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SUMMARY

This internal report explains the performance analysis of virtual machines using three popular benchmark tools, namely, PassMark PerformanceTest, SPEC Workstation and SPEC Viewperf.

Proof of Concept setup for Virtual Graphics Workstations: Performance Analysis

1. Introduction

Physical workstations are used by scientists and engineers for 2D/ 3D modeling, simulation and analysis. They require high end graphics rendering capabilities and computing power than normal desktop PCs. Workstations are expensive and also involve operational costs in terms of air conditioning and power utilization. The infrastructural requirements result in lack of mobility of workstations, forcing users to visit centralized facility for using them. An alternative approach is to provide users with virtual workstations, where a shared, centralized computing environment provides a virtual machine to run interactive 3D graphical computing, which can be accessed from a thin client anywhere within the network.

In a virtual workstation approach, the remote server hosts a virtual representation of the machine that performs computation as well as graphics processing. To achieve this, the software transforms a physical GPU installed on the server to create virtual GPUs that can be shared across multiple virtual machines (VMs). Only the final displayed image (the pixel stream) traverses the network to the thin clients that display those pixels and capture user I/O.

A Proof of Concept (PoC) setup for Virtual Graphics Workstation (VGW) has been implemented at Computer Division. The aim of this setup was to get the working knowledge and performance evaluation of VGW. This internal report explains the performance analysis of virtual machines using three popular benchmark tools, namely, PassMark PerformanceTest, SPEC Workstation and SPEC Viewperf.

2. Configuration of Virtual Graphics Workstations

2.1 Hardware Configuration

The graphics virtualization setup consists of two virtualization servers and two management servers. The virtualization servers are equipped with Nvidia Grid GPU card and are used for hosting the vGPU enabled virtual workstations. Two management servers host the virtual machines required by the virtualization software (VMware software stack) for authentication, management and connection brokering (infrastructure VMs). Table 1 lists the servers used for building the virtualization setup. Table 2 gives the hardware configuration of management servers & virtualization servers

S.No	Server Type	Host Name	IP Address
1	Management Server	VGPU1	10.1.2.110
2	Management Server	VGPU2	10.1.2.111
3	Virtualization Server	VGPU3	10.1.2.112
4	Virtualization Server	VGPU4	10.1.2.113

Table 1: Physical Servers with IP Address and Host name

	Management Server	Virtualization Server
Processor	Intel Xeon E5-2697 V2	Intel Xeon CPU E5-2643 v4
Clock Speed	2.7GHz	3.40 GHz
No. of CPUs	2	2
No. of Cores per CPU	12	6
RAM	128GB	128 GB
HDD	2 TB	4 TB
Graphics Card	Nil	NVIDIA Tesla M60 with 16 GB GDDR5 Memory

Table 2: Hardware configuration of management servers & virtualization servers

The NVIDIA Tesla M60 GPU accelerator works with NVIDIA GRID software to provide the high-end graphics performance for virtualized workstations.

Thin Clients are provided to users for connecting the VMs through network and they support graphics intensive applications with 4K resolution. The thin clients have dual core 2.4 GHz processor, 4GB RAM and 32 GB hard disk space.

2.2. Software Configuration

The main software component used for virtualization is the hypervisor. It is the software that can virtualize hardware resources and manages the resources for every virtual machine. The VMware virtualization software stack and NVIDIA Virtual GPU Manager is used to achieve virtualization of graphics workstations. Table 3 lists the software components of management and virtualization servers.

	Management Server	Virtualization Server
Hypervisor	VMware ESXi 6.5	VMware ESXi 6.5
GPU manager	NA	NVIDIA Grid GPU Manager 7.1
Virtualization Stack	VMware Horizon 7	VMware Horizon 7
Guest OS	Windows Server 2016 R2	Windows 10 Pro.

Table 3: Software configuration of management servers & virtualization servers

A. VMware software stack

VMware ESXi is a bare-metal hypervisor, installed directly onto virtualization servers and management servers. The hypervisor partitions the hardware resources (CPU, Memory, HDD and GPU) to increase the effective utilization of the resources.

B. NVIDIA Virtual GPU Manager

Nvidia virtual GPU manager transforms a physical GPU installed on a server to create virtual GPUs that can be shared across multiple virtual machines. It runs along with the VMware ESXI hypervisor in the virtualization servers.

Fig. 1 depicts the components of the graphics virtualization setup. The NVIDIA Tesla M60 GPU cards are installed on virtualization servers. A network switch is provided to interconnect all the servers. Network Attached Storage (NAS) is configured through iSCSI mount point to provide the additional storage space to user VMs.

VMware's native display protocol, VMware Blast protocol is used for desktop virtualization and remote application-delivery. This uses the H.264 codec as well as the JPG/PNG codec and automatically selects the most suitable codec for the conditions.

The virtualization and management servers are hosted at computer Division. Users from various groups are accessing their assigned VMs through campus backbone network using thin clients. VMware Horizon Client is installed on each endpoint device /thin client. Client software has the provision to provide the IP address and username / password for the users to access their respective virtual machines.

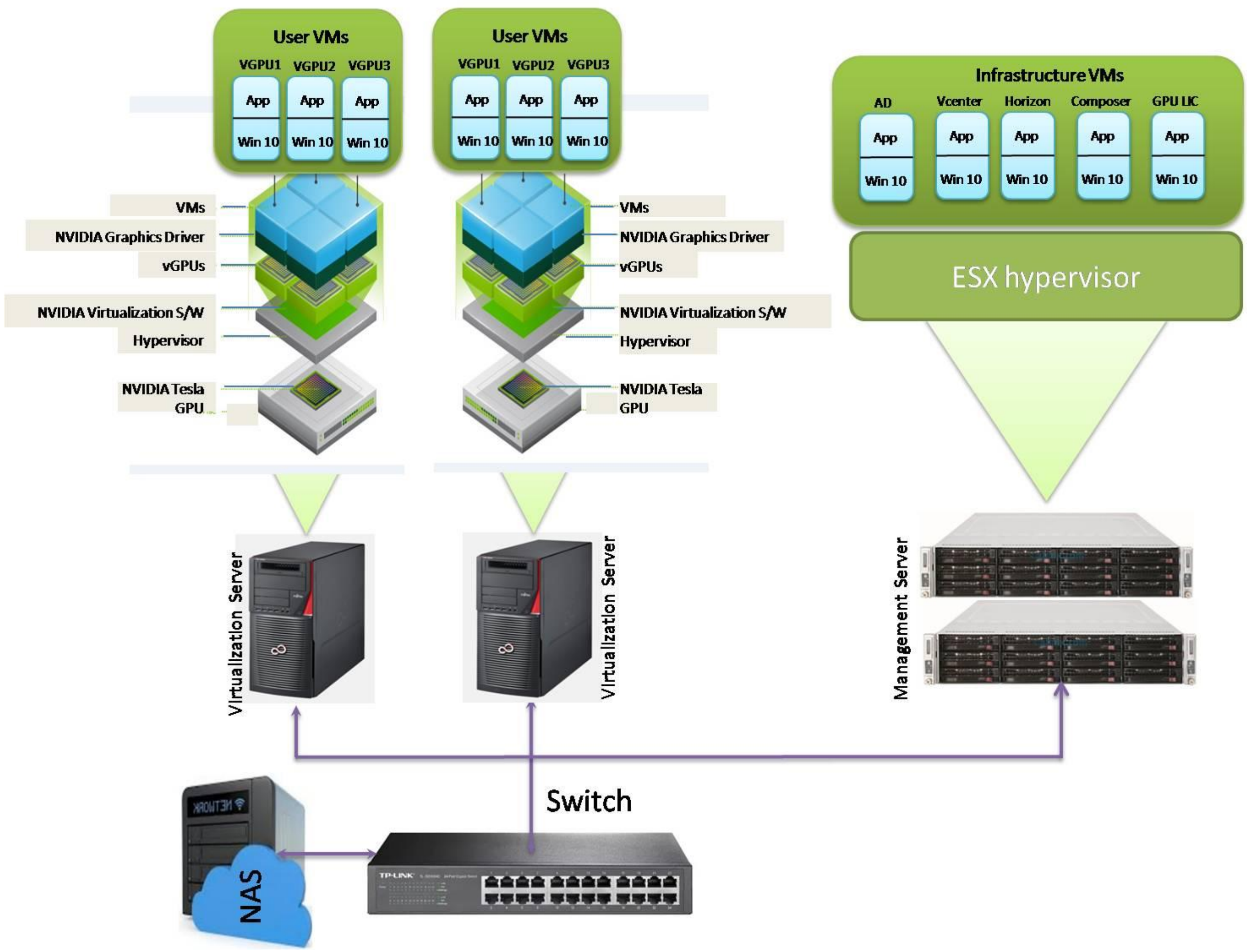

Figure 1: Virtualized Graphics Workstations using VMware

2.3 Configuration of user Virtual Machines

Six numbers of user VMs are provisioned on the two GPU enabled virtualization servers. Server1 hosts VGPU1 to VGPU3 and Server2 hosts VGPU4 to VGPU6. The detailed configuration of the user VMs are listed in Table 3. The entire user VMs are loaded with 64 bit Windows 10 operating system. Software packages such as AutoCAD, SolidWorks, Ansys and Comsol are loaded in the VMs based on user requirements.

S.No	VM Name	Host Name	IP Address	Configuration of the VM
1	VGPUWIN10-1	VGPU1	10.1.2.121	8 vCPU, 48GB RAM with nvidia_vgpu_8q profile
2	VGPUWIN10-2	VGPU2	10.1.2.122	6 vCPU, 40GB RAM with nvidia_vgpu_4q profile
3	VGPUWIN10-3	VGPU3	10.1.2.123	6 vCPU, 32 GB RAM with nvidia_vgpu_4q profile
4	VGPUWIN10-4	VGPU4	10.1.2.124	6 vCPU, 32 GB RAM with nvidia_vgpu_8q profile
5	VGPUWIN10-5	VGPU5	10.1.2.125	8 vCPU, 40 GB RAM with nvidia_vgpu_4q profile
6	VGPUWIN10-6	VGPU6	10.1.2.126	6 vCPU, 48 GB RAM with nvidia_vgpu_4q profile

Table 4: User Virtual Machine Configurations

3. Benchmark software Used

3.1. PassMark PerformanceTest

PassMark PerformanceTest is a fast, easy to use tool for PC speed testing and benchmarking. It allows objectively benchmarking a PC using a variety of different speed tests and comparing the results to other computers. Thirty two standard benchmark tests are available in PassMark PerformanceTest. They are further classified into five test suites as follows:

1. CPU tests: Mathematical operations, compression, encryption, physics

2. 2D graphics tests: Vectors, bitmaps, fonts, text, and GUI elements
3. 3D graphics tests: DirectX 9 to DirectX 12 in 4K resolution; DirectCompute & OpenCL
4. Disk tests: Reading, writing & seeking within disk files + IOPS
5. Memory tests: Memory access speeds and latency

3.2. SPEC ViewPerf Benchmark

The SPEC ViewPerf benchmark is the worldwide standard for measuring graphics performance based on professional applications. The benchmark measures the 3D graphics performance of systems running under OpenGL and Direct X application programming interfaces. The benchmark's workloads, called viewsets, represent graphics content and behavior from actual applications. Following are the workloads (viewsets) of the latest version of the benchmark, SPECviewperf 13:

A. 3dsmax-06 viewset

The 3dsmax-06 viewset was created from traces of the graphics workload generated by 3ds Max 2016 using the default Nitrous DX11 driver. In order to best approximate real-world use cases, several tests incorporate multiple viewsets on screen, each using a different rendering method. The styles of rendering in the viewset reflect those most commonly used in major markets, including realistic, shaded and wireframe.

B. Catia-05 viewset

The Catia-05 viewset was created from traces of the graphics workload generated by the CATIA V6 R2012 application from Dassault Systemes. Model sizes range from 5.1 to 21 million vertices. The viewset includes numerous rendering modes supported by the application such as wireframe, anti-aliasing, shaded, shaded with edges, depth of field, and ambient occlusion. The models include Race Cars, Airplanes, SUV Vehicles and Jet planes.

C. Creo-02 viewset

The Creo-02 viewset was created from traces of the graphics workload generated by the Creo 3 and Creo 4 applications from PTC. Model sizes range from 20 to 48 million vertices. The viewsets include numerous rendering modes supported by the application. The models include: Car in shaded mode, Motorcycle in hidden-line mode, four bombers in no-hidden-edge mode etc

D. Energy-02 Viewset

The energy-02 viewset is based on rendering techniques used by the open-source OpendTect seismic visualization application. Geophysical surveys generate image slices through the subsurface that are built into a 3D grid. Volume rendering provides a 2D projection of this 3D volumetric grid for further analysis and interpretation.

E. Maya -05 Viewset

The maya-05 viewset was created from traces of the graphics workload generated by the Maya 2017 application from Autodesk. The viewset includes numerous rendering modes supported by the application, including shaded mode, ambient occlusion, multi-sample antialiasing and transparency. The models include Toy store, Jungle escape, Ship splash etc..

F. Medical-02 Viewset

The medical-02 viewset uses the Tuvok rendering core of the ImageVis3D volume visualization program. It renders a 2D projection of a 3D volumetric grid. A typical 3D grid in this viewset is a group of 3D slices acquired by a scanner (such as CT or MRI). Two rendering modes are represented – slice-based rendering and ray-casting. There are four datasets in this viewset: a 4D heart dataset comprising multiple 3D volumes iterated over time, a stag beetle dataset, an MRI scan of a human head and a CT scan of human right upper thorax and arm .

G. Showcase-02 Viewset

The showcase-02 viewset was created from traces of Autodesk's Showcase 2013 application. The model used in the viewset contains 8 million vertices. The viewset features DX rendering. Rendering modes included in the viewset include shading, projected shadows, and self-shadows.

H. Siemens NX

The snx-03 viewset was created from traces of the graphics workload generated by the NX 8.0 application from Siemens PLM. Model sizes range from 7.15 to 8.45 million vertices. The viewset includes numerous rendering modes supported by the application, including wireframe, anti-aliasing, shaded, shaded with edges, and studio mode.

I. SolidWorks Viewset

The sw-04 viewset was created from traces of Dassault Systemes' SolidWorks 2013 SP1 application. Models used in the viewset range in size from 2.1 to 21 million vertices. The viewset includes numerous rendering modes supported by the application, including shaded mode, shaded with edges, ambient occlusion, shaders, and environment maps.

3.3. SPEC Workstation Benchmark

The SPEC workstation benchmark tests CPU, graphics, I/O and memory bandwidth based on real applications in the following categories: media and entertainment, financial services, product development, energy, life sciences, and general operations.

Tests within the benchmark are scalable, solve large problems, support multiple architectures, and are freely available. The latest version of the benchmark, SPECWorkstation 3, has more than 30 workloads containing nearly 140 tests. The workloads are divided by application categories that include media and entertainment (3D animation, rendering), product development (CAD/CAM/CAE), life sciences (medical, molecular), financial services, energy (oil and gas), general operations, and GPU compute.

Individual scores are generated for each test and a composite score for each category is calculated based on a reference machine, yielding a "bigger is better" result. The benchmark does not require the full application and associated licensing to be installed on the system under test, simplifying set-up, running and results reporting. Following are the major workloads in different categories of SPEC workstation 3 benchmark.

A. Media and Entertainment

A1. Blender: This workload uses the open-source Blender application to measure the performance of content-creation workflows.
A2. Handbrake: This workload is based on the open-source media encoder Handbrake. It takes a 4K mp4 file and transcodes it with an H.265 encoder at two different resolutions.

A3. LuxRender: LuxRender uses LuxMark, a benchmark based on the LuxCore physically based renderer, to render a chrome sphere resting on a grid of numbers in a beach scene.

A4. Maya : It was created from traces of the graphics workload generated by Maya 2017 application from Autodesk.

A5. 3ds Max : It was created from traces of the graphics workload generated by 3ds Max 2016 using the default Nitrous DX11 driver.

B. Product Development

B1. Rodinia (CFD): Rodinia CFD solver is an unstructured-grid, finite-volume solver for 3D Euler equations representing compressible flow.

B2. WPCcfd: This workload is based on the OpenFOAM open-source CFD solver.

B3. CalculiX: This workload is based on the open-source finite element program Calculix . It models the internal temperature of a jet engine turbine.

B4. Catia : It was created from traces of the graphics workload generated by the CATIA V6 R2012 application from Dassault Systémes.

B5. Creo: It was created from traces of the graphics workload generated by the Creo 3 and Creo 4 applications from PTC.

B6. NX: It was created from traces of the graphics workload generated by the NX 8.0 application from Siemens PLM.

B7. Solidworks: It was created from traces of Dassault Systémes' SolidWorks 2013 SP1 application.

B8. Showcase: It was created from traces of Autodesk's Showcase 2013 application.

C. Life Sciences

C1. LAMMPS: LAMMPS is a molecular dynamics simulator. This workload consists of five tests that simulate a variety of molecular properties, which is run in parallel using MPI.

C2. NAMD: NAMD is a scalable molecular dynamics simulator. The workload consists of three tests that simulate a variety of molecular interactions.

C3. This workload contains the following tests from Rodinia benchmark suite:

a) Heartwall: A medical imaging process used to track movements of a set of sample points in the image of a beating heart.

b) Lavamd: The code calculates particle potential and relocation due to mutual forces between particles within a large 3D space.

c) Hotspot: A thermal simulation tool to estimate processor temperature.

d) SRAD: Speckle Reducing Anisotropic Diffusion, an algorithm to remove speckles in an image without sacrificing features.

C4. Medical: It uses the Tuvok rendering core of the ImageVis3D volume visualization program to render a 2D projection of a 3D volumetric grid.

D. Financial Services

D1. Monte Carlo simulation or probability simulation

D2. Black-Scholes pricing model

D3. Binomial options pricing model

E. Energy (oil and gas)

E1. FFTW: This workload computes the discrete Fourier transform for 1D, 2D and 3D transforms. The 1D transform uses a 16MB vector, the 2D transform uses a 4Kx4K matrix, and the 3D transform uses a 256x256x256 matrix.

E2. Convolution: This workload computes a convolution with a random filter of 100x100 pixels on an image that is 20,000x20,000 pixels.

E3. SRMP: This workload addresses seismic data processing. It implements a Surface-Related Multiples Prediction (SRMP) algorithm to remove multiples from seismic data.

E4. Kirchhoff Migration: This workload uses a Kirchhoff equation form of the wave equation to calculate the back propagation of the seismic wave field.

E5. Poisson: This workload solves the Poisson equation using OpenMP for parallel execution.

E6. Energy: It is based on rendering techniques used by the open-source OpendTect seismic visualization application.

F. General Operations

F1. 7zip: 7zip program offers good scaling performance between processors to compress and extract a hierarchy of files.

F2. Python: This workload uses Python 3.6 to benchmark a variety of math operations, including those using the numpy and scipy math libraries, and the make charts and multithreaded matrix functionalities.

F3. Octave: This workload uses Octave, a programming language for scientific computing, to compute a variety of math operations.

G. Storage

The storage workload is based on storage transaction traces from a wide variety of professional applications engaged in real work. These are grouped according to market segments for scoring purposes.

H. GPU Compute

H1. LuxRender: LuxRender uses LuxMark, a benchmark based on the LuxCore physically based renderer, to render a chrome sphere resting on a grid of numbers in a beach scene.
H2. Caffe: Caffe is a deep-learning framework developed by Berkeley AI Research (BAIR).
H3. Folding@Home (FAH) is a distributed computing project for disease research that simulates protein folding, computational drug design, and other types of molecular dynamics.

4. Benchmark Results

4.1. Results of PassMark PerformanceTest 9

The PassMark PerformanceTest tool benchmarks CPU, Memory, Disk, 2D Graphics and 3D graphics performance of systems. PassMark PerformanceTest 9 was run on virtual machines (VM) with different configurations and a Fujitsu Celsius R940 physical workstation. The virtual machine configurations differ from each other in the number of virtual CPUs, virtual RAM and graphics frame buffer allocated to each VM. The scores obtained for different hardware resources and the corresponding system configurations are summarized in Table 4. Figure 2 gives a graphical representation of the results.

			PassMark performance test scores					
Sl. No	VM Profile / Workstation Name	Configuration	CPU Score	Memory Score	2D Graphics Score	3D graphics Score	Disk Score	Total Score
1	VM: Profile 1	8 vcpu, 48 GB vRAM, 8GB graphics memory	14920	2070	780	4325	8986	4973
2	VM: Profile 2	6 vcpu, 28 GB vRAM, 8GB graphics memory	11585	2194	783	4335	9167	4829

3	VM: Profile 3	8 vcpu, 48 GB vRAM, 4GB graphics memory	14948	2070	793	4344	9405	5023
4	VM: Profile 4	6vcpu, 28 GB vRAM, 4GB graphics memory	11420	2203	792	4324	8980	4833
5	Fujitsu Celsius R940 Workstation	2* Intel Xeon CPU E5-2643 v4, 128 GB RAM, NVIDIA Quadro M4000 (8 GB) graphics card	21694	2262	723	6860	9645	5419

Table 5: Results of PassMark PerformanceTest

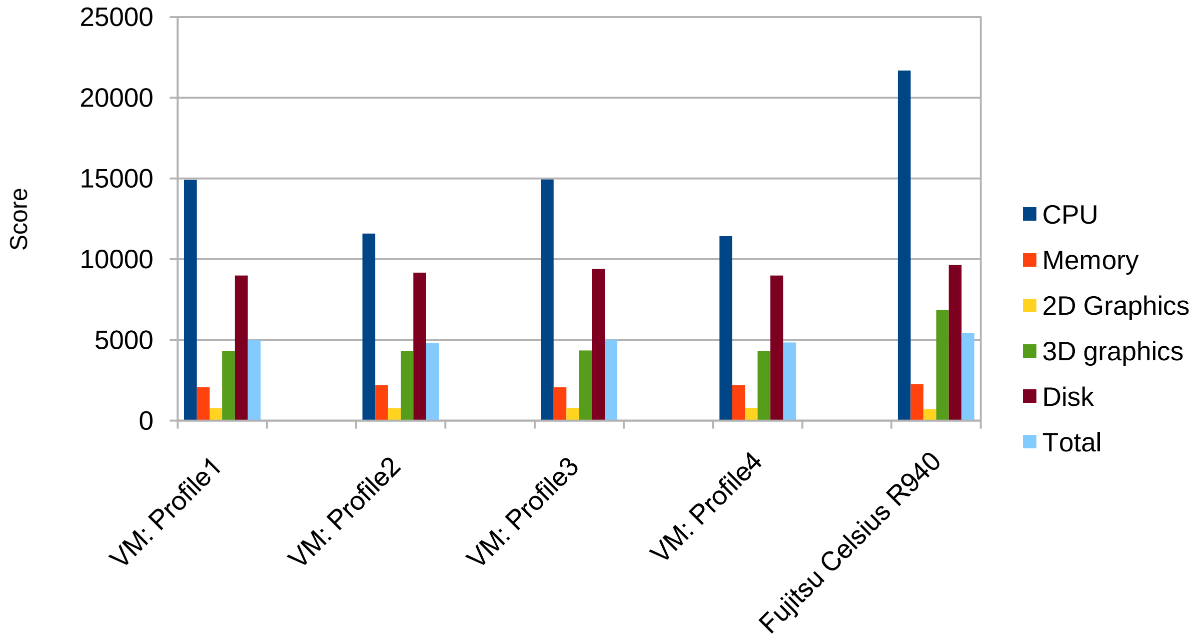

Figure 2: Results of PassMark Performance Test

It is observed that the CPU score is much higher for physical workstation, owing to the higher number of CPU Cores (24 logical cores after hyper threading). Also, among virtual machines, the CPU scores are higher for Profile1 and Profile3, where the number of virtual CPUs is higher than that in Profile2 and Profile4. Scores for memory, disk and 2D graphics tests are comparable with that of the physical workstation for all virtual machines. The 3D graphics test score is higher for physical workstation. It is also noticed that the virtual machines allocated with 4GB graphics memory (Profile3 and Profile4) have more or less same test scores as those allocated with 8GB graphics memory (Profile1 and Profile2).

4.2. Results of SPEC ViewPerf13

SPEC ViewPerf13 benchmark was run on four virtual machines with different configurations and a Fujitsu Celsius R940 physical workstation. The virtual machine configurations differ from each other in the graphics frame buffer allocated to each VM. The results obtained by running the tool and the system configurations are summarized in Table 5. A graphical representation of the results is depicted in Figure 3.

Viewsets	**SPEC ViewPerf13 Scores**				
	Fujitsu Celsius R940 2* Intel Xeon CPU E5-2643v4, 128 GB RAM, NVIDIA Quadro M4000 (8 GB) graphics card	***VM: Profile1*** 8 vCPU, 48 GB vRAM, 8GB graphics memory	***VM: Profile2*** 8 vCPU, 48 GB vRAM, 4GB graphics memory	***VM: Profile3*** 8 vCPU, 48 GB vRAM, 2GB graphics memory	***VM: Profile4*** 8 vCPU, 48 GB vRAM, 1GB graphics memory
3dsmax-06	76.43	18.97	18.98	16.01	9.32
catia-05	124.66	62.36	62.26	63.75	58.62
creo-02	78.98	52.96	51.95	32.62	4.66
energy-02	6.91	8.02	8.01	0.96	0.96
maya-05	157.46	59.38	59.55	60.47	13.4
medical-02	16.94	11.84	11.68	12.02	12.28
showcase-02	42.43	33.42	33.35	33.36	16.47
snx-03	134.38	64.64	64.65	64.61	64.52
sw-04	103.87	44.86	44.09	45.79	46.17

Table 6: Results of SPEC ViewPerf Benchmark

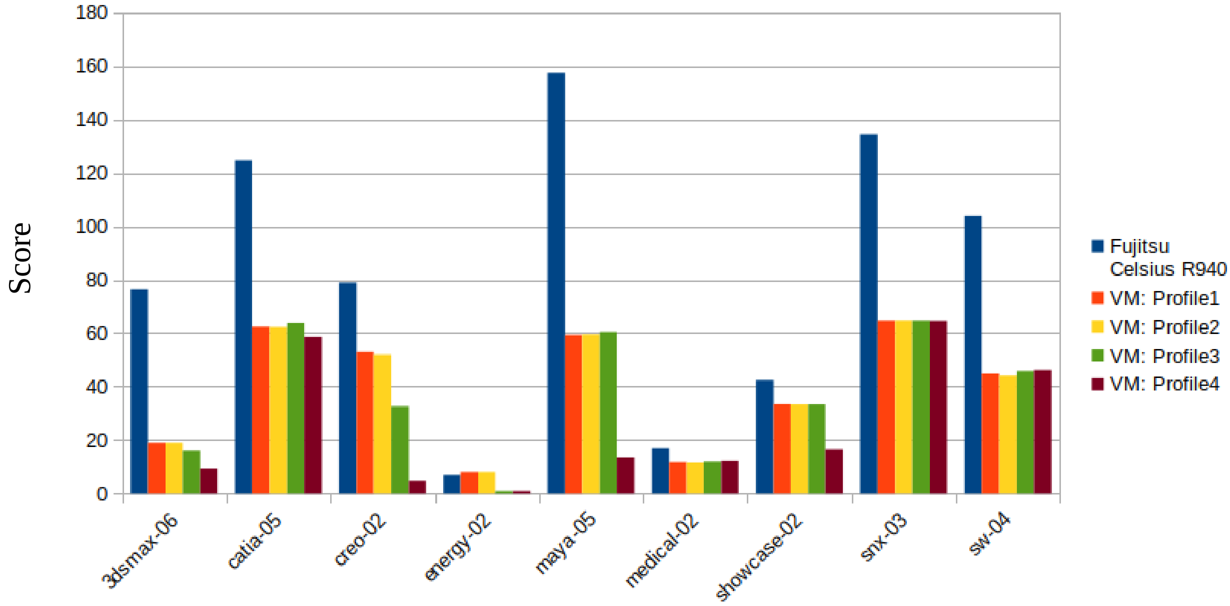

Figure 3: Results of SPEC ViewPerf Benchmark

It is observed that SPEC scores for all viewsets are much higher for the physical workstation. Tests in the viewsets produce a frame rate, which is computed as the average Frames Per Second (FPS), or the total number of frames rendered divided by the time in seconds to render those frames. These FPS values are then used to compute the composite score using the weights for each test. The frames rendered per second were much higher for the physical workstation for all tests. It is also noticed that the virtual machine allocated with 4GB graphics memory (Profile2) has more or less same test scores as that allocated with 8GB graphics memory (Profile1). But those allocated with 2GB and 1GB graphics memory (Profile3 and Profile4) have much lesser scores for many viewsets. This leads to the observation that a minimum graphics frame buffer of 4GB is required by virtual machines for seamless rendering of all modelling applications.

4.3. Results of SPEC Workstation 3

The SPEC Workstation3 benchmark was run on a virtual machine and a Fujitsu Celsius R940 workstation. Configurations of the machines are as follows:

Virtual machine: 8 virtual CPUs, 48 GB virtual memory (vRAM) and 8GB graphics frame buffer (NVIDIA-GRID-8q profile).

Fujitsu Celsius R940: 2* Intel Xeon CPU E5-2643 v4, 128 GB RAM, NVIDIA Quadro M4000 (8 GB) graphics card

The SPEC scores of various categories of tests are summarized in Table 6 and Figure 4. The individual scores of different subsystems under CPU, Graphics, Storage and GPU Compute are summarized in Table 7 and Figure 5.

	SPEC Workstation scores	
Category	**Virtual Machine**	**Fujitsu Celsius R940**
Media & Entertainment (Total)	0	1
Media & Entertainment(CPU)	1.25	2.51
Media & Entertainment (Graphics)	0.75	1.55
Media & Entertainment (Storage)	0.06	0.04
Product Development (Total)	0.54	1
Product Development (CPU)	1.23	2.75
Product Development (Graphics)	0.76	1.15
Product Development (Storage)	0.03	0.04
Life Sciences (Total)	1.04	1.08
Life Sciences (CPU)	1.2	1.62
Life Sciences (Graphics)	1.65	1.12
Life Sciences (Storage)	0.44	0.04
Energy (Total)	0.5	0.8
Energy (CPU)	0.59	1.51
Energy (Graphics)	2.18	1.42
Energy (storage)	0.01	0.02
General Operations (Total)	0.44	0.48
General Operations (CPU)	0.81	1.11
General Operations (Storage)	0.07	0.04
GPU Compute (GPU)	1.63	1.16

Table 7: SPEC Workstation Scores – Category wise

	SPEC Workstation scores	
Subsystem	**Virtual Machine**	**Fujitsu Celsius R940**
CPU		
7zip (2 subtests)	0.61	0.81
Blender (5 subtests)	0.99	1.61
CalculiX (1 subtests)	0.93	1.8
Convolution (1 subtests)	1.26	3.73
FFTW (3 subtests)	2.2	4.74
handbrake (2 subtests)	1.1	2.04
Kirchhoff (1 subtests)	1.35	2.9
lammps (5 subtests)	1.35	1.61
LuxRender (1 subtests)	1.78	4.8
octave (2 subtests)	1.02	1.22
WPCcfd (1 subtests)	2.1	4.95
python36 (3 subtests)	0.84	1.38
rodiniaLifeSci (4 subtests)	1.24	3.21
rodiniaCFD (1 subtests)	0.95	2.33
srmp (1 subtests)	0.03	0.09
Storage		
WPCStorage (60 subtests)	0.07	0.04
Graphics		
catia-05 (14 subtests)	0.7	1.34
creo-02 (16 subtests)	0.56	0.73
energy-02 (6 subtests)	2.18	1.42
maya-05 (10 subtests)	0.75	1.9
medical-02 (8 subtests)	1.65	1.12
snx-03 (10 subtests)	0.57	1.17
sw-04 (11 subtests)	0.53	1.07
showcase-02 (4 subtests)	2.13	1.64
GPU OpenCL	1.57	1.11
LuxRender (1 subtests)	1.88	1.48
caffe (3 subtests)	1.37	0.98
FAH (2 subtests)	1.69	1.09

Table 8: SPEC Workstation Score - Subsystem wise

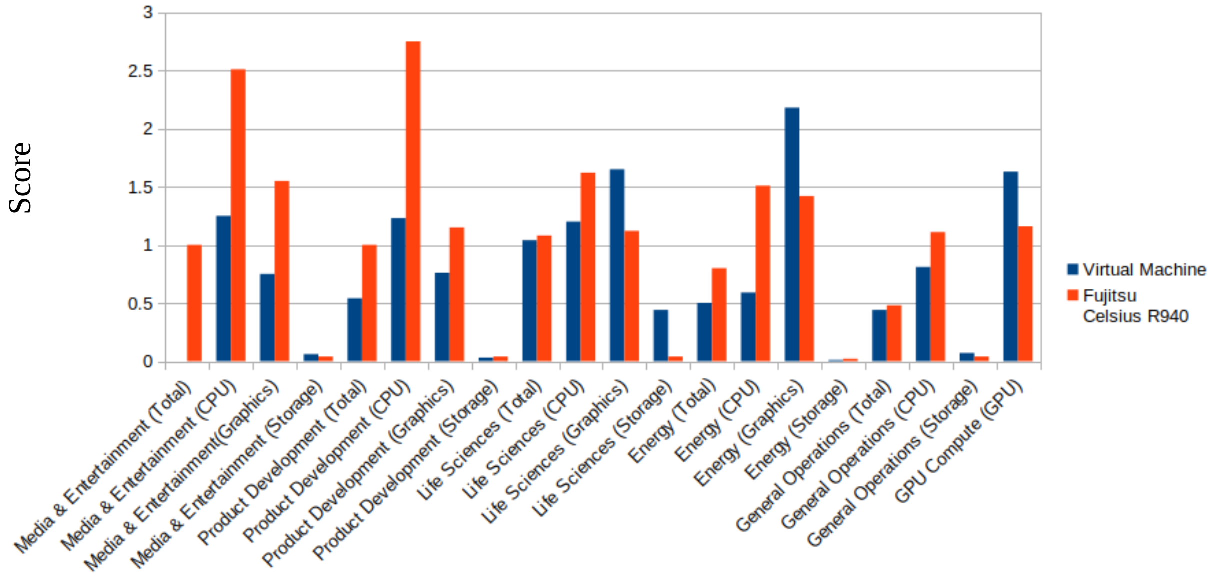

Figure 4: SPEC Workstation Benchmark Scores-Category wise

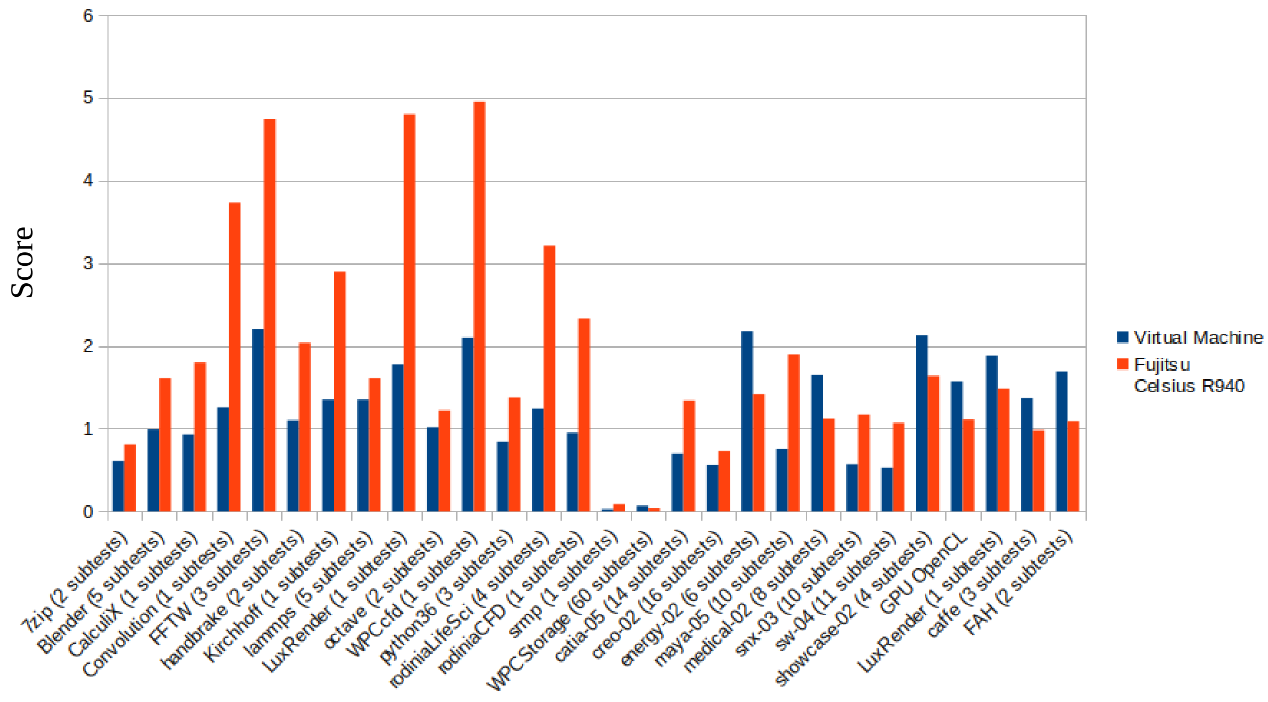

Figure 5: SPEC Workstation Score- Subsystem wise

It is observed that the physical workstation has higher scores in most categories, as it has more number of physical CPUs, memory and dedicated graphics card. Yet, virtual machine is able to run all the benchmark workloads and also outperforms the physical workstation in some of the graphics subsystem tests.

5. Conclusions

A Proof of Concept for Virtual Graphics Workstations was successfully installed, configured and tested at the setup made in Computer Division, IGCAR. Three popular benchmark tools, namely, PassMark PerformanceTest, SPEC Workstation and SPEC Viewperf were installed and tested on virtual machines with different configurations as well as on physical workstation. It was found that the virtual machines were able to run all the benchmark workloads successfully. The scores were comparable to those of the physical workstation for almost all the workloads.

It was concluded that a VM configured with the sufficient amount of resources can successfully run most of the workloads that typically a physical workstation is handling. Thus, VGWs can provide high definition graphics rendering capabilities and computing power for scientific and engineering applications, with the benefits of centralized control, enhanced security and access from anywhere.