



# Red Hat Enterprise Linux 7

## Virtualization Tuning and Optimization Guide

Using KVM performance features for host systems and virtualized guests on RHEL



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## Abstract

The Red Hat Enterprise Linux Virtualization Tuning and Optimization Guide covers KVM and virtualization performance. Within this guide, you can find tips and suggestions for making full use of KVM performance features and options for your host systems and virtualized guests.

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# CHAPTER 1. INTRODUCTION

## 1.1. WHY PERFORMANCE OPTIMIZATION MATTERS IN VIRTUALIZATION

In KVM Virtualization, guests are represented by processes on the host machine. This means that processing power, memory, and other resources of the host are used to emulate the functions and capabilities of the guest's virtual hardware.

However, guest hardware can be less effective at using the resources than the host. Therefore, adjusting the amount of allocated host resources may be needed for the guest to perform its tasks at the expected speed. In addition, various types of virtual hardware may have different levels of overhead, so an appropriate virtual hardware configuration can have significant impact on guest performance. Finally, depending on the circumstances, specific configurations enable virtual machines to use host resources more efficiently.

## 1.2. KVM PERFORMANCE ARCHITECTURE OVERVIEW

The following points provide a brief overview of KVM as it pertains to system performance, as well as process and thread management:

- When using KVM, guests run as a Linux processes on the host.
- Virtual CPUs (vCPUs) are implemented as normal threads, handled by the Linux scheduler.
- Guests do not automatically inherit features such as NUMA and huge pages from the kernel.
- Disk and network I/O settings in the host have a significant performance impact.
- Network traffic typically travels through a software-based bridge.
- Depending on the devices and their models, there might be significant overhead due to emulation of that particular hardware.

## 1.3. VIRTUALIZATION PERFORMANCE FEATURES AND IMPROVEMENTS

### Virtualization Performance Improvements in Red Hat Enterprise Linux 7

The following features improve virtualization performance in Red Hat Enterprise Linux 7:

#### Automatic NUMA Balancing

Automatic NUMA balancing improves the performance of applications running on NUMA hardware systems, without any manual tuning required for Red Hat Enterprise Linux 7 guests. Automatic NUMA balancing moves tasks, which can be threads or processes, closer to the memory they are accessing. This enables good performance with zero configuration. However, in some circumstances, providing more accurate guest configuration or setting up guest to host affinities for CPUs and memory may provide better results.

For more information on automatic NUMA balancing, see [Section 9.2, “Automatic NUMA Balancing”](#).

#### VirtIO models

Any virtual hardware that has the virtio model does not have the overhead of emulating the hardware with all its particularities. VirtIO devices have low overhead thanks to the fact that they are designed specifically for use in Virtualization environments. However not all guest operating systems support such models.

### Multi-queue virtio-net

A networking approach that enables packet sending/receiving processing to scale with the number of available vCPUs of the guest.

For more information on multi-queue virtio-net, see [Section 5.4.2, “Multi-Queue virtio-net”](#).

### Bridge Zero Copy Transmit

Zero copy transmit mode reduces the host CPU overhead in transmitting large packets between a guest network and an external network by up to 15%, without affecting throughput. Bridge zero copy transmit is fully supported on Red Hat Enterprise Linux 7 virtual machines, but disabled by default.

For more information on zero copy transmit, see [Section 5.4.1, “Bridge Zero Copy Transmit”](#).

### APIC Virtualization (APICv)

Newer Intel processors offer hardware virtualization of the Advanced Programmable Interrupt Controller (APICv). APICv improves virtualized AMD64 and Intel 64 guest performance by allowing the guest to directly access the APIC, dramatically cutting down interrupt latencies and the number of virtual machine exits caused by the APIC. This feature is used by default in newer Intel processors and improves I/O performance.

### EOI Acceleration

End-of-interrupt acceleration for high bandwidth I/O on older chipsets without virtual APIC capabilities.

### Multi-queue virtio-scsi

Improved storage performance and scalability provided by multi-queue support in the virtio-scsi driver. This enables each virtual CPU to have a separate queue and interrupt to use without affecting other vCPUs.

For more information on multi-queue virtio-scsi, see [Section 7.4.2, “Multi-Queue virtio-scsi”](#).

### Paravirtualized Ticketlocks

Paravirtualized ticketlocks (pvticketlocks) improve the performance of Red Hat Enterprise Linux 7 guest virtual machines running on Red Hat Enterprise Linux 7 hosts with oversubscribed CPUs.

### Paravirtualized Page Faults

Paravirtualized page faults are injected into a guest when it attempts to access a page swapped out by the host. This improves KVM guest performance when host memory is overcommitted and guest memory is swapped out.

### Paravirtualized Time vsyscall Optimization

The **gettimeofday** and **clock\_gettime** system calls execute in the user space through the **vsyscall** mechanism. Previously, issuing these system calls required the system to switch into kernel mode, and then back into the user space. This greatly improves performance for some applications.



## Virtualization Performance Features in Red Hat Enterprise Linux

- CPU/Kernel
  - NUMA - Non-Uniform Memory Access. See [Chapter 9, NUMA](#) for details on NUMA.
  - CFS - Completely Fair Scheduler. A modern class-focused scheduler.
  - RCU - Read Copy Update. Better handling of shared thread data.
  - Up to 160 virtual CPUs (vCPUs).
- Memory
  - huge pages and other optimizations for memory-intensive environments. See [Chapter 8, Memory](#) for details.
- Networking
  - vhost-net - A fast, kernel-based VirtIO solution.
  - SR-IOV - For near-native networking performance levels.
- Block I/O
  - AIO - Support for a thread to overlap other I/O operations.
  - MSI - PCI bus device interrupt generation.
  - Disk I/O throttling - Controls on guest disk I/O requests to prevent over-utilizing host resources. See [Section 7.4.1, "Disk I/O Throttling"](#) for details.



### NOTE

For more details on virtualization support, limits, and features, see the *Red Hat Enterprise Linux 7 Virtualization Getting Started Guide* and the following URLs:

<https://access.redhat.com/certified-hypervisors>

<https://access.redhat.com/articles/rhel-kvm-limits>

## CHAPTER 2. PERFORMANCE MONITORING TOOLS

This chapter describes tools used to monitor guest virtual machine environments.

### 2.1. PERF KVM

You can use the **perf** command with the **kvm** option to collect and analyze guest operating system statistics from the host. The **perf** package provides the **perf** command. It is installed by running the following command:

```
# yum install perf
```

In order to use **perf kvm** in the host, you must have access to the **/proc/modules** and **/proc/kallsyms** files from the guest. See [Procedure 2.1, "Copying /proc files from guest to host"](#) to transfer the files into the host and run reports on the files.

#### Procedure 2.1. Copying /proc files from guest to host



#### IMPORTANT

If you directly copy the required files (for instance, using **scp**) you will only copy files of zero length. This procedure describes how to first save the files in the guest to a temporary location (with the **cat** command), and then copy them to the host for use by **perf kvm**.

#### 1. Log in to the guest and save files

Log in to the guest and save **/proc/modules** and **/proc/kallsyms** to a temporary location, **/tmp**:

```
# cat /proc/modules > /tmp/modules  
# cat /proc/kallsyms > /tmp/kallsyms
```

#### 2. Copy the temporary files to the host

Once you have logged off from the guest, run the following example **scp** commands to copy the saved files to the host. You should substitute your host name and TCP port if they are different:

```
# scp root@GuestMachine:/tmp/kallsyms guest-kallsyms  
# scp root@GuestMachine:/tmp/modules guest-modules
```

You now have two files from the guest (**guest-kallsyms** and **guest-modules**) on the host, ready for use by **perf kvm**.

#### 3. Recording and reporting events with perf kvm

Using the files obtained in the previous steps, recording and reporting of events in the guest, the host, or both is now possible.

Run the following example command:

```
# perf kvm --host --guest --guestkallsyms=guest-kallsyms \  
--guestmodules=guest-modules record -a -o perf.data
```

**NOTE**

If both `--host` and `--guest` are used in the command, output will be stored in **perf.data.kvm**. If only `--host` is used, the file will be named **perf.data.host**. Similarly, if only `--guest` is used, the file will be named **perf.data.guest**.

Pressing Ctrl-C stops recording.

**4. Reporting events**

The following example command uses the file obtained by the recording process, and redirects the output into a new file, **analyze**.

```
perf kvm --host --guest --guestmodules=guest-modules report -i perf.data.kvm \
--force > analyze
```

View the contents of the **analyze** file to examine the recorded events:

```
# cat analyze

# Events: 7K cycles
#
# Overhead   Command Shared Object   Symbol
# .....
#
95.06%      vi vi                [.] 0x48287
0.61%       init [kernel.kallsyms] [k] intel_idle
0.36%       vi libc-2.12.so      [.] __wordcopy_fwd_aligned
0.32%       vi libc-2.12.so      [.] __strlen_sse42
0.14%      swapper [kernel.kallsyms] [k] intel_idle
0.13%       init [kernel.kallsyms] [k] uhci_irq
0.11%       perf [kernel.kallsyms] [k] generic_exec_single
0.11%       init [kernel.kallsyms] [k] tg_shares_up
0.10%      qemu-kvm [kernel.kallsyms] [k] tg_shares_up
```

[output truncated...]

**2.2. VIRTUAL PERFORMANCE MONITORING UNIT (VPMU)**

The virtual performance monitoring unit (vPMU) displays statistics which indicate how a guest virtual machine is functioning.

The virtual performance monitoring unit allows users to identify sources of possible performance problems in their guest virtual machines. The vPMU is based on Intel's PMU (Performance Monitoring Units) and can only be used on Intel machines.

This feature is only supported with guest virtual machines running Red Hat Enterprise Linux 6 or Red Hat Enterprise Linux 7 and is disabled by default.

To verify if the vPMU is supported on your system, check for the **arch\_perfmon** flag on the host CPU by running:

```
# cat /proc/cpuinfo|grep arch_perfmon
```

To enable the vPMU, specify the **cpu mode** in the guest XML as **host-passthrough**:

```
# virsh dumpxml guest_name |grep "cpu mode"  
<cpu mode='host-passthrough'>
```

After the vPMU is enabled, display a virtual machine's performance statistics by running the **perf** command from the guest virtual machine.

## 2.3. MONITORING PERFORMANCE IN VIRTUAL MACHINE MANAGER

You can use the Virtual Machine Monitor to view performance information for any virtual machine on your system. You can also configure the performance information displayed in Virtual Machine Manager.

### 2.3.1. Viewing a Performance Overview in Virtual Machine Manager

To view a performance overview for a virtual machine using Virtual Machine Manager:

1. In the Virtual Machine Manager main window, highlight the virtual machine that you want to view.

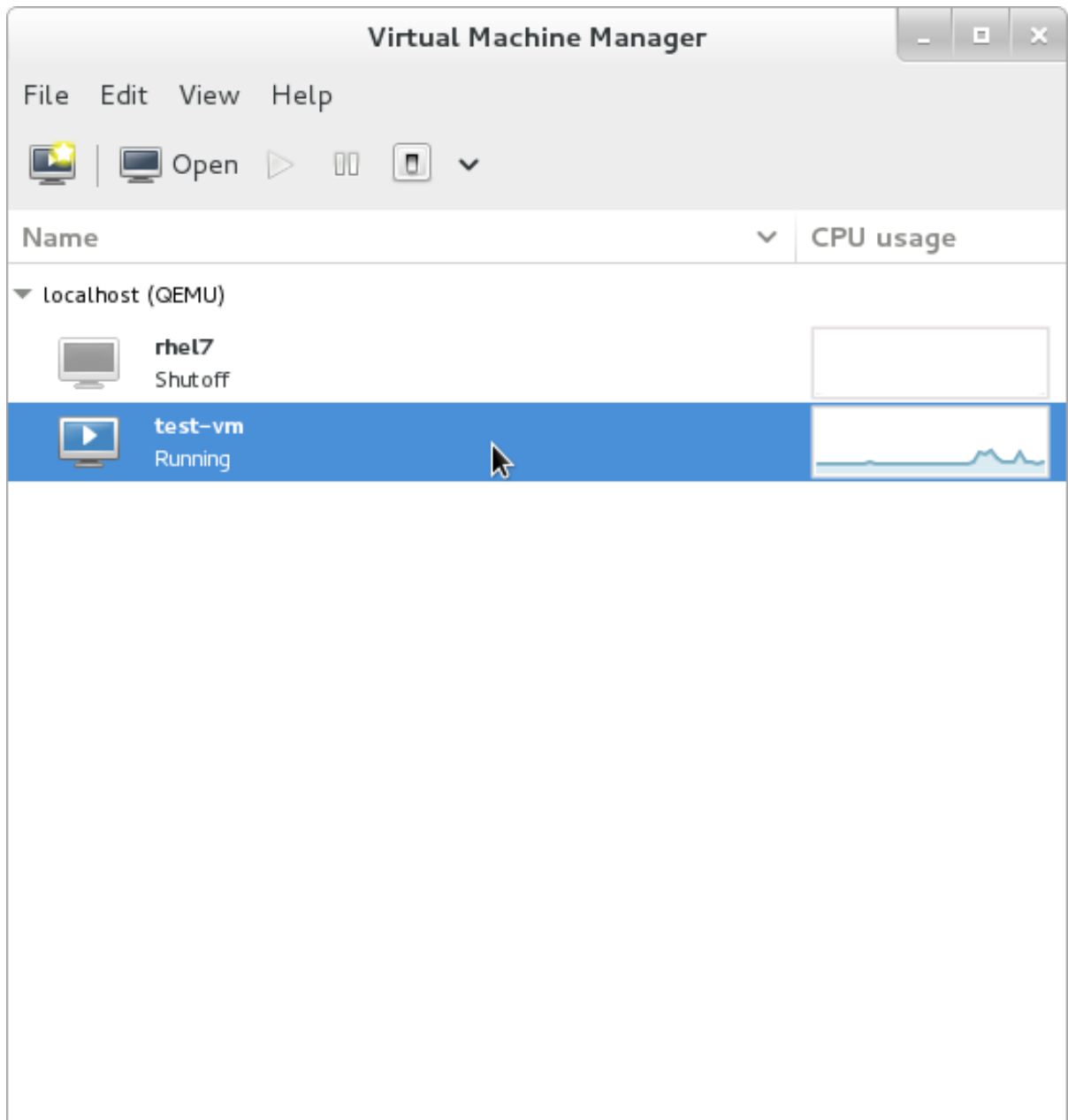


Figure 2.1. Selecting a virtual machine to display

2. From the Virtual Machine Manager **Edit** menu, select **Virtual Machine Details**.

When the Virtual Machine details window opens, there may be a console displayed. Should this happen, click **View** and then select **Details**. The Overview window opens first by default.

3. Select **Performance** from the navigation pane on the left hand side.

The **Performance** view shows a summary of guest performance, including CPU and Memory usage and Disk and Network input and output.

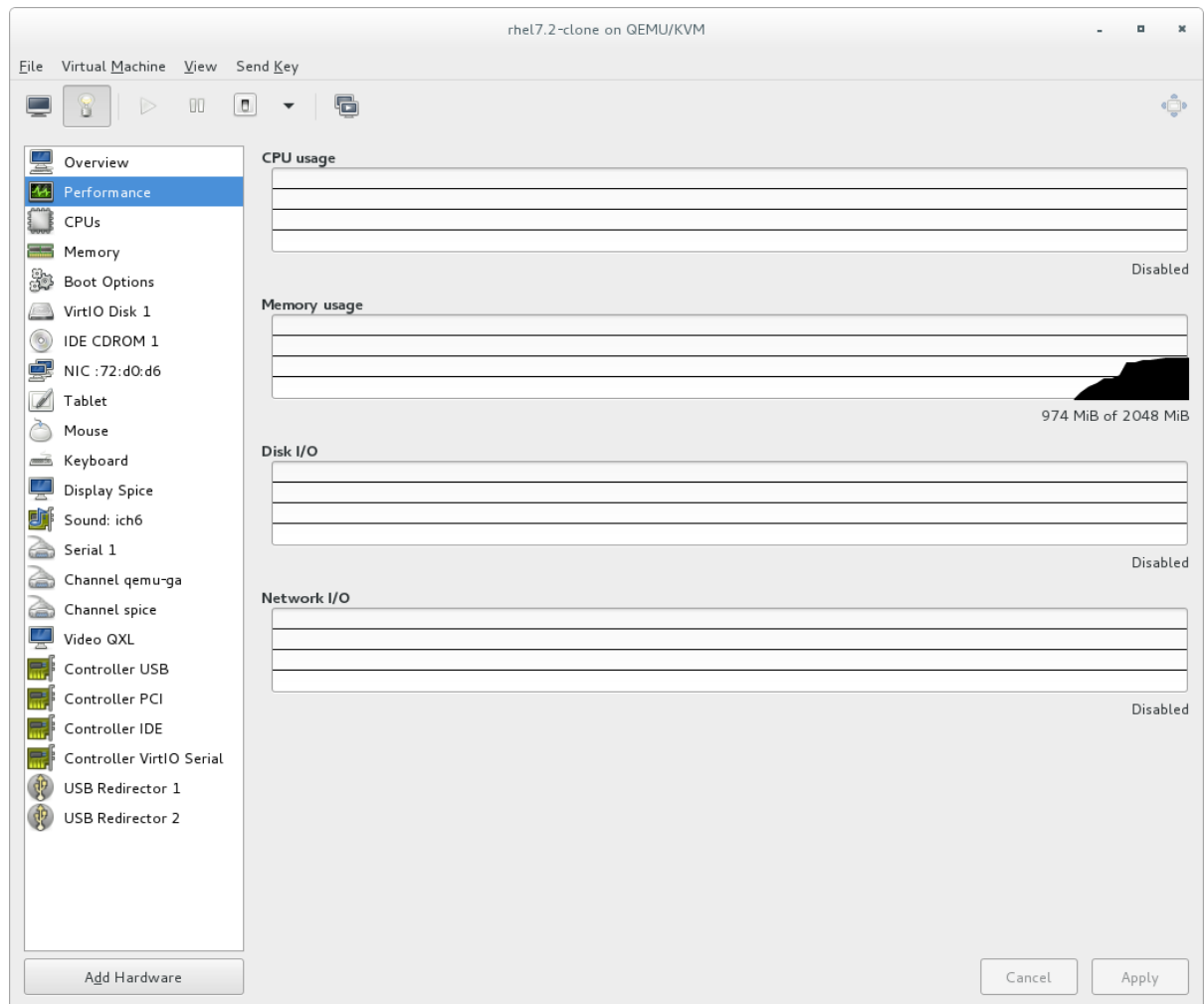


Figure 2.2. Displaying guest performance details

### 2.3.2. Performance Monitoring

Performance monitoring preferences can be modified with **virt-manager**'s preferences window.

To configure performance monitoring:

1. From the **Edit** menu, select **Preferences**.

The **Preferences** window appears.

2. From the **Polling** tab specify the time in seconds or stats polling options.

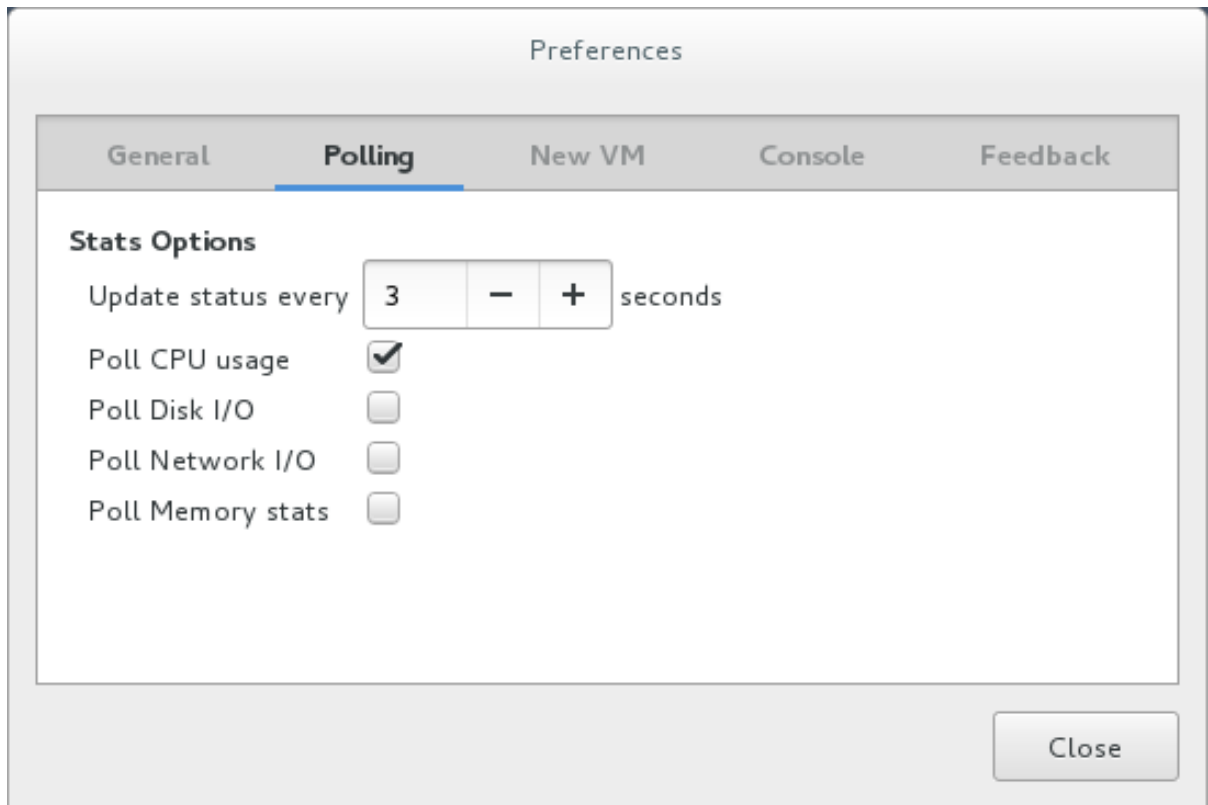


Figure 2.3. Configuring performance monitoring

### 2.3.3. Displaying CPU Usage for Guests

To view the CPU usage for all guests on your system:

1. From the **View** menu, select **Graph**, then the **Guest CPU Usage** check box.
2. The Virtual Machine Manager shows a graph of CPU usage for all virtual machines on your system.

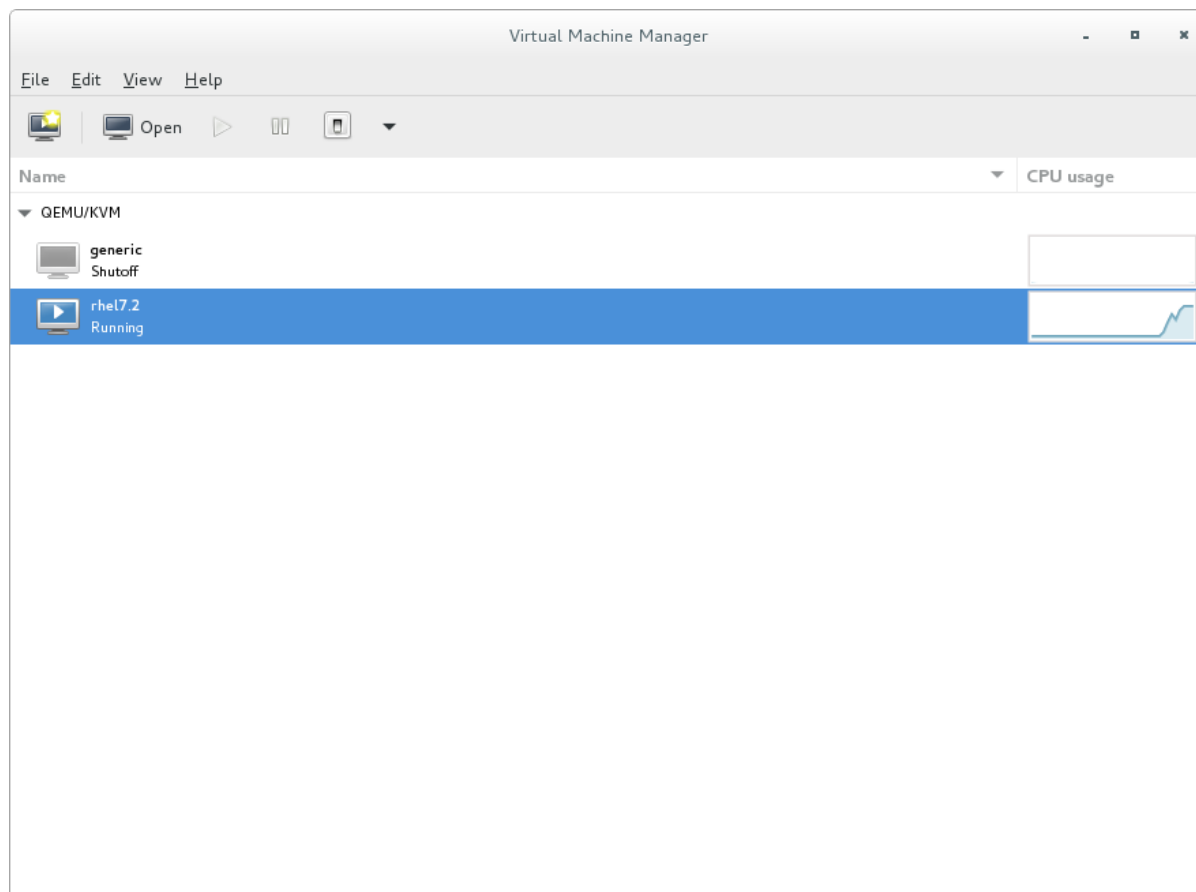


Figure 2.4. Guest CPU usage graph

### 2.3.4. Displaying CPU Usage for Hosts

To view the CPU usage for all hosts on your system:

1. From the **View** menu, select **Graph**, then the **Host CPU Usage** check box.
2. The Virtual Machine Manager shows a graph of host CPU usage on your system.



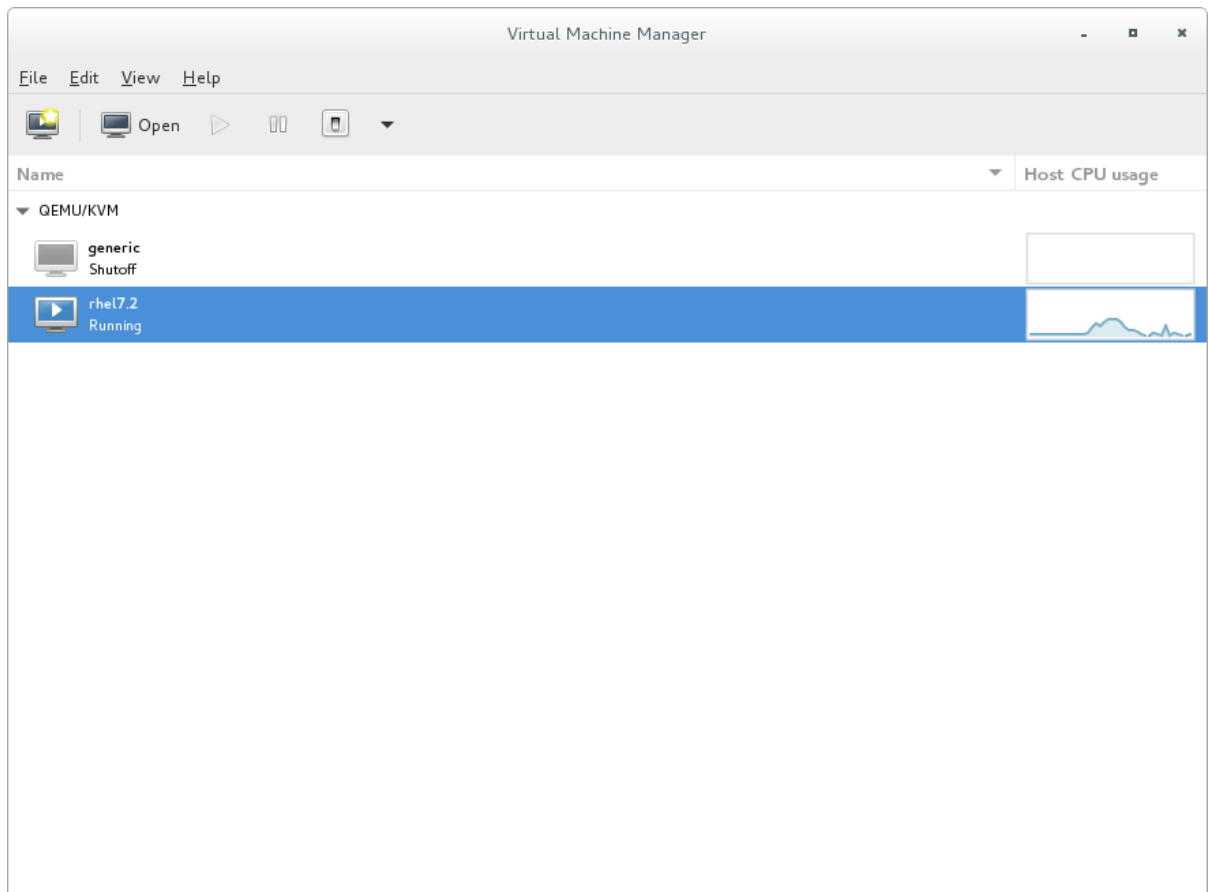


Figure 2.5. Host CPU usage graph

### 2.3.5. Displaying Disk I/O

To view the disk I/O for all virtual machines on your system:

1. Make sure that the Disk I/O statistics collection is enabled. To do this, from the **Edit** menu, select **Preferences** and click the **Polling** tab.
2. Select the **Disk I/O** check box.

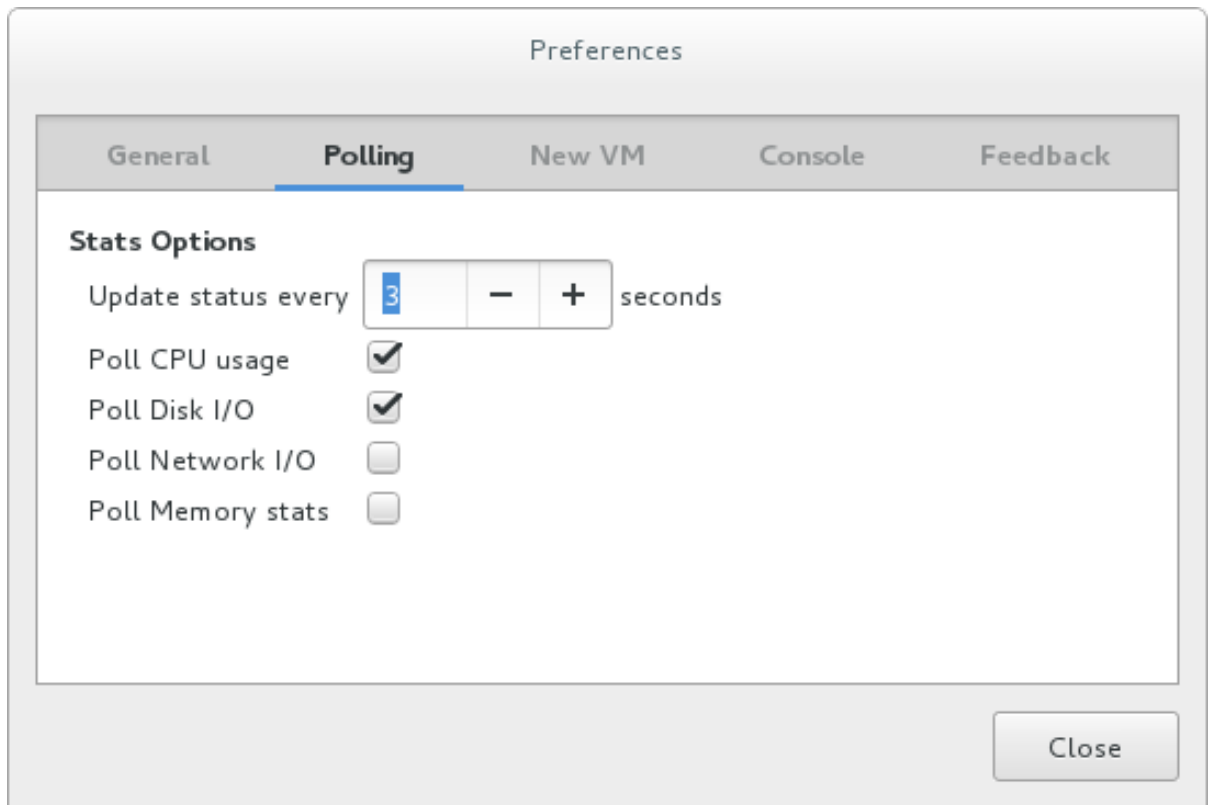


Figure 2.6. Enabling Disk I/O

3. To enable the Disk I/O display, from the **View** menu, select **Graph**, then the **Disk I/O** check box.
4. The Virtual Machine Manager shows a graph of Disk I/O for all virtual machines on your system.

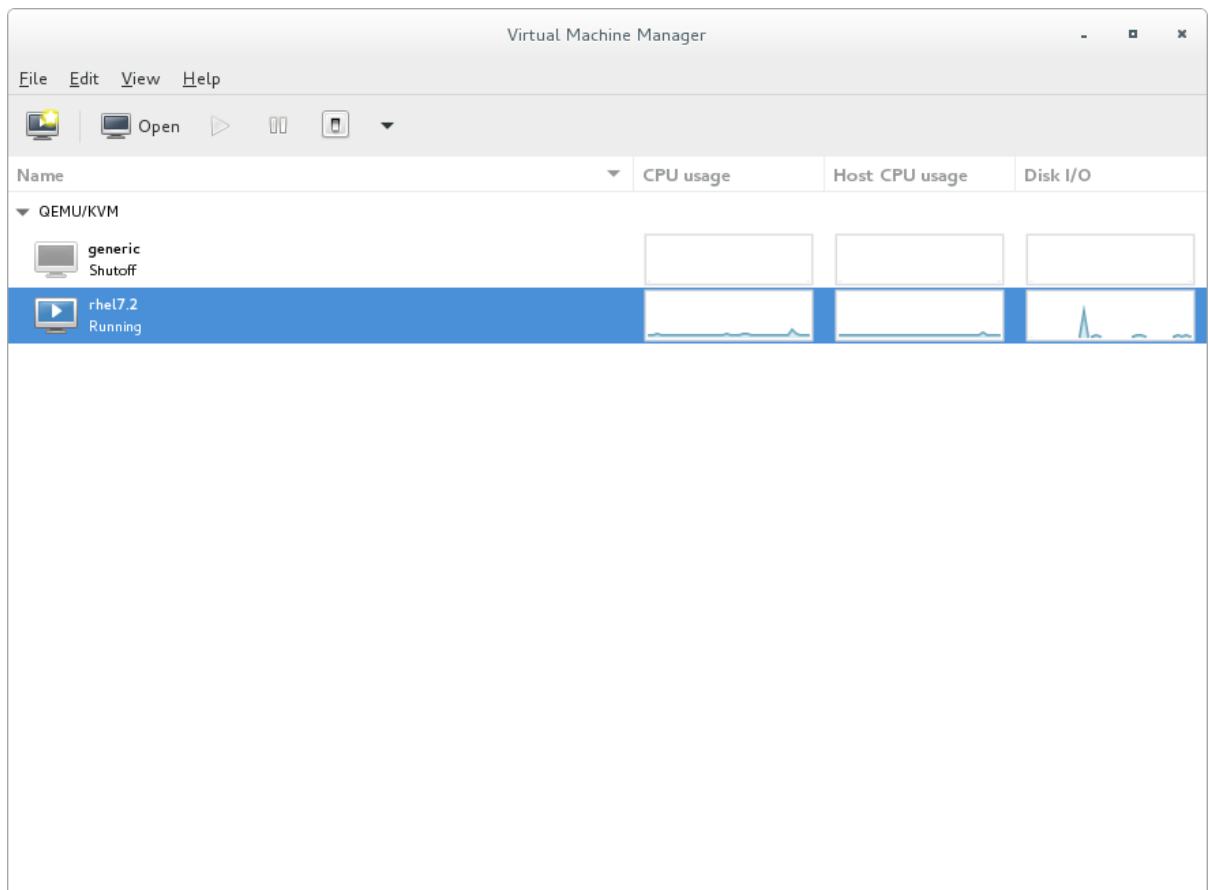
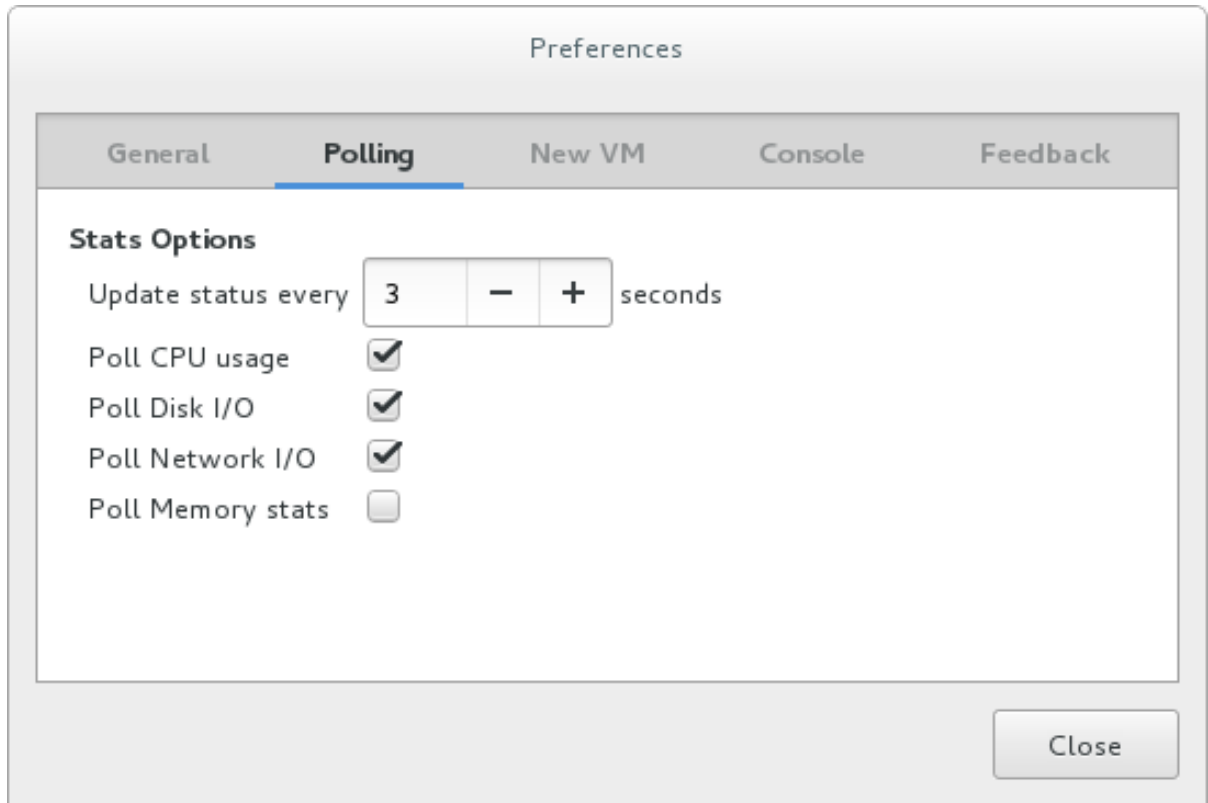


Figure 2.7. Displaying Disk I/O

### 2.3.6. Displaying Network I/O

To view the network I/O for all virtual machines on your system:

1. Make sure that the Network I/O statistics collection is enabled. To do this, from the **Edit** menu, select **Preferences** and click the **Polling** tab.
2. Select the **Network I/O** check box.



**Figure 2.8. Enabling Network I/O**

3. To display the Network I/O statistics, from the **View** menu, select **Graph**, then the **Network I/O** check box.
4. The Virtual Machine Manager shows a graph of Network I/O for all virtual machines on your system.

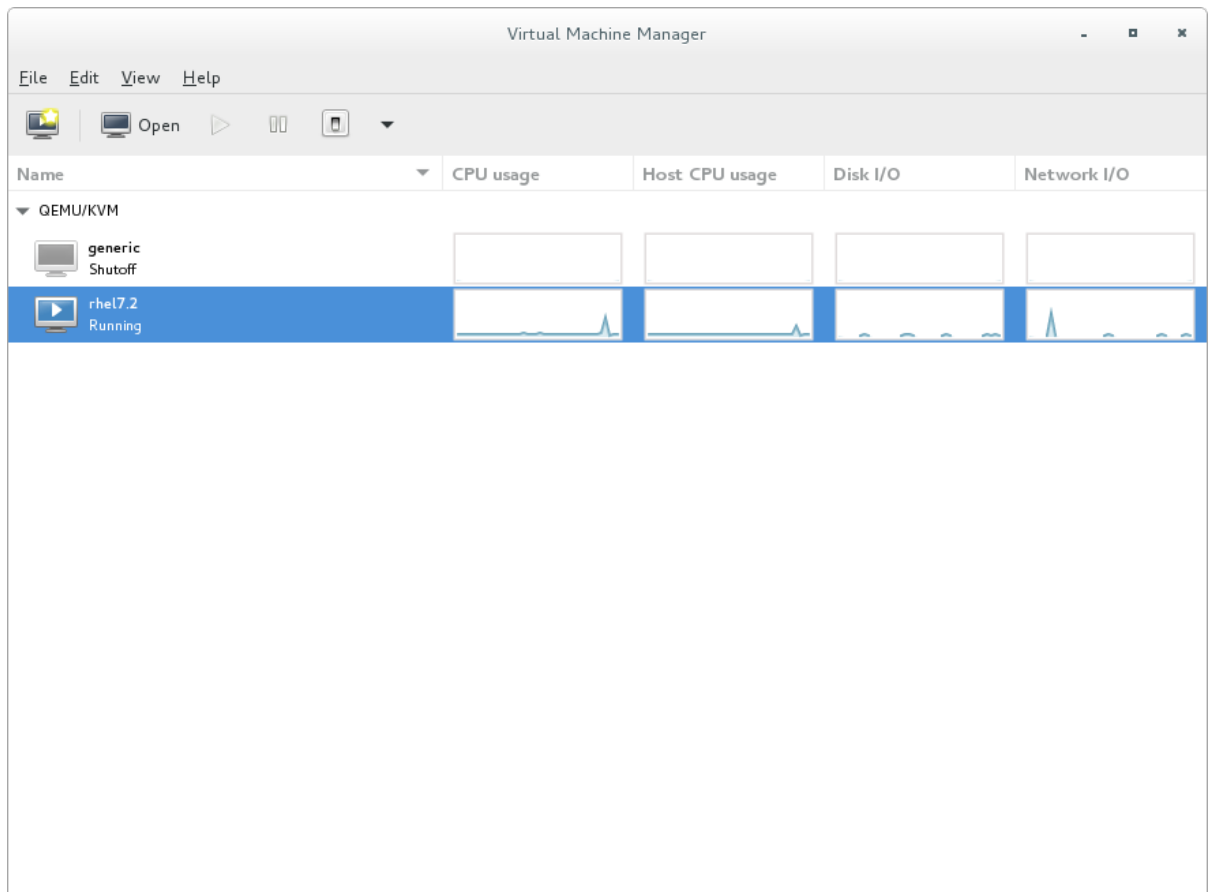


Figure 2.9. Displaying Network I/O

### 2.3.7. Displaying Memory Usage

To view the memory usage for all virtual machines on your system:

1. Make sure that the memory usage statistics collection is enabled. To do this, from the **Edit** menu, select **Preferences** and click the **Polling** tab.
2. Select the **Poll Memory stats** check box.

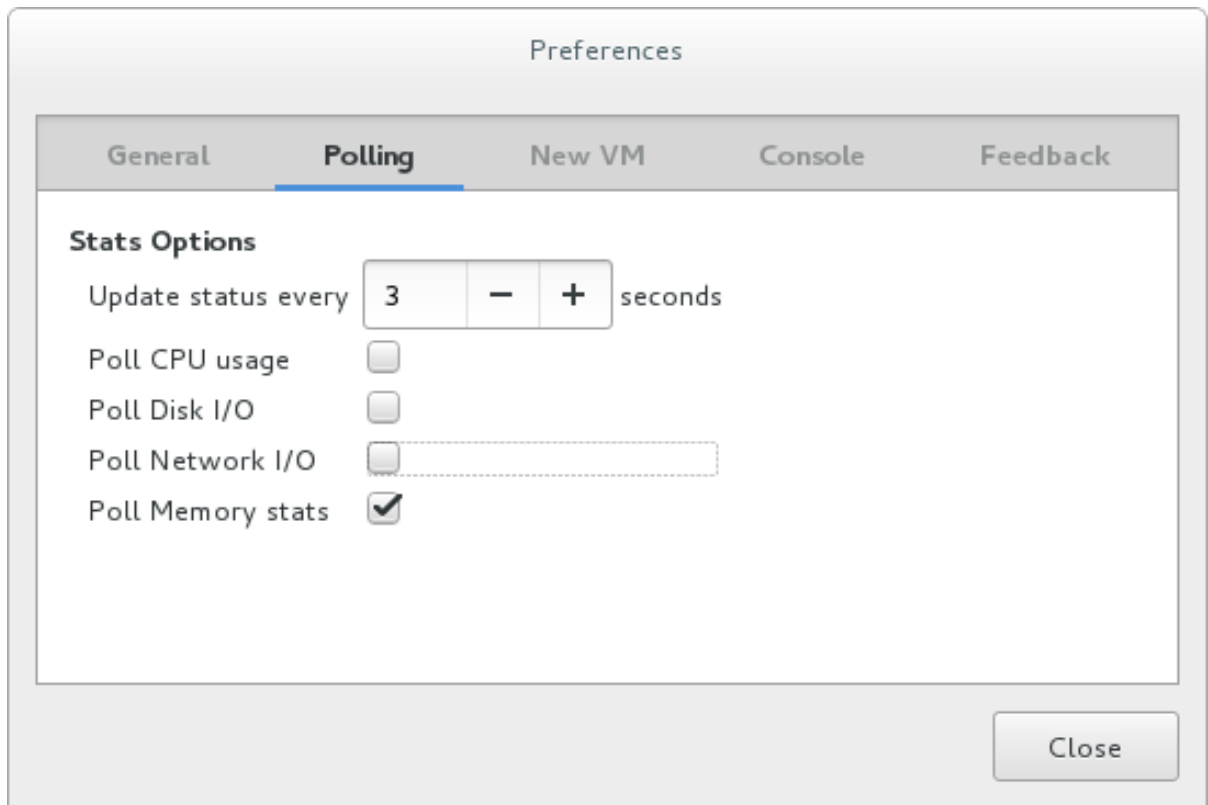


Figure 2.10. Enabling memory usage

3. To display the memory usage, from the **View** menu, select **Graph**, then the **Memory Usage** check box.
4. The Virtual Machine Manager lists the percentage of memory in use (in megabytes) for all virtual machines on your system.

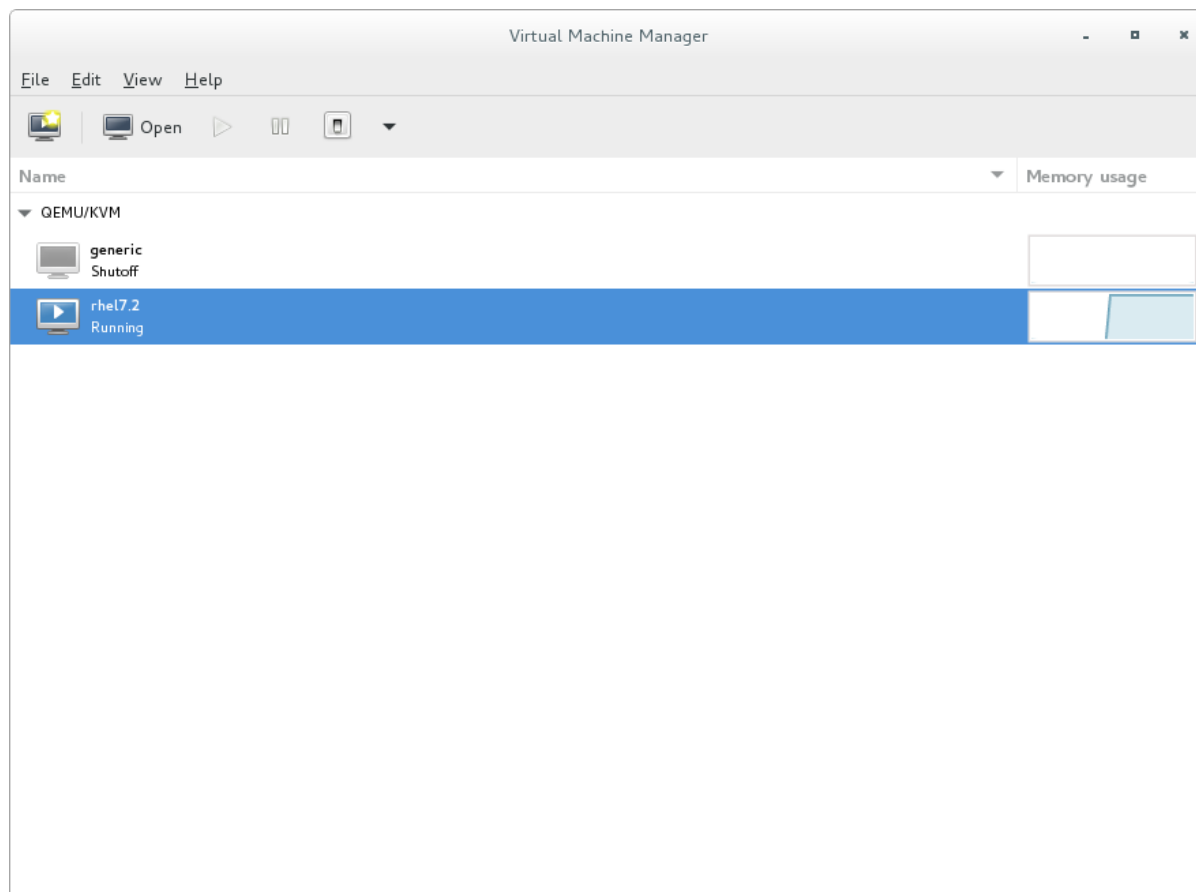


Figure 2.11. Displaying memory usage

## CHAPTER 3. OPTIMIZING VIRTUALIZATION PERFORMANCE WITH VIRT-MANAGER

This chapter covers performance tuning options available in **virt-manager**, a desktop tool for managing guest virtual machines.

### 3.1. OPERATING SYSTEM DETAILS AND DEVICES

#### 3.1.1. Specifying Guest Virtual Machine Details

The **virt-manager** tool provides different profiles depending on what operating system type and version are selected for a new guest virtual machine. When creating a guest, you should provide as many details as possible; this can improve performance by enabling features available for your specific type of guest.

See the following example screen capture of the **virt-manager** tool. When creating a new guest virtual machine, always specify your intended **OS type** and **Version**:

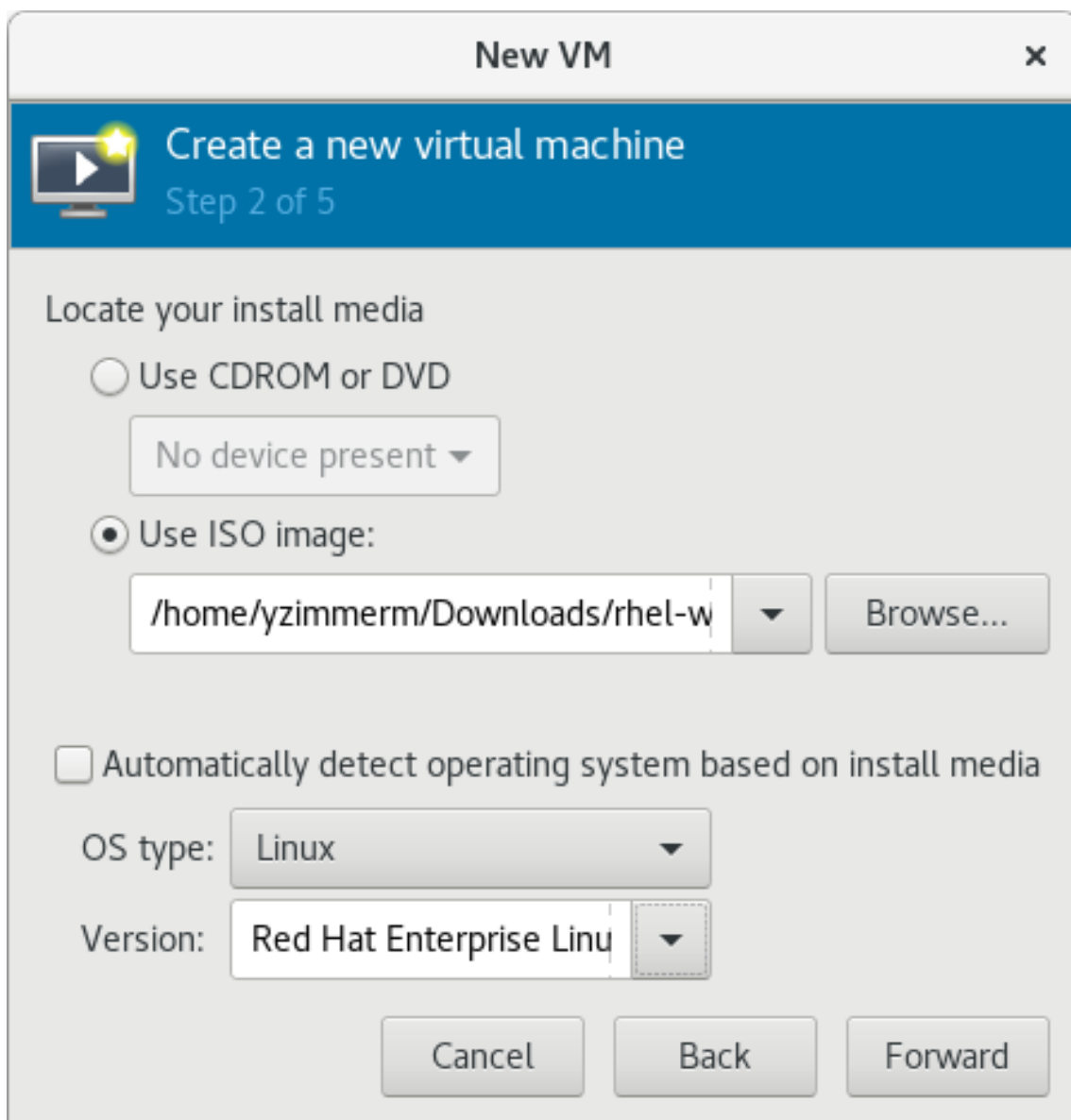


Figure 3.1. Provide the OS type and Version

### 3.1.2. Remove Unused Devices

Removing unused or unnecessary devices can improve performance. For instance, a guest tasked as a web server is unlikely to require audio features or an attached tablet.

See the following example screen capture of the **virt-manager** tool. Click the **Remove** button to remove unnecessary devices:

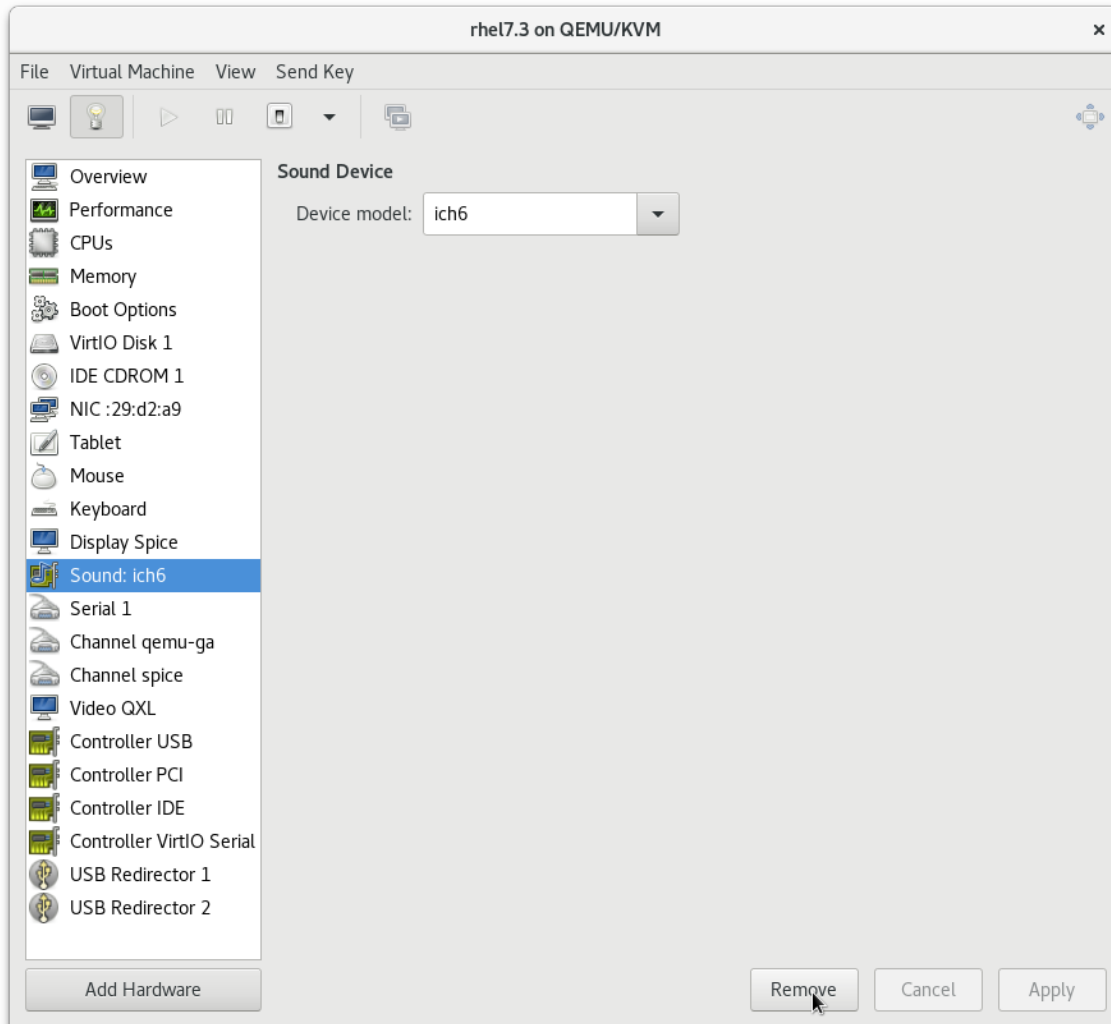


Figure 3.2. Remove unused devices

## 3.2. CPU PERFORMANCE OPTIONS

Several CPU related options are available to your guest virtual machines. Configured correctly, these options can have a large impact on performance. The following image shows the CPU options available to your guests. The remainder of this section shows and explains the impact of these options.



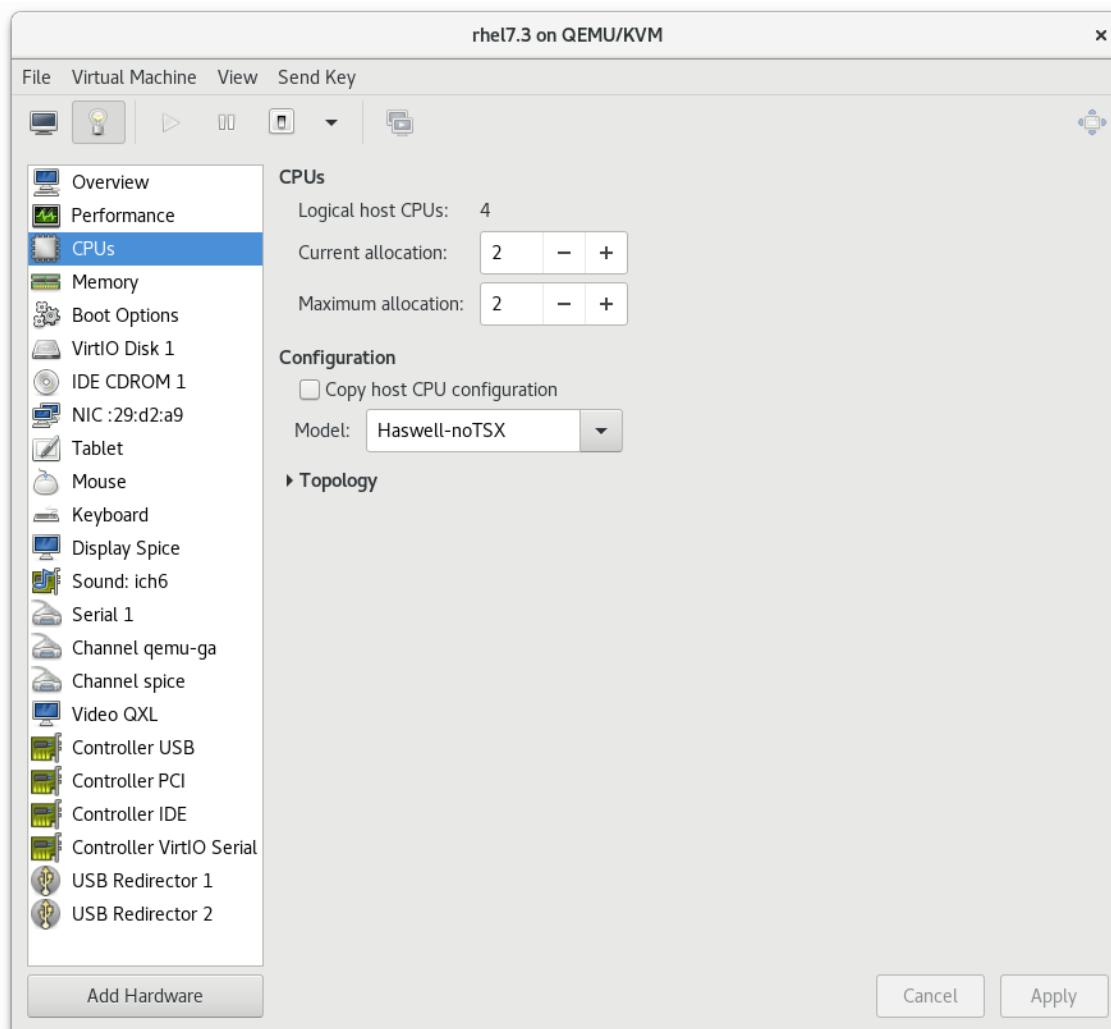


Figure 3.3. CPU Performance Options

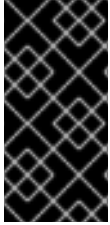
### 3.2.1. Option: Available CPUs

Use this option to adjust the amount of virtual CPUs (vCPUs) available to the guest. If you allocate more than is available on the host (known as *overcommitting*), a warning is displayed, as shown in the following image:



Figure 3.4. CPU overcommit

CPUs are overcommitted when the sum of vCPUs for all guests on the system is greater than the number of host CPUs on the system. You can overcommit CPUs with one or multiple guests if the total number of vCPUs is greater than the number of host CPUs.



## IMPORTANT

As with memory overcommitting, CPU overcommitting can have a negative impact on performance, for example in situations with a heavy or unpredictable guest workload. See the [Virtualization Deployment and Administration Guide](#) for more details on overcommitting.

### 3.2.2. Option: CPU Configuration

Use this option to select the CPU configuration type, based on the intended CPU model. Click the *Copy host CPU configuration* check box to detect and apply the physical host's CPU model and configuration, or expand the list to see available options. Once you select a CPU configuration, its available CPU features/instructions are displayed and can be individually enabled/disabled in the *CPU Features* list.

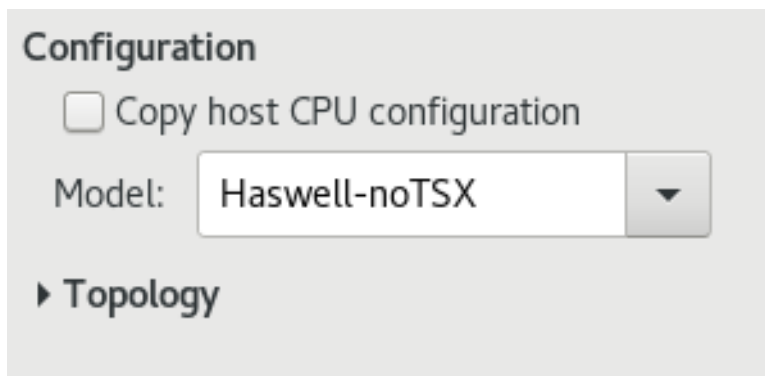


Figure 3.5. CPU Configuration Options



## NOTE

Copying the host CPU configuration is recommended over manual configuration.



## NOTE

Alternately, run the **virsh capabilities** command on your host machine to view the virtualization capabilities of your system, including CPU types and NUMA capabilities.

### 3.2.3. Option: CPU Topology

Use this option to apply a particular CPU topology (Sockets, Cores, Threads) to the virtual CPUs for your guest virtual machine.

Figure 3.6. CPU Topology Options

**NOTE**

Although your environment may dictate other requirements, selecting any intended number of sockets, but with only a single core and a single thread usually gives the best performance results.

### 3.3. VIRTUAL DISK PERFORMANCE OPTIONS

Several virtual disk related options are available to your guest virtual machines during installation that can impact performance. The following image shows the virtual disk options available to your guests.

The cache mode, IO mode, and IO tuning can be selected in the **Virtual Disk** section in **virt-manager**. Set these parameters in the fields under **Performance options**, as shown in the following image:

Figure 3.7. Virtual Disk Performance Options

**IMPORTANT**

When setting the virtual disk performance options in **virt-manager**, the virtual machine must be restarted for the settings to take effect.

See [Section 7.2, “Caching”](#) and [Section 7.3, “I/O Mode”](#) for descriptions of these settings and instructions for editing these settings in the guest XML configuration.

## CHAPTER 4. TUNED AND TUNED-ADM

This chapter covers using the **tuned** daemon for tuning system settings in virtualized environments.

**tuned** is a tuning profile delivery mechanism that adapts Red Hat Enterprise Linux for certain workload characteristics, such as requirements for CPU-intensive tasks, or storage/network throughput responsiveness. It provides a number of tuning profiles that are pre-configured to enhance performance and reduce power consumption in a number of specific use cases. Edit these profiles or create new profiles to create performance solutions tailored to your environment.

The virtualization-related profiles provided as part of **tuned** include:

### **virtual-guest**

Based on the **throughput-performance** profile, **virtual-guest** also decreases the swappiness of virtual memory.

The **virtual-guest** profile is automatically selected when creating a Red Hat Enterprise Linux 7 guest virtual machine. It is the recommended profile for virtual machines.

This profile is available in Red Hat Enterprise Linux 6.3 and later, but must be manually selected when installing a virtual machine.

### **virtual-host**

Based on the **throughput-performance** profile, **virtual-host** also enables more aggressive writeback of dirty pages. This profile is the recommended profile for virtualization hosts, including both KVM and Red Hat Virtualization (RHV) hosts.

By default in a Red Hat Enterprise Linux 7 installation, the **tuned** package is installed and the **tuned** service is enabled.

To list all available profiles and identify the current active profile, run:

```
# tuned-adm list
Available profiles:
- balanced
- desktop
- latency-performance
- network-latency
- network-throughput
- powersave
- sap
- throughput-performance
- virtual-guest
- virtual-host
Current active profile: throughput-performance
```

It is also possible to create custom **tuned** profiles to encapsulate a set of tuning parameters. For instructions on creating custom **tuned** profiles, see the **tuned.conf** man page.

To only display the currently active profile, run:

```
tuned-adm active
```

To switch to one of the available profiles, run:

```
tuned-adm profile profile_name
```

For example, to switch to the **virtual-host** profile, run:

```
tuned-adm profile virtual-host
```



### IMPORTANT

After setting a tuned profile in Red Hat Enterprise Linux 7.1 and above, make sure the **tuned** service is enabled for the configured profile to be applied after a reboot:

```
# systemctl enable tuned
```

In some cases, it is preferable to disable **tuned** to use parameters set manually. To disable all tuning for the current session, run:

```
# tuned-adm off
```

To permanently disable **tuned** and revert all changes it performed, run:

```
# tuned-adm off; systemctl disable tuned
```



### NOTE

For further information about **tuned**, see the [Red Hat Enterprise Linux 7 Performance Tuning Guide](#).

## CHAPTER 5. NETWORKING

This chapter covers network optimization topics for virtualized environments.

### 5.1. NETWORKING TUNING TIPS

- Use multiple networks to avoid congestion on a single network. For example, have dedicated networks for management, backups, or live migration.
- Red Hat recommends not using multiple interfaces in the same network segment. However, if this is unavoidable, you can use `arp_filter` to prevent ARP Flux, an undesirable condition that can occur in both hosts and guests and is caused by the machine responding to ARP requests from more than one network interface: `echo 1 > /proc/sys/net/ipv4/conf/all/arp_filter` or edit `/etc/sysctl.conf` to make this setting persistent.



#### NOTE

For more information on ARP Flux, see <http://linux-ip.net/html/ether-arp.html#ether-arp-flux>

### 5.2. VIRTIO AND VHOST\_NET

The following diagram demonstrates the involvement of the kernel in the Virtio and vhost\_net architectures.

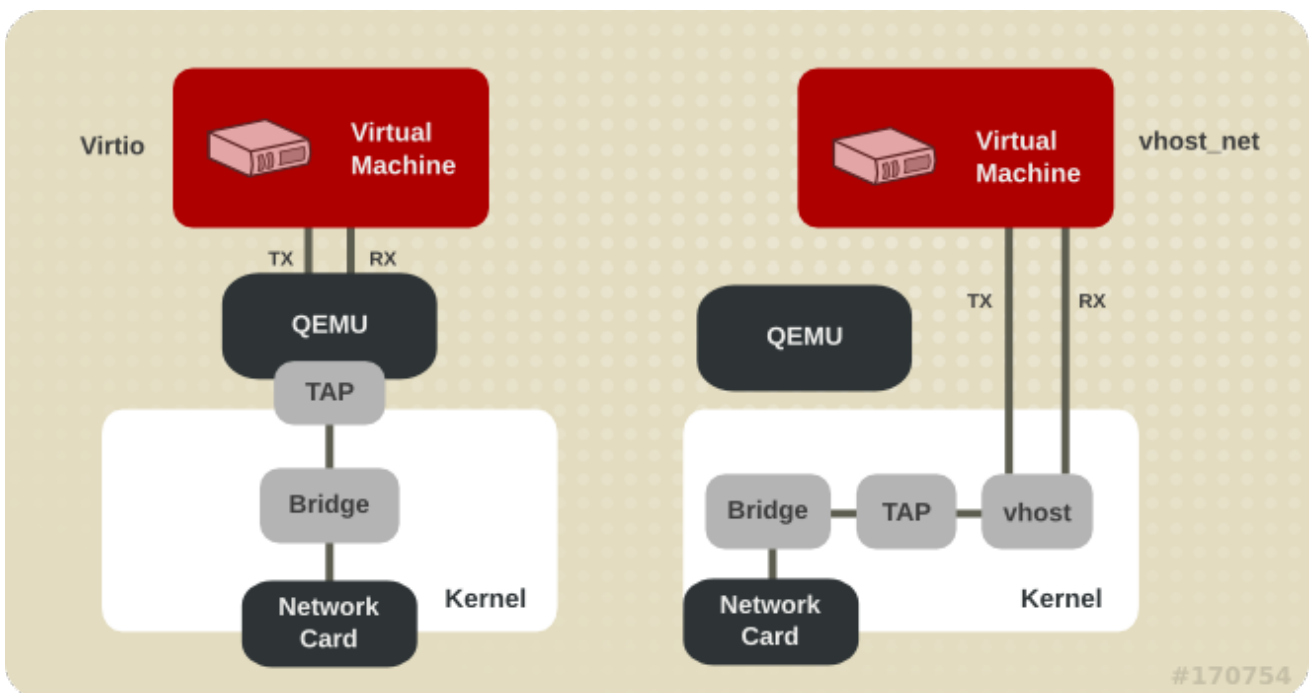


Figure 5.1. Virtio and vhost\_net architectures

vhost\_net moves part of the Virtio driver from the user space into the kernel. This reduces copy operations, lowers latency and CPU usage.

### 5.3. DEVICE ASSIGNMENT AND SR-IOV

The following diagram demonstrates the involvement of the kernel in the Device Assignment and SR-IOV architectures.

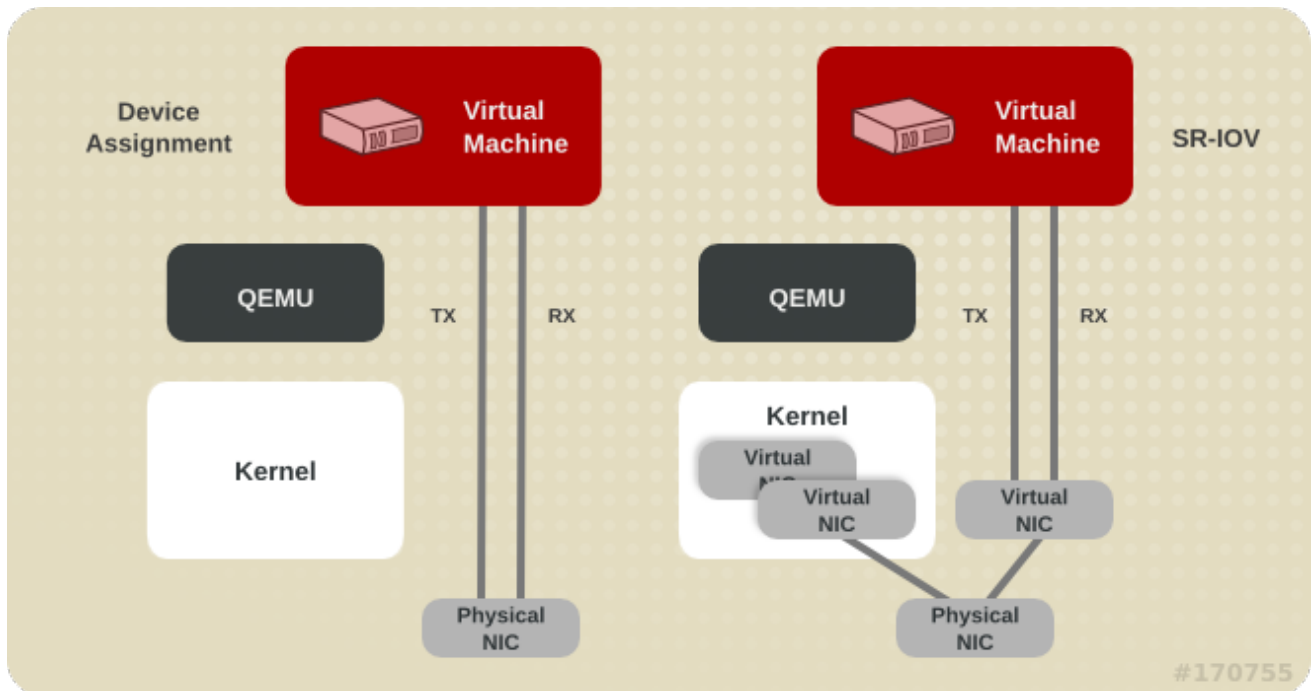
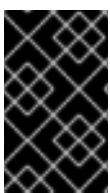


Figure 5.2. Device assignment and SR-IOV

Device assignment presents the entire device to the guest. SR-IOV needs support in drivers and hardware, including the NIC and the system board and allows multiple virtual devices to be created and passed into different guests. A vendor-specific driver is required in the guest, however, SR-IOV offers the lowest latency of any network option.

## 5.4. NETWORK TUNING TECHNIQUES

This section describes techniques for tuning network performance in virtualized environments.



### IMPORTANT

The following features are supported on Red Hat Enterprise Linux 7 hypervisors and virtual machines, but also on virtual machines running Red Hat Enterprise Linux 6.6 and later.

#### 5.4.1. Bridge Zero Copy Transmit

Zero copy transmit mode is effective on large packet sizes. It typically reduces the host CPU overhead by up to 15% when transmitting large packets between a guest network and an external network, without affecting throughput.

It does not affect performance for guest-to-guest, guest-to-host, or small packet workloads.

Bridge zero copy transmit is fully supported on Red Hat Enterprise Linux 7 virtual machines, but disabled by default. To enable zero copy transmit mode, set the ***experimental\_zcopytx*** kernel module parameter for the `vhost_net` module to 1. For detailed instructions, see the [Virtualization Deployment and Administration Guide](#).

**NOTE**

An additional data copy is normally created during transmit as a threat mitigation technique against denial of service and information leak attacks. Enabling zero copy transmit disables this threat mitigation technique.

If performance regression is observed, or if host CPU utilization is not a concern, zero copy transmit mode can be disabled by setting ***experimental\_zcopytx*** to 0.

### 5.4.2. Multi-Queue virtio-net

Multi-queue virtio-net provides an approach that scales the network performance as the number of vCPUs increases, by allowing them to transfer packets through more than one virtqueue pair at a time.

Today's high-end servers have more processors, and guests running on them often have an increasing number of vCPUs. In single queue virtio-net, the scale of the protocol stack in a guest is restricted, as the network performance does not scale as the number of vCPUs increases. Guests cannot transmit or retrieve packets in parallel, as virtio-net has only one TX and RX queue.

Multi-queue support removes these bottlenecks by allowing paralleled packet processing.

Multi-queue virtio-net provides the greatest performance benefit when:

- Traffic packets are relatively large.
- The guest is active on many connections at the same time, with traffic running between guests, guest to host, or guest to an external system.
- The number of queues is equal to the number of vCPUs. This is because multi-queue support optimizes RX interrupt affinity and TX queue selection in order to make a specific queue private to a specific vCPU.

**NOTE**

Currently, setting up a multi-queue virtio-net connection can have a negative effect on the performance of outgoing traffic. Specifically, this may occur when sending packets under 1,500 bytes over the Transmission Control Protocol (TCP) stream. For more information, see [the Red Hat Knowledgebase](#).

#### 5.4.2.1. Configuring Multi-Queue virtio-net

To use multi-queue virtio-net, enable support in the guest by adding the following to the guest XML configuration (where the value of  $N$  is from 1 to 256, as the kernel supports up to 256 queues for a multi-queue tap device):

```
<interface type='network'>
  <source network='default'/>
  <model type='virtio'/>
  <driver name='vhost' queues='N'/>
</interface>
```

When running a virtual machine with  $N$  virtio-net queues in the guest, enable the multi-queue support with the following command (where the value of  $M$  is from 1 to  $N$ ):



```
# ethtool -L eth0 combined M
```

## 5.5. BATCHING NETWORK PACKETS

In configurations with a long transmission path, batching packets before submitting them to the kernel may improve cache utilization.

To configure the maximum number of packets that can be batched where  $N$  is the maximum number of packets to batch:

```
# ethtool -C $tap rx-frames  $N$ 
```

To provide support for **tun/tap** rx batching for `type='bridge'` or `type='network'` interfaces, add a snippet similar to the following to the domain XML file.

```
...  
<devices>  
  <interface type='network'>  
    <source network='default'>  
    <target dev='vnet0'>  
      <coalesce>  
        <rx>  
          <frames max='7'>  
        </rx>  
      </coalesce>  
    </interface>  
  </devices>
```

## CHAPTER 6. I/O SCHEDULING

You can use an input/output (I/O) scheduler to improve disk performance both when Red Hat Enterprise Linux 7 is a virtualization [host](#) as well as when it is a virtualization [guest](#).

### 6.1. I/O SCHEDULING WITH RED HAT ENTERPRISE LINUX AS A VIRTUALIZATION HOST

When using Red Hat Enterprise Linux 7 as a host for virtualized guests, the default **deadline** scheduler is usually ideal. This scheduler performs well on nearly all workloads.

However, if maximizing I/O throughput is more important than minimizing I/O latency on the guest workloads, it may be beneficial to use the **cfq** scheduler instead.

### 6.2. I/O SCHEDULING WITH RED HAT ENTERPRISE LINUX AS A VIRTUALIZATION GUEST

You can use I/O scheduling on a Red Hat Enterprise Linux guest virtual machine, regardless of the hypervisor on which the guest is running. The following is a list of benefits and issues that should be considered:

- Red Hat Enterprise Linux guests often benefit greatly from using the **noop** scheduler. The scheduler merges small requests from the guest operating system into larger requests before sending the I/O to the hypervisor. This enables the hypervisor to process the I/O requests more efficiently, which can significantly improve the guest's I/O performance.
- Depending on the workload I/O and how storage devices are attached, schedulers like **deadline** can be more beneficial than **noop**. Red Hat recommends performance testing to verify which scheduler offers the best performance impact.
- Guests that use storage accessed by iSCSI, SR-IOV, or physical device passthrough should not use the **noop** scheduler. These methods do not allow the host to optimize I/O requests to the underlying physical device.



#### NOTE

In virtualized environments, it is sometimes not beneficial to schedule I/O on both the host and guest layers. If multiple guests use storage on a file system or block device managed by the host operating system, the host may be able to schedule I/O more efficiently because it is aware of requests from all guests. In addition, the host knows the physical layout of storage, which may not map linearly to the guests' virtual storage.

All scheduler tuning should be tested under normal operating conditions, as synthetic benchmarks typically do not accurately compare performance of systems using shared resources in virtual environments.

#### 6.2.1. Configuring the I/O Scheduler for Red Hat Enterprise Linux 7

The default scheduler used on a Red Hat Enterprise Linux 7 system is **deadline**. However, on a Red Hat Enterprise Linux 7 guest machine, it may be beneficial to change the scheduler to **noop**, by doing the following:

1. In the `/etc/default/grub` file, change the `elevator=deadline` string on the `GRUB_CMDLINE_LINUX` line to `elevator=noop`. If there is no `elevator=` string, add `elevator=noop` at the end of the line.

The following shows the `/etc/default/grub` file after a successful change.

```
# cat /etc/default/grub
[...]
GRUB_CMDLINE_LINUX="crashkernel=auto rd.lvm.lv=vg00/lvroot rhgb quiet
elevator=noop"
[...]
```

2. Rebuild the `/boot/grub2/grub.cfg` file.

- On a BIOS-based machine:

```
# grub2-mkconfig -o /boot/grub2/grub.cfg
```

- On an UEFI-based machine:

```
# grub2-mkconfig -o /boot/efi/EFI/redhat/grub.cfg
```

## CHAPTER 7. BLOCK I/O

This chapter covers optimizing I/O settings in virtualized environments.

### 7.1. BLOCK I/O TUNING

The **virsh blkio tune** command allows administrators to set or display a guest virtual machine's block I/O parameters manually in the **<blkio>** element in the guest XML configuration.

To display current **<blkio>** parameters for a virtual machine:

```
# virsh blkio tune virtual_machine
```

To set a virtual machine's **<blkio>** parameters, use the **virsh blkio tune** command and replace option values according to your environment:

```
# virsh blkio tune virtual_machine [--weight number] [--device-weights string] [--config] [--live] [--current]
```

Parameters include:

#### **weight**

The I/O weight, within the range 100 to 1000.

Increasing the I/O weight of a device increases its priority for I/O bandwidth, and therefore provides it with more host resources. Similarly, reducing a device's weight makes it consume less host resources.

#### **device-weights**

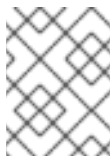
A single string listing one or more device/weight pairs, in the format of **/path/to/device,weight,/path/to/device,weight**. Each weight must be within the range 100-1000, or the value 0 to remove that device from per-device listings. Only the devices listed in the string are modified; any existing per-device weights for other devices remain unchanged.

#### **config**

Add the **--config** option for changes to take effect at next boot.

#### **live**

Add the **--live** option to apply the changes to the running virtual machine.



#### **NOTE**

The **--live** option requires the hypervisor to support this action. Not all hypervisors allow live changes of the maximum memory limit.

#### **current**

Add the **--current** option to apply the changes to the current virtual machine.

For example, the following changes the weight of the **/dev/sda** device in the *liftbrul* VM to 500.

```
# virsh blkio tune liftbrul --device-weights /dev/sda, 500
```



## NOTE

Use the **virsh help blkio tune** command for more information on using the **virsh blkio tune** command.

## 7.2. CACHING

Caching options can be configured with **virt-manager** during guest installation, or on an existing guest virtual machine by editing the guest XML configuration.

Table 7.1. Caching options

Caching Option	Description
Cache=none	I/O from the guest is not cached on the host, but may be kept in a writeback disk cache. Use this option for guests with large I/O requirements. This option is generally the best choice, and is the only option to support migration.
Cache=writethrough	I/O from the guest is cached on the host but written through to the physical medium. This mode is slower and prone to scaling problems. Best used for small number of guests with lower I/O requirements. Suggested for guests that do not support a writeback cache (such as Red Hat Enterprise Linux 5.5 and earlier), where migration is not needed.
Cache=writeback	I/O from the guest is cached on the host.
Cache=directsync	Similar to <b>writethrough</b> , but I/O from the guest bypasses the host page cache.
Cache=unsafe	The host may cache all disk I/O, and sync requests from guest are ignored.
Cache=default	If no cache mode is specified, the system's default settings are chosen.

In **virt-manager**, the caching mode can be specified under **Virtual Disk**. For information on using **virt-manager** to change the cache mode, see [Section 3.3, "Virtual Disk Performance Options"](#)

To configure the cache mode in the guest XML, edit the **cache** setting inside the **driver** tag to specify a caching option. For example, to set the cache as **writeback**:

```
<disk type='file' device='disk'>
  <driver name='qemu' type='raw' cache='writeback'/>
</disk>
```

## 7.3. I/O MODE

I/O mode options can be configured with **virt-manager** during guest installation, or on an existing guest virtual machine by editing the guest XML configuration.

**Table 7.2. IO mode options**

IO Mode Option	Description
IO=native	The default for Red Hat Virtualization (RHV) environments. This mode refers to kernel asynchronous I/O with direct I/O options.
IO=threads	The default are host user-mode based threads.
IO=default	The default in Red Hat Enterprise Linux 7 is threads mode.

In **virt-manager**, the I/O mode can be specified under **Virtual Disk**. For information on using **virt-manager** to change the I/O mode, see [Section 3.3, “Virtual Disk Performance Options”](#)

To configure the I/O mode in the guest XML, edit the **io** setting inside the **driver** tag, specifying **native**, **threads**, or **default**. For example, to set the I/O mode to **threads**:

```
<disk type='file' device='disk'>
  <driver name='qemu' type='raw' io='threads'/>
```

## 7.4. BLOCK I/O TUNING TECHNIQUES

This section describes more techniques for tuning block I/O performance in virtualized environments.

### 7.4.1. Disk I/O Throttling

When several virtual machines are running simultaneously, they can interfere with system performance by using excessive disk I/O. Disk I/O throttling in KVM provides the ability to set a limit on disk I/O requests sent from virtual machines to the host machine. This can prevent a virtual machine from over-utilizing shared resources and impacting the performance of other virtual machines.

Disk I/O throttling can be useful in various situations, for example when guest virtual machines belonging to different customers are running on the same host, or when quality of service guarantees are given for different guests. Disk I/O throttling can also be used to simulate slower disks.

I/O throttling can be applied independently to each block device attached to a guest and supports limits on throughput and I/O operations. Use the **virsh blkdeviotune** command to set I/O limits for a virtual machine:

```
# virsh blkdeviotune virtual_machine device --parameter limit
```

*Device* specifies a unique target name (**<target dev='name'/>**) or source file (**<source file='name'/>**) for one of the disk devices attached to the virtual machine. Use the **virsh domblklist** command for a list of disk device names.

Optional parameters include:

***total-bytes-sec***

The total throughput limit in bytes per second.

***read-bytes-sec***

The read throughput limit in bytes per second.

***write-bytes-sec***

The write throughput limit in bytes per second.

***total-iops-sec***

The total I/O operations limit per second.

***read-iops-sec***

The read I/O operations limit per second.

***write-iops-sec***

The write I/O operations limit per second.

For example, to throttle **vda** on **virtual\_machine** to 1000 I/O operations per second and 50 MB per second throughput, run this command:

```
# virsh blkdeviotune virtual_machine vda --total-iops-sec 1000 --total-bytes-sec 52428800
```

## 7.4.2. Multi-Queue virtio-scsi

Multi-queue virtio-scsi provides improved storage performance and scalability in the virtio-scsi driver. It enables each virtual CPU to have a separate queue and interrupt to use without affecting other vCPUs.

### 7.4.2.1. Configuring Multi-Queue virtio-scsi

Multi-queue virtio-scsi is disabled by default on Red Hat Enterprise Linux 7.

To enable multi-queue virtio-scsi support in the guest, add the following to the guest XML configuration, where *N* is the total number of vCPU queues:

```
<controller type='scsi' index='0' model='virtio-scsi'>
  <driver queues='N' />
</controller>
```

## CHAPTER 8. MEMORY

This chapter covers memory optimization options for virtualized environments.

### 8.1. MEMORY TUNING TIPS

To optimize memory performance in a virtualized environment, consider the following:

- Do not allocate more resources to guest than it will use.
- If possible, assign a guest to a single NUMA node, providing that resources are sufficient on that NUMA node. For more information on using NUMA, see [Chapter 9, NUMA](#).

### 8.2. MEMORY TUNING ON VIRTUAL MACHINES

#### 8.2.1. Memory Monitoring Tools

Memory usage can be monitored in virtual machines using tools used in bare metal environments. Tools useful for monitoring memory usage and diagnosing memory-related problems include:

- **top**
- **vmstat**
- **numastat**
- **/proc/**



#### NOTE

For details on using these performance tools, see the *Red Hat Enterprise Linux 7 Performance Tuning Guide* and the man pages for these commands.

#### 8.2.2. Memory Tuning with virsh

The optional **<memtune>** element in the guest XML configuration allows administrators to configure guest virtual machine memory settings manually. If **<memtune>** is omitted, default memory settings apply.

Display or set memory parameters in the **<memtune>** element in a virtual machine with the **virsh memtune** command, replacing values according to your environment:

```
# virsh memtune virtual_machine --parameter size
```

Optional parameters include:

##### **hard\_limit**

The maximum memory the virtual machine can use, in kibibytes (blocks of 1024 bytes).



**WARNING**

Setting this limit too low can result in the virtual machine being killed by the kernel.

***soft\_limit***

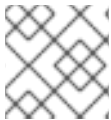
The memory limit to enforce during memory contention, in kibibytes (blocks of 1024 bytes).

***swap\_hard\_limit***

The maximum memory plus swap the virtual machine can use, in kibibytes (blocks of 1024 bytes). The ***swap\_hard\_limit*** value must be more than the ***hard\_limit*** value.

***min\_guarantee***

The guaranteed minimum memory allocation for the virtual machine, in kibibytes (blocks of 1024 bytes).

**NOTE**

See **# virsh help memtune** for more information on using the **virsh memtune** command.

The optional **<memoryBacking>** element may contain several elements that influence how virtual memory pages are backed by host pages.

Setting **locked** prevents the host from swapping out memory pages belonging to the guest. Add the following to the guest XML to lock the virtual memory pages in the host's memory:

```
<memoryBacking>
  <locked/>
</memoryBacking>
```

**IMPORTANT**

When setting **locked**, a **hard\_limit** must be set in the **<memtune>** element to the maximum memory configured for the guest, plus any memory consumed by the process itself.

Setting **nosharepages** prevents the host from merging the same memory used among guests. To instruct the hypervisor to disable share pages for a guest, add the following to the guest's XML:

```
<memoryBacking>
  <nosharepages/>
</memoryBacking>
```

### 8.2.3. Huge Pages and Transparent Huge Pages

AMD64 and Intel 64 CPUs usually address memory in 4kB pages, but they are capable of using larger 2MB or 1GB pages known as *huge pages*. KVM guests can be deployed with huge page memory support in order to improve performance by increasing CPU cache hits against the *Transaction Lookaside Buffer* (TLB).

A kernel feature enabled by default in Red Hat Enterprise Linux 7, huge pages can significantly increase performance, particularly for large memory and memory-intensive workloads. Red Hat Enterprise Linux 7 is able to manage large amounts of memory more effectively by increasing the page size through the use of huge pages. To increase the effectiveness and convenience of managing huge pages, Red Hat Enterprise Linux 7 uses *Transparent Huge Pages* (THP) by default. For more information on huge pages and THP, see the [Performance Tuning Guide](#).

Red Hat Enterprise Linux 7 systems support 2MB and 1GB huge pages, which can be allocated at boot or at runtime. See [Section 8.2.3.3, “Enabling 1 GB huge pages for guests at boot or runtime”](#) for instructions on enabling multiple huge page sizes.

### 8.2.3.1. Configuring Transparent Huge Pages

Transparent huge pages (THP) are an abstraction layer that automates most aspects of creating, managing, and using huge pages. By default, they automatically optimize system settings for performance.



#### NOTE

Using KSM can reduce the occurrence of transparent huge pages, so it is recommended to disable KSM before enabling THP. For more information, see [Section 8.3.4, “Deactivating KSM”](#).

Transparent huge pages are enabled by default. To check the current status, run:

```
# cat /sys/kernel/mm/transparent_hugepage/enabled
```

To enable transparent huge pages to be used by default, run:

```
# echo always > /sys/kernel/mm/transparent_hugepage/enabled
```

This will set `/sys/kernel/mm/transparent_hugepage/enabled` to ***always***.

To disable transparent huge pages:

```
# echo never > /sys/kernel/mm/transparent_hugepage/enabled
```

Transparent Huge Page support does not prevent the use of static huge pages. However, when static huge pages are not used, KVM will use transparent huge pages instead of the regular 4kB page size.

### 8.2.3.2. Configuring Static Huge Pages

In some cases, greater control of huge pages is preferable. To use static huge pages on guests, add the following to the guest XML configuration using **virsh edit**:

```
<memoryBacking>
  <hugepages/>
</memoryBacking>
```

This instructs the host to allocate memory to the guest using huge pages, instead of using the default page size.

View the current huge pages value by running the following command:

```
cat /proc/sys/vm/nr_hugepages
```

### Procedure 8.1. Setting huge pages

The following example procedure shows the commands to set huge pages.

1. View the current huge pages value:

```
# cat /proc/meminfo | grep Huge
AnonHugePages:    2048 kB
HugePages_Total:  0
HugePages_Free:   0
HugePages_Rsvd:   0
HugePages_Surp:   0
Hugepagesize:     2048 kB
```

2. Huge pages are set in increments of 2MB. To set the number of huge pages to 25000, use the following command:

```
echo 25000 > /proc/sys/vm/nr_hugepages
```



#### NOTE

To make the setting persistent, add the following lines to the `/etc/sysctl.conf` file on the guest machine, with X being the intended number of huge pages:

```
# echo 'vm.nr_hugepages = X' >> /etc/sysctl.conf
# sysctl -p
```

Afterwards, add **transparent\_hugepage=never** to the kernel boot parameters by appending it to the end of the `/kernel` line in the `/etc/grub2.cfg` file on the guest.

3. Mount the huge pages:

```
# mount -t hugetlbfs hugetlbfs /dev/hugepages
```

4. Add the following lines to the **memoryBacking** section in the virtual machine's XML configuration:

```
<hugepages>
  <page size='1' unit='GiB'/>
</hugepages>
```

5. Restart **libvirtd**, then restart the virtual machine with the following commands:

```
# systemctl start libvirtd
```

```
# virsh start virtual_machine
```

- Verify the changes in `/proc/meminfo`:

```
# cat /proc/meminfo | grep Huge
AnonHugePages:      0 kB
HugePages_Total:    25000
HugePages_Free:     23425
HugePages_Rsvd:     0
HugePages_Surp:     0
Hugepagesize:       2048 kB
```

Huge pages can benefit not only the host but also guests, however, their total huge pages value must be less than what is available in the host.

### 8.2.3.3. Enabling 1 GB huge pages for guests at boot or runtime

Red Hat Enterprise Linux 7 systems support 2MB and 1GB huge pages, which can be allocated at boot or at runtime.

#### Procedure 8.2. Allocating 1GB huge pages at boot time

- To allocate different sizes of huge pages at boot time, use the following command, specifying the number of huge pages. This example allocates four 1GB huge pages and 1024 2MB huge pages:

```
'default_hugepagesz=1G hugepagesz=1G hugepages=4 hugepagesz=2M hugepages=1024'
```

Change this command line to specify a different number of huge pages to be allocated at boot.



#### NOTE

The next two steps must also be completed the first time you allocate 1GB huge pages at boot time.

- Mount the 2MB and 1GB huge pages on the host:

```
# mkdir /dev/hugepages1G
# mount -t hugetlbfs -o pagesize=1G none /dev/hugepages1G
# mkdir /dev/hugepages2M
# mount -t hugetlbfs -o pagesize=2M none /dev/hugepages2M
```

- Add the following lines to the **memoryBacking** section in the virtual machine's XML configuration:

```
<hugepages>
  <page size='1' unit='GiB'/>
</hugepages>
```

- Restart `libvirtd` to enable the use of 1GB huge pages on guests:

```
# systemctl restart libvirtd
```

### Procedure 8.3. Allocating 1GB huge pages at runtime

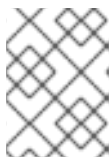
1GB huge pages can also be allocated at runtime. Runtime allocation allows the system administrator to choose which NUMA node to allocate those pages from. However, runtime page allocation can be more prone to allocation failure than boot time allocation due to memory fragmentation.

1. To allocate different sizes of huge pages at runtime, use the following command, replacing values for the number of huge pages, the NUMA node to allocate them from, and the huge page size:

```
# echo 4 > /sys/devices/system/node/node1/hugepages/hugepages-
1048576kB/nr_hugepages
# echo 1024 > /sys/devices/system/node/node3/hugepages/hugepages-
2048kB/nr_hugepages
```

This example command allocates four 1GB huge pages from **node1** and 1024 2MB huge pages from **node3**.

These huge page settings can be changed at any time with the above command, depending on the amount of free memory on the host system.



#### NOTE

The next two steps must also be completed the first time you allocate 1GB huge pages at runtime.

2. Mount the 2MB and 1GB huge pages on the host:

```
# mkdir /dev/hugepages1G
# mount -t hugetlbfs -o pagesize=1G none /dev/hugepages1G
# mkdir /dev/hugepages2M
# mount -t hugetlbfs -o pagesize=2M none /dev/hugepages2M
```

3. Add the following lines to the **memoryBacking** section in the virtual machine's XML configuration:

```
<hugepages>
  <page size='1' unit='GiB'/>
</hugepages>
```

4. Restart libvirtd to enable the use of 1GB huge pages on guests:

```
# systemctl restart libvirtd
```

## 8.3. KERNEL SAME-PAGE MERGING (KSM)

Kernel same-page Merging (KSM), used by the KVM hypervisor, allows KVM guests to share identical memory pages. These shared pages are usually common libraries or other identical, high-use data. KSM allows for greater guest density of identical or similar guest operating systems by avoiding memory duplication.

The concept of shared memory is common in modern operating systems. For example, when a program is first started, it shares all of its memory with the parent program. When either the child or parent program tries to modify this memory, the kernel allocates a new memory region, copies the original contents and allows the program to modify this new region. This is known as copy on write.

KSM is a Linux feature which uses this concept in reverse. KSM enables the kernel to examine two or more already running programs and compare their memory. If any memory regions or pages are identical, KSM reduces multiple identical memory pages to a single page. This page is then marked copy on write. If the contents of the page is modified by a guest virtual machine, a new page is created for that guest.

This is useful for virtualization with KVM. When a guest virtual machine is started, it only inherits the memory from the host **qemu-kvm** process. Once the guest is running, the contents of the guest operating system image can be shared when guests are running the same operating system or applications. KSM allows KVM to request that these identical guest memory regions be shared.

KSM provides enhanced memory speed and utilization. With KSM, common process data is stored in cache or in main memory. This reduces cache misses for the KVM guests, which can improve performance for some applications and operating systems. Secondly, sharing memory reduces the overall memory usage of guests, which allows for higher densities and greater utilization of resources.



#### NOTE

In Red Hat Enterprise Linux 7, KSM is NUMA aware. This allows it to take NUMA locality into account while coalescing pages, thus preventing performance drops related to pages being moved to a remote node. Red Hat recommends avoiding cross-node memory merging when KSM is in use. If KSM is in use, change the `/sys/kernel/mm/ksm/merge_across_nodes` tunable to `0` to avoid merging pages across NUMA nodes. This can be done with the `virsh node-memory-tune --shm-merge-across-nodes 0` command. Kernel memory accounting statistics can eventually contradict each other after large amounts of cross-node merging. As such, `numad` can become confused after the KSM daemon merges large amounts of memory. If your system has a large amount of free memory, you may achieve higher performance by turning off and disabling the KSM daemon. See [Chapter 9, NUMA](#) for more information on NUMA.



#### IMPORTANT

Ensure the swap size is sufficient for the committed RAM even without taking KSM into account. KSM reduces the RAM usage of identical or similar guests. Overcommitting guests with KSM without sufficient swap space may be possible, but is not recommended because guest virtual machine memory use can result in pages becoming unshared.

Red Hat Enterprise Linux uses two separate methods for controlling KSM:

- The **ksm** service starts and stops the KSM kernel thread.
- The **ksmtuned** service controls and tunes the **ksm** service, dynamically managing same-page merging. **ksmtuned** starts the **ksm** service and stops the **ksm** service if memory sharing is not necessary. When new guests are created or destroyed, **ksmtuned** must be instructed with the **retune** parameter to run.

Both of these services are controlled with the standard service management tools.

**NOTE**

KSM is off by default on Red Hat Enterprise Linux 6.7.

**8.3.1. The KSM Service**

- The **ksm** service is included in the `qemu-kvm` package.
- When the **ksm** service is not started, Kernel same-page merging (KSM) shares only 2000 pages. This default value provides limited memory-saving benefits.
- When the **ksm** service is started, KSM will share up to half of the host system's main memory. Start the **ksm** service to enable KSM to share more memory.

```
# systemctl start ksm
Starting ksm: [ OK ]
```

The **ksm** service can be added to the default startup sequence. Make the **ksm** service persistent with the `systemctl` command.

```
# systemctl enable ksm
```

**8.3.2. The KSM Tuning Service**

The **ksmtuned** service fine-tunes the kernel same-page merging (KSM) configuration by looping and adjusting **ksm**. In addition, the **ksmtuned** service is notified by `libvirt` when a guest virtual machine is created or destroyed. The **ksmtuned** service has no options.

```
# systemctl start ksmtuned
Starting ksmtuned: [ OK ]
```

The **ksmtuned** service can be tuned with the `retune` parameter, which instructs **ksmtuned** to run tuning functions manually.

The `/etc/ksmtuned.conf` file is the configuration file for the **ksmtuned** service. The file output below is the default `ksmtuned.conf` file:

```
# Configuration file for ksmtuned.
# How long ksmtuned should sleep between tuning adjustments
# KSM_MONITOR_INTERVAL=60

# Millisecond sleep between ksm scans for 16Gb server.
# Smaller servers sleep more, bigger sleep less.
# KSM_SLEEP_MSEC=10

# KSM_NPAGES_BOOST - is added to the `npages` value, when `free memory` is less than `thres`.
# KSM_NPAGES_BOOST=300

# KSM_NPAGES_DECAY - is the value given is subtracted to the `npages` value, when `free
memory` is greater than `thres`.
# KSM_NPAGES_DECAY=-50

# KSM_NPAGES_MIN - is the lower limit for the `npages` value.
# KSM_NPAGES_MIN=64
```

```
# KSM_NPAGES_MAX - is the upper limit for the `npages` value.
# KSM_NPAGES_MAX=1250

# KSM_THRES_COEF - is the RAM percentage to be calculated in parameter `thres`.
# KSM_THRES_COEF=20

# KSM_THRES_CONST - If this is a low memory system, and the `thres` value is less than
`KSM_THRES_CONST`, then reset `thres` value to `KSM_THRES_CONST` value.
# KSM_THRES_CONST=2048

# uncomment the following to enable ksmtuned debug information
# LOGFILE=/var/log/ksmtuned
# DEBUG=1
```

Within the `/etc/ksmtuned.conf` file, **npages** sets how many pages **ksm** will scan before the **ksmd** daemon becomes inactive. This value will also be set in the `/sys/kernel/mm/ksm/pages_to_scan` file.

The **KSM\_THRES\_CONST** value represents the amount of available memory used as a threshold to activate **ksm**. **ksmd** is activated if either of the following occurs:

- The amount of free memory drops below the threshold, set in **KSM\_THRES\_CONST**.
- The amount of committed memory plus the threshold, **KSM\_THRES\_CONST**, exceeds the total amount of memory.

### 8.3.3. KSM Variables and Monitoring

Kernel same-page merging (KSM) stores monitoring data in the `/sys/kernel/mm/ksm/` directory. Files in this directory are updated by the kernel and are an accurate record of KSM usage and statistics.

The variables in the list below are also configurable variables in the `/etc/ksmtuned.conf` file, as noted above.

#### Files in `/sys/kernel/mm/ksm/`:

##### **full\_scans**

Full scans run.

##### **merge\_across\_nodes**

Whether pages from different NUMA nodes can be merged.

##### **pages\_shared**

Total pages shared.

##### **pages\_sharing**

Pages currently shared.

##### **pages\_to\_scan**

Pages not scanned.

##### **pages\_unshared**



Pages no longer shared.

### **pages\_volatile**

Number of volatile pages.

### **run**

Whether the KSM process is running.

### **sleep\_millisecs**

Sleep milliseconds.

These variables can be manually tuned using the **virsh node-memory-tune** command. For example, the following specifies the number of pages to scan before the shared memory service goes to sleep:

```
# virsh node-memory-tune --shm-pages-to-scan number
```

KSM tuning activity is stored in the **/var/log/ksmtuned** log file if the **DEBUG=1** line is added to the **/etc/ksmtuned.conf** file. The log file location can be changed with the **LOGFILE** parameter. Changing the log file location is not advised and may require special configuration of SELinux settings.

## 8.3.4. Deactivating KSM

Kernel same-page merging (KSM) has a performance overhead which may be too large for certain environments or host systems. KSM may also introduce side channels that could be potentially used to leak information across guests. If this is a concern, KSM can be disabled on per-guest basis.

KSM can be deactivated by stopping the **ksmtuned** and the **ksm** services. However, this action does not persist after restarting. To deactivate KSM, run the following in a terminal as root:

```
# systemctl stop ksmtuned
Stopping ksmtuned:                [ OK ]
# systemctl stop ksm
Stopping ksm:                      [ OK ]
```

Stopping the **ksmtuned** and the **ksm** deactivates KSM, but this action does not persist after restarting. Persistently deactivate KSM with the **systemctl** commands:

```
# systemctl disable ksm
# systemctl disable ksmtuned
```

When KSM is disabled, any memory pages that were shared prior to deactivating KSM are still shared. To delete all of the PageKSM in the system, use the following command:

```
# echo 2 >/sys/kernel/mm/ksm/run
```

After this is performed, the **khugepaged** daemon can rebuild transparent hugepages on the KVM guest physical memory. Using **# echo 0 >/sys/kernel/mm/ksm/run** stops KSM, but does not unshare all the previously created KSM pages (this is the same as the **# systemctl stop ksmtuned** command).

## CHAPTER 9. NUMA

Historically, all memory on AMD64 and Intel 64 systems is equally accessible by all CPUs. Known as Uniform Memory Access (UMA), access times are the same no matter which CPU performs the operation.

This behavior is no longer the case with recent AMD64 and Intel 64 processors. In Non-Uniform Memory Access (NUMA), system memory is divided across NUMA *nodes*, which correspond to sockets or to a particular set of CPUs that have identical access latency to the local subset of system memory.

This chapter describes memory allocation and NUMA tuning configurations in virtualized environments.

### 9.1. NUMA MEMORY ALLOCATION POLICIES

The following policies define how memory is allocated from the nodes in a system:

#### **Strict**

Strict policy means that the allocation will fail if the memory cannot be allocated on the target node.

Specifying a NUMA nodeset list without defining a memory mode attribute defaults to **strict** mode.

#### **Interleave**

Memory pages are allocated across nodes specified by a nodeset, but are allocated in a round-robin fashion.

#### **Preferred**

Memory is allocated from a single preferred memory node. If sufficient memory is not available, memory can be allocated from other nodes.

To enable the intended policy, set it as the value of the **<memory mode>** element of the domain XML file:

```
<numatune>
  <memory mode='preferred' nodeset='0'>
</numatune>
```



#### **IMPORTANT**

If memory is overcommitted in **strict** mode and the guest does not have sufficient swap space, the kernel will kill some guest processes to retrieve additional memory. Red Hat recommends using **preferred** allocation and specifying a single nodeset (for example, nodeset='0') to prevent this situation.

### 9.2. AUTOMATIC NUMA BALANCING

Automatic NUMA balancing improves the performance of applications running on NUMA hardware systems. It is enabled by default on Red Hat Enterprise Linux 7 systems.

An application will generally perform best when the threads of its processes are accessing memory on the same NUMA node as the threads are scheduled. Automatic NUMA balancing moves tasks (which can be threads or processes) closer to the memory they are accessing. It also moves application data to

memory closer to the tasks that reference it. This is all done automatically by the kernel when automatic NUMA balancing is active.

Automatic NUMA balancing uses a number of algorithms and data structures, which are only active and allocated if automatic NUMA balancing is active on the system:

- Periodic NUMA unmapping of process memory
- NUMA hinting fault
- Migrate-on-Fault (MoF) - moves memory to where the program using it runs
- `task_numa_placement` - moves running programs closer to their memory

### 9.2.1. Configuring Automatic NUMA Balancing

Automatic NUMA balancing is enabled by default in Red Hat Enterprise Linux 7, and will automatically activate when booted on hardware with NUMA properties.

Automatic NUMA balancing is enabled when both of the following conditions are met:

- `# numactl --hardware` shows multiple nodes
- `# cat /proc/sys/kernel/numa_balancing` shows **1**

Manual NUMA tuning of applications will override automatic NUMA balancing, disabling periodic unmapping of memory, NUMA faults, migration, and automatic NUMA placement of those applications.

In some cases, system-wide manual NUMA tuning is preferred.

To disable automatic NUMA balancing, use the following command:

```
# echo 0 > /proc/sys/kernel/numa_balancing
```

To enable automatic NUMA balancing, use the following command:

```
# echo 1 > /proc/sys/kernel/numa_balancing
```

## 9.3. LIBVIRT NUMA TUNING

Generally, best performance on NUMA systems is achieved by limiting guest size to the amount of resources on a single NUMA node. Avoid unnecessarily splitting resources across NUMA nodes.

Use the **numastat** tool to view per-NUMA-node memory statistics for processes and the operating system.

In the following example, the **numastat** tool shows four virtual machines with suboptimal memory alignment across NUMA nodes:

```
# numastat -c qemu-kvm
```

```
Per-node process memory usage (in MBs)
```

```
PID          Node 0 Node 1 Node 2 Node 3 Node 4 Node 5 Node 6 Node 7 Total
```

```
-----
51722 (qemu-kvm) 68  16  357 6936  2  3  147  598 8128
```

```

51747 (qemu-kvm) 245 11 5 18 5172 2532 1 92 8076
53736 (qemu-kvm) 62 432 1661 506 4851 136 22 445 8116
53773 (qemu-kvm) 1393 3 1 2 12 0 0 6702 8114
-----
Total          1769 463 2024 7462 10037 2672 169 7837 32434

```

Run **numad** to align the guests' CPUs and memory resources automatically.

Then run **numastat -c qemu-kvm** again to view the results of running **numad**. The following output shows that resources have been aligned:

```

# numastat -c qemu-kvm

Per-node process memory usage (in MBs)
PID          Node 0 Node 1 Node 2 Node 3 Node 4 Node 5 Node 6 Node 7 Total
-----
51747 (qemu-kvm) 0 0 7 0 8072 0 1 0 8080
53736 (qemu-kvm) 0 0 7 0 0 0 8113 0 8120
53773 (qemu-kvm) 0 0 7 0 0 0 1 8110 8118
59065 (qemu-kvm) 0 0 8050 0 0 0 0 0 8051
-----
Total          0 0 8072 0 8072 0 8114 8110 32368

```



#### NOTE

Running **numastat** with **-c** provides compact output; adding the **-m** option adds system-wide memory information on a per-node basis to the output. See the **numastat** man page for more information.

### 9.3.1. Monitoring Memory per host NUMA Node

You can use the **nodestats.py** script to report the total memory and free memory for each NUMA node on a host. This script also reports how much memory is strictly bound to certain host nodes for each running domain. For example:

```

# /usr/share/doc/libvirt-python-2.0.0/examples/nodestats.py
NUMA stats
NUMA nodes: 0 1 2 3
MemTotal: 3950 3967 3937 3943
MemFree: 66 56 42 41
Domain 'rhel7-0':
    Overall memory: 1536 MiB
Domain 'rhel7-1':
    Overall memory: 2048 MiB
Domain 'rhel6':
    Overall memory: 1024 MiB nodes 0-1
    Node 0: 1024 MiB nodes 0-1
Domain 'rhel7-2':
    Overall memory: 4096 MiB nodes 0-3
    Node 0: 1024 MiB nodes 0
    Node 1: 1024 MiB nodes 1
    Node 2: 1024 MiB nodes 2
    Node 3: 1024 MiB nodes 3

```

This example shows four host NUMA nodes, each containing approximately 4GB of RAM in total (**MemTotal**). Nearly all memory is consumed on each domain ( **MemFree**). There are four domains (virtual machines) running: domain *'rhel7-0'* has 1.5GB memory which is not pinned onto any specific host NUMA node. Domain *'rhel7-2'* however, has 4GB memory and 4 NUMA nodes which are pinned 1:1 to host nodes.

To print host NUMA node statistics, create a **nodestats.py** script for your environment. An example script can be found in the `libvirt-python` package files in `/usr/share/doc/libvirt-python-version/examples/nodestats.py`. The specific path to the script can be displayed by using the `rpm -ql libvirt-python` command.

### 9.3.2. NUMA vCPU Pinning

vCPU pinning provides similar advantages to task pinning on bare metal systems. Since vCPUs run as user-space tasks on the host operating system, pinning increases cache efficiency. One example of this is an environment where all vCPU threads are running on the same physical socket, therefore sharing a L3 cache domain.



#### NOTE

In Red Hat Enterprise Linux versions 7.0 to 7.2, it is only possible to pin active vCPUs. However, with Red Hat Enterprise Linux 7.3, pinning inactive vCPUs is available as well.

Combining vCPU pinning with **numatune** can avoid NUMA misses. The performance impacts of NUMA misses are significant, generally starting at a 10% performance hit or higher. vCPU pinning and **numatune** should be configured together.

If the virtual machine is performing storage or network I/O tasks, it can be beneficial to pin all vCPUs and memory to the same physical socket that is physically connected to the I/O adapter.



#### NOTE

The **Istopo** tool can be used to visualize NUMA topology. It can also help verify that vCPUs are binding to cores on the same physical socket. See the following Knowledgebase article for more information on **Istopo**: <https://access.redhat.com/site/solutions/62879>.



#### IMPORTANT

Pinning causes increased complexity where there are many more vCPUs than physical cores.

The following example XML configuration has a domain process pinned to physical CPUs 0-7. The vCPU thread is pinned to its own cpuset. For example, vCPU0 is pinned to physical CPU 0, vCPU1 is pinned to physical CPU 1, and so on:

```
<vcpu cpuset='0-7'>8</vcpu>
  <cpuset>
    <vcupin vcpu='0' cpuset='0'>
    <vcupin vcpu='1' cpuset='1'>
    <vcupin vcpu='2' cpuset='2'>
    <vcupin vcpu='3' cpuset='3'>
    <vcupin vcpu='4' cpuset='4'>
```

```

    <vcpupin vcpu='5' cpuset='5'/>
    <vcpupin vcpu='6' cpuset='6'/>
    <vcpupin vcpu='7' cpuset='7'/>
  </cputune>

```

There is a direct relationship between the `vcpu` and `vcpupin` tags. If a `vcpupin` option is not specified, the value will be automatically determined and inherited from the parent `vcpu` tag option. The following configuration shows `<vcpupin>` for `vcpu 5` missing. Hence, `vCPU5` would be pinned to physical CPUs 0-7, as specified in the parent tag `<vcpu>`:

```

<vcpu cpuset='0-7'>8</vcpu>
  <cputune>
    <vcpupin vcpu='0' cpuset='0'/>
    <vcpupin vcpu='1' cpuset='1'/>
    <vcpupin vcpu='2' cpuset='2'/>
    <vcpupin vcpu='3' cpuset='3'/>
    <vcpupin vcpu='4' cpuset='4'/>
    <vcpupin vcpu='6' cpuset='6'/>
    <vcpupin vcpu='7' cpuset='7'/>
  </cputune>

```



### IMPORTANT

`<vcpupin>`, `<numatune>`, and `<emulatorpin>` should be configured together to achieve optimal, deterministic performance. For more information on the `<numatune>` tag, see [Section 9.3.3, "Domain Processes"](#). For more information on the `<emulatorpin>` tag, see [Section 9.3.6, "Using emulatorpin"](#).

### 9.3.3. Domain Processes

As provided in Red Hat Enterprise Linux, libvirt uses libnuma to set memory binding policies for domain processes. The nodeset for these policies can be configured either as *static* (specified in the domain XML) or *auto* (configured by querying numad). See the following XML configuration for examples on how to configure these inside the `<numatune>` tag:

```

<numatune>
  <memory mode='strict' placement='auto'/>
</numatune>

```

```

<numatune>
  <memory mode='strict' nodeset='0,2-3'/>
</numatune>

```

libvirt uses `sched_setaffinity(2)` to set CPU binding policies for domain processes. The `cpuset` option can either be *static* (specified in the domain XML) or *auto* (configured by querying numad). See the following XML configuration for examples on how to configure these inside the `<vcpu>` tag:

```

<vcpu placement='auto'>8</vcpu>

```

```

<vcpu placement='static' cpuset='0-10,^5'>8</vcpu>

```

There are implicit inheritance rules between the placement mode you use for `<vcpu>` and `<numatune>`:

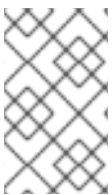
- The placement mode for `<numatune>` defaults to the same placement mode of `<vcpu>`, or to *static* if a `<nodeset>` is specified.
- Similarly, the placement mode for `<vcpu>` defaults to the same placement mode of `<numatune>`, or to *static* if `<cpuset>` is specified.

This means that CPU tuning and memory tuning for domain processes can be specified and defined separately, but they can also be configured to be dependent on the other's placement mode.

It is also possible to configure your system with numad to boot a selected number of vCPUs without pinning all vCPUs at startup.

For example, to enable only 8 vCPUs at boot on a system with 32 vCPUs, configure the XML similar to the following:

```
<vcpu placement='auto' current='8'>32</vcpu>
```



#### NOTE

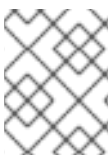
See the following URLs for more information on vcpu and numatune:  
<http://libvirt.org/formatdomain.html#elementsCPUAllocation> and  
<http://libvirt.org/formatdomain.html#elementsNUMATuning>

### 9.3.4. Domain vCPU Threads

In addition to tuning domain processes, libvirt also permits the setting of the pinning policy for each vcpu thread in the XML configuration. Set the pinning policy for each vcpu thread inside the `<cputune>` tags:

```
<cputune>
  <vcupin vcpu="0" cpuset="1-4,^2"/>
  <vcupin vcpu="1" cpuset="0,1"/>
  <vcupin vcpu="2" cpuset="2,3"/>
  <vcupin vcpu="3" cpuset="0,4"/>
</cputune>
```

In this tag, libvirt uses either cgroup or `sched_setaffinity(2)` to pin the vcpu thread to the specified cpuset.



#### NOTE

For more details on `<cputune>`, see the following URL:  
<http://libvirt.org/formatdomain.html#elementsCPUTuning>

In addition, if you need to set up a virtual machines with more vCPU than a single NUMA node, configure the host so that the guest detects a NUMA topology on the host. This allows for 1:1 mapping of CPUs, memory, and NUMA nodes. For example, this can be applied with a guest with 4 vCPUs and 6 GB memory, and a host with the following NUMA settings:

```
4 available nodes (0-3)
Node 0: CPUs 0 4, size 4000 MiB
Node 1: CPUs 1 5, size 3999 MiB
```

Node 2: CPUs 2 6, size 4001 MiB  
 Node 3: CPUs 0 4, size 4005 MiB

In this scenario, use the following Domain XML setting:

```
<cputune>
  <vcpupin vcpu="0" cpuset="1"/>
  <vcpupin vcpu="1" cpuset="5"/>
  <vcpupin vcpu="2" cpuset="2"/>
  <vcpupin vcpu="3" cpuset="6"/>
</cputune>
<numatune>
  <memory mode="strict" nodeset="1-2"/>
</numatune>
<cpu>
  <numa>
    <cell id="0" cpus="0-1" memory="3" unit="GiB"/>
    <cell id="1" cpus="2-3" memory="3" unit="GiB"/>
  </numa>
</cpu>
```

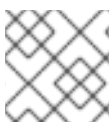
### 9.3.5. Using Cache Allocation Technology to Improve Performance

You can make use of Cache Allocation Technology (CAT) provided by the kernel on specific CPU models. This enables allocation of part of the host CPU's cache for vCPU threads, which improves real-time performance.

See the following XML configuration for an example on how to configure vCPU cache allocation inside the **cachetune** tag:

```
<domain>
  <cputune>
    <cachetune vcpus='0-1'>
      <cache id='0' level='3' type='code' size='3' unit='MiB'/>
      <cache id='0' level='3' type='data' size='3' unit='MiB'/>
    </cachetune>
  </cputune>
</domain>
```

The XML file above configures the thread for vCPUs 0 and 1 to have 3 MiB from the first L3 cache (level='3' id='0') allocated, once for the L3CODE and once for L3DATA.



#### NOTE

A single virtual machine can have multiple **<cachetune>** elements.

For more information see **cachetune** in the [upstream libvirt documentation](#).

### 9.3.6. Using emulatorpin

Another way of tuning the domain process pinning policy is to use the **<emulatorpin>** tag inside of **<cputune>**.



The `<emulatorpin>` tag specifies which host physical CPUs the *emulator* (a subset of a domain, not including vCPUs) will be pinned to. The `<emulatorpin>` tag provides a method of setting a precise affinity to emulator thread processes. As a result, vhost threads run on the same subset of physical CPUs and memory, and therefore benefit from cache locality. For example:

```
<cputune>
  <emulatorpin cpuset="1-3"/>
</cputune>
```



#### NOTE

In Red Hat Enterprise Linux 7, automatic NUMA balancing is enabled by default. Automatic NUMA balancing reduces the need for manually tuning `<emulatorpin>`, since the vhost-net emulator thread follows the vCPU tasks more reliably. For more information about automatic NUMA balancing, see [Section 9.2, "Automatic NUMA Balancing"](#).

### 9.3.7. Tuning vCPU Pinning with virsh



#### IMPORTANT

These are example commands only. You will need to substitute values according to your environment.

The following example **virsh** command will pin the vcpu thread *rhel7* which has an ID of 1 to the physical CPU 2:

```
% virsh vcpupin rhel7 1 2
```

You can also obtain the current vcpu pinning configuration with the **virsh** command. For example:

```
% virsh vcpupin rhel7
```

### 9.3.8. Tuning Domain Process CPU Pinning with virsh



#### IMPORTANT

These are example commands only. You will need to substitute values according to your environment.

The **emulatorpin** option applies CPU affinity settings to threads that are associated with each domain process. For complete pinning, you must use both **virsh vcpupin** (as shown previously) and **virsh emulatorpin** for each guest. For example:

```
% virsh emulatorpin rhel7 3-4
```

### 9.3.9. Tuning Domain Process Memory Policy with virsh

Domain process memory can be dynamically tuned. See the following example command:

■

```
% virsh numatune rhel7 --nodeset 0-10
```

More examples of these commands can be found in the **virsh** man page.

### 9.3.10. Guest NUMA Topology

Guest NUMA topology can be specified using the **<numa>** tag inside the **<cpu>** tag in the guest virtual machine's XML. See the following example, and replace values accordingly:

```
<cpu>
...
  <numa>
    <cell cpus='0-3' memory='512000'/>
    <cell cpus='4-7' memory='512000'/>
  </numa>
...
</cpu>
```

Each **<cell>** element specifies a NUMA cell or a NUMA node. **cpus** specifies the CPU or range of CPUs that are part of the node, and **memory** specifies the node memory in kibibytes (blocks of 1024 bytes). Each cell or node is assigned a **cellid** or **nodeid** in increasing order starting from 0.



#### IMPORTANT

When modifying the NUMA topology of a guest virtual machine with a configured topology of CPU sockets, cores, and threads, make sure that cores and threads belonging to a single socket are assigned to the same NUMA node. If threads or cores from the same socket are assigned to different NUMA nodes, the guest may fail to boot.



#### WARNING

Using guest NUMA topology simultaneously with [huge pages](#) is not supported on Red Hat Enterprise Linux 7 and is only available in layered products such as [Red Hat Virtualization](#) or [Red Hat OpenStack Platform](#).

### 9.3.11. NUMA Node Locality for PCI Devices

When starting a new virtual machine, it is important to know both the host NUMA topology and the PCI device affiliation to NUMA nodes, so that when PCI passthrough is requested, the guest is pinned onto the correct NUMA nodes for optimal memory performance.

For example, if a guest is pinned to NUMA nodes 0-1, but one of its PCI devices is affiliated with node 2, data transfer between nodes will take some time.

In Red Hat Enterprise Linux 7.1 and above, libvirt reports the NUMA node locality for PCI devices in the guest XML, enabling management applications to make better performance decisions.

This information is visible in the **sysfs** files in **/sys/devices/pci\*/\*/numa\_node**. One way to verify these settings is to use the **lstopo** tool to report **sysfs** data:

-

**# Istopo-no-graphics**

Machine (126GB)

NUMANode L#0 (P#0 63GB)

Socket L#0 + L3 L#0 (20MB)

L2 L#0 (256KB) + L1d L#0 (32KB) + L1i L#0 (32KB) + Core L#0 + PU L#0 (P#0)

L2 L#1 (256KB) + L1d L#1 (32KB) + L1i L#1 (32KB) + Core L#1 + PU L#1 (P#2)

L2 L#2 (256KB) + L1d L#2 (32KB) + L1i L#2 (32KB) + Core L#2 + PU L#2 (P#4)

L2 L#3 (256KB) + L1d L#3 (32KB) + L1i L#3 (32KB) + Core L#3 + PU L#3 (P#6)

L2 L#4 (256KB) + L1d L#4 (32KB) + L1i L#4 (32KB) + Core L#4 + PU L#4 (P#8)

L2 L#5 (256KB) + L1d L#5 (32KB) + L1i L#5 (32KB) + Core L#5 + PU L#5 (P#10)

L2 L#6 (256KB) + L1d L#6 (32KB) + L1i L#6 (32KB) + Core L#6 + PU L#6 (P#12)

L2 L#7 (256KB) + L1d L#7 (32KB) + L1i L#7 (32KB) + Core L#7 + PU L#7 (P#14)

HostBridge L#0

PCIBridge

PCI 8086:1521

Net L#0 "em1"

PCI 8086:1521

Net L#1 "em2"

PCI 8086:1521

Net L#2 "em3"

PCI 8086:1521

Net L#3 "em4"

PCIBridge

PCI 1000:005b

Block L#4 "sda"

Block L#5 "sdb"

Block L#6 "sdc"

Block L#7 "sdd"

PCIBridge

PCI 8086:154d

Net L#8 "p3p1"

PCI 8086:154d

Net L#9 "p3p2"

PCIBridge

PCIBridge

PCIBridge

PCIBridge

PCI 102b:0534

GPU L#10 "card0"

GPU L#11 "controlD64"

PCI 8086:1d02

NUMANode L#1 (P#1 63GB)

Socket L#1 + L3 L#1 (20MB)

L2 L#8 (256KB) + L1d L#8 (32KB) + L1i L#8 (32KB) + Core L#8 + PU L#8 (P#1)

L2 L#9 (256KB) + L1d L#9 (32KB) + L1i L#9 (32KB) + Core L#9 + PU L#9 (P#3)

L2 L#10 (256KB) + L1d L#10 (32KB) + L1i L#10 (32KB) + Core L#10 + PU L#10 (P#5)

L2 L#11 (256KB) + L1d L#11 (32KB) + L1i L#11 (32KB) + Core L#11 + PU L#11 (P#7)

L2 L#12 (256KB) + L1d L#12 (32KB) + L1i L#12 (32KB) + Core L#12 + PU L#12 (P#9)

L2 L#13 (256KB) + L1d L#13 (32KB) + L1i L#13 (32KB) + Core L#13 + PU L#13 (P#11)

L2 L#14 (256KB) + L1d L#14 (32KB) + L1i L#14 (32KB) + Core L#14 + PU L#14 (P#13)

L2 L#15 (256KB) + L1d L#15 (32KB) + L1i L#15 (32KB) + Core L#15 + PU L#15 (P#15)

HostBridge L#8

PCIBridge

PCI 1924:0903

Net L#12 "p1p1"

PCI 1924:0903

```

Net L#13 "p1p2"
PCIBridge
PCI 15b3:1003
Net L#14 "ib0"
Net L#15 "ib1"
OpenFabrics L#16 "mlx4_0"

```

This output shows:

- NICs **em\*** and disks **sd\*** are connected to NUMA node 0 and cores 0,2,4,6,8,10,12,14.
- NICs **p1\*** and **ib\*** are connected to NUMA node 1 and cores 1,3,5,7,9,11,13,15.

## 9.4. NUMA-AWARE KERNEL SAMEPAGE MERGING (KSM)

Kernel SamePage Merging (KSM) allows virtual machines to share identical memory pages. KSM can detect that a system is using NUMA memory and control merging pages across different NUMA nodes.

Use the **sysfs /sys/kernel/mm/ksm/merge\_across\_nodes** parameter to control merging of pages across different NUMA nodes. By default, pages from all nodes can be merged together. When this parameter is set to zero, only pages from the same node are merged.

Generally, unless you are oversubscribing the system memory, you will get better runtime performance by disabling KSM sharing.



### IMPORTANT

When KSM merges across nodes on a NUMA host with multiple guest virtual machines, guests and CPUs from more distant nodes can suffer a significant increase of access latency to the merged KSM page.

To instruct the hypervisor to disable share pages for a guest, add the following to the guest's XML:

```

<memoryBacking>
  <nosharepages/>
</memoryBacking>

```

For more information about tuning memory settings with the **<memoryBacking>** element, see [Section 8.2.2, "Memory Tuning with virsh"](#).

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## APPENDIX A. REVISION HISTORY

<b>Revision 1.0-35</b> Version for 7.7 Beta publication	<b>Thus May 23 2019</b>	<b>Jiri Herrmann</b>
<b>Revision 1.0-34</b> Version for 7.6 GA publication	<b>Tue Oct 25 2018</b>	<b>Jiri Herrmann</b>
<b>Revision 1.0-32</b> Version for 7.6 Beta publication	<b>Tue Aug 14 2018</b>	<b>Jiri Herrmann</b>
<b>Revision 1.0-31</b> Version for 7.5 GA publication	<b>Wed Apr 4 2018</b>	<b>Jiri Herrmann</b>
<b>Revision 1.0-27</b> Version for 7.4 GA publication	<b>Mon Jul 27 2017</b>	<b>Jiri Herrmann</b>
<b>Revision 1.0-24</b> Version for 7.3 GA publication	<b>Mon Oct 17 2016</b>	<b>Jiri Herrmann</b>
<b>Revision 1.0-22</b> Republished Guide to fix several bugs	<b>Mon Dec 21 2015</b>	<b>Laura Novich</b>
<b>Revision 1.0-19</b> Cleaned up Revision History	<b>Thu Oct 08 2015</b>	<b>Jiri Herrmann</b>