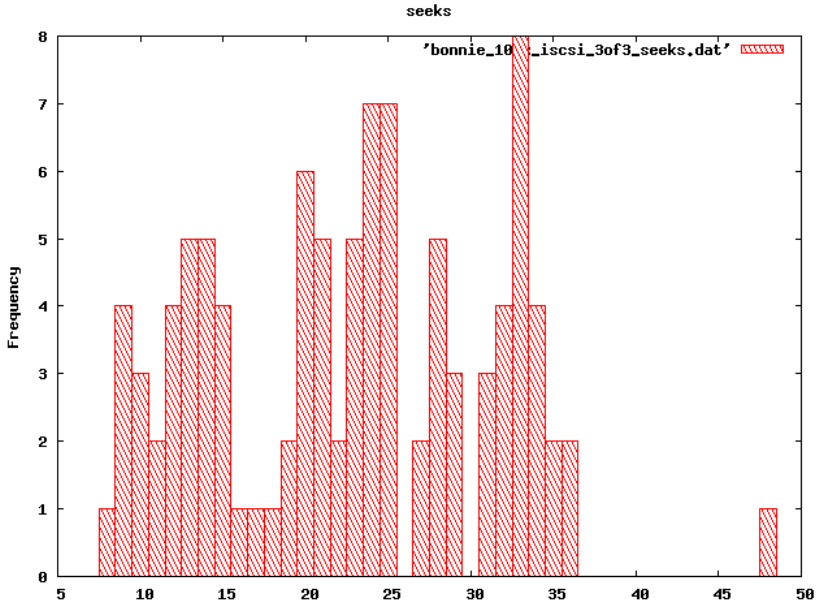
2.5
3
3.5
4
4.5
5
5.5


get_block
'bonnie_100x_iscsi_3of3_get_block.dat'
Frequency
0
10
20
30
40
50
60
4
6
8
10
12
14
16
18
20


seeks
'bonnie_10 _iscsi_3of3_seeks.dat'
Frequency
0
1
2
3
4
5
6
7
8
5
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15
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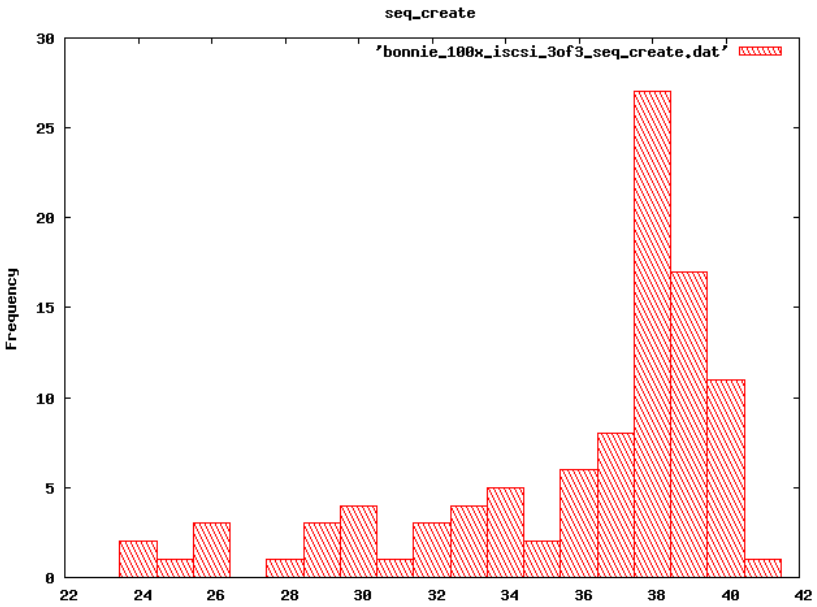
25
30
35
40
45
50


seq_create
'bonnie_100x_iscsi_3of3_seq_create.dat'
Frequency
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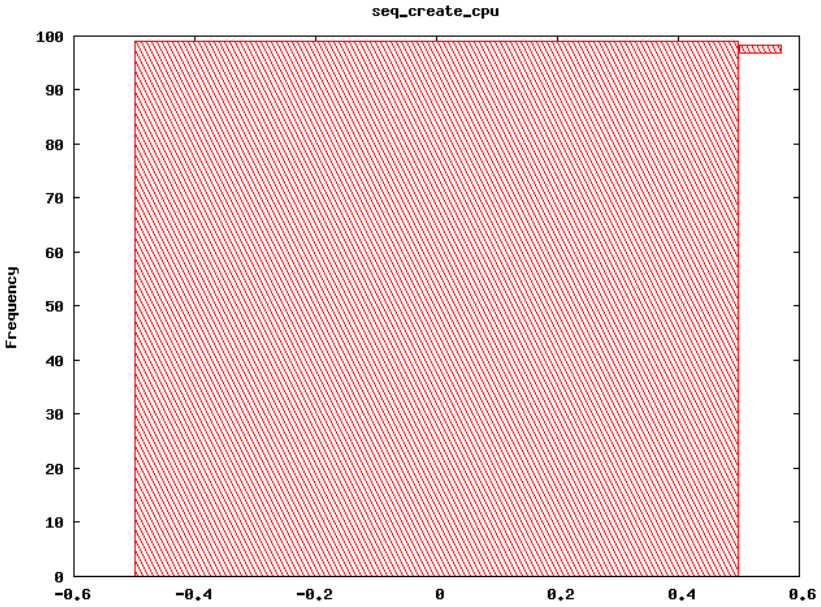
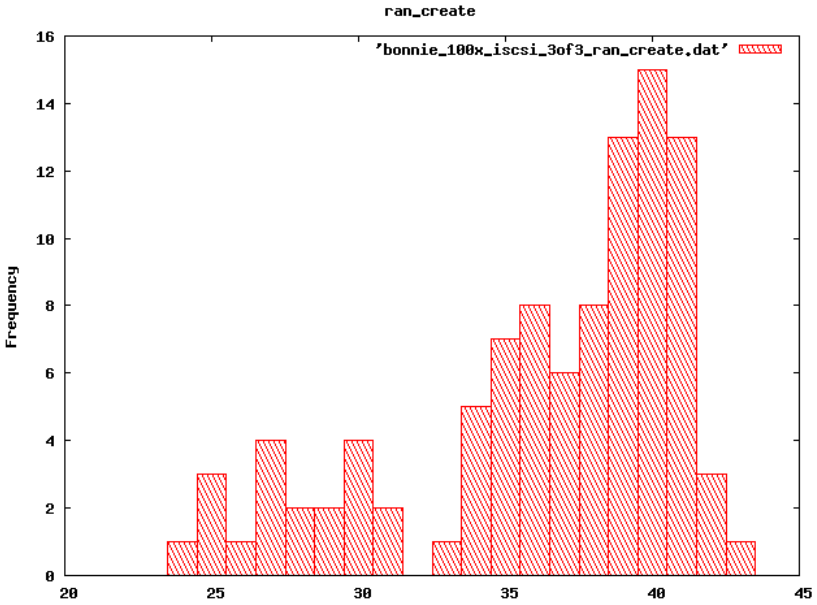
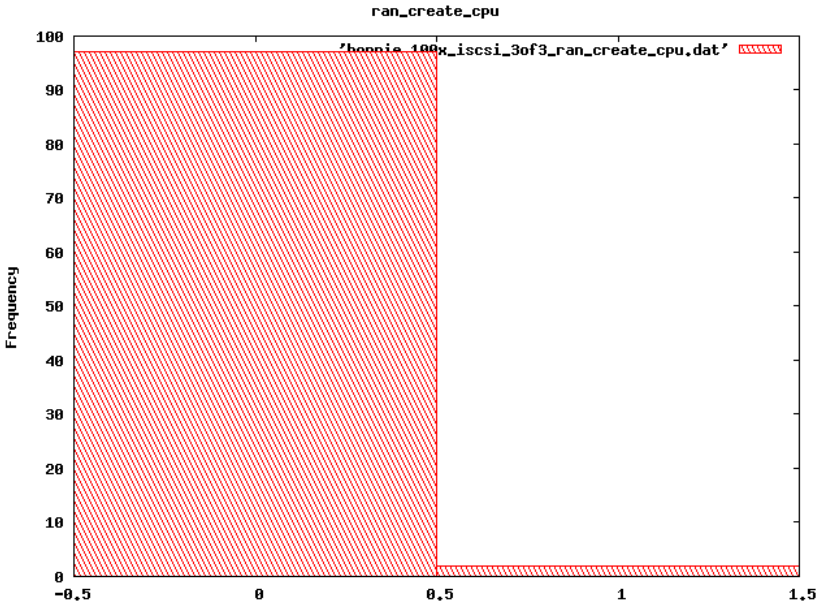
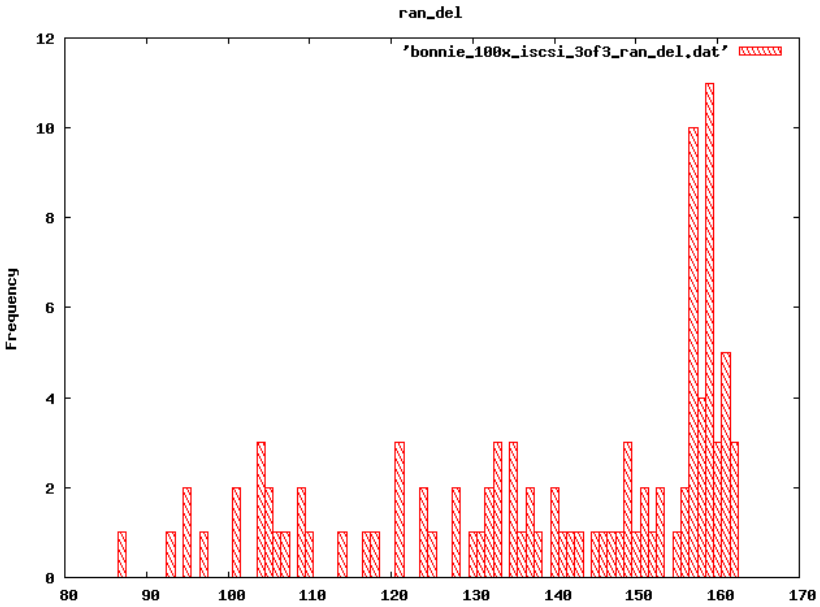
5
10
15
20
25
30
22
24
26
28
30
32
34
36
38
40
42


seq_create_cpu
Frequency
0
10
20
30
40
50
60
70
80
90
100
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


ran_create
'bonnie_100x_iscsi_3of3_ran_create.dat'
Frequency
0
2
4
6
8
10
12
14
16
20
25
30
35
40
45

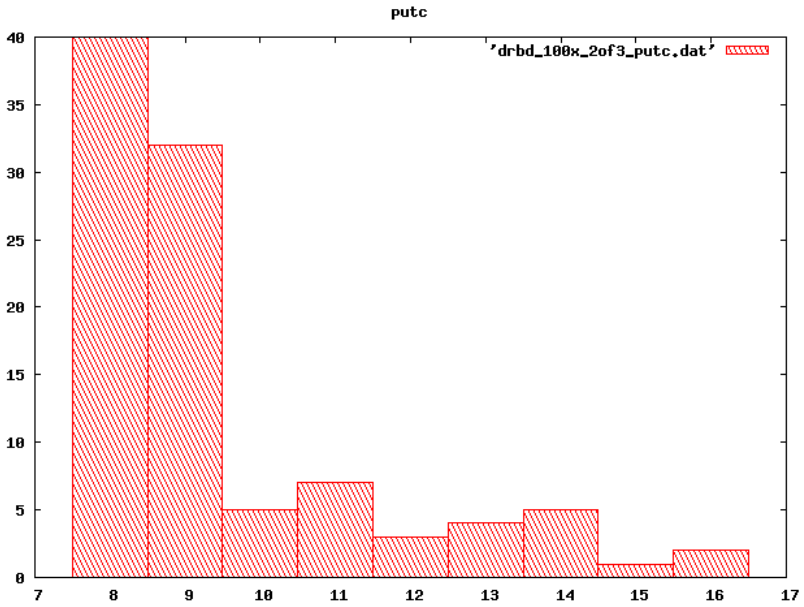

ran_create_cpu
'bonnie_100x_iscsi_3of3_ran_create_cpu.dat'
Frequency
0
10
20
30
40
50
60
70
80
90
100
-0.5
0
0.5
1
1.5


ran_del
'bonnie_100x_iscsi_3of3_ran_del.dat'
Frequency
0
2
4
6
8
10
12
80
90
100
110
120
130
140
150
160
170

drbd 100x 2of3

May 7, 2009

Name	Mean	Median	(Mean - Median)	Variance	Min	Max	Range
name	0.000	0.000	0.000	nan	etch	etch	0
file_size	300.000	300.000	0.000	nan	300M	300M	0
putc	10024.525	9206.000	818.525	3988750.613	8181	16904	8723
putc_cpu	21.141	19.000	2.141	22.950	17	36	19
put_block	10918.495	10976.000	57.505	745612.129	8558	12888	4330
put_block_cpu	1.657	2.000	0.343	0.225	1	2	1
rewrite	7033.495	6891.000	142.495	439018.311	5794	9071	3277
rewrite_cpu	0.000	0.000	0.000	nan	0	0	0
getc	11255.434	11279.000	23.566	604215.599	8971	13099	4128
getc_cpu	12.121	12.000	0.121	1.157	9	15	6
get_block	38747.242	36494.000	2253.242	62389843.840	26706	66601	39895
get_block_cpu	0.000	0.000	0.000	nan	0	0	0
seeks	147.859	148.500	0.641	70.800	123.4	166.2	42.8
seeks_cpu	0.000	0.000	0.000	nan	0	0	0
num_files	16.000	16.000	0.000	nan	16	16	0
seq_create	3134.626	2996.000	138.626	205190.214	2502	4009	1507
seq_create_cpu	95.455	96.000	0.545	5.056	88	99	11
seq_stat	0.000	0.000	0.000	nan	0	0	0
seq_stat_cpu	0.000	0.000	0.000	nan	0	0	0
seq_del	299.283	0.000	299.283	8777880.708	0	29629	29629
seq_del_cpu	0.343	0.000	0.343	11.559	0	34	34
ran_create	3139.636	2958.000	181.636	202127.565	2509	4216	1707
ran_create_cpu	95.253	95.000	0.253	3.623	89	100	11
ran_stat	0.000	0.000	0.000	nan	0	0	0
ran_stat_cpu	0.000	0.000	0.000	nan	0	0	0
ran_del	12651.162	12275.000	376.162	2870622.237	8715	16349	7634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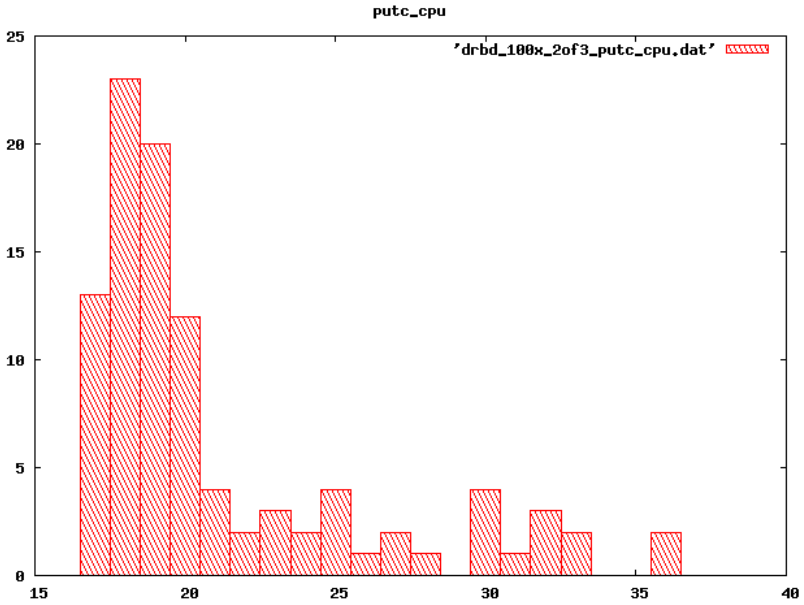
16
17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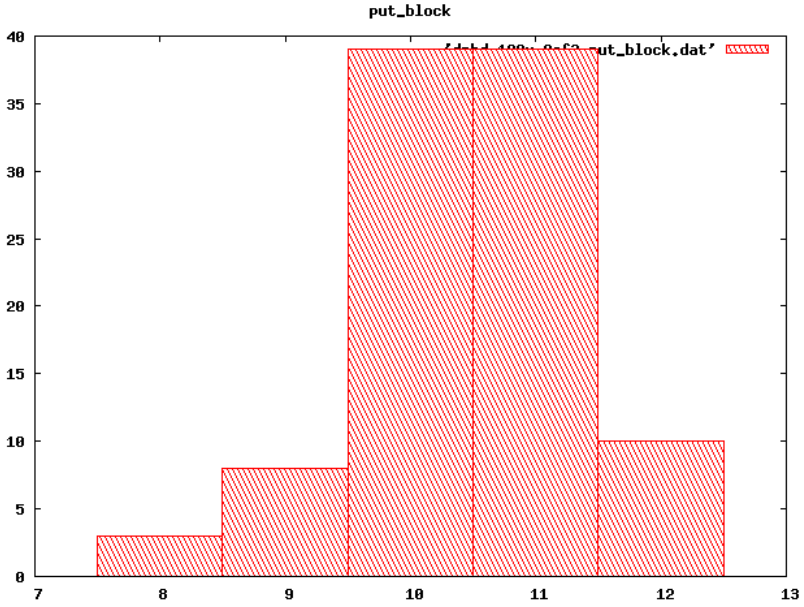
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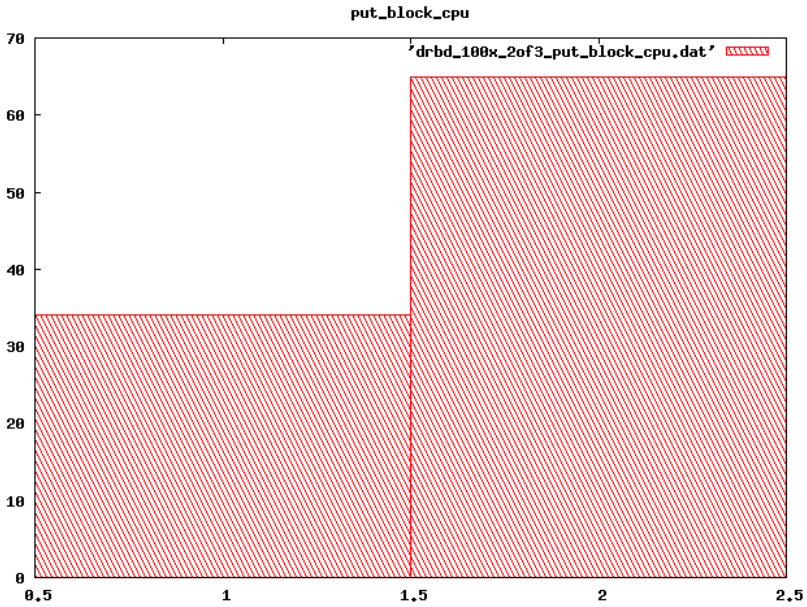
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10
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0.5
1
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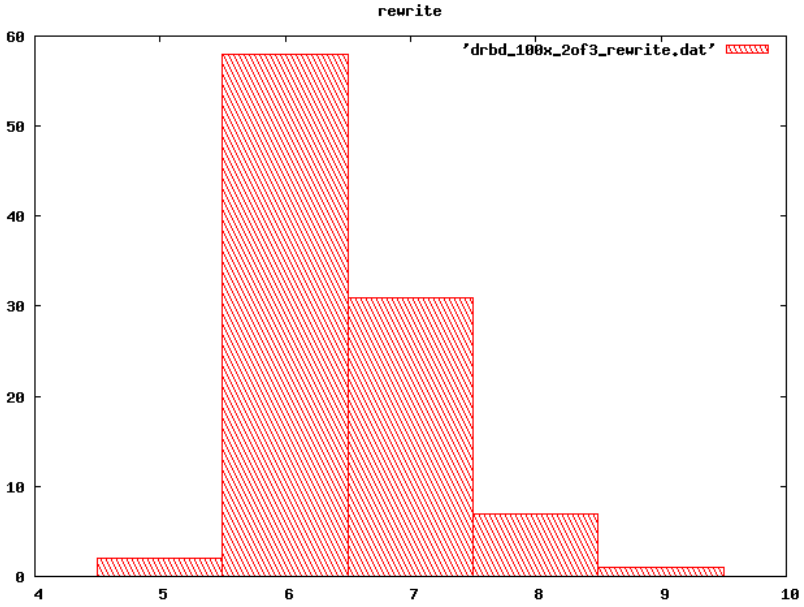
2
2.5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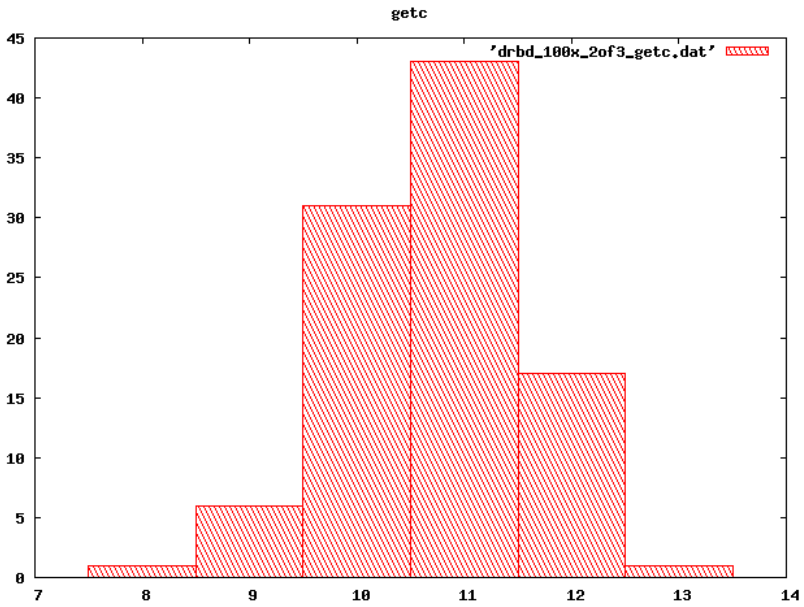
10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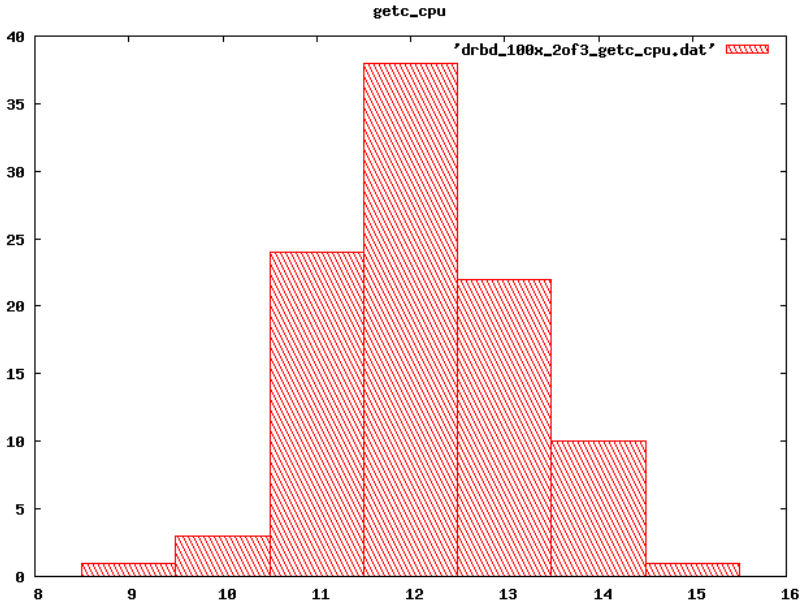
14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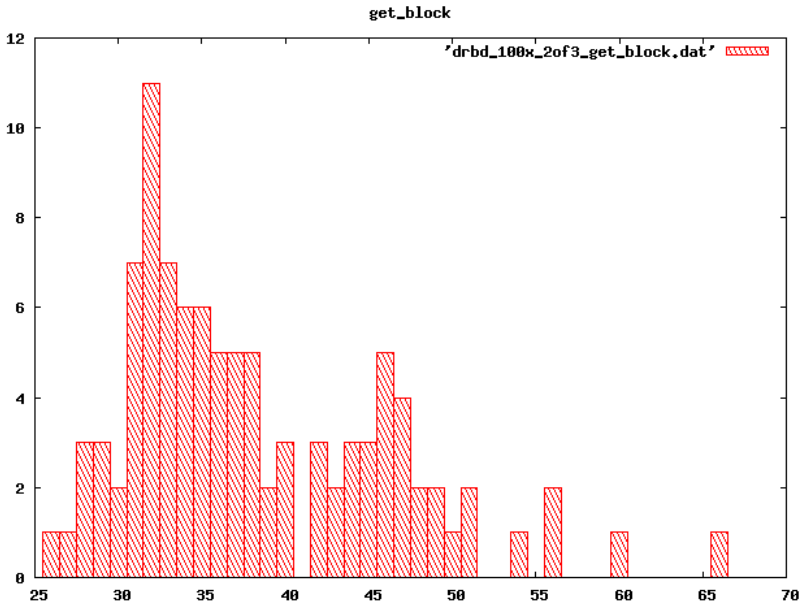
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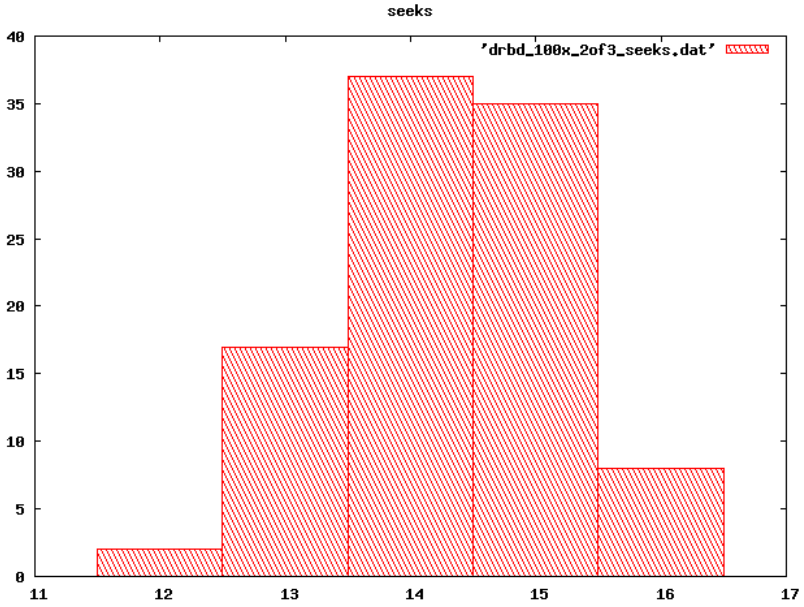
55
60
65
70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16
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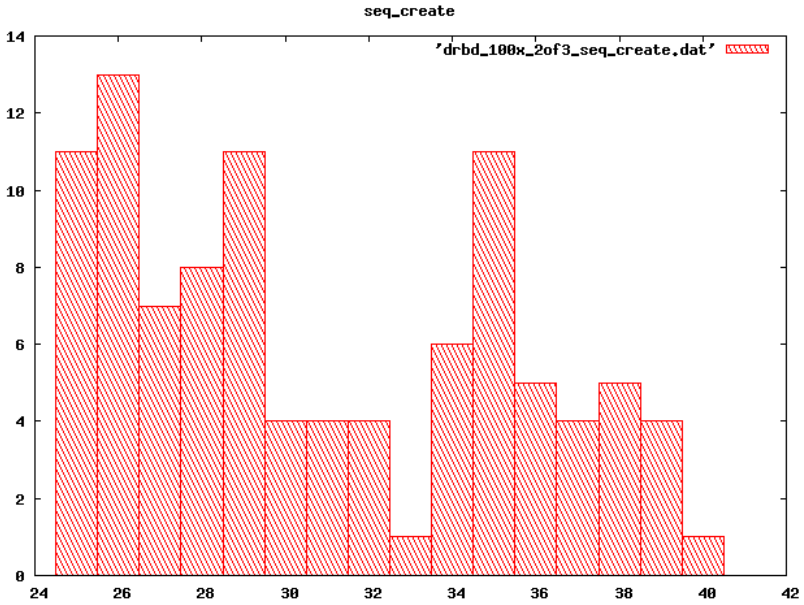
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8
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4
2
0
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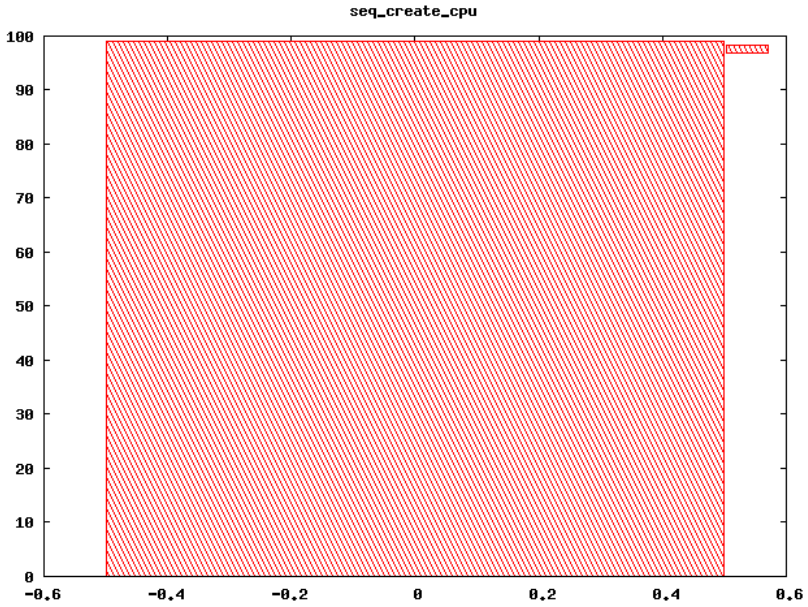
26
28
30
32
34
36
38
40
42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80
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30
20
10
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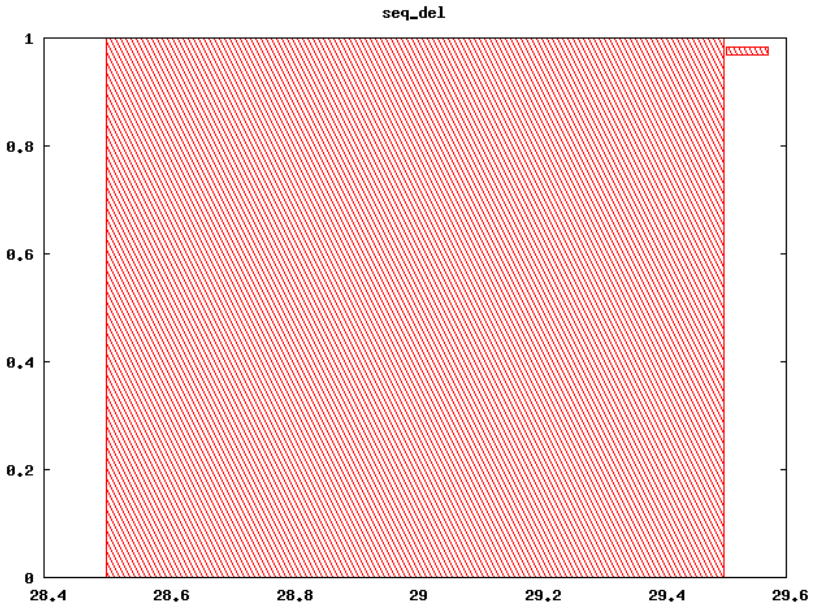
-0.4
-0.2
0
0.2
0.4
0.6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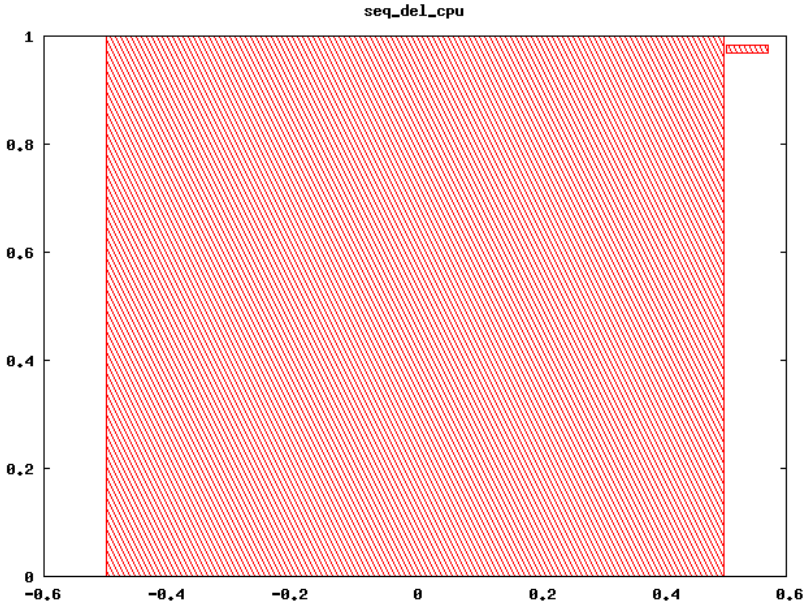
0.4
0.2
0
28.4
28.6
28.8
29
29.2
29.4
29.6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0.4
0.2
0
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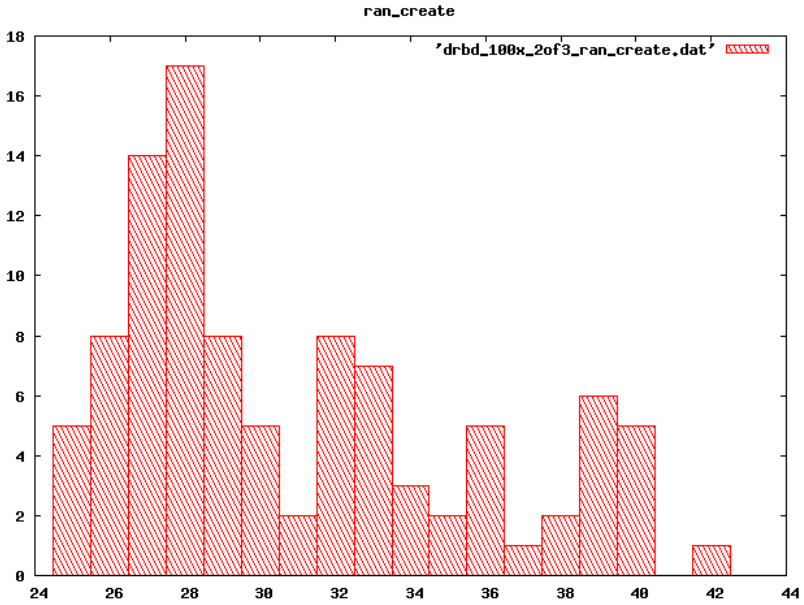
-0.2
0
0.2
0.4
0.6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32
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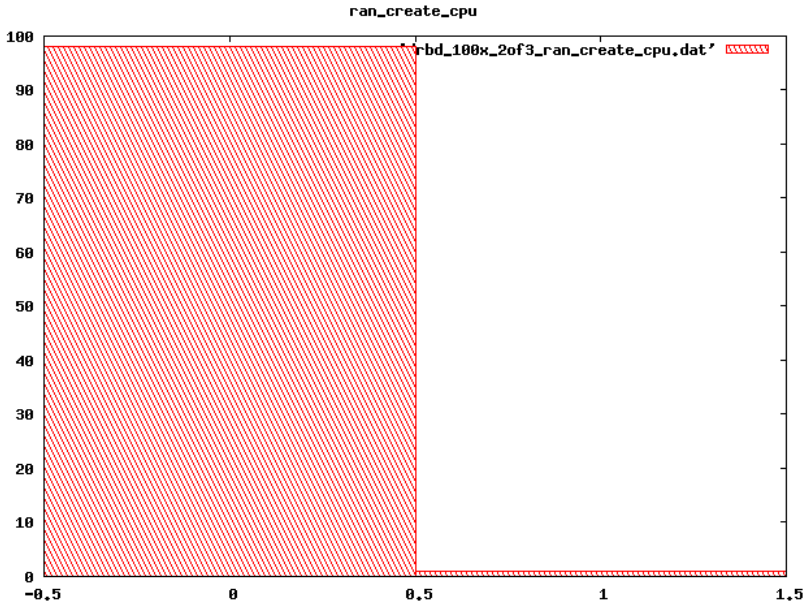
42
44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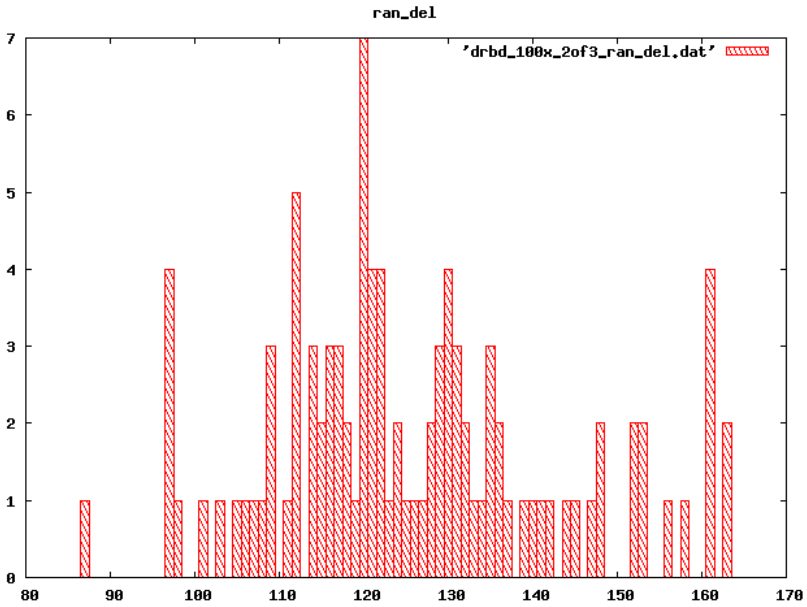
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170