Comparing the MUI, VirtualCenter, and vmkusage

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Introduction

Thousands of enterprise customers have deployed VMware® virtual infrastructure in their production environments. Monitoring the health and performance of the virtual machines and physical platforms that host VMware ESX Server is vital to the operations of these customers' data centers.

VMware provides a number of tools for monitoring the performance of virtual machines. These tools also provide information about the performance of the physical machine that is hosting a particular virtual machine or set of virtual machines.

For example, performance information is available through the management user interface (MUI)[1], VMware VirtualCenter[2], and `vmkusage`[3]. The MUI allows a user to view the performance of virtual machines on a given physical host, and to see some simple performance data for that host. The vmkusage tool also provides information for a given physical host and its virtual machines. VirtualCenter allows a user to view information for entire groups of hosts and their associated virtual machines.

Although these tools use similar performance metrics across hosts and virtual machines, and each collects raw data generated by ESX Server machines from the same source in order to compute these performance metrics, the output that each tool displays can differ for several reasons, including:

- Differences in sampling frequency.

- Differences in data update frequency.

- Differences in data normalization.

- Differences in frequency of display updates.

This paper compares these tools and highlights where the values of the output can differ. This paper describes only CPU and memory statistics, although the tools behave similarly for other statistics as well (such as disk performance or network performance).

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[1] For more information about ESX Server MUI, refer to http://www.vmware.com/support/esx25/doc/esx25admin_using_statusmon_running.html#1035629

[2] For more information about VirtualCenter performance monitoring, refer to http://www.vmware.com/support/vc12/doc/c17perfchartdata.html#1067182

[3] For more information about vmkusage, refer to VMware Knowledge Base article #1078, at http://www.vmware.com/support/kb/

Sampling Frequency

Each ESX Server machine collects performance information for all the virtual machines running on it, as well as performance information for the host. The ESX Service Console logs current performance data to the root partition under `/proc/<node>` (also called proc nodes). Proc nodes are the source of raw information for all three tools. The tools sample these proc nodes at different frequencies:

- The MUI samples the proc nodes every 20 seconds.

- VirtualCenter samples the proc nodes every minute.

- The `vmkusage` tool samples proc nodes every minute.

Data Presentation and Update Frequency

Each tool displays its results over a different time span. In addition, the data for the graphs are updated at different intervals. Note that while the data for the graphs may be updated, the display itself may not be updated unless the user manually refreshes it.

MUI Display

The MUI displays results averaged over the last five minutes: the 20-second samples from the last five minutes are collected and averaged. Unlike the other tools, which display historical data over daily, weekly or monthly time spans, the MUI shows information only at a five-minute granularity.

VirtualCenter Display

VirtualCenter shows two types of statistics:

1. Statistics over the last minute (i.e., the most recent sample).
2. Historical statistics, where each data point is the average of one-minute samplings over a longer interval that depends on the setting selected for the historical statistics display.

For historical statistics, VirtualCenter displays information from the time the VirtualCenter server was started until the present. You can use the **Past Day, Past Week, Past Month**, and **Past Year** options to show data averaged over different intervals (see Table 1 below):

Configuration Option	Display Period	Averaging Period	Sampling Period	Number of Data Points
Past Day	Day	5 minutes	1 minute	288
Past Week	Week	1 hour	1 minute	168
Past Month	Month	6 hours	1 minute	120
Past Year	Year	24 hours	1 minute	365

Table 1: Historical Statistics Displayed By VirtualCenter

The vmkusage Tool

The `vmkusage` tool samples every minute, and updates its data every five minutes with an average of the one-minute statistics over the given five-minute interval. The start time on the graphs corresponds to the time that the `vmkusage` data collection daemon is started on the host, and updates occur every five minutes thereafter.

The **Recent, Daily, Weekly**, and **Monthly** historical statistics correspond to intervals that are slightly different from those in VirtualCenter (see Table 2 below):

Configuration Option	Display Period	Averaging Period	Sampling Period	Number of Data Points
Recent	7 hours	1 minute	1 minute	420
Daily	36 hours	5 minutes	1 minute	432
Weekly	8 days	30 minutes	1 minute	384
Monthly	32 days	120 minutes	1 minute	384

Table 2: Historical Statistics Displayed by vmkusage

Normalization

Some of the pages present information as an absolute value. For example, on the VirtualCenter Virtual Machine Memory Utilization page, memory utilization is shown in megabytes (MBs). Other pages present utilization as a percentage of the available resource. In the latter case, the utilization number depends on the chosen normalization convention.

CPU Utilization

All of the tools express CPU utilization on a scale from 0 to 100%. If a host has one CPU, then if the CPU is saturated, the host CPU shows a utilization of 100%. If a host has two or more CPUs, then the CPU utilization displayed should be 100% only if all CPUs are saturated. For example, if each of the two CPUs is capable of performing 1000 MIPS, than the host is utilized by 100% when it is executing 2000 MIPS. Similarly, if a virtual machine has two or more CPUs, then the CPU utilization for the virtual machine reaches 100% only if all VCPUs are saturated. If a host has two CPUs, and one is saturated (runs 1000 MIPS) while the other is idle, then the average CPU utilization is 50%, which is calculated as follows: the average CPU utilization is (1000MIPS + 0)/2000MIPS, or 50%.

The main differences between the tools arise when the number of VCPUs for a virtual machine does not match the number of CPUs on the host. For example, a single-CPU virtual machine can consume at most 100% of the single physical CPU on which it is executed (assuming the virtual machine is locked to that CPU). Thus, if this virtual machine runs on a dual-CPU host, it can take advantage of at most 1000MIPS of the 2000MIPS total that is available in the system. If the CPU utilization of the virtual machine is displayed as a percentage of the maximum CPU *that is available to the virtual machine*, then the utilization ranges from 0% to 100%: However, if the CPU utilization is expressed as a percentage of the total available CPU *in the system*, then the utilization of the virtual machine ranges from 0% to 50% which reflects the fact that while the virtual machine is fully utilized, that the system still has CPU available for other work from other virtual machines.

When the CPU utilization of a host or virtual machine is expressed as a percentage of the total host CPU available in the system, it is said to be *normalized* by the total host CPU utiliza-tion. Unless a host's CPU utilization is explicitly broken down on a per-CPU basis (i.e., utilization of CPU 0, utilization of CPU 1, etc.), then the CPU utilization of a host is always normalized by the total host CPU utilization. In contrast, when the CPU utiliza-tion of a virtual machine is expressed as a percentage of the total CPU available to that virtual machine, then it is said to be normalized by the amount of *virtual* CPU available.

Consider the following example. Suppose a process in a single-CPU virtual machine executes for two seconds on a single CPU of a dual-CPU system, and the host machine has been up for four seconds. The total host CPU available is eight seconds (4 seconds per CPU * 2 CPUs), while a single CPU has four seconds available. Expressed as a percentage of the total host CPU avail-able, CPU utilization is 25% (2 seconds/8 seconds); expressed as a percentage of CPU available to the virtual machine, it is 50% (2 seconds/4 seconds).

In subsequent sections the CPU utilization may be expressed as, for example, 20% of two CPUs. Stating utilization in this manner is equivalent to saying that the host or virtual machine had two CPUs available to it, and that 20% of the total available CPU was utilized. In other words, the system was performing 400MIPS out of its 2000 MIPS capacity.

Each tool displays CPU utilization in a different way:

- The MUI normalizes both host and virtual machine CPU utilization by the total host CPU utilization.

- VirtualCenter normalizes host CPU utilization by the total host CPU utilization.

- VirtualCenter normalizes the CPU utilization of each virtual machine by the total virtual CPU available to that virtual machine.

- The `vmkusage` tool breaks host CPU utilization into CPU0 and CPU1, and virtual machine CPU into VCPU0 and VCPU1. VCPU0 represents the fraction of time VCPU0 ran on any of the physical host's CPUs. This distinction is relevant, because if you have multiple physical CPUs, virtual CPUs (VCPUs) may run on different physical CPUs at different times.

Memory Usage

For this discussion, memory normalization is defined as follows. If memory used by a virtual machine or host is shown as a percentage of the total amount of the host memory, then the memory is normalized to the host memory. If memory used by a virtual machine is shown as a percentage of the total amount of memory that the virtual machine has, then it is normalized to the virtual machine memory.

For example, suppose there is a virtual machine with 256MB of memory on an ESX Server host that contains 2GB of memory, and that the virtual machine actively uses 64MB. The memory being used is 25% of the memory allocated to the virtual machine, and 6.25% of the total memory in the system. The former is normalization based on the virtual machine memory, and the latter is normalization based on the total amount of host memory.

Each of the tools displays memory usage data in a different way:

- The MUI displays the total amount of host memory in use. For each virtual machine, it shows the absolute amount of memory in use by that virtual machine. Memory usage is not normalized in this case.

- On the host's Summary page, VirtualCenter normalizes per-host memory usage according to the total amount of memory on the host.

- On the host's Historical Data page, VirtualCenter displays the absolute amount of memory in use by a host.

- On the virtual machine's Summary page, VirtualCenter normalizes virtual machine memory usage by the size of the virtual machine's memory.

- On the virtual machine's Historical Data page, VirtualCenter displays the amount of memory in use by a virtual machine. The range is from 0 to the size of the virtual machine's memory.

- The `vmkusage` tool does not normalize memory usage. It displays the total amount of memory in use.

Display Updates

The graphs that appear onscreen are refreshed periodically with updated data. Some tools automatically redisplay the updated graphs, while others wait for the user to initiate a redisplay of the updated charts:

- The MUI updates its data every 20 seconds, and refreshes the display automatically every 90 seconds.

- VirtualCenter updates its per-minute information once per minute, and historical information once every five minutes. The VirtualCenter display is updated either when the CPU or memory information changes (such as when a virtual machine is powered on or its CPU utilization changes), or when the user clicks on a different tab and then returns to the Performance tab. The exception to this is when a long-running operation is in progress (since the CPU utilization value for the relevant virtual machine or host in this case is constantly changing and therefore would require constant updates).

- The vmkusage tool updates its data every five minutes. The display is refreshed only when the user manually reloads the Web page.

Summary of Statistics

Table 3 summarizes the various sampling rates and other differences between the MUI, VirtualCenter and `vmkusage.`

Category	Description	MUI	VirtualCenter	vmkusage
CPU	System CPU normalization	Total host CPU	Total host CPU	CPU % is split into CPU0/CPU1
	VM CPU normalization	Total host CPU	Total CPU for that VM	CPU % is split into VCPU0/VCPU1. Each is normalized to 100%
	Sampling rate	Once per 20 seconds	Once per minute	Once per minute
	CPU % displayed	Average of samples over last five minutes	Minute-by-minute updates	Data updates every five minutes, with the average of the samples over that five-minute span
	VM CPU % displayed	Average of samples over last five minutes	Minute-by-minute updates	Data updates every five minutes, with the average of the samples over that five-minute span
	Historical data	None	Data is updated every five minutes, with the average of the five one-minute samples over that five-minute span (assumes **Past Day** option is selected)	All charts are historical data charts, and are updated as described above (assumes **Daily** option is selected)
	Display refresh	Every 90 seconds	User-initiated, or when a change event occurs	When Web page is reloaded by user
Memory	System memory normalization	Not normalized; shows total host memory active	Total host memory	Not normalized; shows total host memory active
	VM memory normalization	Not normalized; shows active memory used out of the total amount of memory a VM is allocated	Total memory for that VM	Not normalized; shows active memory used out of the total amount of memory a VM is allocated.
	Memory information displayed	Average of samples over last five minutes	Minute-by-minute updates	Data updates every five minutes with the average of the samples over that five-minute span
	VM memory information displayed	Average of samples over last five minutes	Minute-by-minute updates	Data updates every five minutes, with the average of the samples over that five-minute span
	Historical data	None	Data is updated every five minutes, with the average of the 5 one-minute samples over that five-minute span (assumes **Past Day** option is selected)	All charts are historical data charts (assumes **Daily** option is selected)
	Display refresh	Every 90 seconds	User-initiated, or when a change event occurs	When Web page is reloaded by user

Table 3: Differences in Statistics Between the MUI, VirtualCenter and vmkusage. (Virtual machine is abbreviated "VM.").

Because of all details mentioned above, the three sets of statistics might not agree at any given time. For example, a benchmark that consumes 50% of a virtual machine's CPU on a dual-CPU ESX Server system over an hour shows approximately 25% CPU utilization in the MUI, 50% in VirtualCenter and 50% for CPU0/VCPU0 in `vmkusage`.

Example

This section shows data from an existing setup and shows examples of the statistics gathered from each tool. The potential differences between the statistics displayed by the various tools are also highlighted and explained.

The experimental setup consists of a single dual-CPU ESX Server host with 2GB of memory. It has a number of virtual machines, but we consider only six for this discussion. Table 4 summarizes the properties of these virtual machines.

Virtual Machine Name	Virtual CPUs	Memory
Win2K Perf on Namib	1	256MB
ravi-tmp-test-2-namib.eng.vmware.com	1	40MB
ravi-tmp-test-4-namib.eng.vmware.com	1	40MB
ravi-tmp-test-5-namib.eng.vmware.com	1	40MB
Win2K server on Namib	1	256MB
Ravi_WS2003ENT_SMP	2	256MB

Table 4: Characteristics of Virtual Machines in Sample Setup

In the case of the MUI and `vmkusage`, the client connects directly to the ESX Server host via a Web browser. For VirtualCenter, the client connects to the VirtualCenter server through the VirtualCenter client application. The VirtualCenter server connects to the ESX Server host on behalf of the client and obtains the relevant statistical data.

The following subsections show performance charts from VirtualCenter, the MUI and `vmkusage.`

Example Using VirtualCenter

VirtualCenter presents numerous graphs that comprise short-term and historical data for hosts and virtual machines. We describe each of these below.

The Host Summary Page

The VirtualCenter host's Summary page is shown in **Figure 1**. The CPU utilization numbers are shown normalized to the total host CPU available. The virtual machines consume 73% of the two CPUs (i.e., 146% out of 200%), and 5% of the memory (i.e., around 100MB of 2GB). The total CPU usage is about 79%, and the total memory actively being used is about 6% of 2GB. If a virtual machine has 256MB of memory but is actively using only 4MB, then the 4MB is counted in this percentage. The **Memory Available to New VMs** is the amount of memory that can be used to power on and run new virtual machines. This value includes swap.
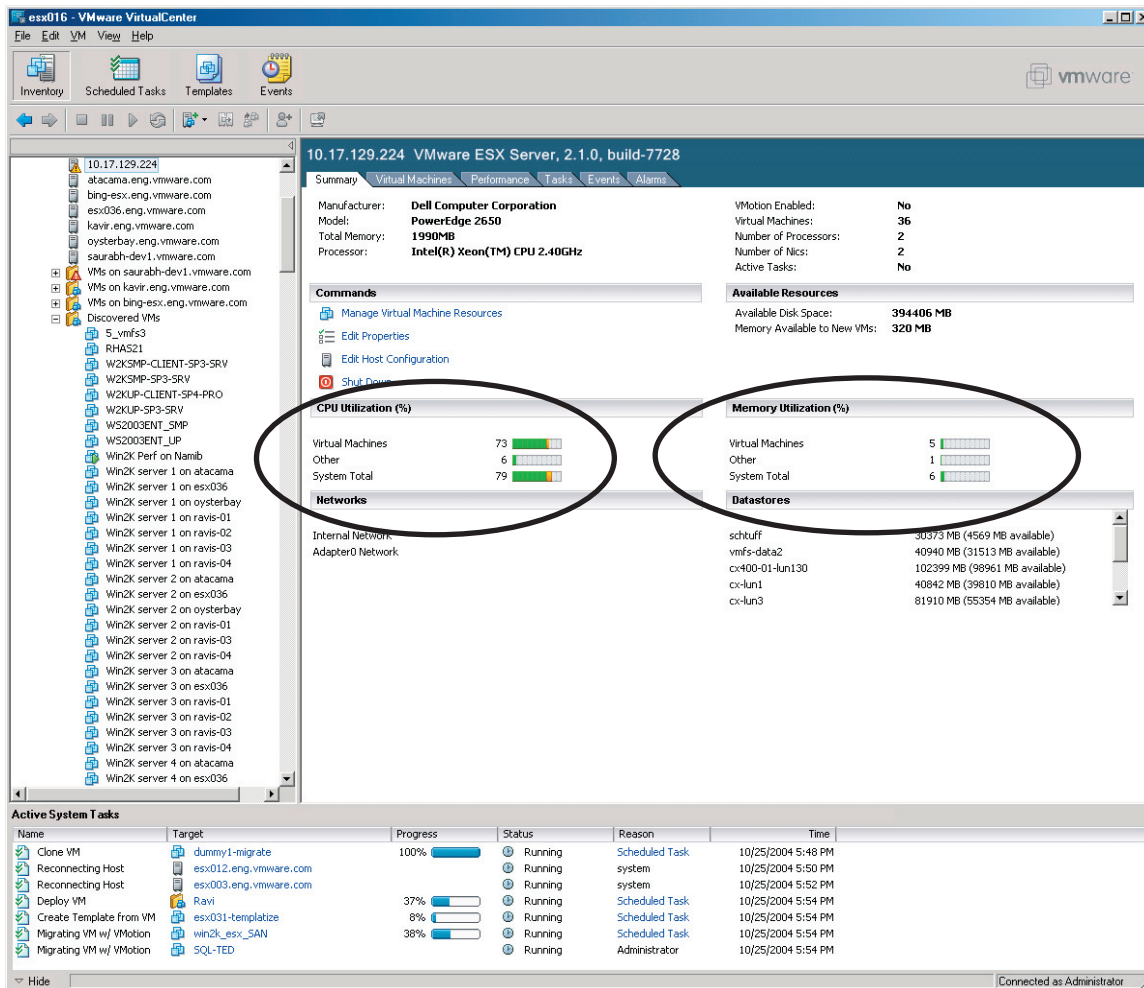
Figure 1: VirtualCenter Host Summary Page

The Virtual Machine Summary Page

The VirtualCenter virtual machine's Summary page is shown in **Figure 2.** These CPU numbers are normalized to the amount of CPU available to the virtual machine. You can use this data to verify information from the host's Summary page:

• Win2K Perf on Namib takes 44% of a single CPU and 10% of 256MB.

• ravi-tmp-test-2-namib.eng.vmware.com takes 6% of a single CPU and 14% of 40MB.

• ravi-tmp-test-4-namib.eng.vmware.com takes 6% of a single CPU and 17% of 40MB.

• ravi-tmp-test-5-namib.eng.vmware.com takes 6% of a single CPU and 15 % of 40MB.

• Win2K server on Namib takes 5% of a single CPU and 17% of 256MB.

• Ravi_WS2003ENT_SMP takes 42% of 2 CPUs and 6% of 256MB.
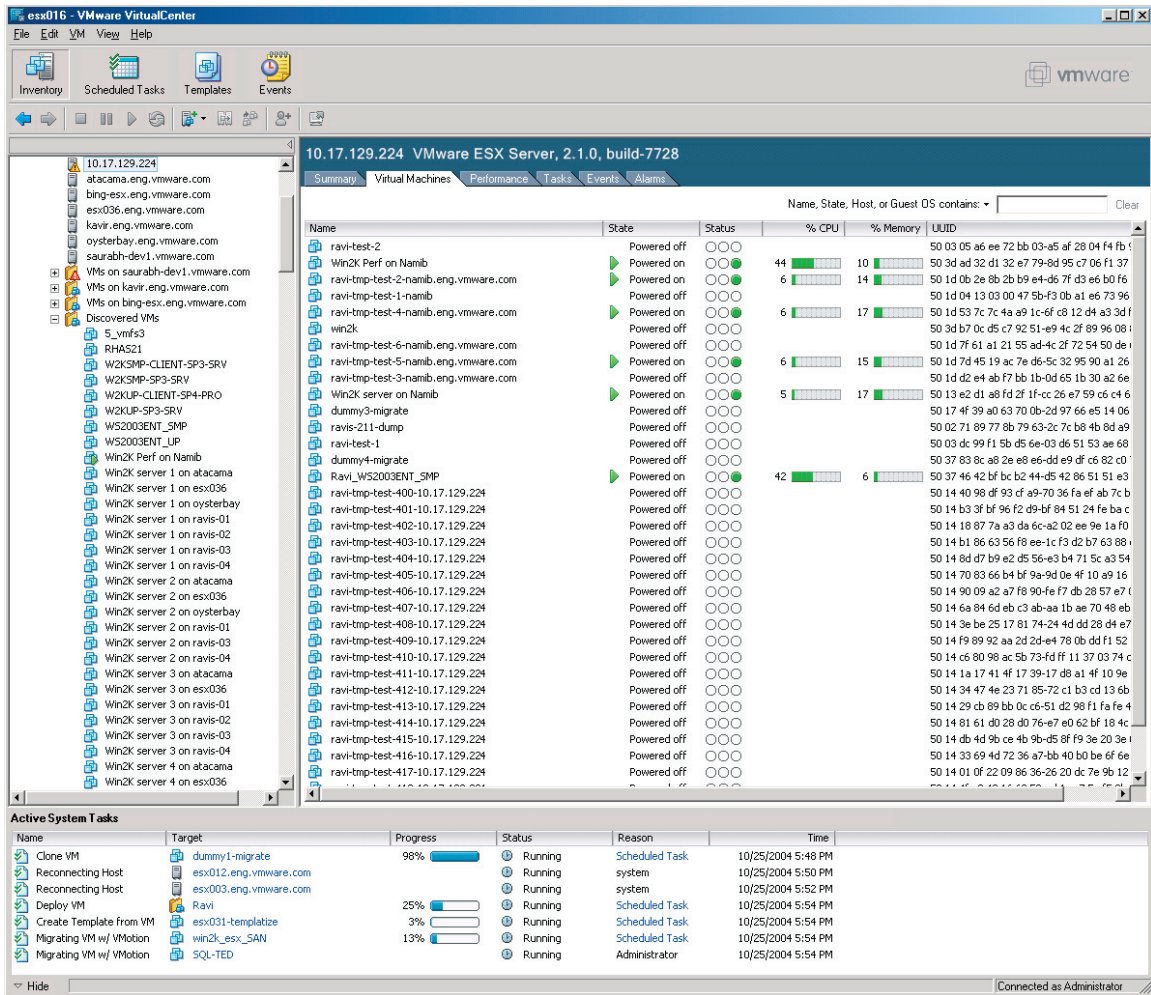
Figure 2: VirtualCenter Virtual Machine Summary Page

Add up the CPU percentages to get the value on the host's Summary page. Note that 44% of a single CPU is 22% of a dual-CPU: (44/2) + (6/2) + (6/2) + (6/2) + (5/2) + 42 = 75.5% (which is approximately the value on the host's Summary page—rounding numbers per virtual machine accounts for the difference).

You can also add up the memory percentages to get the value on the host's Summary page:

(10%)256 + (14%)40 + (17%)40 + (15%)40 + (17%)256 + (6%)256 = 103MB/2GB = 5%.

Host Historical Data for the CPU

Figure 3 shows historical data over the past day for the host CPUs. Note that near the end of the interval, when snapshots were taken, the total utilization is around 80% of two CPUs (as shown on the host's Summary page).
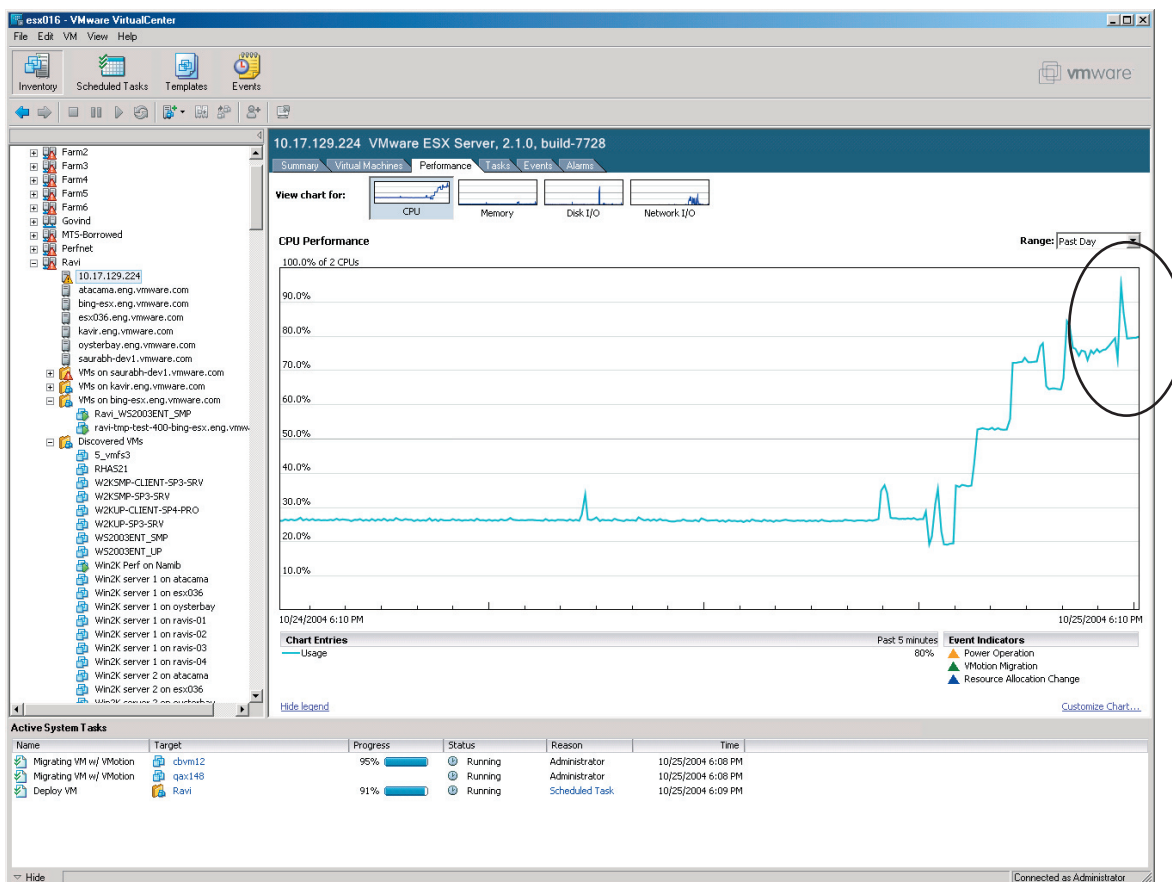
Figure 3: VirtualCenter Historical Data for Host CPU Utilization

Host Historical Data for Memory

Figure 4 shows historical data over the past day for the host memory. Note that near the end of the interval, when snapshots were taken, the total utilization is around 100MB, or 5% of 2GB (as shown on the host's Summary page).
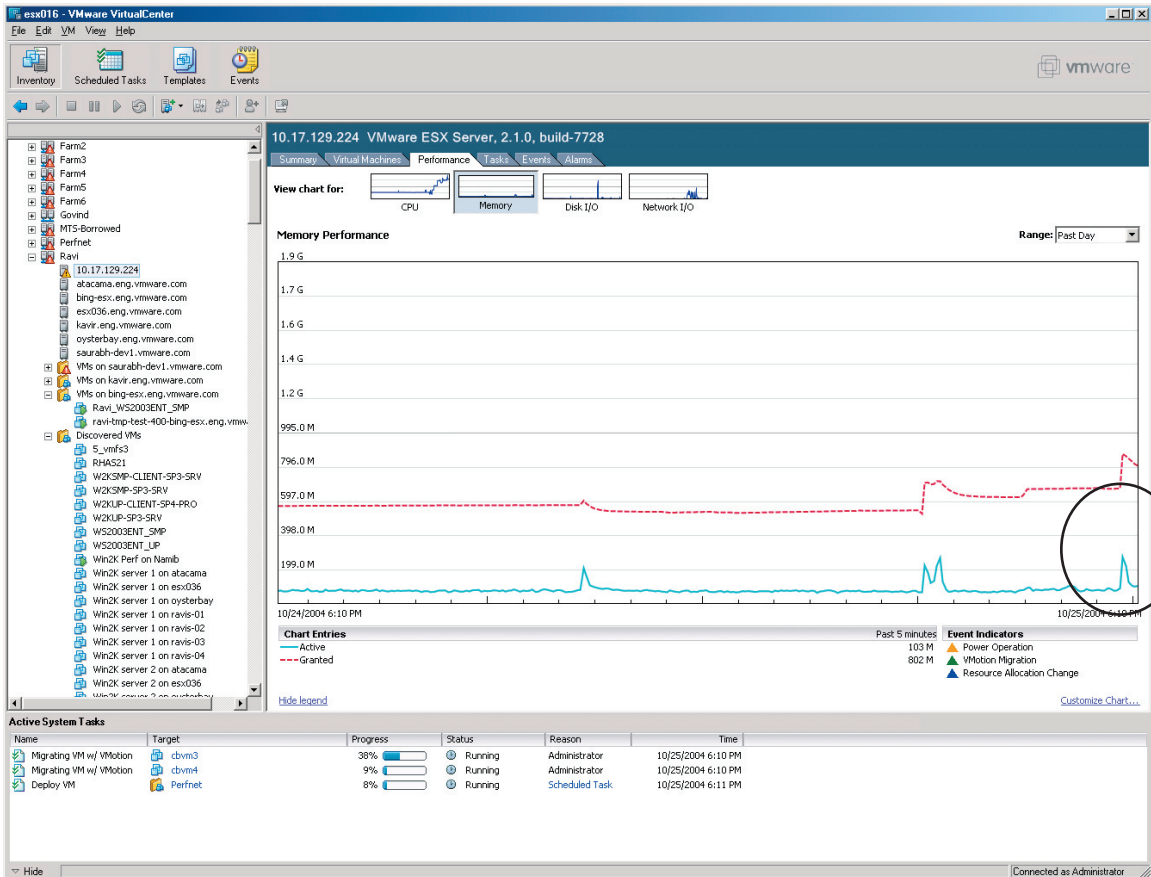
Figure 4: VirtualCenter Historical Data for Host Memory Usage

Virtual Machine Historical Data for the CPU

Figure 5 shows data over the past day for the CPUs of the
Ravi_WS2003ENT_SMP dual-CPU virtual machine. Note that
near the end of the interval, when snapshots were taken, the
total utilization is around 40% of two CPUs. This matches the
value of 42% on the virtual machine's Summary page.
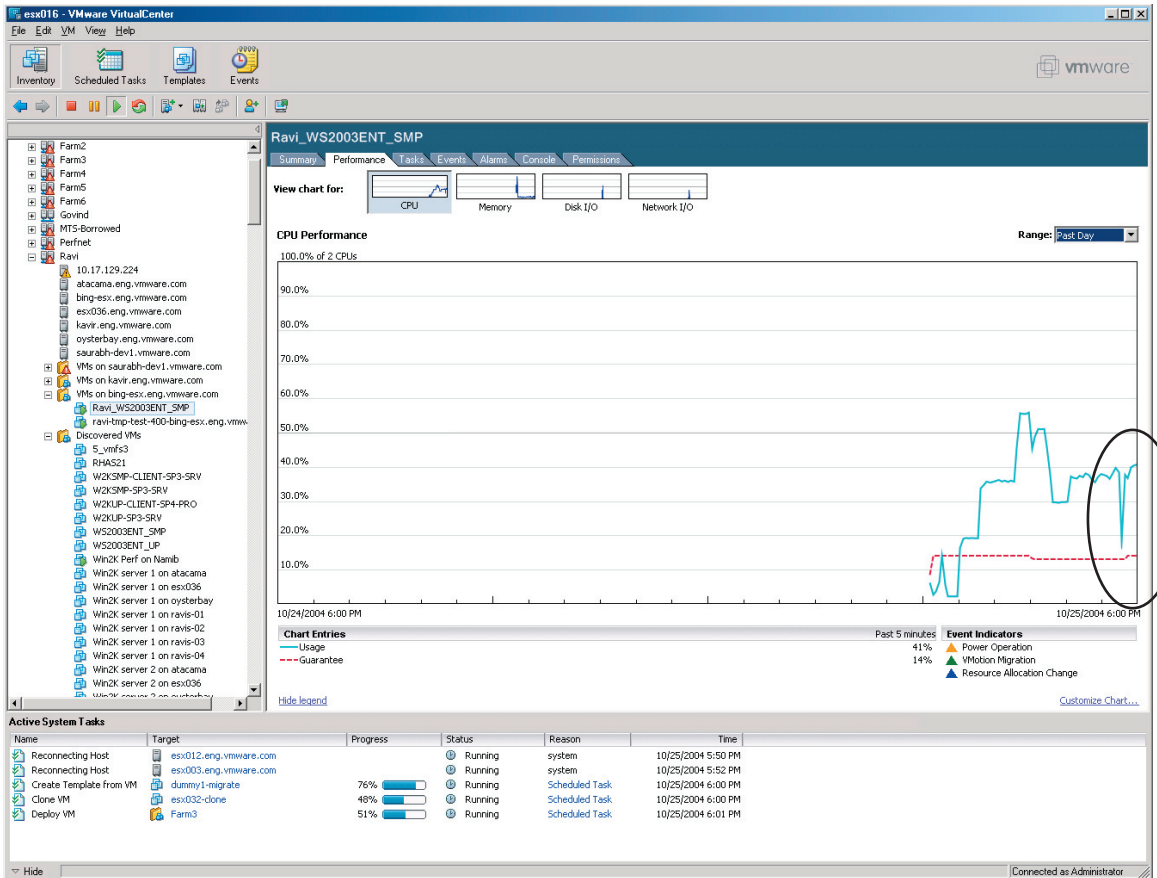
Figure 5: VirtualCenter Historical Data for Virtual Machine CPU Utilization

Virtual Machine Historical Data for Memory

Figure 6 shows historical data over the past day for the memory associated with the virtual machine Ravi_WS2003ENT_SMP dual-CPU virtual machine. Note that near the end of the interval, when snapshots were taken, the virtual machine was using around 15MB. This matches the value of 6% of 256MB shown on the virtual machine's Summary page.
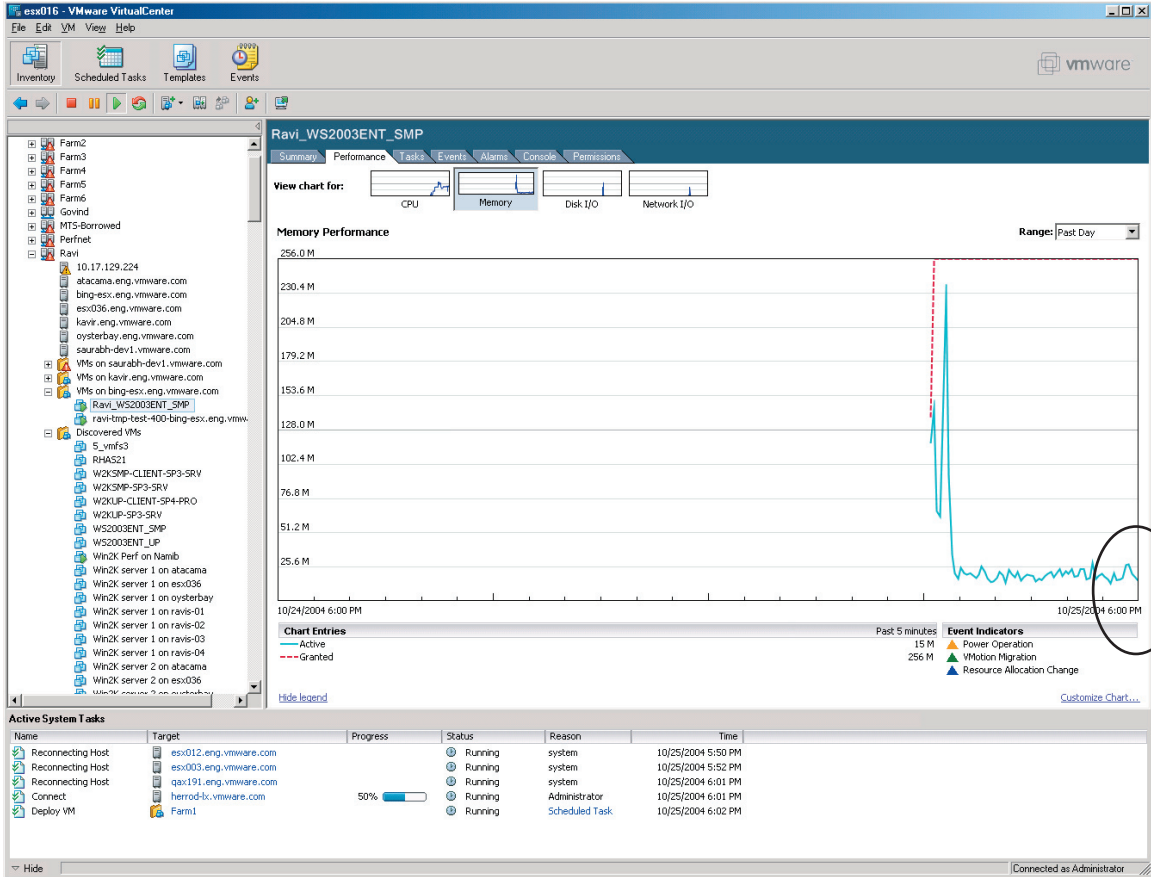
Figure 6: VirtualCenter Historical Data for Virtual Machine Memory Usage

Example Using the MUI

The Host Summary Page

Figure 7 shows the MUI's Summary page, which contains information for both the host and its virtual machines. The **System Summary** area shows the CPU utilization of the virtual machines, as well as the CPU utilization of the service console and the virtualization overhead. The CPU utilization of the virtual machines is shown under the **Virtual Machines** category, while the latter overheads are shown under **System Services**. As with VirtualCenter, the MUI shows that the virtual machines take around 70% of CPU utilization. Small differences from VirtualCenter are probably attributable to different sampling intervals. Total memory consumed by the virtual machines and system services is around 1.1GB. This value includes the memory allocated to a virtual machine even if that memory is not actively being used. This value differs from the value shown by VirtualCenter, which shows memory actively being used by virtual machines on the host's Summary page.
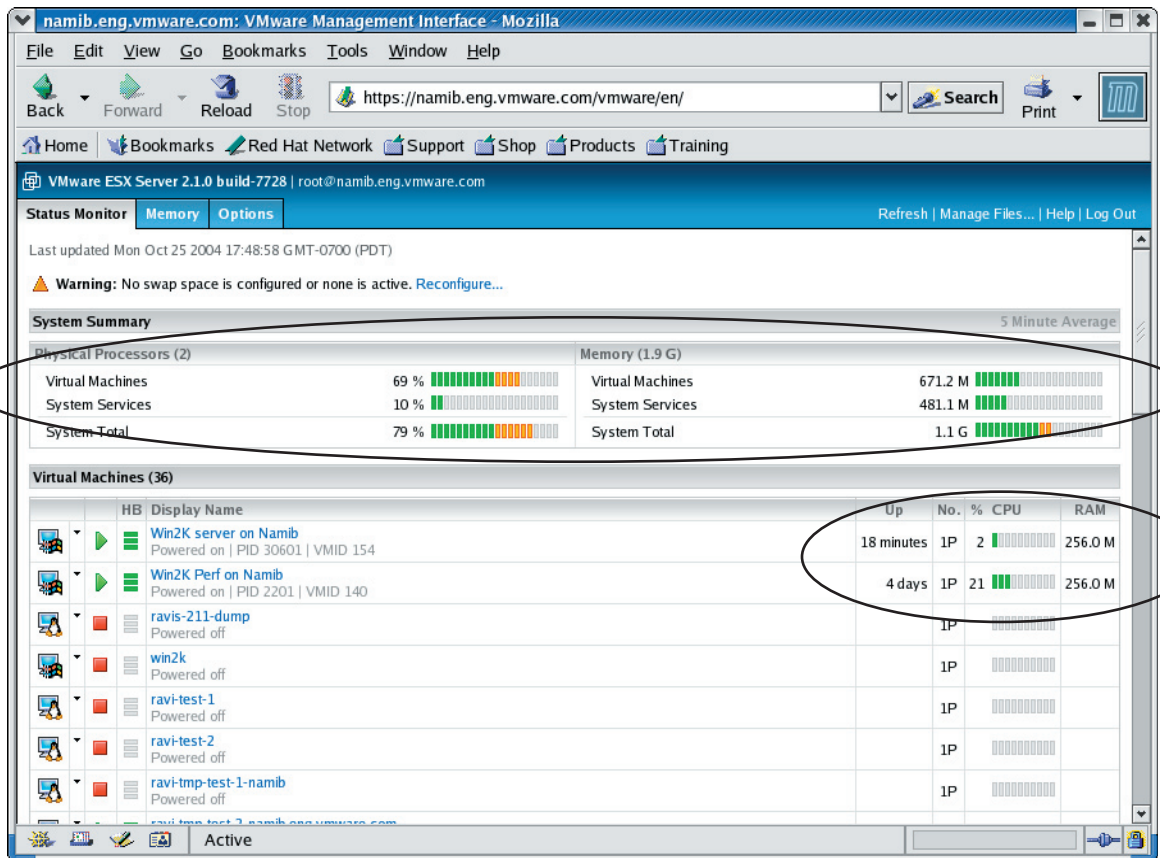

Figure 7: MUI Host/Virtual Machine Summary Page

Virtual Machine Summary Page: CPU Usage

Figure 7 also shows the virtual machine's Summary page for the MUI. (Not all virtual machines appear in the page due to lack of screen space.) Use this data to verify the CPU utilization on the host's Summary page. These figures differ from the corresponding values in VirtualCenter because they are normalized differently, as described above in the section titled "Normalization."

Considering only the CPU, look at the utilization levels shown in the MUI. Unfortunately, due to lack of space in the screenshot, not all utilizations can be seen in the figure.

- Win2K Perf on Namib takes 21% of the dual-CPU host. Note that VirtualCenter showed 44% of a single CPU, so the numbers are roughly equivalent.

- Win2K server on Namib takes 2% of a dual-CPU host. (VirtualCenter reported 5%).

- ravi-tmp-test-2-namib.eng.vmware.com (not shown in the figure) takes 2% of a dual-CPU host. This differs from VirtualCenter's value of 6% for a single CPU. The difference is partially normalization and partially rounding issues.

- ravi-tmp-test-4-namib.eng.vmware.com (not shown in the figure) takes 2% of the dual-CPU host. (VirtualCenter reported 6%), exactly like ravi-tmp-test-2-namib.eng.vmware.com

- ravi-tmp-test-5-namib.eng.vmware.com (not shown in the figure) takes 2% of the dual-CPU host. (VirtualCenter reported 6%), exactly like ravi-tmp-test-2-namib.eng.vmware.com.

- Ravi_WS2003ENT_SMP takes 42% of 2 CPUs. This figure matches VirtualCenter because the number of virtual CPUs matches the number of physical CPUs.

Add the values together: 22%+2%+2%+2%+2%+42% = 72% of two CPUs. This roughly matches the value shown as the total CPU consumed by virtual machines.

Virtual Machine Summary Page: Memory Usage

The Memory Summary page, shown in **Figure 8,** provides detailed memory usage in the MUI. This page shows the amount of memory allocated to each virtual machine (e.g., 256MB for Win2K server on Namib), as well as the amount of memory actively being accessed (in the **Active** column). Numbers in the **Active** column roughly match the percent memory utilization from the VirtualCenter virtual machine Summary page. For example, Win2K server on Namib actively uses 44.9MB memory. This is roughly 44.9MB/256MB = 17% of its memory, as shown in VirtualCenter.
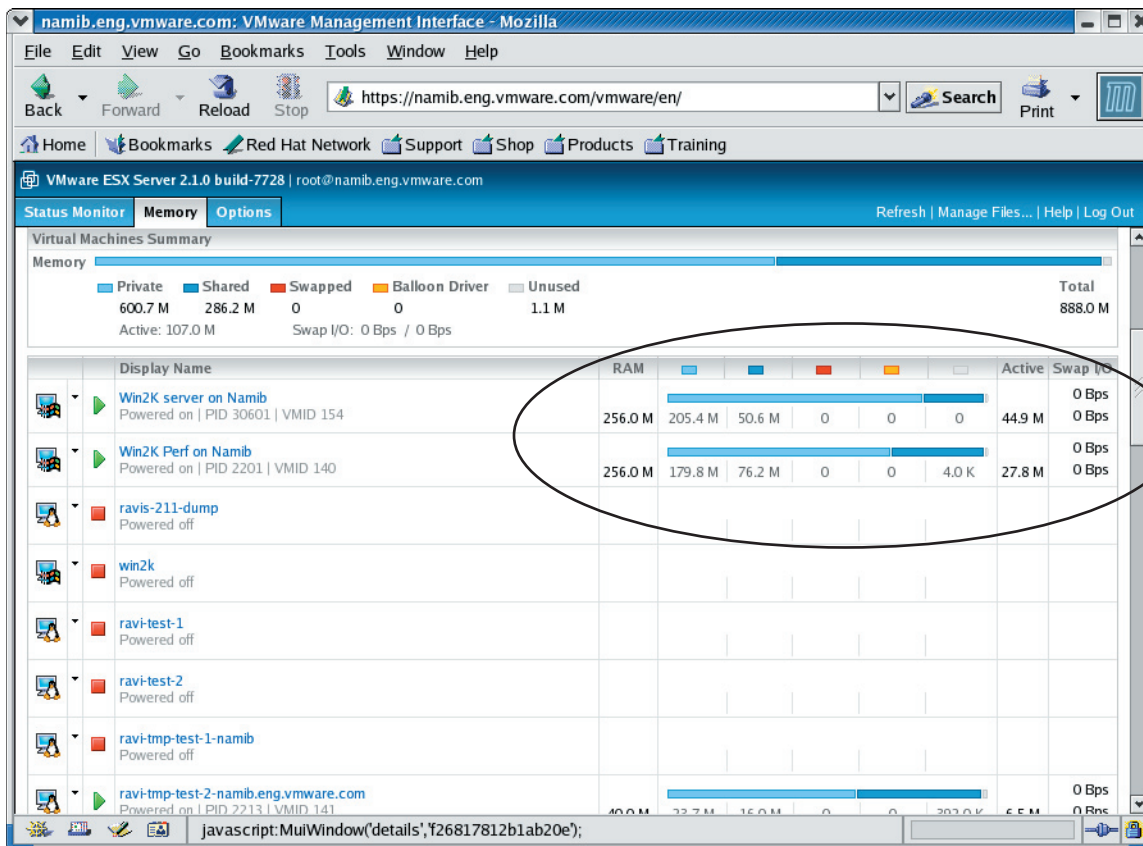
Figure 8: Detailed Memory Usage Page in the MUI

Example Using vmkusage

Host Historical Data: CPU

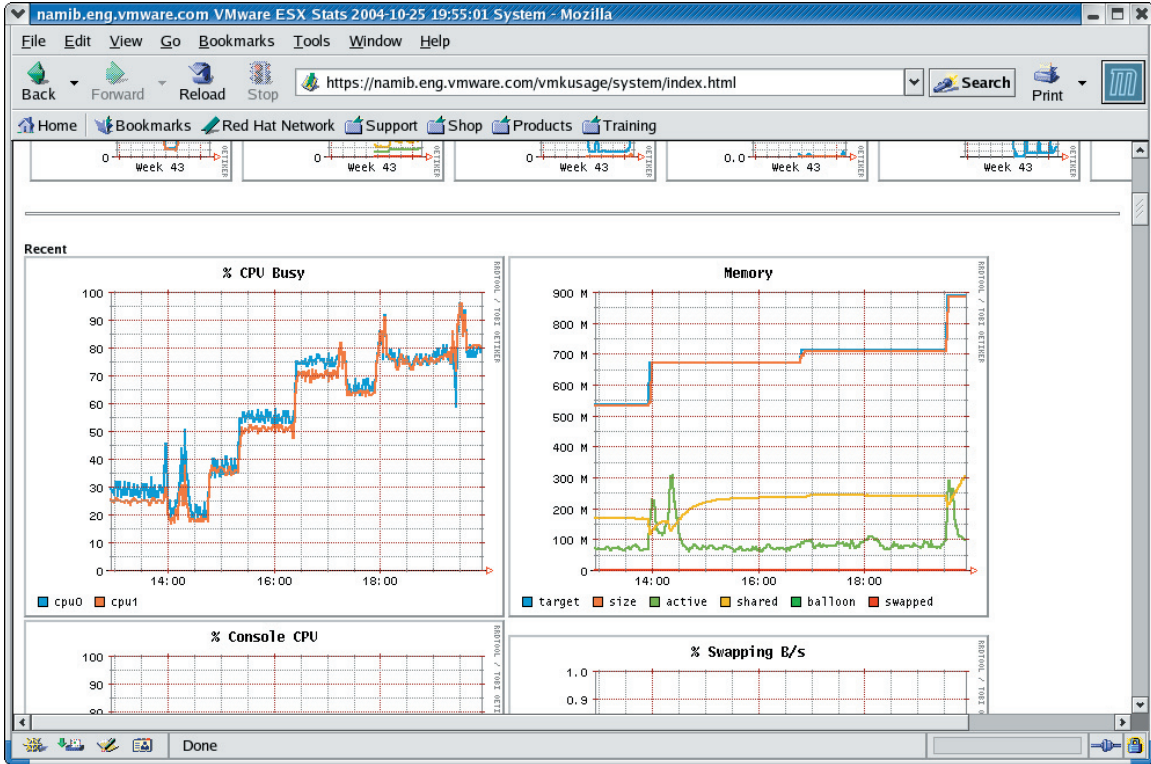Look at the Recent Activity page for `vmkusage` to see a historical breakdown of CPU time. See **Figure 9.**

Figure 9: Recent Activity Page for vmkusage

You can also get daily information, as shown in **Figure 10,** below. The daily information correlates roughly to the historical Past Day charts for VirtualCenter. One big difference between `vmkusage` and VirtualCenter is that `vmkusage` breaks down host CPU utilization by CPU, while VirtualCenter combines the information and presents it using the normalization method described in the "Normalization" section. If the two CPUs do not behave similarly, the `vmkusage` and VirtualCenter charts may differ.
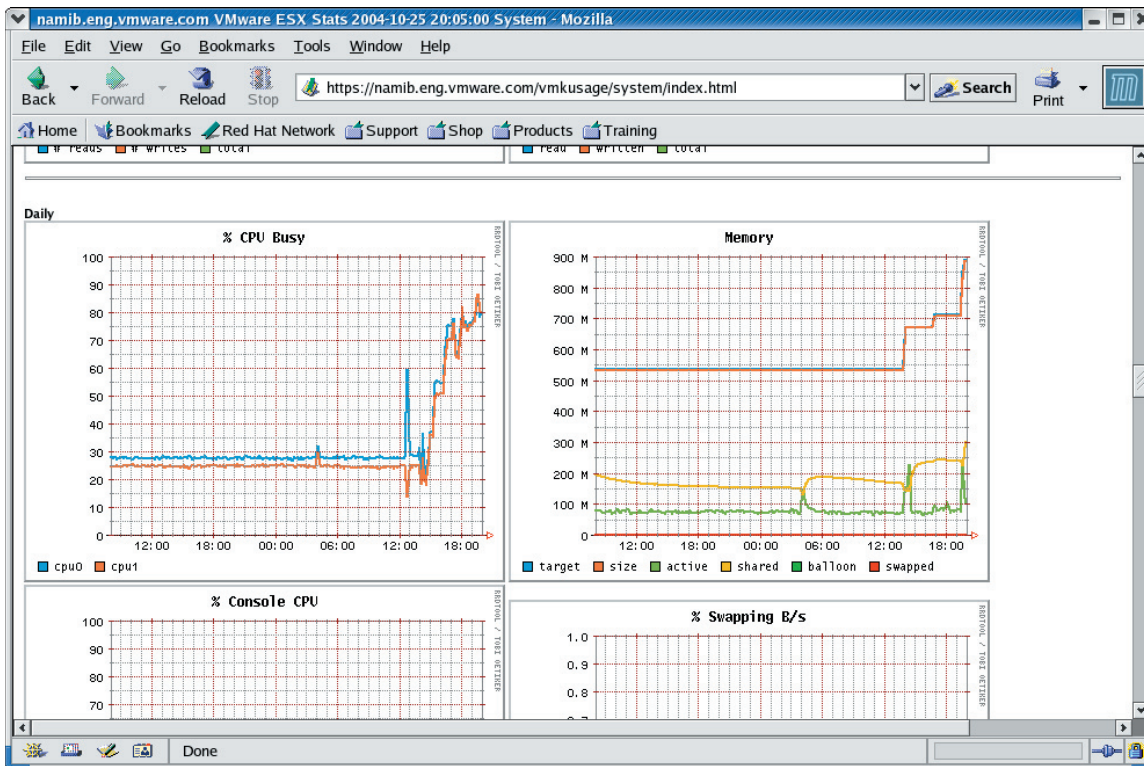
Figure 10: Daily Usage Page in vmkusage

Host Historical Data: Memory

If you look at the Recent Activity page for `vmkusage`, you see
a historical breakdown of memory usage (refer back to Figure 9).
You can also get daily information, as shown in Figure 10. The
daily information correlates roughly to the historical Past Day
charts for VirtualCenter. The maximum of the VirtualCenter plot is
the total amount of memory on the host, while the maximum of
the `vmkusage` plot is the total amount of memory currently
allocated on the host. The Active portion of the `vmkusage` graph
corresponds to the Active portion of the VirtualCenter graph. The
Size portion of the `vmkusage` graph corresponds to the Granted
portion of the VirtualCenter graph.

Virtual Machine Historical Data: CPU
Figure 11 shows a sample, recent, historical graph for a dual-CPU virtual machine. The CPU time is split into %CPU for VCPU0 (as a percentage of a single CPU) and %CPU for VCPU1. The page also shows Ready0 and Ready1, which indicate the percentage of time that each VCPU was ready to run but was not scheduled. These charts are unlike VirtualCenter's charts because they show the CPU time per-CPU, as opposed to aggregated.
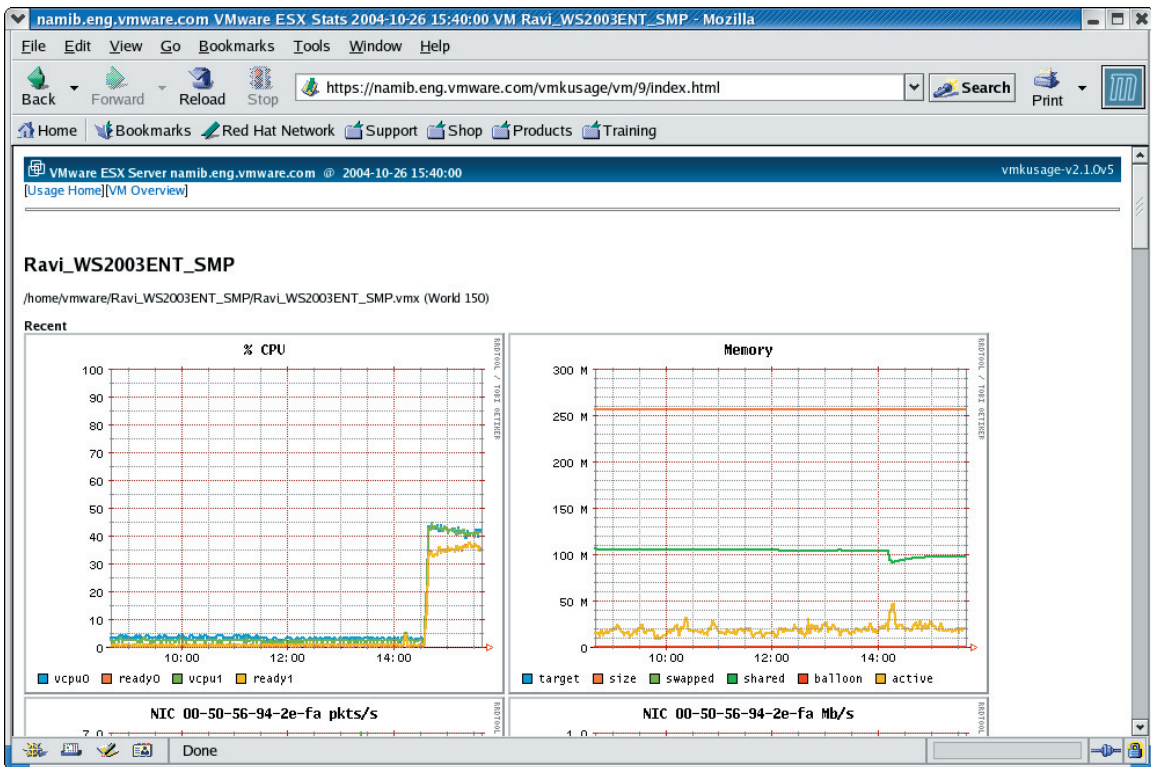

Figure 11: vmkusage Recent Historical Data for Virtual Machine CPU/ Memory Usage

Virtual Machine Historical Data: Memory
Figure 11 also shows a sample, recent, historical graph for a dual-CPU virtual machine. The graph shows memory usage where the maximum is the total amount of memory available to the virtual machine (in this case, 256MB). This graph is similar to the virtual machine historical chart for VirtualCenter, although the VirtualCenter chart is a 24-hour chart while this particular vmkusage chart is recent.

Conclusion

The MUI, VirtualCenter and `vmkusage` are powerful tools for profiling performance of hosts and virtual machines in virtual infrastructure environments. Each has a rich set of features with applicability in different contexts:

• In small ESX Server environments (with one or two ESX Server hosts) in which VirtualCenter is not used for infrastructure management, the MUI is valuable as a configuration tool (e.g., adding virtual networks or creating VMFS partitions) and to obtain basic short-term data (i.e., over the last five minutes or so). In such environments, for more detailed historical information and information that spans more than the last few minutes, `vmkusage` is useful as a complement to the MUI.

• In large ESX Server environments (with ten or more ESX Server hosts), VirtualCenter is an invaluable virtual infrastructure management tool, because it allows the display of information for numerous hosts and numerous virtual machines from a single application. In contrast, the MUI and `vmkusage` require logging onto each individual host in order to view information about that host or its virtual machines.

• For more-detailed per-CPU or memory information than VirtualCenter currently provides (e.g., breakdown of virtual machine performance by VCPU), `vmkusage` is useful. The charts for `vmkusage` provide more sample points for per-day or per-month statistics, providing slightly more fine-grained information than VirtualCenter. Also, `vmkusage` statistics can be accessed from a Web browser, making it conveniently accessible from either Windows or Linux client machines.

• In mixed ESX/GSX Server environments, VirtualCenter is extremely valuable, as it is the only tool of the three that can display information for both ESX Server and GSX Server hosts.

Notes

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