Red Hat Enterprise Linux 6 Resource Management Guide

Managing system resources on Red Hat Enterprise Linux 6
Edition 6

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Abstract

Managing system resources on Red Hat Enterprise Linux 6.

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Chapter 1. Introduction to Control Groups (Cgroups)

Red Hat Enterprise Linux 6 provides a new kernel feature: *control groups*, which are called by their shorter name *cgroups* in this guide. Cgroups allow you to allocate resources—such as CPU time, system memory, network bandwidth, or combinations of these resources—among user-defined groups of tasks (processes) running on a system. You can monitor the cgroups you configure, deny cgroups access to certain resources, and even reconfigure your cgroups dynamically on a running system. The **cgconfig** (*control group config*) service can be configured to start up at boot time and reestablish your predefined cgroups, thus making them persistent across reboots.

By using cgroups, system administrators gain fine-grained control over allocating, prioritizing, denying, managing, and monitoring system resources. Hardware resources can be appropriately divided up among tasks and users, increasing overall efficiency.

1.1. How Control Groups Are Organized

Cgroups are organized hierarchically, like processes, and child cgroups inherit some of the attributes of their parents. However, there are differences between the two models.

The Linux Process Model

All processes on a Linux system are child processes of a common parent: the **init** process, which is executed by the kernel at boot time and starts other processes (which may in turn start child processes of their own). Because all processes descend from a single parent, the Linux process model is a single hierarchy, or tree.

Additionally, every Linux process except **init** inherits the environment (such as the PATH variable) [1] and certain other attributes (such as open file descriptors) of its parent process.

The Cgroup Model

Cgroups are similar to processes in that:

- they are hierarchical, and
- child cgroups inherit certain attributes from their parent cgroup.

The fundamental difference is that many different hierarchies of cgroups can exist simultaneously on a system. If the Linux process model is a single tree of processes, then the cgroup model is one or more separate, unconnected trees of tasks (i.e. processes).

Multiple separate hierarchies of cgroups are necessary because each hierarchy is attached to *one or more subsystems*. A subsystem [2] represents a single resource, such as CPU time or memory. Red Hat Enterprise Linux 6 provides ten cgroup subsystems, listed below by name and function.

Available Subsystems in Red Hat Enterprise Linux

- **blkio** — this subsystem sets limits on input/output access to and from block devices such as physical drives (disk, solid state, USB, etc.).
- **cpu** — this subsystem uses the scheduler to provide cgroup tasks access to the CPU.

- **cpuacct** — this subsystem generates automatic reports on CPU resources used by tasks in a cgroup.
- **cpuset** — this subsystem assigns individual CPUs (on a multicore system) and memory nodes to tasks in a cgroup.
- **devices** — this subsystem allows or denies access to devices by tasks in a cgroup.
- **freezer** — this subsystem suspends or resumes tasks in a cgroup.
- **memory** — this subsystem sets limits on memory use by tasks in a cgroup, and generates automatic reports on memory resources used by those tasks.
- **net_cls** — this subsystem tags network packets with a class identifier (classid) that allows the Linux traffic controller (**tc**) to identify packets originating from a particular cgroup task.
- **net_prio** — this subsystem provides a way to dynamically set the priority of network traffic per network interface.
- **ns** — the *namespace* subsystem.

Subsystems are also known as resource controllers

You may come across the term *resource controller* or simply *controller* in cgroup literature such as the man pages or kernel documentation. Both of these terms are synonymous with "subsystem", and arise from the fact that a subsystem typically schedules a resource or applies a limit to the cgroups in the hierarchy it is attached to.

The definition of a subsystem (resource controller) is quite general: it is something that acts upon a group of tasks, i.e. processes.

1.2. Relationships Between Subsystems, Hierarchies, Control Groups and Tasks

Remember that system processes are called tasks in cgroup terminology.

Here are a few simple rules governing the relationships between subsystems, hierarchies of cgroups, and tasks, along with explanatory consequences of those rules.

Rule 1

A single hierarchy can have one or more subsystems attached to it.

*As a consequence, the **cpu** and **memory** subsystems (or any number of subsystems) can be attached to a single hierarchy, as long as each one is not attached to any other hierarchy which has any other subsystems attached to it already (see Rule 2).*

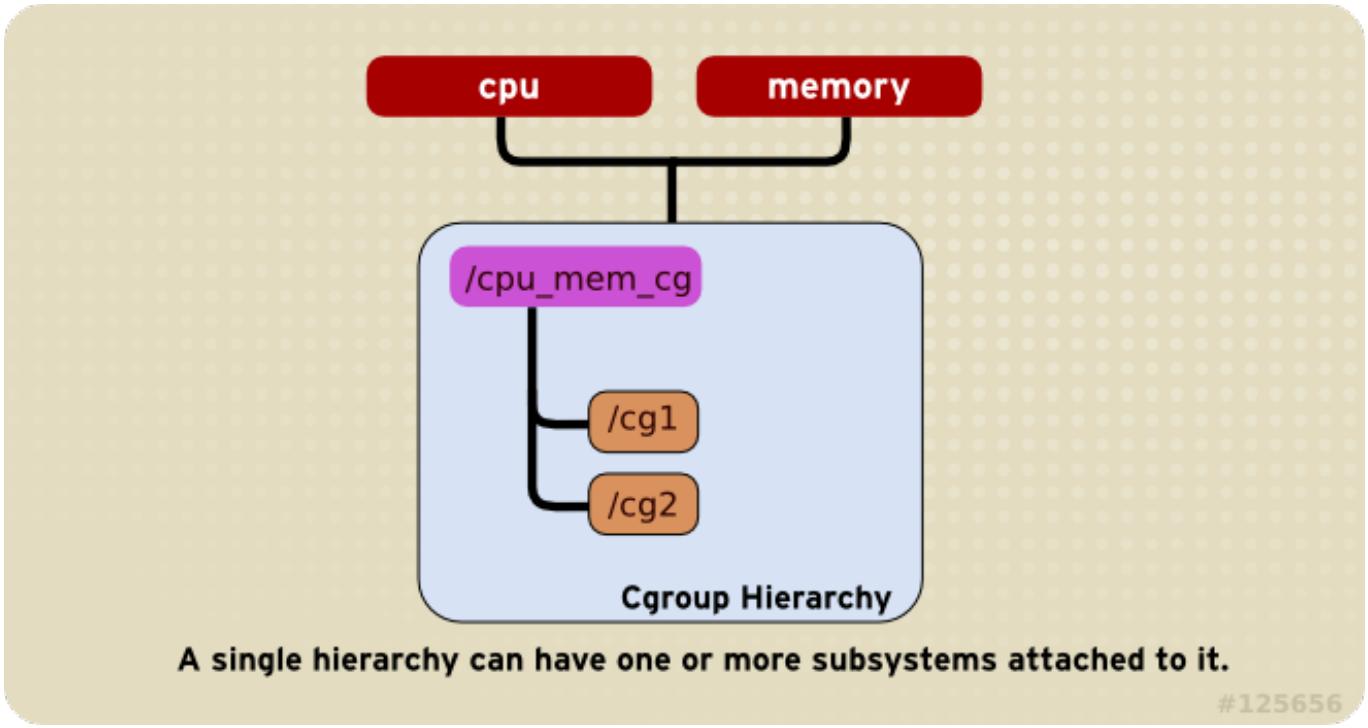


Figure 1.1. Rule 1

Rule 2

Any single subsystem (such as **cpu**) cannot be attached to more than one hierarchy if one of those hierarchies has a different subsystem attached to it already.

*As a consequence, the **cpu** subsystem can never be attached to two different hierarchies if one of those hierarchies already has the **memory** subsystem attached to it. However, a single subsystem can be attached to two hierarchies if both of those hierarchies have only that subsystem attached.*

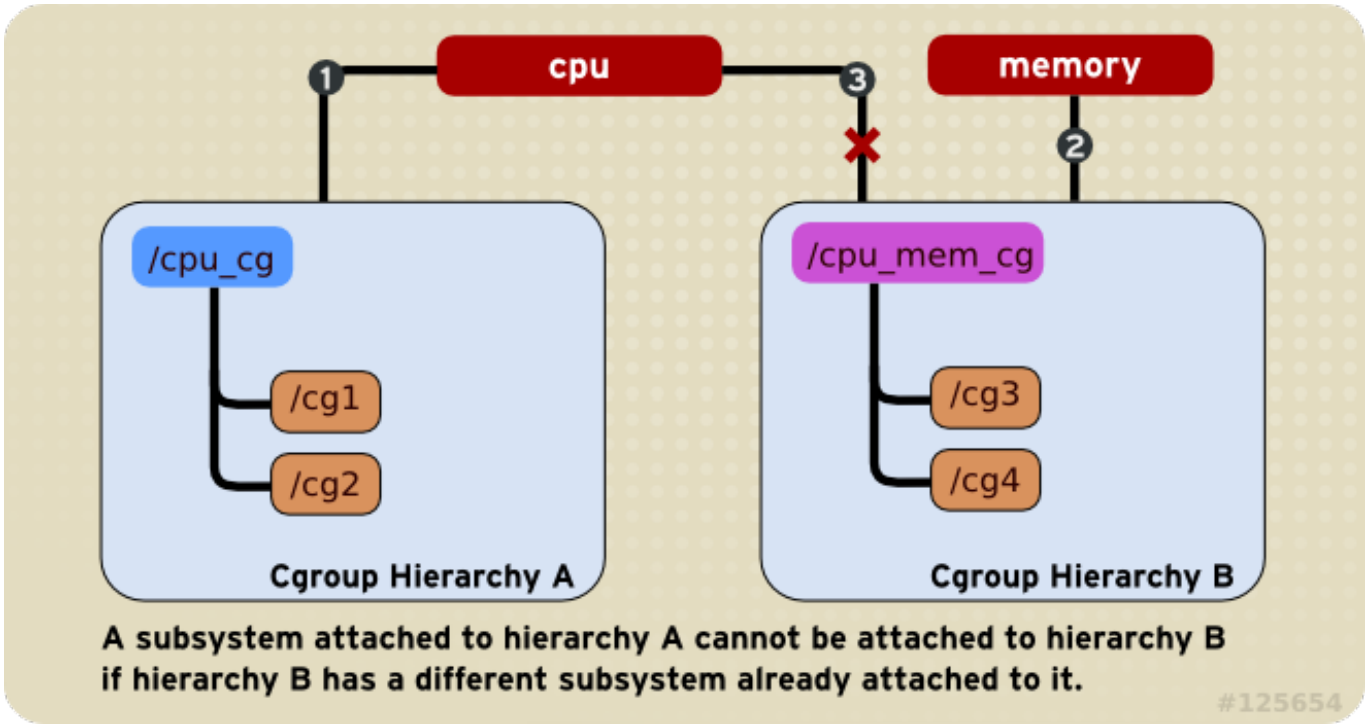


Figure 1.2. Rule 2—The numbered bullets represent a time sequence in which the subsystems are attached.

Rule 3

Each time a new hierarchy is created on the systems, all tasks on the system are initially members of the default cgroup of that hierarchy, which is known as the *root cgroup*. For any single hierarchy you create, each task on the system can be a member of *exactly one* cgroup in that hierarchy. A single task may be in multiple cgroups, as long as each of those cgroups is in a different hierarchy. As soon as a task becomes a member of a second cgroup in the same hierarchy, it is removed from the first cgroup in that hierarchy. At no time is a task ever in two different cgroups in the same hierarchy.

*As a consequence, if the **`cpu`** and **`memory`** subsystems are attached to a hierarchy named **`cpu_mem_cg`**, and the **`net_cls`** subsystem is attached to a hierarchy named **`net`**, then a running **`httpd`** process could be a member of any one cgroup in **`cpu_mem_cg`**, and any one cgroup in **`net`**.*

*The cgroup in **`cpu_mem_cg`** that the **`httpd`** process is a member of might restrict its CPU time to half of that allotted to other processes, and limit its memory usage to a maximum of **`1024`** MB. Additionally, the cgroup in **`net`** that it is a member of might limit its transmission rate to **`30`** megabytes per second.*

When the first hierarchy is created, every task on the system is a member of at least one cgroup: the root cgroup. When using cgroups, therefore, every system task is always in at least one cgroup.

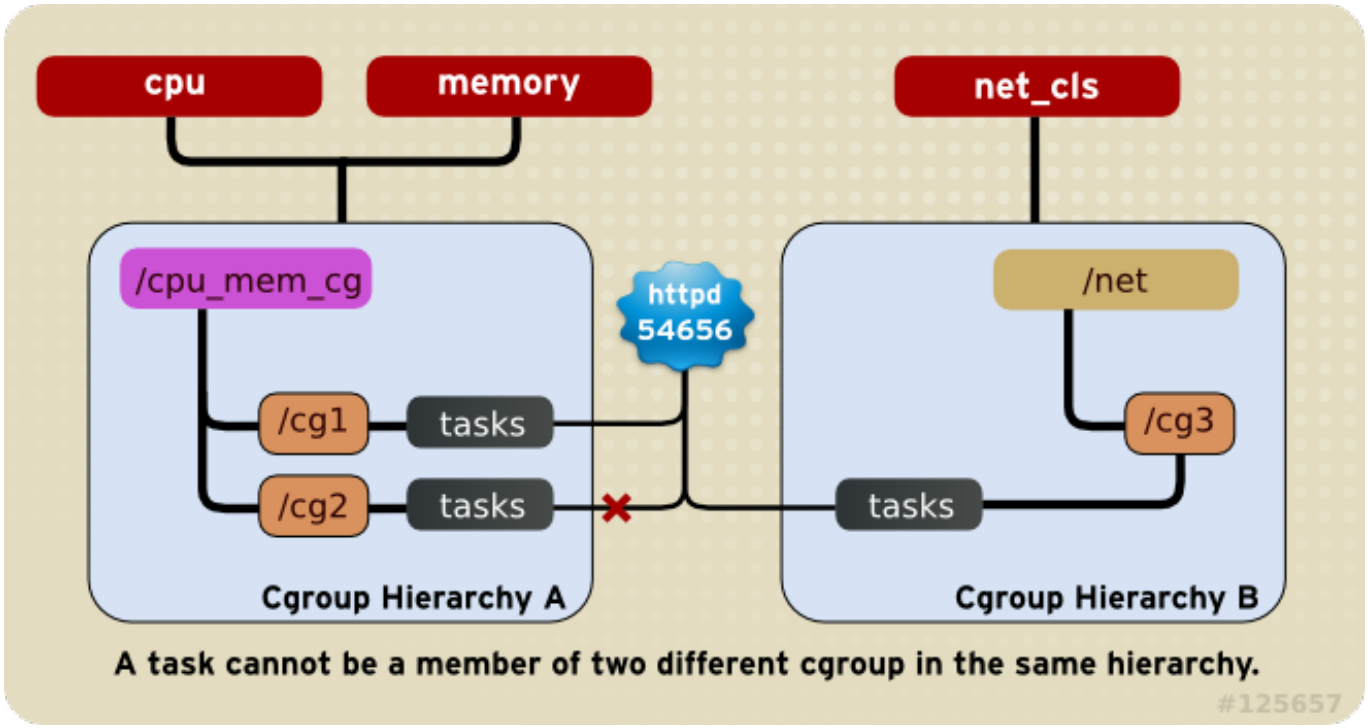


Figure 1.3. Rule 3

Rule 4

Any process (task) on the system which forks itself creates a child task. A child task automatically inherits the cgroup membership of its parent but can be moved to different cgroups as needed. Once forked, the parent and child processes are completely independent.

*As a consequence, consider the **`httpd`** task that is a member of the cgroup named **`half_cpu_1gb_max`** in the **`cpu_and_mem`** hierarchy, and a member of the cgroup **`trans_rate_30`** in the **`net`** hierarchy. When that **`httpd`** process forks itself, its child process automatically becomes a member of the **`half_cpu_1gb_max`** cgroup, and the **`trans_rate_30`** cgroup. It inherits the exact same cgroups its parent task belongs to.*

From that point forward, the parent and child tasks are completely independent of each other: changing the cgroups that one task belongs to does not affect the other. Neither will changing cgroups of a parent task affect any of its grandchildren in any way. To summarize: any child task always initially inherit memberships to the exact same cgroups as their parent task, but those memberships can be changed or removed later.

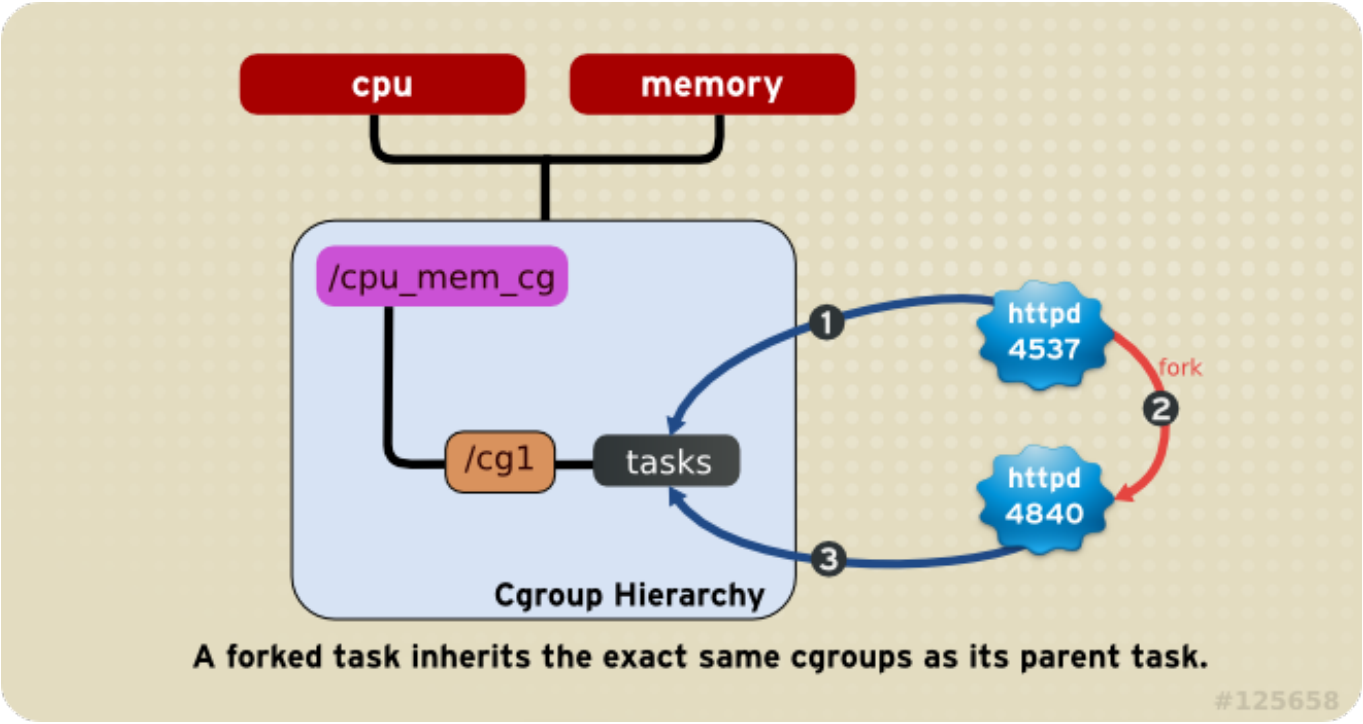


Figure 1.4. Rule 4—The numbered bullets represent a time sequence in which the task forks.

1.3. Implications for Resource Management

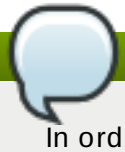
- Because a task can belong to only a single cgroup in any one hierarchy, there is only one way that a task can be limited or affected by any single subsystem. This is logical: a feature, not a limitation.
- You can group several subsystems together so that they affect all tasks in a single hierarchy. Because cgroups in that hierarchy have different parameters set, those tasks will be affected differently.
- It may sometimes be necessary to *refactor* a hierarchy. An example would be removing a subsystem from a hierarchy that has several subsystems attached, and attaching it to a new, separate hierarchy.
- Conversely, if the need for splitting subsystems among separate hierarchies is reduced, you can remove a hierarchy and attach its subsystems to an existing one.
- The design allows for simple cgroup usage, such as setting a few parameters for specific tasks in a single hierarchy, such as one with just the **cpu** and **memory** subsystems attached.
- The design also allows for highly specific configuration: each task (process) on a system could be a member of each hierarchy, each of which has a single attached subsystem. Such a configuration would give the system administrator absolute control over all parameters for every single task.

[1] The parent process is able to alter the environment before passing it to a child process.

[2] You should be aware that subsystems are also called *resource controllers*, or simply *controllers*, in the *libcgroup* man pages and other documentation.

Chapter 2. Using Control Groups

As explained in Chapter 3, *Subsystems and Tunable Parameters*, control groups and the subsystems to which they relate can be manipulated using shell commands and utilities. However, the easiest way to work with cgroups is to install the *libcgroup* package, which contains a number of cgroup-related command line utilities and their associated man pages. It is possible to *mount* hierarchies and set cgroup parameters (non-persistently) using shell commands and utilities available on any system. However, using the *libcgroup*-provided utilities simplifies the process and extends your capabilities. Therefore, this guide focuses on *libcgroup* commands throughout. In most cases, we have included the equivalent shell commands to help describe the underlying mechanism. However, we recommend that you use the *libcgroup* commands wherever practical.



Installing the libcgroup package

In order to use cgroups, first ensure the libcgroup package is installed on your system by running, as root:

```
~]# yum install libcgroup
```

2.1. The cgconfig Service

The **cgconfig** service installed with the *libcgroup* package provides a convenient way to create hierarchies, attach subsystems to hierarchies, and manage cgroups within those hierarchies. It is recommended that you use **cgconfig** to manage hierarchies and cgroups on your system.

The **cgconfig** service is not started by default on Red Hat Enterprise Linux 6. When you start the service with **chkconfig**, it reads the cgroup configuration file — **/etc/cgconfig.conf**. Cgroups are therefore recreated from session to session and remain persistent. Depending on the contents of the configuration file, **cgconfig** can create hierarchies, mount necessary file systems, create cgroups, and set subsystem parameters for each group.

The default **/etc/cgconfig.conf** file installed with the *libcgroup* package creates and mounts an individual hierarchy for each subsystem, and attaches the subsystems to these hierarchies. The **cgconfig** service also allows to create configuration files in the **/etc/cgconfig.d/** directory and to invoke them from **/etc/cgconfig.conf**.

If you stop the **cgconfig** service (with the **service cgconfig stop** command), it unmounts all the hierarchies that it mounted.

2.1.1. The /etc/cgconfig.conf File

The **/etc/cgconfig.conf** file contains two major types of entry — *mount* and *group*. Mount entries create and mount hierarchies as virtual file systems, and attach subsystems to those hierarchies. Mount entries are defined using the following syntax:

```
mount {
    subsystem = /cgroup/hierarchy;
    …
}
```

The *libcgroup* package automatically creates a default **/etc/cgconfig.conf** file when it is installed. The default configuration file looks as follows:

```
mount {
 cpuset = /cgroup/cpuset;
 cpu = /cgroup/cpu;
 cpuacct = /cgroup/cpuacct;
 memory = /cgroup/memory;
 devices = /cgroup/devices;
 freezer = /cgroup/freezer;
 net_cls = /cgroup/net_cls;
 blkio = /cgroup/blkio;
}
```

The subsystems listed in the above configuration are automatically mounted to their respective hierarchies under the **/cgroup/** directory. It is recommended to use these default hierarchies for specifying control groups. However, in certain cases you may need to create hierarchies manually, for example when they were deleted before, or it is beneficial to have a single hierarchy for multiple subsystems (as in Section 4.3, “Per-group Division of CPU and Memory Resources”). Note that multiple subsystems can be mounted to a single hierarchy, but each subsystem can be mounted only once. See Example 2.1, “Creating a mount entry” for an example of creating a hierarchy.

Example 2.1. Creating a mount entry

The following example creates a hierarchy for the **cpuset** subsystem:

```
mount {
    cpuset = /cgroup/red;
}
```

the equivalent of the shell commands:

```
~]# mkdir /cgroup/red
~]# mount -t cgroup -o cpuset red /cgroup/red
```

Since each subsystem can be mounted only once, the above commands would fail if **cpuset** is already mounted.

Group entries create cgroups and set subsystem parameters. Group entries are defined using the following syntax:

```
group <name> {
    [<permissions>]
    <controller> {
        <param name> = <param value>;
        …
    }
    …
}
```

Note that the **permissions** section is optional. To define permissions for a group entry, use the following syntax:

```
perm {
    task {
        uid = <task user>;
        gid = <task group>;
    }
    admin {
       uid = <admin name>;
       gid = <admin group>;
    }
}
```

See Example 2.2, “Creating a group entry” for example usage:

Example 2.2. Creating a group entry

The following example creates a cgroup for SQL daemons, with permissions for users in the **sqladmin** group to add tasks to the cgroup and the **root** user to modify subsystem parameters:

```
group daemons {
     cpuset {
         cpuset.mems = 0;
         cpuset.cpus = 0;
     }
}
group daemons/sql {
     perm {
         task {
             uid = root;
             gid = sqladmin;
         } admin {
             uid = root;
             gid = root;
         }
     }
     cpuset {
         cpuset.mems = 0;
         cpuset.cpus = 0;
     }
}
```

When combined with the example of the mount entry in Example 2.1, “Creating a mount entry”, the equivalent shell commands are:

```
~]# mkdir -p /cgroup/red/daemons/sql
~]# chown root:root /cgroup/red/daemons/sql/*
~]# chown root:sqladmin /cgroup/red/daemons/sql/tasks
~]# echo $(cgget -n -v -r cpuset.mems /) >
/cgroup/red/daemons/cpuset.mems
~]# echo $(cgget -n -v -r cpuset.cpus /) >
/cgroup/red/daemons/cpuset.cpus
~]# echo 0 > /cgroup/red/daemons/sql/cpuset.mems
~]# echo 0 > /cgroup/red/daemons/sql/cpuset.cpus
```

Restart the cgconfig service for the changes to take effect

You must restart the **cgconfig** service for the changes in the **/etc/cgconfig.conf** to take effect. However, note that restarting this service causes the entire cgroup hierarchy to be rebuilt, which removes any previously existing cgroups (for example, any existing cgroups used by **libvirtd**). To restart the **cgconfig** service, use the following command:

```
~]# service cgconfig restart
```

When you install the *libcgroup* package, a sample configuration file is written to **/etc/cgconfig.conf**. The hash symbols ('#') at the start of each line comment that line out and make it invisible to the **cgconfig** service.

2.1.2. The /etc/cgconfig.d/ Directory

The **/etc/cgconfig.d/** directory is reserved for storing configuration files for specific applications and use cases. These files should be created with the *.conf* suffix, and they adhere the same syntax rules as **/etc/cgconfig.conf**.

The **cgconfig** service first parses the **/etc/cgconfig.conf** file and then continues with files in the **/etc/cgconfig.d/** directory. Note that the order of file parsing is not defined, because it does not make a difference provided that each configuration file is unique. Therefore, do not define the same group or template in multiple configuration files, otherwise they would interfere with each other.

Storing specific configuration files in a separate directory makes them easily reusable. If an application is shipped with a dedicated configuration file, you can easily set up cgroups for this application just by copying its configuration file to **/etc/cgconfig.d/**.

2.2. Creating a Hierarchy and Attaching Subsystems

Effects on running systems

The following instructions, which cover creating a new hierarchy and attaching subsystems to it, assume that cgroups are not already configured on your system. In this case, these instructions will not affect the operation of the system. Changing the tunable parameters in a cgroup with tasks, however, may immediately affect those tasks. This guide alerts you the first time it illustrates changing a tunable cgroup parameter that may affect one or more tasks.

On a system on which cgroups are already configured (either manually, or by the **cgconfig** service) these commands will fail unless you first unmount existing hierarchies, which will affect the operation of the system. Do not experiment with these instructions on production systems.

To create a hierarchy and attach subsystems to it, edit the **mount** section of the **/etc/cgconfig.conf** file as root. Entries in the **mount** section have the following format:

```
subsystem = /cgroup/hierarchy;
```

When **cgconfig** next starts, it will create the hierarchy and attach the subsystems to it.

The following example creates a hierarchy called **cpu_and_mem** and attaches the **cpu**, **cpuset**, **cpuacct**, and **memory** subsystems to it.

```
mount {
    cpuset  = /cgroup/cpu_and_mem;
    cpu     = /cgroup/cpu_and_mem;
    cpuacct = /cgroup/cpu_and_mem;
    memory  = /cgroup/cpu_and_mem;
}
```

Alternative method

You can also use shell commands and utilities to create hierarchies and attach subsystems to them.

Create a *mount point* for the hierarchy as root. Include the name of the cgroup in the mount point:

```
~]# mkdir /cgroup/name
```

For example:

```
~]# mkdir /cgroup/cpu_and_mem
```

Next, use the **mount** command to mount the hierarchy and simultaneously attach one or more subsystems. For example:

```
~]# mount -t cgroup -o subsystems name /cgroup/name
```

Where *subsystems* is a comma-separated list of subsystems and *name* is the name of the hierarchy. Brief descriptions of all available subsystems are listed in Available Subsystems in Red Hat Enterprise Linux, and Chapter 3, *Subsystems and Tunable Parameters* provides a detailed reference.

Example 2.3. Using the mount command to attach subsystems

In this example, a directory named **/cgroup/cpu_and_mem** already exists, which will serve as the mount point for the hierarchy that you create. Attach the **cpu**, **cpuset** and **memory** subsystems to a hierarchy named **cpu_and_mem**, and **mount** the **cpu_and_mem** hierarchy on **/cgroup/cpu_and_mem**:

```
~]# mount -t cgroup -o cpu,cpuset,memory cpu_and_mem
/cgroup/cpu_and_mem
```

You can list all available subsystems along with their current mount points (i.e. where the hierarchy they are attached to is mounted) with the **lssubsys** [3] command:

```
~]# lssubsys -am
cpu,cpuset,memory /cgroup/cpu_and_mem
net_cls
ns
cpuacct
devices
freezer
blkio
```

This output indicates that:

- the **cpu**, **cpuset** and **memory** subsystems are attached to a hierarchy mounted on **/cgroup/cpu_and_mem**, and
- the **net_cls**, **ns**, **cpuacct**, **devices**, **freezer** and **blkio** subsystems are as yet unattached to any hierarchy, as illustrated by the lack of a corresponding mount point.

2.3. Attaching Subsystems to, and Detaching Them From, an Existing Hierarchy

To add a subsystem to an existing hierarchy, detach it from an existing hierarchy, or move it to a different hierarchy, edit the **mount** section of the **/etc/cgconfig.conf** file as root, using the same syntax described in Section 2.2, “Creating a Hierarchy and Attaching Subsystems”. When **cgconfig** next starts, it will reorganize the subsystems according to the hierarchies that you specify.

Alternative method

To add an unattached subsystem to an existing hierarchy, remount the hierarchy. Include the extra subsystem in the **mount** command, together with the **remount** option.

Example 2.4. Remounting a hierarchy to add a subsystem

The **lssubsys** command shows **cpu**, **cpuset**, and **memory** subsystems attached to the **cpu_and_mem** hierarchy:

```
~]# lssubsys -am
cpu,cpuset,memory /cgroup/cpu_and_mem
net_cls
ns
cpuacct
devices
freezer
blkio
```

Remount the **cpu_and_mem** hierarchy, using the **remount** option, and include **cpuacct** in the list of subsystems:

```
~]# mount -t cgroup -o remount,cpu,cpuset,cpuacct,memory cpu_and_mem
/cgroup/cpu_and_mem
```

The **lssubsys** command now shows **cpuacct** attached to the **cpu_and_mem** hierarchy:

```
~]# lssubsys -am
cpu,cpuacct,cpuset,memory /cgroup/cpu_and_mem
net_cls
ns
devices
freezer
blkio
```

Analogously, you can detach a subsystem from an existing hierarchy by remounting the hierarchy and omitting the subsystem name from the -o options. For example, to then detach the **cpuacct** subsystem, simply remount and omit it:

```
~]# mount -t cgroup -o remount,cpu,cpuset,memory cpu_and_mem
/cgroup/cpu_and_mem
```

2.4. Unmounting a Hierarchy

You can *unmount* a hierarchy of cgroups with the **umount** command:

```
~]# umount /cgroup/name
```

For example:

```
~]# umount /cgroup/cpu_and_mem
```

If the hierarchy is currently empty (that is, it contains only the root cgroup) the hierarchy is deactivated when it is unmounted. If the hierarchy contains any other cgroups, the hierarchy remains active in the kernel even though it is no longer mounted.

To remove a hierarchy, ensure that all child cgroups are removed before you unmount the hierarchy, or use the **cgclear** command which can deactivate a hierarchy even when it is not empty — refer to Section 2.12, “Unloading Control Groups”.

2.5. Creating Control Groups

Use the **cgcreate** command to create cgroups. The syntax for **cgcreate** is:

```
cgcreate -t uid:gid -a uid:gid -g subsystems:path
```

where:

- **-t** (optional) — specifies a user (by user ID, uid) and a group (by group ID, gid) to own the **tasks** pseudo-file for this cgroup. This user can add tasks to the cgroup.

Removing tasks

Note that the only way to remove a task from a cgroup is to move it to a different cgroup. To move a task, the user must have write access to the *destination* cgroup; write access to the source cgroup is unimportant.

- **-a** (optional) — specifies a user (by user ID, uid) and a group (by group ID, gid) to own all pseudo-files other than **tasks** for this cgroup. This user can modify the access that the tasks in this cgroup have to system resources.
- **-g** — specifies the hierarchy in which the cgroup should be created, as a comma-separated list of the *subsystems* associated with those hierarchies. If the subsystems in this list are in different hierarchies, the group is created in each of these hierarchies. The list of hierarchies is followed by a colon and the *path* to the child group relative to the hierarchy. Do not include the hierarchy mount point in the path.

For example, the cgroup located in the directory **/cgroup/cpu_and_mem/lab1/** is called just **lab1** — its path is already uniquely determined because there is at most one hierarchy for a given subsystem. Note also that the group is controlled by all the subsystems that exist in the hierarchies in which the cgroup is created, even though these subsystems have not been specified in the **cgcreate** command — refer to Example 2.5, “cgcreate usage”.

Because all cgroups in the same hierarchy have the same controllers, the child group has the same controllers as its parent.

Example 2.5. cgcreate usage

Consider a system where the **cpu** and **memory** subsystems are mounted together in the **cpu_and_mem** hierarchy, and the **net_cls** controller is mounted in a separate hierarchy called **net**. Run the following command:

```
~]# cgcreate -g cpu,net_cls:/test-subgroup
```

The **cgcreate** command creates two groups named **test-subgroup**, one in the **cpu_and_mem** hierarchy and one in the **net** hierarchy. The **test-subgroup** group in the **cpu_and_mem** hierarchy is controlled by the **memory** subsystem, even though it was not specified in the **cgcreate** command.

Alternative method

To create a child of the cgroup directly, use the **mkdir** command:

```
~]# mkdir /cgroup/hierarchy/name/child_name
```

For example:

```
~]# mkdir /cgroup/cpu_and_mem/group1
```

2.6. Removing Control Groups

Remove cgroups with the **cgdelete**, which has a syntax similar to that of **cgcreate**. Run the following command:

```
cgdelete subsystems:path
```

where:

- *subsystems* is a comma-separated list of subsystems.
- *path* is the path to the cgroup relative to the root of the hierarchy.

For example:

```
~]# cgdelete cpu,net_cls:/test-subgroup
```

cgdelete can also recursively remove all subgroups with the option **-r**.

When you delete a cgroup, all its tasks move to its parent group.

2.7. Setting Parameters

Set subsystem parameters by running the **cgset** command from a user account with permission to modify the relevant cgroup. For example, if **cpuset** is mounted to **/cgroup/cpu_and_mem/** and the **/cgroup/cpu_and_mem/group1** subdirectory exists, specify the CPUs to which this group has access with the following command:

```
cpu_and_mem]# cgset -r cpuset.cpus=0-1 group1
```

The syntax for **cgset** is:

```
cgset -r parameter=value path_to_cgroup
```

where:

- *parameter* is the parameter to be set, which corresponds to the file in the directory of the given cgroup
- *value* is the value for the parameter
- *path_to_cgroup* is the path to the cgroup *relative to the root of the hierarchy*. For example, to set the parameter of the root group (if the **cpuacct** subsystem is mounted to **/cgroup/cpu_and_mem/**), change to the **/cgroup/cpu_and_mem/** directory, and run:

  ```
  cpu_and_mem]# cgset -r cpuacct.usage=0 /
  ```

  Alternatively, because **.** is relative to the root group (that is, the root group itself) you could also run:

  ```
  cpu_and_mem]# cgset -r cpuacct.usage=0 .
  ```

  Note, however, that **/** is the preferred syntax.

Setting parameters for the root group

Only a small number of parameters can be set for the root group (such as the **cpuacct.usage** parameter shown in the examples above). This is because a root group owns all of the existing resources, therefore, it would make no sense to limit all existing processes by defining certain parameters, for example the **cpuset.cpu** parameter.

  To set the parameter of **group1**, which is a subgroup of the root group, run:

  ```
  cpu_and_mem]# cgset -r cpuacct.usage=0 group1
  ```

  A trailing slash on the name of the group (for example, **cpuacct.usage=0 group1/**) is optional.

The values that you can set with **cgset** might depend on values set higher in a particular hierarchy. For example, if **group1** is limited to use only CPU 0 on a system, you cannot set **group1/subgroup1** to use CPUs 0 and 1, or to use only CPU 1.

You can also use **cgset** to copy the parameters of one cgroup into another, existing cgroup. For example:

```
cpu_and_mem]# cgset --copy-from group1/ group2/
```

The syntax to copy parameters with **cgset** is:

```
cgset --copy-from path_to_source_cgroup path_to_target_cgroup
```

where:

- *path_to_source_cgroup* is the path to the cgroup whose parameters are to be copied, relative to the root group of the hierarchy
- *path_to_target_cgroup* is the path to the destination cgroup, relative to the root group of the hierarchy

Ensure that any mandatory parameters for the various subsystems are set before you copy parameters from one group to another, or the command will fail. For more information on mandatory parameters, refer to Mandatory parameters.

Alternative method

To set parameters in a cgroup directly, insert values into the relevant subsystem pseudo-file using the **echo** command. For example, this command inserts the value **0-1** into the **cpuset.cpus** pseudo-file of the cgroup **group1**:

```
~]# echo 0-1 > /cgroup/cpu_and_mem/group1/cpuset.cpus
```

With this value in place, the tasks in this cgroup are restricted to CPUs 0 and 1 on the system.

2.8. Moving a Process to a Control Group

Move a process into a cgroup by running the **cgclassify** command, for example:

```
~]# cgclassify -g cpu,memory:group1 1701
```

The syntax for **cgclassify** is:

```
cgclassify -g subsystems:path_to_cgroup pidlist
```

where:

- *subsystems* is a comma-separated list of subsystems, or ***** to launch the process in the hierarchies associated with all available subsystems. Note that if cgroups of the same name exist in multiple hierarchies, the **-g** option moves the processes in each of those groups. Ensure that the cgroup exists within each of the hierarchies whose subsystems you specify here.
- *path_to_cgroup* is the path to the cgroup within its hierarchies
- *pidlist* is a space-separated list of *process identifier* (PIDs)

If the **-g** option is not specified, **cgclassify** automatically searches the **/etc/cgrules.conf** (see Section 2.8.1, “The cgred Service”), and uses the first applicable configuration line. According to this line, **cgclassify** determines the hierarchies and cgroups to move the process under. Note that for the move to be successful, the destination hierarchies must exist. The subsystems specified in

/etc/cgrules.conf must be also properly configured for the corresponding hierarchy in **/etc/cgconfig.conf**.

You can also add the **--sticky** option before the *pid* to keep any child processes in the same cgroup. If you do not set this option and the **cgred** service is running, child processes will be allocated to cgroups based on the settings found in **/etc/cgrules.conf**. However, the parent process remains in the cgroup in which it was first started.

Using **cgclassify**, you can move several processes simultaneously. For example, this command moves the processes with PIDs **1701** and **1138** into cgroup **group1/**:

```
~]# cgclassify -g cpu,memory:group1 1701 1138
```

Note that the PIDs to be moved are separated by spaces and that the groups specified should be in different hierarchies.

Alternative method

To move a process into a cgroup directly, write its PID to the **tasks** file of the cgroup. For example, to move a process with the PID **1701** into a cgroup at **/cgroup/cpu_and_mem/group1/**:

```
~]# echo 1701 > /cgroup/cpu_and_mem/group1/tasks
```

2.8.1. The cgred Service

Cgred is a service (which starts the **cgrulesengd** daemon) that moves tasks into cgroups according to parameters set in the **/etc/cgrules.conf** file. Entries in the **/etc/cgrules.conf** file can take one of the two forms:

```
user subsystems control_group
```

```
user:command subsystems control_group
```

Replace *user* with a user name or a group name prefixed with the "@" character. Replace *subsystems* with a comma-separated list of subsystem names, *control_group* represents a path to the cgroup, and *command* stands for a process name or a full command path of a process.

For example:

```
maria   devices  /usergroup/staff
```

This entry specifies that any processes that belong to the user named **maria** access the **devices** subsystem according to the parameters specified in the **/usergroup/staff** cgroup. To associate particular commands with particular cgroups, add the *command* parameter, as follows:

```
maria:ftp  devices  /usergroup/staff/ftp
```

The entry now specifies that when the user named **maria** uses the **ftp** command, the process is automatically moved to the **/usergroup/staff/ftp** cgroup in the hierarchy that contains the **devices** subsystem. Note, however, that the daemon moves the process to the cgroup only after the appropriate condition is fulfilled. Therefore, the **ftp** process might run for a short time in the wrong group. Furthermore, if the process quickly spawns children while in the wrong group, these children might not be moved.

Entries in the **/etc/cgrules.conf** file can include the following extra notation:

- **@** — indicates a group instead of an individual user. For example, **@admins** are all users in the **admins** group.
- ***** — represents "all". For example, ***** in the **subsystem** field represents all mounted subsystems.
- **%** — represents an item the same as the item in the line above.

For example, the entries specified in the **/etc/cgrules.conf** file can have the following form:

```
@adminstaff  devices  /admingroup
@labstaff  %  %
```

The above configuration ensures that processes owned by the **andminstaff** and **labstaff** access the **devices** subsystem according to the limits set in the **admingroup** cgroup.

Rules specified in **/etc/cgrules.conf** can be linked to templates configured either in the **/etc/cgconfig.conf** file or in configuration files stored in the **/etc/cgconfig.d/** directory, allowing for flexible cgroup assignment and creation.

For example, specify the following template in **/etc/cgconfig.conf**:

```
template users/%g/%u {
                     cpuacct{
                     }
                     cpu {
                        cpu.shares = "1000";
                     }
          }
```

Then use the *users/%g/%u* template in the third row of a **/etc/cgrules.conf** entry, which can look as follows:

```
peter:ftp  cpu  users/%g/%u
```

The **%g** and **%u** variables used above are automatically replaced with group and user name depending on the owner of the **ftp** process. If the process belongs to **peter** from the **andminstaff** group, the above path is translated to **users/adminstaff/peter**. The **cgred** service then searches for this directory, and if it does not exist, **cgred** creates it and assigns the process to **users/adminstaff/peter/tasks**. Note that template rules apply only to definitions of templates in configuration files, so even if "*group users/adminstaff/peter*" was defined in **/etc/cgconfig.conf**, it would be ignored in favor of "*template users/%g/%u*".

There are several other variables that can be used for specifying cgroup paths in templates:

- **%u** — is replaced with the name of the user who owns the current process. If name resolution fails, UID is used instead.
- **%U** — is replaced with the UID of the specified user who owns the current process.
- **%g** — is replaced with the name of the user group that owns the current process, or with the GID if name resolution fails.
- **%G** — is replaced with the GID of the cgroup that owns the current process.
- **%p** — is replaced with the name of the current process. PID is used in case of name resolution failure.

- **%P** — is replaced with the of the PID of the current processes.

2.9. Starting a Process in a Control Group

Mandatory parameters

Some subsystems have mandatory parameters that must be set before you can move a task into a cgroup which uses any of those subsystems. For example, before you move a task into a cgroup which uses the **cpuset** subsystem, the **cpuset.cpus** and **cpuset.mems** parameters must be defined for that cgroup.

The examples in this section illustrate the correct syntax for the command, but only work on systems on which the relevant mandatory parameters have been set for any controllers used in the examples. If you have not already configured the relevant controllers, you cannot copy example commands directly from this section and expect them to work on your system.

Refer to Chapter 3, *Subsystems and Tunable Parameters* for a description of which parameters are mandatory for given subsystems.

Launch processes in a cgroup by running the **cgexec** command. For example, this command launches the **firefox** web browser within the **group1** cgroup, subject to the limitations imposed on that group by the **cpu** subsystem:

```
~]# cgexec -g cpu:group1 firefox http://www.redhat.com
```

The syntax for **cgexec** is:

```
cgexec -g subsystems:path_to_cgroup command arguments
```

where:

- *subsystems* is a comma-separated list of subsystems, or ***** to launch the process in the hierarchies associated with all available subsystems. Note that, as with **cgset** described in Section 2.7, "Setting Parameters", if cgroups of the same name exist in multiple hierarchies, the **-g** option creates processes in each of those groups. Ensure that the cgroup exists within each of the hierarchies whose subsystems you specify here.
- *path_to_cgroup* is the path to the cgroup relative to the hierarchy.
- *command* is the command to run.
- *arguments* are any arguments for the command.

You can also add the **--sticky** option before the *command* to keep any child processes in the same cgroup. If you do not set this option and the **cgred** daemon is running, child processes will be allocated to cgroups based on the settings found in **/etc/cgrules.conf**. The process itself, however, will remain in the cgroup in which you started it.

Alternative method

When you start a new process, it inherits the group of its parent process. Therefore, an alternative method for starting a process in a particular cgroup is to move your shell process to that group (refer to Section 2.8, “Moving a Process to a Control Group”), and then launch the process from that shell. For example:

```
~]# echo $$ > /cgroup/cpu_and_mem/group1/tasks
~]# firefox
```

Note that after exiting **firefox**, your existing shell is still in the **group1** cgroup. Therefore, an even better way would be:

```
~]# sh -c "echo \$$ > /cgroup/cpu_and_mem/group1/tasks && firefox"
```

2.9.1. Starting a Service in a Control Group

You can start certain services in a cgroup. Services that can be started in cgroups must:

- use a **/etc/sysconfig/*servicename*** file
- use the **daemon()** function from **/etc/init.d/functions** to start the service

To make an eligible service start in a cgroup, edit its file in the **/etc/sysconfig** directory to include an entry in the form **CGROUP_DAEMON="*subsystem*:*control_group*"** where *subsystem* is a subsystem associated with a particular hierarchy, and *control_group* is a cgroup in that hierarchy. For example:

```
CGROUP_DAEMON="cpuset:group1"
```

If **cpuset** is mounted to **/cgroup/cpu_and_mem/**, the above configuration translates to **/cgroup/cpu_and_mem/group1**.

2.9.2. Process Behavior in the Root Control Group

Certain **blkio** and **cpu** configuration options affect processes (tasks) running in the root cgroup in a different way than those in a subgroup. Consider the following example:

1. Create two subgroups under one root group: **/rootgroup/red/** and **/rootgroup/blue/**
2. In each subgroup and in the root group, define the **cpu.shares** configuration option and set it to **1**.

In the scenario configured above, one process placed in each group (that is, one task in **/rootgroup/tasks**, **/rootgroup/red/tasks** and **/rootgroup/blue/tasks**) ends up consuming 33.33% of the CPU:

```
/rootgroup/ process:      33.33%
/rootgroup/blue/ process: 33.33%
/rootgroup/red/ process:  33.33%
```

Any other processes placed in subgroups **blue** and **red** result in the 33.33% percent of the CPU assigned to that specific subgroup to be split among the multiple processes in that subgroup.

However, multiple processes placed in the root group cause the CPU resource to be split per process, rather than per group. For example, if **/rootgroup/** contains three processes, **/rootgroup/red/** contains one process and **/rootgroup/blue/** contains one process, and the **cpu.shares** option is set to **1** in all groups, the CPU resource is divided as follows:

```
/rootgroup/ processes:    20% + 20% + 20%
/rootgroup/blue/ process: 20%
/rootgroup/red/ process:  20%
```

Therefore, it is recommended to move all processes from the root group to a specific subgroup when using the **blkio** and **cpu** configuration options which divide an available resource based on a weight or a share (for example, **cpu.shares** or **blkio.weight**). To move all tasks from the root group into a specific subgroup, you can use the following commands:

```
rootgroup]# cat tasks >> red/tasks
rootgroup]# echo > tasks
```

2.10. Generating the /etc/cgconfig.conf File

Configuration for the **/etc/cgconfig.conf** file can be generated from the current cgroup configuration using the **cgsnapshot** utility. This utility takes a snapshot of the current state of all subsystems and their cgroups and returns their configuration as it would appear in the **/etc/cgconfig.conf** file. Example 2.6, “Using the cgsnapshot utility” shows an example usage of the **cgsnapshot** utility.

Example 2.6. Using the cgsnapshot utility

Configure cgroups on the system using the following commands:

```
~]# mkdir /cgroup/cpu
~]# mount -t cgroup -o cpu cpu /cgroup/cpu
~]# mkdir /cgroup/cpu/lab1
~]# mkdir /cgroup/cpu/lab2
~]# echo 2 > /cgroup/cpu/lab1/cpu.shares
~]# echo 3 > /cgroup/cpu/lab2/cpu.shares
~]# echo 5000000 > /cgroup/cpu/lab1/cpu.rt_period_us
~]# echo 4000000 > /cgroup/cpu/lab1/cpu.rt_runtime_us
~]# mkdir /cgroup/cpuacct
~]# mount -t cgroup -o cpuacct cpuacct /cgroup/cpuacct
```

The above commands mounted two subsystems and created two cgroups, for the **cpu** subsystem, with specific values for some of their parameters. Executing the **cgsnapshot** command (with the **-s** option and an empty **/etc/cgsnapshot_blacklist.conf** file [4]) then produces the following output:

```
~]$ cgsnapshot -s
# Configuration file generated by cgsnapshot
mount {
        cpu = /cgroup/cpu;
        cpuacct = /cgroup/cpuacct;
}
```

```
group lab2 {
        cpu {
                cpu.rt_period_us="1000000";
                cpu.rt_runtime_us="0";
                cpu.shares="3";
        }
}

group lab1 {
        cpu {
                cpu.rt_period_us="5000000";
                cpu.rt_runtime_us="4000000";
                cpu.shares="2";
        }
}
```

The **-s** option used in the example above tells **cgsnapshot** to ignore all warnings in the output file caused by parameters not being defined in the blacklist or whitelist of the **cgsnapshot** utility. For more information on parameter blacklisting, refer to Section 2.10.1, “Blacklisting Parameters”. For more information on parameter whitelisting, refer to Section 2.10.2, “Whitelisting Parameters”.

By default, the output generated by **cgsnapshot** is returned on the standard output. Use the **-f** to specify a file to which the output should be redirected. For example:

```
~]$ cgsnapshot -f ~/test/cgconfig_test.conf
```

The -f option overwrites the specified file

When using the **-f** option, note that it overwrites any content in the file you specify. Therefore, it is recommended not to direct the output straight to the **/etc/cgconfig.conf** file.

The cgsnapshot utility can also create configuration files per subsystem. By specifying the name of a subsystem, the output will consist of the corresponding configuration for that subsystem:

```
~]$ cgsnapshot cpuacct
# Configuration file generated by cgsnapshot
mount {
        cpuacct = /cgroup/cpuacct;
}
```

2.10.1. Blacklisting Parameters

The **cgsnapshot** utility allows parameter blacklisting. If a parameter is blacklisted, it does not appear in the output generated by **cgsnapshot**. By default, the **/etc/cgsnapshot_blacklist.conf** file is checked for blacklisted parameters. If a parameter is not present in the blacklist, the whitelist is checked. To specify a different blacklist, use the **-b** option. For example:

```
~]$ cgsnapshot -b ~/test/my_blacklist.conf
```

2.10.2. Whitelisting Parameters

The **cgsnapshot** utility also allows parameter whitelisting. If a parameter is whitelisted, it appears in the output generated by **cgsnapshot**. If a parameter is neither blacklisted or whitelisted, a warning appears informing of this:

```
~]$ cgsnapshot -f ~/test/cgconfig_test.conf
WARNING: variable cpu.rt_period_us is neither blacklisted nor whitelisted
WARNING: variable cpu.rt_runtime_us is neither blacklisted nor
whitelisted
```

By default, there is no whitelist configuration file. To specify which file to use as a whitelist, use the **-w** option. For example:

```
~]$ cgsnapshot -w ~/test/my_whitelist.conf
```

Specifying the **-t** option tells **cgsnapshot** to generate a configuration with parameters from the whitelist only.

2.11. Obtaining Information About Control Groups

There are several ways to find and monitor control groups, subsystems, and hierarchies configured on your system.

2.11.1. Finding a Process

To find the cgroup to which a process belongs, run:

```
~]$ ps -O cgroup
```

Or, if you know the PID for the process, run:

```
~]$ cat /proc/PID/cgroup
```

where *PID* stands for a PID of the inspected process.

2.11.2. Finding a Subsystem

To find the subsystems that are available in your kernel and how are they mounted together to hierarchies, run:

```
~]$ cat /proc/cgroups
#subsys_name    hierarchy       num_cgroups     enabled
cpuset  2       1       1
ns      0       1       1
cpu     3       1       1
cpuacct 4       1       1
memory  5       1       1
devices 6       1       1
freezer 7       1       1
```

```
net_cls 8       1       1
blkio   9       3       1
perf_event      0       1       1
net_prio        0       1       1
```

In the example output above, the **hierarchy** column lists IDs of the existing hierarchies on the system. Subsystems with the same hierarchy ID are attached to the same hierarchy. The **num_cgroup** column lists the number of existing cgroups in the hierarchy that uses a particular subsystem. The **enabled** column reports a value of **1** if a particular subsystem is enabled, or **0** if it is not.

Or, to find the mount points of particular subsystems, run:

```
~]$ lssubsys -m subsystems
```

where *subsystems* is a list of the subsystems in which you are interested. Note that the **lssubsys -m** command returns only the top-level mount point per each hierarchy.

2.11.3. Finding Hierarchies

It is recommended that you mount hierarchies under the **/cgroup/** directory. Assuming this is the case on your system, list or browse the contents of that directory to obtain a list of hierarchies. If the **tree** utility is installed on your system, run it to obtain an overview of all hierarchies and the cgroups within them:

```
~]$ tree /cgroup
```

2.11.4. Finding Control Groups

To list the cgroups on a system, run:

```
~]$ lscgroup
```

You can restrict the output to a specific hierarchy by specifying a controller and path in the format ***controller*:*path***. For example:

```
~]$ lscgroup cpuset:group1
```

lists only subgroups of the **group1** cgroup in the hierarchy to which the **cpuset** subsystem is attached.

2.11.5. Displaying Parameters of Control Groups

To display the parameters of specific cgroups, run:

```
~]$ cgget -r parameter list_of_cgroups
```

where *parameter* is a pseudo-file that contains values for a subsystem, and *list_of_cgroups* is a list of cgroups separated with spaces. For example:

```
~]$ cgget -r cpuset.cpus -r memory.limit_in_bytes group1 group2
```

displays the values of **cpuset.cpus** and **memory.limit_in_bytes** for cgroups **group1** and **group2**.

If you do not know the names of the parameters themselves, use a command like:

```
~]$ cgget -g cpuset /
```

2.12. Unloading Control Groups

This command destroys all control groups

The **cgclear** command destroys all cgroups in all hierarchies. If you do not have these hierarchies stored in a configuration file, you will not be able to readily reconstruct them.

To clear an entire cgroup file system, use the **cgclear** command.

All tasks in the cgroup are reallocated to the root node of the hierarchies, all cgroups are removed, and the file system itself is unmounted from the system, destroying all previously mounted hierarchies. Finally, the directory where the cgroup file system was mounted is removed.

Accurate listing of all mounted cgroups

Using the **mount** command to create cgroups (as opposed to creating them using the **cgconfig** service) results in the creation of an entry in the **/etc/mtab** file (the mounted file systems table). This change is also reflected into the **/proc/mounts** file. However, the unloading of cgroups with the **cgclear** command, along with other **cgconfig** commands, uses a direct kernel interface which does not reflect its changes into the **/etc/mtab** file and only writes the new information into the **/proc/mounts** file. After unloading cgroups with the **cgclear** command, the unmounted cgroups may still be visible in the **/etc/mtab** file, and, consequently, displayed when the **mount** command is executed. Refer to the **/proc/mounts** file for an accurate listing of all mounted cgroups.

2.13. Using the Notification API

The cgroups notification API allows user space applications to receive notifications about the changing status of a cgroup. Currently, the notification API only supports monitoring of the Out of Memory (OOM) control file: **memory.oom_control**. To create a notification handler, write a C program using the following instructions:

1. Using the **eventfd()** function, create a file descriptor for event notifications. For more information, refer to the **eventfd(2)** man page.

2. To monitor the **memory.oom_control** file, open it using the **open()** function. For more information, refer to the **open(2)** man page.

3. Use the **write()** function to write the following arguments to the **cgroup.event_control** file of the cgroup whose **memory.oom_control** file you are monitoring:

   ```
   <event_file_descriptor> <OOM_control_file_descriptor>
   ```

where:

- *event_file_descriptor* is used to open the **cgroup.event_control** file,
- and *OOM_control_file_descriptor* is used to open the respective **memory.oom_control** file.

For more information on writing to a file, refer to the **write(1)** man page.

When the above program is started, it will be notified of any OOM situation in the cgroup it is monitoring. Note that OOM notifications only work in non-root cgroups.

For more information on the **memory.oom_control** tunable parameter, refer to Section 3.7, “memory”. For more information on configuring notifications for OOM control, refer to Example 3.3, “OOM Control and Notifications”.

2.14. Additional Resources

The definitive documentation for cgroup commands are the manual pages provided with the *libcgroup* package. The section numbers are specified in the list of man pages below.

The libcgroup Man Pages

- **man 1 cgclassify** — the **cgclassify** command is used to move running tasks to one or more cgroups.

  man 1 cgclear — the **cgclear** command is used to delete all cgroups in a hierarchy.

  man 5 cgconfig.conf — cgroups are defined in the **cgconfig.conf** file.

  man 8 cgconfigparser — the **cgconfigparser** command parses the **cgconfig.conf** file and mounts hierarchies.

  man 1 cgcreate — the **cgcreate** command creates new cgroups in hierarchies.

  man 1 cgdelete — the **cgdelete** command removes specified cgroups.

  man 1 cgexec — the **cgexec** command runs tasks in specified cgroups.

  man 1 cgget — the **cgget** command displays cgroup parameters.

  man 1 cgsnapshot — the **cgsnapshot** command generates a configuration file from existing subsystems.

  man 5 cgred.conf — **cgred.conf** is the configuration file for the **cgred** service.

  man 5 cgrules.conf — **cgrules.conf** contains the rules used for determining when tasks belong to certain cgroups.

  man 8 cgrulesengd — the **cgrulesengd** service distributes tasks to cgroups.

  man 1 cgset — the **cgset** command sets parameters for a cgroup.

  man 1 lscgroup — the **lscgroup** command lists the cgroups in a hierarchy.

  man 1 lssubsys — the **lssubsys** command lists the hierarchies containing the specified subsystems.

[3] The **lssubsys** command is one of the utilities provided by the *libcgroup* package. You must install *libcgroup* to use it: refer to Chapter 2, *Using Control Groups* if you are unable to run **lssubsys**.

[4] The **cpu.shares** parameter is specified in the **/etc/cgsnapshot_blacklist.conf** file by default, which would cause it to be omitted in the generated output in Example 2.6, “Using the cgsnapshot utility”. Thus, for the purposes of the example, an empty **/etc/cgsnapshot_blacklist.conf** file is used.

Chapter 3. Subsystems and Tunable Parameters

Subsystems are kernel modules that are aware of cgroups. Typically, they are resource controllers that allocate varying levels of system resources to different cgroups. However, subsystems could be programmed for any other interaction with the kernel where the need exists to treat different groups of processes differently. The *application programming interface* (API) to develop new subsystems is documented in **cgroups.txt** in the kernel documentation, installed on your system at **/usr/share/doc/kernel-doc-*kernel-version*/Documentation/cgroups/** (provided by the *kernel-doc* package). The latest version of the cgroups documentation is also available on line at http://www.kernel.org/doc/Documentation/cgroups/cgroups.txt. Note, however, that the features in the latest documentation might not match those available in the kernel installed on your system.

State objects that contain the subsystem parameters for a cgroup are represented as *pseudofiles* within the cgroup virtual file system. These pseudo-files can be manipulated by shell commands or their equivalent system calls. For example, **cpuset.cpus** is a pseudo-file that specifies which CPUs a cgroup is permitted to access. If **/cgroup/cpuset/webserver** is a cgroup for the web server that runs on a system, and the following command is executed:

```
~]# echo 0,2 > /cgroup/cpuset/webserver/cpuset.cpus
```

The value **0,2** is written to the **cpuset.cpus** pseudofile and therefore limits any tasks whose PIDs are listed in **/cgroup/cpuset/webserver/tasks** to use only CPU 0 and CPU 2 on the system.

3.1. blkio

The Block I/O (**blkio**) subsystem controls and monitors access to I/O on block devices by tasks in cgroups. Writing values to some of these pseudofiles limits access or bandwidth, and reading values from some of these pseudofiles provides information on I/O operations.

The **blkio** subsystem offers two policies for controlling access to I/O:

- *Proportional weight division* — implemented in the Completely Fair Queuing I/O scheduler, this policy allows you to set weights to specific cgroups. This means that each cgroup has a set percentage (depending on the weight of the cgroup) of all I/O operations reserved. For more information, refer to Section 3.1.1, “Proportional Weight Division Tunable Parameters”
- *I/O throttling (Upper limit)* — this policy is used to set an upper limit for the number of I/O operations performed by a specific device. This means that a device can have a limited rate of *read* or *write* operations. For more information, refer to Section 3.1.2, “I/O Throttling Tunable Parameters”

Buffered *write* operations

Currently, the Block I/O subsystem does not work for buffered *write* operations. It is primarily targeted at direct I/O, although it works for buffered *read* operations.

3.1.1. Proportional Weight Division Tunable Parameters

blkio.weight

specifies the relative proportion (*weight*) of block I/O access available by default to a cgroup, in the range **100** to **1000**. This value is overridden for specific devices by the **blkio.weight_device** parameter. For example, to assign a default weight of **500** to a cgroup for access to block devices, run:

```
~]# echo 500 > blkio.weight
```

blkio.weight_device

specifies the relative proportion (*weight*) of I/O access on specific devices available to a cgroup, in the range **100** to **1000**. The value of this parameter overrides the value of the **blkio.weight** parameter for the devices specified. Values take the format *major*:*minor weight*, where *major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, otherwise known as the *Linux Devices List* and available from http://www.kernel.org/doc/Documentation/devices.txt. For example, to assign a weight of **500** to a cgroup for access to **/dev/sda**, run:

```
~]# echo 8:0 500 > blkio.weight_device
```

In the *Linux Allocated Devices* notation, **8:0** represents **/dev/sda**.

3.1.2. I/O Throttling Tunable Parameters

blkio.throttle.read_bps_device

specifies the upper limit on the number of *read* operations a device can perform. The rate of the *read* operations is specified in bytes per second. Entries have three fields: *major*, *minor*, and *bytes_per_second*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *bytes_per_second* is the upper limit rate at which *read* operations can be performed. For example, to allow the **/dev/sda** device to perform *read* operations at a maximum of 10 MBps, run:

```
~]# echo "8:0 10485760" >
/cgroup/blkio/test/blkio.throttle.read_bps_device
```

blkio.throttle.read_iops_device

specifies the upper limit on the number of *read* operations a device can perform. The rate of the *read* operations is specified in operations per second. Entries have three fields: *major*, *minor*, and *operations_per_second*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *operations_per_second* is the upper limit rate at which *read* operations can be performed. For example, to allow the **/dev/sda** device to perform a maximum of 10 *read* operations per second, run:

```
~]# echo "8:0 10" >
/cgroup/blkio/test/blkio.throttle.read_iops_device
```

blkio.throttle.write_bps_device

specifies the upper limit on the number of *write* operations a device can perform. The rate of the *write* operations is specified in bytes per second. Entries have three fields: *major*, *minor*, and *bytes_per_second*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *bytes_per_second* is the upper limit rate at which *write* operations can be performed. For example, to allow the **/dev/sda** device to perform *write* operations at a maximum of 10 MBps, run:

```
~]# echo "8:0 10485760" >
/cgroup/blkio/test/blkio.throttle.write_bps_device
```

blkio.throttle.write_iops_device

specifies the upper limit on the number of *write* operations a device can perform. The rate of the *write* operations is specified in operations per second. Entries have three fields: *major*, *minor*, and *operations_per_second*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *operations_per_second* is the upper limit rate at which *write* operations can be performed. For example, to allow the **/dev/sda** device to perform a maximum of 10 *write* operations per second, run:

```
~]# echo "8:0 10" >
/cgroup/blkio/test/blkio.throttle.write_iops_device
```

blkio.throttle.io_serviced

reports the number of I/O operations performed on specific devices by a cgroup as seen by the throttling policy. Entries have four fields: *major*, *minor*, *operation*, and *number*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, *operation* represents the type of operation (**read**, **write**, **sync**, or **async**) and *number* represents the number of operations.

blkio.throttle.io_service_bytes

reports the number of bytes transferred to or from specific devices by a cgroup. The only difference between ***blkio.io_service_bytes*** and ***blkio.throttle.io_service_bytes*** is that the former is not updated when the CFQ scheduler is operating on a request queue. Entries have four fields: *major*, *minor*, *operation*, and *bytes*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, *operation* represents the type of operation (**read**, **write**, **sync**, or **async**) and *bytes* is the number of bytes transferred.

3.1.3. blkio Common Tunable Parameters

The following parameters may be used for either of the policies listed in Section 3.1, “blkio”.

blkio.reset_stats

resets the statistics recorded in the other pseudofiles. Write an integer to this file to reset the statistics for this cgroup.

blkio.time

reports the time that a cgroup had I/O access to specific devices. Entries have three fields: *major*, *minor*, and *time*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *time* is the length of time in milliseconds (ms).

blkio.sectors

reports the number of sectors transferred to or from specific devices by a cgroup. Entries have three fields: *major*, *minor*, and *sectors*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *sectors* is the number of disk sectors.

blkio.avg_queue_size

reports the average queue size for I/O operations by a cgroup, over the entire length of time of the group's existence. The queue size is sampled every time a queue for this cgroup gets a timeslice. Note that this report is available only if **CONFIG_DEBUG_BLK_CGROUP=y** is set on the system.

blkio.group_wait_time

reports the total time (in nanoseconds — ns) a cgroup spent waiting for a timeslice for one of its queues. The report is updated every time a queue for this cgroup gets a timeslice, so if you read this pseudofile while the cgroup is waiting for a timeslice, the report will not contain time spent waiting for the operation currently queued. Note that this report is available only if **CONFIG_DEBUG_BLK_CGROUP=y** is set on the system.

blkio.empty_time

reports the total time (in nanoseconds — ns) a cgroup spent without any pending requests. The report is updated every time a queue for this cgroup has a pending request, so if you read this pseudofile while the cgroup has no pending requests, the report will not contain time spent in the current empty state. Note that this report is available only if **CONFIG_DEBUG_BLK_CGROUP=y** is set on the system.

blkio.idle_time

reports the total time (in nanoseconds — ns) the scheduler spent idling for a cgroup in anticipation of a better request than those requests already in other queues or from other groups. The report is updated every time the group is no longer idling, so if you read this pseudofile while the cgroup is idling, the report will not contain time spent in the current idling state. Note that this report is available only if **CONFIG_DEBUG_BLK_CGROUP=y** is set on the system.

blkio.dequeue

reports the number of times requests for I/O operations by a cgroup were dequeued by specific devices. Entries have three fields: *major*, *minor*, and *number*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, and *number* is the number of requests the group was dequeued. Note that this report is available only if **CONFIG_DEBUG_BLK_CGROUP=y** is set on the system.

blkio.io_serviced

reports the number of I/O operations performed on specific devices by a cgroup as seen by the CFQ scheduler. Entries have four fields: *major*, *minor*, *operation*, and *number*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, *operation* represents the type of operation (**read**, **write**, **sync**, or **async**) and *number* represents the number of operations.

blkio.io_service_bytes

reports the number of bytes transferred to or from specific devices by a cgroup as seen by the CFQ scheduler. Entries have four fields: *major*, *minor*, *operation*, and *bytes*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, *operation* represents the type of operation (**read**, **write**, **sync**, or **async**) and *bytes* is the number of bytes transferred.

blkio.io_service_time

reports the total time between request dispatch and request completion for I/O operations on specific devices by a cgroup as seen by the CFQ scheduler. Entries have four fields: *major*, *minor*, *operation*, and *time*. *Major* and *minor* are device types and node numbers

specified in *Linux Allocated Devices*, *operation* represents the type of operation (**read**, **write**, **sync**, or **async**) and *time* is the length of time in nanoseconds (ns). The time is reported in nanoseconds rather than a larger unit so that this report is meaningful even for solid-state devices.

blkio.io_wait_time

reports the total time I/O operations on specific devices by a cgroup spent waiting for service in the scheduler queues. When you interpret this report, note:

- the time reported can be greater than the total time elapsed, because the time reported is the cumulative total of all I/O operations for the cgroup rather than the time that the cgroup itself spent waiting for I/O operations. To find the time that the group as a whole has spent waiting, use the **blkio.group_wait_time** parameter.
- if the device has a **queue_depth** > 1, the time reported only includes the time until the request is dispatched to the device, not any time spent waiting for service while the device re-orders requests.

Entries have four fields: *major*, *minor*, *operation*, and *time*. *Major* and *minor* are device types and node numbers specified in *Linux Allocated Devices*, *operation* represents the type of operation (**read**, **write**, **sync**, or **async**) and *time* is the length of time in nanoseconds (ns). The time is reported in nanoseconds rather than a larger unit so that this report is meaningful even for solid-state devices.

blkio.io_merged

reports the number of BIOS requests merged into requests for I/O operations by a cgroup. Entries have two fields: *number* and *operation*. *Number* is the number of requests, and *operation* represents the type of operation (**read**, **write**, **sync**, or **async**).

blkio.io_queued

reports the number of requests queued for I/O operations by a cgroup. Entries have two fields: *number* and *operation*. *Number* is the number of requests, and *operation* represents the type of operation (**read**, **write**, **sync**, or **async**).

3.1.4. Example Usage

Refer to Example 3.1, “blkio proportional weight division” for a simple test of running two **dd** threads in two different cgroups with various **blkio.weight** values.

Example 3.1. blkio proportional weight division

1. Mount the **blkio** subsystem:

```
~]# mount -t cgroup -o blkio blkio /cgroup/blkio/
```

2. Create two cgroups for the **blkio** subsystem:

```
~]# mkdir /cgroup/blkio/test1/
~]# mkdir /cgroup/blkio/test2/
```

3. Set **blkio** weights in the previously-created cgroups:

```
~]# echo 1000 > /cgroup/blkio/test1/blkio.weight
~]# echo 500 > /cgroup/blkio/test2/blkio.weight
```

4. Create two large files:

```
~]# dd if=/dev/zero of=file_1 bs=1M count=4000
~]# dd if=/dev/zero of=file_2 bs=1M count=4000
```

   The above commands create two files (**file_1** and **file_2**) of size 4 GB.

5. For each of the test cgroups, execute a **dd** command (which reads the contents of a file and outputs it to the null device) on one of the large files:

```
~]# cgexec -g blkio:test1 time dd if=file_1 of=/dev/null
~]# cgexec -g blkio:test2 time dd if=file_2 of=/dev/null
```

   Both commands will output their completion time once they have finished.

6. Simultaneously with the two running **dd** threads, you can monitor the performance in real time by using the **iotop** utility. To install the **iotop** utility, execute, as root, the **yum install iotop** command. The following is an example of the output as seen in the **iotop** utility while running the previously-started **dd** threads:

```
Total DISK READ: 83.16 M/s | Total DISK WRITE: 0.00 B/s
    TIME  TID  PRIO  USER     DISK READ  DISK WRITE  SWAPIN
IO    COMMAND
15:18:04 15071 be/4 root       27.64 M/s    0.00 B/s  0.00 %
92.30 % dd if=file_2 of=/dev/null
15:18:04 15069 be/4 root       55.52 M/s    0.00 B/s  0.00 %
88.48 % dd if=file_1 of=/dev/null
```

In order to get the most accurate result in Example 3.1, “blkio proportional weight division”, prior to the execution of the **dd** commands, flush all file system buffers and free pagecache, dentries and inodes using the following commands:

```
~]# sync
~]# echo 3 > /proc/sys/vm/drop_caches
```

Additionally, you can enable *group isolation* which provides stronger isolation between groups at the expense of throughput. When group isolation is disabled, fairness can be expected only for a sequential workload. By default, group isolation is enabled and fairness can be expected for random I/O workloads as well. To enable group isolation, use the following command:

```
~]# echo 1 > /sys/block/<disk_device>/queue/iosched/group_isolation
```

where <*disk_device*> stands for the name of the desired device, for example **sda**.

3.2. cpu

The **cpu** subsystem schedules CPU access to cgroups. Access to CPU resources can be scheduled using two schedulers:

- *Completely Fair Scheduler (CFS)* — a proportional share scheduler which divides the CPU time (CPU bandwidth) proportionately between groups of tasks (cgroups) depending on the priority/weight of the task or shares assigned to cgroups. For more information about resource limiting using CFS, refer to Section 3.2.1, “CFS Tunable Parameters”.
- *Real-Time scheduler (RT)* — a task scheduler that provides a way to specify the amount of CPU time that real-time tasks can use. For more information about resource limiting of real-time tasks, refer to Section 3.2.2, “RT Tunable Parameters”.

3.2.1. CFS Tunable Parameters

In CFS, a cgroup can get more than its share of CPU if there are enough idle CPU cycles available in the system, due to the work conserving nature of the scheduler. This is usually the case for cgroups that consume CPU time based on relative shares. Ceiling enforcement can be used for cases when a hard limit on the amount of CPU that a cgroup can utilize is required (that is, tasks cannot use more than a set amount of CPU time).

The following options can be used to configure ceiling enforcement or relative sharing of CPU:

Ceiling Enforcement Tunable Parameters

`cpu.cfs_period_us`

specifies a period of time in microseconds (µs, represented here as "***us***") for how regularly a cgroup's access to CPU resources should be reallocated. If tasks in a cgroup should be able to access a single CPU for 0.2 seconds out of every 1 second, set **`cpu.cfs_quota_us`** to **`200000`** and **`cpu.cfs_period_us`** to **`1000000`**. The upper limit of the **`cpu.cfs_quota_us`** parameter is 1 second and the lower limit is 1000 microseconds.

`cpu.cfs_quota_us`

specifies the total amount of time in microseconds (µs, represented here as "***us***") for which all tasks in a cgroup can run during one period (as defined by **`cpu.cfs_period_us`**). As soon as tasks in a cgroup use up all the time specified by the quota, they are throttled for the remainder of the time specified by the period and not allowed to run until the next period. If tasks in a cgroup should be able to access a single CPU for 0.2 seconds out of every 1 second, set **`cpu.cfs_quota_us`** to **`200000`** and **`cpu.cfs_period_us`** to **`1000000`**. Note that the quota and period parameters operate on a CPU basis. To allow a process to fully utilize two CPUs, for example, set **`cpu.cfs_quota_us`** to **`200000`** and **`cpu.cfs_period_us`** to **`100000`**.

Setting the value in **`cpu.cfs_quota_us`** to **`-1`** indicates that the cgroup does not adhere to any CPU time restrictions. This is also the default value for every cgroup (except the root cgroup).

`cpu.stat`

reports CPU time statistics using the following values:

- **`nr_periods`** — number of period intervals (as specified in **`cpu.cfs_period_us`**) that have elapsed.
- **`nr_throttled`** — number of times tasks in a cgroup have been throttled (that is, not allowed to run because they have exhausted all of the available time as specified by their quota).

- **throttled_time** — the total time duration (in nanoseconds) for which tasks in a cgroup have been throttled.

Relative Shares Tunable Parameters

cpu.shares

contains an integer value that specifies a relative share of CPU time available to the tasks in a cgroup. For example, tasks in two cgroups that have **cpu.shares** set to **100** will receive equal CPU time, but tasks in a cgroup that has **cpu.shares** set to **200** receive twice the CPU time of tasks in a cgroup where **cpu.shares** is set to **100**. The value specified in the **cpu.shares** file must be **2** or higher.

Note that shares of CPU time are distributed per all CPU cores on multi-core systems. Even if a cgroup is limited to less than 100% of CPU on a multi-core system, it may use 100% of each individual CPU core. Consider the following example: if cgroup **A** is configured to use 25% and cgroup **B** 75% of the CPU, starting four CPU-intensive processes (one in **A** and three in **B**) on a system with four cores results in the following division of CPU shares:

Table 3.1. CPU share division

PID	cgroup	CPU	CPU share
100	A	0	100% of CPU0
101	B	1	100% of CPU1
102	B	2	100% of CPU2
103	B	3	100% of CPU3

Using relative shares to specify CPU access has two implications on resource management that should be considered:

- Because the CFS does not demand equal usage of CPU, it is hard to predict how much CPU time a cgroup will be allowed to utilize. When tasks in one cgroup are idle and are not using any CPU time, this left-over time is collected in a global pool of unused CPU cycles. Other cgroups are allowed to borrow CPU cycles from this pool.

- The actual amount of CPU time that is available to a cgroup can vary depending on the number of cgroups that exist on the system. If a cgroup has a relative share of **1000** and two other cgroups have a relative share of **500**, the first cgroup receives 50% of all CPU time in cases when processes in all cgroups attempt to use 100% of the CPU. However, if another cgroup is added with a relative share of **1000**, the first cgroup is only allowed 33% of the CPU (the rest of the cgroups receive 16.5%, 16.5%, and 33% of CPU).

3.2.2. RT Tunable Parameters

The RT scheduler works similar to the ceiling enforcement control of the CFS (for more information, refer to Section 3.2.1, “CFS Tunable Parameters”) but limits CPU access to real-time tasks only. The amount of time for which real-time task can access the CPU is decided by allocating a run time and a period for each cgroup. All tasks in a cgroup are then allowed to access the CPU for the defined period of time for one run time (for example, tasks in a cgroup may be allowed to run 0.1 seconds in every 1 second). Please note that the following parameters take into account all available logical CPUs, therefore the access times specified with these parameters are in fact multiplied by the number of CPUs.

cpu.rt_period_us

applicable to real-time scheduling tasks only, this parameter specifies a period of time in microseconds (µs, represented here as "***us***") for how regularly a cgroup's access to CPU resources be reallocated.

cpu.rt_runtime_us

applicable to real-time scheduling tasks only, this parameter specifies a period of time in microseconds (µs, represented here as "***us***") for the longest continuous period in which the tasks in a cgroup have access to CPU resources. Establishing this limit prevents tasks in one cgroup from monopolizing CPU time. As mentioned above, the access times are multiplied by the number of logical CPUs. For example, setting **cpu.rt_runtime_us** to **200000** and **cpu.rt_period_us** to **1000000** translates to the task being able to access a single CPU for 0.4 seconds out of every 1 second on systems with two CPUs (0.2 x 2), or 0.8 seconds on systems with four CPUs (0.2 x 4).

3.2.3. Example Usage

Example 3.2. Limiting CPU access

The following examples assume you have an existing hierarchy of cgroups configured and the **cpu** subsystem mounted on your system:

- To allow one cgroup to use 25% of a single CPU and a different cgroup to use 75% of that same CPU, use the following commands:

```
~]# echo 250 > /cgroup/cpu/blue/cpu.shares
~]# echo 750 > /cgroup/cpu/red/cpu.shares
```

- To limit a cgroup to fully utilize a single CPU, use the following commands:

```
~]# echo 10000 > /cgroup/cpu/red/cpu.cfs_quota_us
~]# echo 10000 > /cgroup/cpu/red/cpu.cfs_period_us
```

- To limit a cgroup to utilize 10% of a single CPU, use the following commands:

```
~]# echo 10000 > /cgroup/cpu/red/cpu.cfs_quota_us
~]# echo 100000 > /cgroup/cpu/red/cpu.cfs_period_us
```

- On a multi-core system, to allow a cgroup to fully utilize two CPU cores, use the following commands:

```
~]# echo 200000 > /cgroup/cpu/red/cpu.cfs_quota_us
~]# echo 100000 > /cgroup/cpu/red/cpu.cfs_period_us
```

3.3. cpuacct

The CPU Accounting (**cpuacct**) subsystem generates automatic reports on CPU resources used by the tasks in a cgroup, including tasks in child groups. Three reports are available:

cpuacct.usage

reports the total CPU time (in nanoseconds) consumed by all tasks in this cgroup (including tasks lower in the hierarchy).

Resetting cpuacct.usage

To reset the value in **cpuacct.usage**, execute the following command:

```
~]# echo 0 > /cgroup/cpuacct/cpuacct.usage
```

The above command also resets values in **cpuacct.usage_percpu**.

cpuacct.stat

reports the user and system CPU time consumed by all tasks in this cgroup (including tasks lower in the hierarchy) in the following way:

- **user** — CPU time consumed by tasks in user mode.
- **system** — CPU time consumed by tasks in system (kernel) mode.

CPU time is reported in the units defined by the **USER_HZ** variable.

cpuacct.usage_percpu

reports the CPU time (in nanoseconds) consumed on each CPU by all tasks in this cgroup (including tasks lower in the hierarchy).

3.4. cpuset

The **cpuset** subsystem assigns individual CPUs and memory nodes to cgroups. Each cpuset can be specified according to the following parameters, each one in a separate *pseudofile* within the cgroup virtual file system:

Mandatory parameters

Some subsystems have mandatory parameters that must be set before you can move a task into a cgroup which uses any of those subsystems. For example, before you move a task into a cgroup which uses the **cpuset** subsystem, the **cpuset.cpus** and **cpuset.mems** parameters must be defined for that cgroup.

cpuset.cpus (mandatory)

specifies the CPUs that tasks in this cgroup are permitted to access. This is a comma-separated list, with dashes ("**-**") to represent ranges. For example,

```
0-2,16
```

represents CPUs 0, 1, 2, and 16.

cpuset.mems (mandatory)

specifies the memory nodes that tasks in this cgroup are permitted to access. This is a

specifies the memory nodes that tasks in this cgroup are permitted to access. This is a comma-separated list in ASCII format, with dashes ("**-**") to represent ranges. For example,

```
0-2,16
```

represents memory nodes 0, 1, 2, and 16.

cpuset.memory_migrate

contains a flag (**0** or **1**) that specifies whether a page in memory should migrate to a new node if the values in **cpuset.mems** change. By default, memory migration is disabled (**0**) and pages stay on the node to which they were originally allocated, even if this node is no longer one of the nodes now specified in **cpuset.mems**. If enabled (**1**), the system will migrate pages to memory nodes within the new parameters specified by **cpuset.mems**, maintaining their relative placement if possible — for example, pages on the second node on the list originally specified by **cpuset.mems** will be allocated to the second node on the list now specified by **cpuset.mems**, if this place is available.

cpuset.cpu_exclusive

contains a flag (**0** or **1**) that specifies whether cpusets other than this one and its parents and children can share the CPUs specified for this cpuset. By default (**0**), CPUs are not allocated exclusively to one cpuset.

cpuset.mem_exclusive

contains a flag (**0** or **1**) that specifies whether other cpusets can share the memory nodes specified for this cpuset. By default (**0**), memory nodes are not allocated exclusively to one cpuset. Reserving memory nodes for the exclusive use of a cpuset (**1**) is functionally the same as enabling a memory hardwall with the **cpuset.mem_hardwall** parameter.

cpuset.mem_hardwall

contains a flag (**0** or **1**) that specifies whether kernel allocations of memory page and buffer data should be restricted to the memory nodes specified for this cpuset. By default (**0**), page and buffer data is shared across processes belonging to multiple users. With a hardwall enabled (**1**), each tasks' user allocation can be kept separate.

cpuset.memory_pressure

a read-only file that contains a running average of the *memory pressure* created by the processes in this cpuset. The value in this pseudofile is automatically updated when **cpuset.memory_pressure_enabled** is enabled, otherwise, the pseudofile contains the value **0**.

cpuset.memory_pressure_enabled

contains a flag (**0** or **1**) that specifies whether the system should compute the *memory pressure* created by the processes in this cgroup. Computed values are output to **cpuset.memory_pressure** and represent the rate at which processes attempt to free in-use memory, reported as an integer value of attempts to reclaim memory per second, multiplied by 1000.

cpuset.memory_spread_page

contains a flag (**0** or **1**) that specifies whether file system buffers should be spread evenly across the memory nodes allocated to this cpuset. By default (**0**), no attempt is made to spread memory pages for these buffers evenly, and buffers are placed on the same node on which the process that created them is running.

cpuset.memory_spread_slab

contains a flag (**0** or **1**) that specifies whether kernel slab caches for file input/output operations should be spread evenly across the cpuset. By default (**0**), no attempt is made to spread kernel slab caches evenly, and slab caches are placed on the same node on which the process that created them is running.

cpuset.sched_load_balance

contains a flag (**0** or **1**) that specifies whether the kernel will balance loads across the CPUs in this cpuset. By default (**1**), the kernel balances loads by moving processes from overloaded CPUs to less heavily used CPUs.

Note, however, that setting this flag in a cgroup has no effect if load balancing is enabled in any parent cgroup, as load balancing is already being carried out at a higher level. Therefore, to disable load balancing in a cgroup, disable load balancing also in each of its parents in the hierarchy. In this case, you should also consider whether load balancing should be enabled for any siblings of the cgroup in question.

cpuset.sched_relax_domain_level

contains an integer between **-1** and a small positive value, which represents the width of the range of CPUs across which the kernel should attempt to balance loads. This value is meaningless if **cpuset.sched_load_balance** is disabled.

The precise effect of this value varies according to system architecture, but the following values are typical:

Values of cpuset.sched_relax_domain_level

Value	Effect
-1	Use the system default value for load balancing
0	Do not perform immediate load balancing; balance loads only periodically
1	Immediately balance loads across threads on the same core
2	Immediately balance loads across cores in the same package or book (in case of s390x architectures)
3	Immediately balance loads across books in the same package (available only for s390x architectures)
4	Immediately balance loads across CPUs on the same node or blade
5	Immediately balance loads across several CPUs on architectures with non-uniform memory access (NUMA)
6	Immediately balance loads across all CPUs on architectures with NUMA

Note

With the release of Red Hat Enterprise Linux 6.1 the BOOK scheduling domain has been added to the list of supported domain levels. This change affected the meaning of **cpuset.sched_relax_domain_level** values. Please note that the effect of values from 3 to 5 changed. For example, to get the old effect of value 3, which was "Immediately balance loads across CPUs on the same node or blade" the value 4 needs to be selected. Similarly, the old 4 is now 5, and the old 5 is now 6.

3.5. devices

The **devices** subsystem allows or denies access to devices by tasks in a cgroup.

Technology preview

The Device Whitelist (**devices**) subsystem is considered to be a Technology Preview in Red Hat Enterprise Linux 6.

Technology preview features are currently not supported under Red Hat Enterprise Linux 6 subscription services, might not be functionally complete, and are generally not suitable for production use. However, Red Hat includes these features in the operating system as a customer convenience and to provide the feature with wider exposure. You might find these features useful in a non-production environment and are also free to provide feedback and functionality suggestions for a technology preview feature before it becomes fully supported.

devices.allow

specifies devices to which tasks in a cgroup have access. Each entry has four fields: *type*, *major*, *minor*, and *access*. The values used in the *type*, *major*, and *minor* fields correspond to device types and node numbers specified in *Linux Allocated Devices*, otherwise known as the *Linux Devices List* and available from http://www.kernel.org/doc/Documentation/devices.txt.

type

type can have one of the following three values:

- **a** — applies to all devices, both *character devices* and *block devices*
- **b** — specifies a block device
- **c** — specifies a character device

major, minor

major and *minor* are device node numbers specified by *Linux Allocated Devices*. The major and minor numbers are separated by a colon. For example, **8** is the major number that specifies SCSI disk drives, and the minor number **1** specifies the first partition on the first SCSI disk drive; therefore **8:1** fully specifies this partition, corresponding to a file system location of **/dev/sda1**.

***** can stand for all major or all minor device nodes, for example **9:*** (all RAID devices) or ***:*** (all devices).

access

access is a sequence of one or more of the following letters:

- **r** — allows tasks to read from the specified device
- **w** — allows tasks to write to the specified device
- **m** — allows tasks to create device files that do not yet exist

For example, when *access* is specified as **r**, tasks can only read from the specified device, but when *access* is specified as **rw**, tasks can read from and write to the device.

devices.deny

specifies devices that tasks in a cgroup cannot access. The syntax of entries is identical with **devices.allow**.

devices.list

reports the devices for which access controls have been set for tasks in this cgroup.

3.6. freezer

The **freezer** subsystem suspends or resumes tasks in a cgroup.

freezer.state

freezer.state is only available in non-root cgroups, and has three possible values:

- **FROZEN** — tasks in the cgroup are suspended.
- **FREEZING** — the system is in the process of suspending tasks in the cgroup.
- **THAWED** — tasks in the cgroup have resumed.

To suspend a specific process:

1. Move that process to a cgroup in a hierarchy which has the **freezer** subsystem attached to it.
2. Freeze that particular cgroup to suspend the process contained in it.

It is not possible to move a process into a suspended (frozen) cgroup.

Note that while the **FROZEN** and **THAWED** values can be written to **freezer.state**, **FREEZING** cannot be written, only read.

3.7. memory

The **memory** subsystem generates automatic reports on memory resources used by the tasks in a cgroup, and sets limits on memory use of those tasks:

Note

By default, the **memory** subsystem uses 40 bytes of memory per physical page on x86_64 systems. These resources are consumed even if **memory** is not used in any hierarchy. If you do not plan to use the **memory** subsystem, you can disable it to reduce the resource consumption of the kernel.

To permanently disable the **memory** subsystem, open the **/boot/grub/grub.conf** configuration file as **root** and append the following text to the line that starts with the *kernel* keyword:

```
cgroup_disable=memory
```

For more information on working with **/boot/grub/grub.conf**, see the *Configuring the GRUB Boot Loader* chapter in the Red Hat Enterprise Linux 6 Deployment Guide.

To temporarily disable the **memory** subsystem for a single session, perform the following steps when starting the system:

1. At the GRUB boot screen, press any key to enter the GRUB interactive menu.
2. Select Red Hat Enterprise Linux with the version of the kernel that you want to boot and press the **a** key to modify the kernel parameters.
3. Type **cgroup_disable=memory** at the end of the line and press **Enter** to exit GRUB edit mode.

With **cgroup_disable=memory** enabled, **memory** is not visible as an individually mountable subsystem and it is not automatically mounted when mounting all cgroups in a single hierarchy. Please note that **memory** is currently the only subsystem that can be effectively disabled with **cgroup_disabe** to save resources. Using this option with other subsystems only disables their usage, but does not cut their resource consumption. However, other subsystems do not consume as much resources as the **memory** subsystem.

The following tunable parameters are available for the **memory** subsystem:

memory.stat

reports a wide range of memory statistics, as described in the following table:

Table 3.2. Values reported by memory.stat

Statistic	Description
cache	page cache, including **tmpfs** (**shmem**), in bytes
rss	anonymous and swap cache, *not* including **tmpfs** (**shmem**), in bytes
mapped_file	size of memory-mapped mapped files, including **tmpfs** (**shmem**), in bytes
pgpgin	number of pages paged into memory
pgpgout	number of pages paged out of memory
swap	swap usage, in bytes
active_anon	anonymous and swap cache on active least-recently-used (LRU) list, including **tmpfs** (**shmem**), in bytes
inactive_anon	anonymous and swap cache on inactive LRU list, including **tmpfs** (**shmem**), in bytes

Statistic	Description
active_file	file-backed memory on active LRU list, in bytes
inactive_file	file-backed memory on inactive LRU list, in bytes
unevictable	memory that cannot be reclaimed, in bytes
hierarchical_memory_limit	memory limit for the hierarchy that contains the **memory** cgroup, in bytes
hierarchical_memsw_limit	memory plus swap limit for the hierarchy that contains the **memory** cgroup, in bytes

Additionally, each of these files other than **hierarchical_memory_limit** and **hierarchical_memsw_limit** has a counterpart prefixed **total_** that reports not only on the cgroup, but on all its children as well. For example, **swap** reports the swap usage by a cgroup and **total_swap** reports the total swap usage by the cgroup and all its child groups.

When you interpret the values reported by **memory.stat**, note how the various statistics inter-relate:

- **active_anon** + **inactive_anon** = anonymous memory + file cache for **tmpfs** + swap cache

  Therefore, **active_anon** + **inactive_anon** ≠ **rss**, because **rss** does not include **tmpfs**.

- **active_file** + **inactive_file** = cache - size of **tmpfs**

memory.usage_in_bytes

reports the total current memory usage by processes in the cgroup (in bytes).

memory.memsw.usage_in_bytes

reports the sum of current memory usage plus swap space used by processes in the cgroup (in bytes).

memory.max_usage_in_bytes

reports the maximum memory used by processes in the cgroup (in bytes).

memory.memsw.max_usage_in_bytes

reports the maximum amount of memory and swap space used by processes in the cgroup (in bytes).

memory.limit_in_bytes

sets the maximum amount of user memory (including file cache). If no units are specified, the value is interpreted as bytes. However, it is possible to use suffixes to represent larger units — **k** or **K** for kilobytes, **m** or **M** for Megabytes, and **g** or **G** for Gigabytes. For example, to set the limit to 1 Gigabyte, execute:

```
~]# echo 1G > /cgroup/memory/lab1/memory.limit_in_bytes
```

You cannot use **memory.limit_in_bytes** to limit the root cgroup; you can only apply values to groups lower in the hierarchy.

Write **-1** to **memory.limit_in_bytes** to remove any existing limits.

memory.memsw.limit_in_bytes

sets the maximum amount for the sum of memory and swap usage. If no units are specified, the value is interpreted as bytes. However, it is possible to use suffixes to represent larger units — **k** or **K** for kilobytes, **m** or **M** for Megabytes, and **g** or **G** for Gigabytes.

You cannot use **memory.memsw.limit_in_bytes** to limit the root cgroup; you can only apply values to groups lower in the hierarchy.

Write **-1** to **memory.memsw.limit_in_bytes** to remove any existing limits.

Setting the memory.memsw.limit_in_bytes and memory.limit_in_bytes parameters

It is important to set the **memory.limit_in_bytes** parameter *before* setting the **memory.memsw.limit_in_bytes** parameter: attempting to do so in the reverse order results in an error. This is because **memory.memsw.limit_in_bytes** becomes available only after all memory limitations (previously set in **memory.limit_in_bytes**) are exhausted.

Consider the following example: setting **memory.limit_in_bytes = 2G** and **memory.memsw.limit_in_bytes = 4G** for a certain cgroup will allow processes in that cgroup to allocate 2 GB of memory and, once exhausted, allocate another 2 GB of swap only. The **memory.memsw.limit_in_bytes** parameter represents the sum of memory and swap. Processes in a cgroup that does not have the **memory.memsw.limit_in_bytes** parameter set can potentially use up all the available swap (after exhausting the set memory limitation) and trigger an Out Of Memory situation caused by the lack of available swap.

The order in which the **memory.limit_in_bytes** and **memory.memsw.limit_in_bytes** parameters are set in the **/etc/cgconfig.conf** file is important as well. The following is a correct example of such a configuration:

```
memory {
    memory.limit_in_bytes = 1G;
    memory.memsw.limit_in_bytes = 1G;
}
```

memory.failcnt

reports the number of times that the memory limit has reached the value set in **memory.limit_in_bytes**.

memory.memsw.failcnt

reports the number of times that the memory plus swap space limit has reached the value set in **memory.memsw.limit_in_bytes**.

memory.soft_limit_in_bytes

enables flexible sharing of memory. Under normal circumstances, control groups are allowed to use as much of the memory as needed, constrained only by their hard limits set with the **memory.limit_in_bytes** parameter. However, when the system detects memory contention or low memory, control groups are forced to restrict their consumption to their

soft limits. To set the soft limit for example to 256 MB, execute:

```
~]# echo 256M > /cgroup/memory/lab1/memory.soft_limit_in_bytes
```

This parameter accepts the same suffixes as **memory.limit_in_bytes** to represent units. To have any affect, the soft limit must be set below the hard limit. If lowering the memory usage to the soft limit does not solve the contention, cgroups are pushed back as much as possible to make sure that one control group does not starve the others of memory. Note that soft limits take effect over a long period of time, since they involve reclaiming memory for balancing between memory cgroups.

memory.force_empty

when set to **0**, empties memory of all pages used by tasks in this cgroup. This interface can only be used when the cgroup has no tasks. If memory cannot be freed, it is moved to a parent cgroup if possible. Use the **memory.force_empty** parameter before removing a cgroup to avoid moving out-of-use page caches to its parent cgroup.

memory.swappiness

sets the tendency of the kernel to swap out process memory used by tasks in this cgroup instead of reclaiming pages from the page cache. This is the same tendency, calculated the same way, as set in **/proc/sys/vm/swappiness** for the system as a whole. The default value is **60**. Values lower than **60** decrease the kernel's tendency to swap out process memory, values greater than **60** increase the kernel's tendency to swap out process memory, and values greater than **100** permit the kernel to swap out pages that are part of the address space of the processes in this cgroup.

Note that a value of **0** does not prevent process memory being swapped out; swap out might still happen when there is a shortage of system memory because the global virtual memory management logic does not read the cgroup value. To lock pages completely, use **mlock()** instead of cgroups.

You cannot change the swappiness of the following groups:

- the root cgroup, which uses the swappiness set in **/proc/sys/vm/swappiness**.
- a cgroup that has child groups below it.

memory.move_charge_at_immigrate

allows moving charges associated with a task along with task migration. Charging is a way of giving a penalty to cgroups which access shared pages too often. These penalties, also called *charges*, are by default not moved when a task migrates from one cgroup to another. The pages allocated from the original cgroup still remain charged to it; the charge is dropped when the page is freed or reclaimed.

With **memory.move_charge_at_immigrate** enabled, the pages associated with a task are taken from the old cgroup and charged to the new cgroup. The following example shows how to enable **memory.move_charge_at_immigrate**:

```
~]# echo 1 > /cgroup/memory/lab1/memory.move_charge_at_immigrate
```

Charges are moved only when the moved task is a leader of a thread group. If there is not enough memory for the task in the destination cgroup, an attempt to reclaim memory is performed. If the reclaim is not successful, the task migration is aborted.

To disable **memory.move_charge_at_immigrate**, execute:

```
~]# echo 0 > /cgroup/memory/lab1/memory.move_charge_at_immigrate
```

memory.use_hierarchy

contains a flag (**0** or **1**) that specifies whether memory usage should be accounted for throughout a hierarchy of cgroups. If enabled (**1**), the memory subsystem reclaims memory from the children of and process that exceeds its memory limit. By default (**0**), the subsystem does not reclaim memory from a task's children.

memory.oom_control

contains a flag (**0** or **1**) that enables or disables the Out of Memory killer for a cgroup. If enabled (**0**), tasks that attempt to consume more memory than they are allowed are immediately killed by the OOM killer. The OOM killer is enabled by default in every cgroup using the **memory** subsystem; to disable it, write **1** to the **memory.oom_control** file:

```
~]# echo 1 > /cgroup/memory/lab1/memory.oom_control
```

When the OOM killer is disabled, tasks that attempt to use more memory than they are allowed are paused until additional memory is freed.

The **memory.oom_control** file also reports the OOM status of the current cgroup under the **under_oom** entry. If the cgroup is out of memory and tasks in it are paused, the **under_oom** entry reports the value **1**.

The **memory.oom_control** file is capable of reporting an occurrence of an OOM situation using the notification API. For more information, refer to Section 2.13, “Using the Notification API” and Example 3.3, “OOM Control and Notifications”.

3.7.1. Example Usage

Example 3.3. OOM Control and Notifications

The following example demonstrates how the OOM killer takes action when a task in a cgroup attempts to use more memory than allowed, and how a notification handler can report OOM situations:

1. Attach the **memory** subsystem to a hierarchy and create a cgroup:

```
~]# mount -t memory -o memory memory /cgroup/memory
~]# mkdir /cgroup/memory/blue
```

2. Set the amount of memory which tasks in the **blue** cgroup can use to 100MB:

```
~]# echo 104857600 > memory.limit_in_bytes
```

3. Change into the **blue** directory and make sure the OOM killer is enabled:

```
~]# cd /cgroup/memory/blue
blue]# cat memory.oom_control
oom_kill_disable 0
under_oom 0
```

4. Move the current shell process into the **tasks** file of the **blue** cgroup so that all other processes started in this shell are automatically moved to the **blue** cgroup:

```
blue]# echo $$ > tasks
```

5. Start a test program that attempts to allocate a large amount of memory exceeding the limit you set in Step 2. As soon as the **blue** cgroup runs out of free memory, the OOM killer kills the test program and reports **Killed** to the standard output:

```
blue]# ~/mem-hog
Killed
```

The following is an example of such a test program [5]:

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>

#define KB (1024)
#define MB (1024 * KB)
#define GB (1024 * MB)

int main(int argc, char *argv[])
{
 char *p;

again:
 while ((p = (char *)malloc(GB)))
  memset(p, 0, GB);

 while ((p = (char *)malloc(MB)))
  memset(p, 0, MB);

 while ((p = (char *)malloc(KB)))
  memset(p, 0,
    KB);

 sleep(1);

 goto again;

 return 0;
}
```

6. Disable the OOM killer and re-run the test program. This time, the test program remains paused waiting for additional memory to be freed:

```
blue]# echo 1 > memory.oom_control
blue]# ~/mem-hog
```

7. While the test program is paused, note that the **under_oom** state of the cgroup has changed to indicate that the cgroup is out of available memory:

```
~]# cat /cgroup/memory/blue/memory.oom_control
oom_kill_disable 1
under_oom 1
```

Re-enabling the OOM killer immediately kills the test program.

8. To receive notifications about every OOM situation, create a program as specified in Section 2.13, “Using the Notification API”. For example [6]:

```
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <sys/eventfd.h>
#include <errno.h>
#include <string.h>
#include <stdio.h>
#include <stdlib.h>

static inline void die(const char *msg)
{
 fprintf(stderr, "error: %s: %s(%d)\n", msg, strerror(errno),
errno);
 exit(EXIT_FAILURE);
}

static inline void usage(void)
{
 fprintf(stderr, "usage: oom_eventfd_test <cgroup.event_control>
<memory.oom_control>\n");
 exit(EXIT_FAILURE);
}

#define BUFSIZE 256

int main(int argc, char *argv[])
{
 char buf[BUFSIZE];
 int efd, cfd, ofd, rb, wb;
 uint64_t u;

 if (argc != 3)
  usage();

 if ((efd = eventfd(0, 0)) == -1)
  die("eventfd");

 if ((cfd = open(argv[1], O_WRONLY)) == -1)
  die("cgroup.event_control");

 if ((ofd = open(argv[2], O_RDONLY)) == -1)
  die("memory.oom_control");

 if ((wb = snprintf(buf, BUFSIZE, "%d %d", efd, ofd)) >= BUFSIZE)
  die("buffer too small");
```

```
 if (write(cfd, buf, wb) == -1)
  die("write cgroup.event_control");

 if (close(cfd) == -1)
  die("close cgroup.event_control");

 for (;;) {
  if (read(efd, &u, sizeof(uint64_t)) != sizeof(uint64_t))
   die("read eventfd");

  printf("mem_cgroup oom event received\n");
 }

 return 0;
}
```

The above program detects OOM situations in a cgroup specified as an argument on the command line and reports them using the **mem_cgroup oom event received** string to the standard output.

9. Run the above notification handler program in a separate console, specifying the **blue** cgroup's control files as arguments:

```
~]$ ./oom_notification /cgroup/memory/blue/cgroup.event_control
/cgroup/memory/blue/memory.oom_control
```

10. In a different console, run the **mem_hog** test program to create an OOM situation to see the **oom_notification** program report it on the standard output:

```
blue]# ~/mem-hog
```

3.8. net_cls

The **net_cls** subsystem tags network packets with a class identifier (classid) that allows the Linux traffic controller (**tc**) to identify packets originating from a particular cgroup. The traffic controller can be configured to assign different priorities to packets from different cgroups.

net_cls.classid

net_cls.classid contains a single value that indicates a traffic control *handle*. The value of ***classid*** read from the **net_cls.classid** file is presented in the decimal format while the value to be written to the file is expected in the hexadecimal format. For example, **0x100001** represents the handle conventionally written as **10:1** in the format used by the **ip** utility. In the **net_cls.classid** file, it would be represented by the number **1048577**.

The format for these handles is: **0x*AAAABBBB***, where *AAAA* is the major number in hexadecimal and *BBBB* is the minor number in hexadecimal. You can omit any leading zeroes; **0x10001** is the same as **0x00010001**, and represents **1:1**. The following is an example of setting a **10:1** handle in the **net_cls.classid** file:

```
~]# echo 0x100001 > /cgroup/net_cls/red/net_cls.classid
~]# cat /cgroup/net_cls/red/net_cls.classid
1048577
```

Refer to the man page for **tc** to learn how to configure the traffic controller to use the handles that the **net_cls** adds to network packets.

3.9. net_prio

The Network Priority (**net_prio**) subsystem provides a way to dynamically set the priority of network traffic per each network interface for applications within various cgroups. A network's priority is a number assigned to network traffic and used internally by the system and network devices. Network priority is used to differentiate packets that are sent, queued, or dropped. The **tc** command may be used to set a network's priority (setting the network priority via the **tc** command is outside the scope of this guide; for more information, refer to the **tc** man page).

Typically, an application sets the priority of its traffic via the **SO_PRIORITY** socket option. However, applications are often not coded to set the priority value, or the application's traffic is site-specific and does not provide a defined priority.

Using the **net_prio** subsystem in a cgroup allows an administrator to assign a process to a specific cgroup which defines the priority of outgoing traffic on a given network interface.

Note

The **net_prio** subsystem is not compiled in the kernel like the rest of the subsystems, rather it is a module that has to be loaded before attempting to mount it. To load this module, type as **root**:

```
modprobe netprio_cgroup
```

The following tunable parameters are available for the **memory** subsystem.

net_prio.prioidx

a read-only file which contains a unique integer value that the kernel uses as an internal representation of this cgroup.

net_prio.ifpriomap

contains a map of priorities assigned to traffic originating from processes in this group and leaving the system on various interfaces. This map is represented by a list of pairs in the form ***<network_interface> <priority>***:

```
~]# cat /cgroup/net_prio/iscsi/net_prio.ifpriomap
eth0 5
eth1 4
eth2 6
```

Contents of the **net_prio.ifpriomap** file can be modified by echoing a string into the file using the above format, for example:

```
~]# echo "eth0 5" > /cgroup/net_prio/iscsi/net_prio.ifpriomap
```

The above command forces any traffic originating from processes belonging to the **iscsi net_prio** cgroup, and with traffic outgoing on the **eth0** network interface, to have the priority set to the value **5**. The parent cgroup also has a writable **net_prio.ifpriomap** file that can be used to set a system default priority.

3.10. ns

The **ns** subsystem provides a way to group processes into separate *namespaces*. Within a particular namespace, processes can interact with each other but are isolated from processes running in other namespaces. These separate namespaces are sometimes referred to as *containers* when used for operating-system-level virtualization.

3.11. perf_event

When the **perf_event** subsystem is attached to a hierarchy, all cgroups in that hierarchy can be used to group processes and threads which can then be monitored with the **perf** tool, as opposed to monitoring each process or thread separately or per-CPU. Cgroups which use the **perf_event** subsystem do not contain any special tunable parameters other than the common parameters listed in Section 3.12, “Common Tunable Parameters”.

For additional information on how tasks in a cgroup can be monitored using the **perf** tool, refer to the Red Hat Enterprise Linux *Developer Guide*, available from http://access.redhat.com/site/documentation/Red_Hat_Enterprise_Linux/.

3.12. Common Tunable Parameters

The following parameters are present in every created cgroup, regardless of the subsystem that the cgroup is using:

tasks

contains a list of processes, represented by their PIDs, that are running in a cgroup. The list of PIDs is not guaranteed to be ordered or unique (that is, it may contain duplicate entries). Writing a PID into the **tasks** file of a cgroup moves that process into that cgroup.

cgroup.procs

contains a list of thread groups, represented by their TGIDs, that are running in a cgroup. The list of TGIDs is not guaranteed to be ordered or unique (that is, it may contain duplicate entries). Writing a TGID into the **cgroup.procs** file of a cgroup moves that thread group into that cgroup.

cgroup.event_control

along with the cgroup notification API, allows notifications to be sent about a changing status of a cgroup.

notify_on_release

contains a Boolean value, **1** or **0**, that either enables or disables the execution of the release agent. If the ***notify_on_release*** is enabled, the kernel executes the contents of the **release_agent** file when a cgroup no longer contains any tasks (that is, the cgroup's **tasks** file contained some PIDs and those PIDs were removed, leaving the file empty). A path to the empty cgroup is provided as an argument to the release agent.

The default value of the ***notify_on_release*** parameter in the root cgroup is **0**. All non-root cgroups inherit the value in ***notify_on_release*** from their parent cgroup.

release_agent (present in the root cgroup only)

contains a command to be executed when a “notify on release” is triggered. Once a cgroup is emptied of all processes, and the ***notify_on_release*** flag is enabled, the kernel runs the command in the **release_agent** file and supplies it with a relative path (relative to the root cgroup) to the emptied cgroup as an argument. The release agent can be used, for example, to automatically remove empty cgroups; for more information, see Example 3.4, “Automatically removing empty cgroups”.

Example 3.4. Automatically removing empty cgroups

Follow these steps to configure automatic removal of any emptied cgroup from the **cpu** cgroup:

1. Create a shell script that removes empty **cpu** cgroups, place it in, for example, **/usr/local/bin**, and make it executable.

```
~]# cat /usr/local/bin/remove-empty-cpu-cgroup.sh
#!/bin/sh
rmdir /cgroup/cpu/$1
~]# chmod +x /usr/local/bin/remove-empty-cpu-cgroup.sh
```

   The **$1** variable contains a relative path to the emptied cgroup.

2. In the **cpu** cgroup, enable the ***notify_on_release*** flag:

```
~]# echo 1 > /cgroup/cpu/notify_on_release
```

3. In the **cpu** cgroup, specify a release agent to be used:

```
~]# echo "/usr/local/bin/remove-empty-cpu-cgroup.sh" >
/cgroup/cpu/release_agent
```

4. Test your configuration to make sure emptied cgroups are properly removed:

```
cpu]# pwd; ls
/cgroup/cpu
cgroup.event_control  cgroup.procs  cpu.cfs_period_us
cpu.cfs_quota_us  cpu.rt_period_us  cpu.rt_runtime_us
cpu.shares  cpu.stat  libvirt  notify_on_release
release_agent  tasks
cpu]# cat notify_on_release
1
cpu]# cat release_agent
/usr/local/bin/remove-empty-cpu-cgroup.sh
cpu]# mkdir blue; ls
blue  cgroup.event_control  cgroup.procs
cpu.cfs_period_us  cpu.cfs_quota_us  cpu.rt_period_us
cpu.rt_runtime_us  cpu.shares  cpu.stat  libvirt
notify_on_release  release_agent  tasks
cpu]# cat blue/notify_on_release
1
```

```
cpu]# cgexec -g cpu:blue dd if=/dev/zero of=/dev/null
bs=1024k &
[1] 8623
cpu]# cat blue/tasks
8623
cpu]# kill -9 8623
cpu]# ls
cgroup.event_control  cgroup.procs  cpu.cfs_period_us
cpu.cfs_quota_us  cpu.rt_period_us  cpu.rt_runtime_us
cpu.shares  cpu.stat  libvirt  notify_on_release
release_agent  tasks
```

3.13. Additional Resources

Subsystem-Specific Kernel Documentation

All of the following files are located under the **/usr/share/doc/kernel-doc-<*kernel_version*>/Documentation/cgroups/** directory (provided by the *kernel-doc* package).

- **blkio** subsystem — **blkio-controller.txt**
- **cpuacct** subsystem — **cpuacct.txt**
- **cpuset** subsystem — **cpusets.txt**
- **devices** subsystem — **devices.txt**
- **freezer** subsystem — **freezer-subsystem.txt**
- **memory** subsystem — **memory.txt**
- **net_prio** subsystem — **net_prio.txt**

Additionally, refer to the following files on further information about the **cpu** subsystem:

- Real-Time scheduling — **/usr/share/doc/kernel-doc-<*kernel_version*>/Documentation/scheduler/sched-rt-group.txt**
- CFS scheduling — **/usr/share/doc/kernel-doc-<*kernel_version*>/Documentation/scheduler/sched-bwc.txt**

[5] Source code provided by Red Hat Engineer František Hrbata.

[6] Source code provided by Red Hat Engineer František Hrbata.

Chapter 4. Control Group Application Examples

This chapter provides application examples that take advantage of the cgroup functionality.

4.1. Prioritizing Database I/O

Running each instance of a database server inside its own dedicated virtual guest allows you to allocate resources per database based on their priority. Consider the following example: a system is running two database servers inside two KVM guests. One of the databases is a high priority database and the other one a low priority database. When both database servers are run simultaneously, the I/O throughput is decreased to accommodate requests from both databases equally; Figure 4.1, “I/O throughput without resource allocation” indicates this scenario — once the low priority database is started (around time 45), I/O throughput is the same for both database servers.

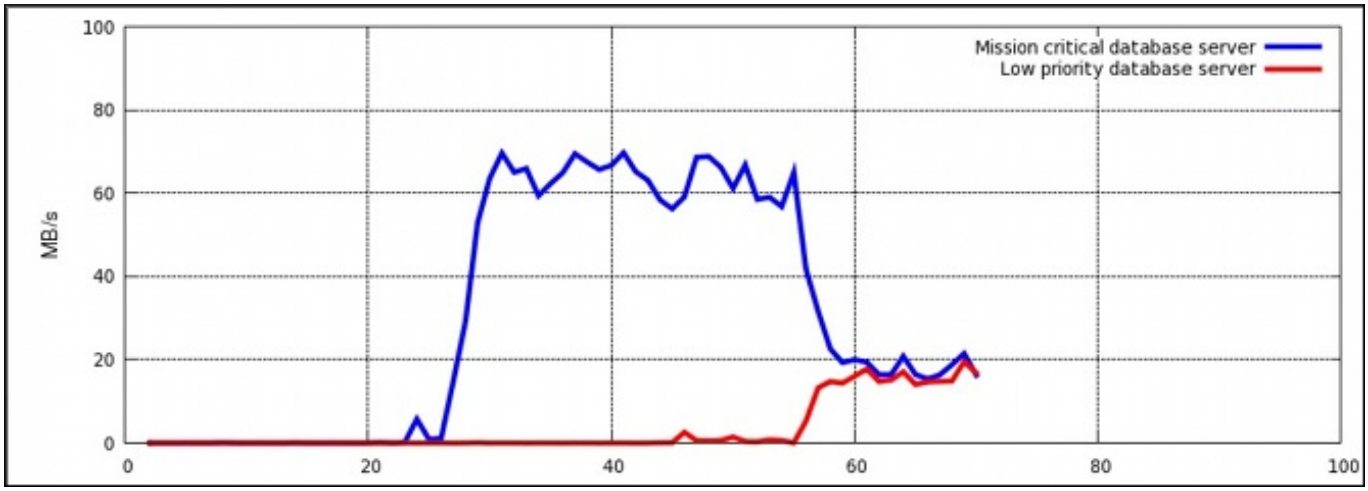


Figure 4.1. I/O throughput without resource allocation

To prioritize the high priority database server, it can be assigned to a cgroup with a high number of reserved I/O operations, whereas the low priority database server can be assigned to a cgroup with a low number of reserved I/O operations. To achieve this, follow the steps in Procedure 4.1, “I/O throughput prioritization”, all of which are performed on the host system.

Procedure 4.1. I/O throughput prioritization

1. Attach the **blkio** subsystem to the **/cgroup/blkio** cgroup:

```
~]# mkdir /cgroup/blkio
~]# mount -t cgroup -o blkio blkio /cgroup/blkio
```

2. Create a high and low priority cgroup:

```
~]# mkdir /cgroup/blkio/high_prio
~]# mkdir /cgroup/blkio/low_prio
```

3. Acquire the PIDs of the processes that represent both virtual guests (in which the database servers are running) and move them to their specific cgroup. In our example, **VM_high** represents a virtual guest running a high priority database server, and **VM_low** represents a virtual guest running a low priority database server. For example:

```
~]# ps -eLf | grep qemu | grep VM_high | awk '{print $4}' | while
read pid; do echo $pid >> /cgroup/blkio/high_prio/tasks; done
~]# ps -eLf | grep qemu | grep VM_low | awk '{print $4}' | while
read pid; do echo $pid >> /cgroup/blkio/low_prio/tasks; done
```

4. Set a ratio of 10:1 for the **high_prio** and **low_prio** cgroups. Processes in those cgroups (that is, processes running the virtual guests that have been added to those cgroups in the previous step) will immediately use only the resources made available to them.

```
~]# echo 1000 > /cgroup/blkio/high_prio/blkio.weight
~]# echo 100 > /cgroup/blkio/low_prio/blkio.weight
```

In our example, the low priority cgroup permits the low priority database server to use only about 10% of the I/O operations, whereas the high priority cgroup permits the high priority database server to use about 90% of the I/O operations.

Figure 4.2, “I/O throughput with resource allocation” illustrates the outcome of limiting the low priority database and prioritizing the high priority database. As soon as the database servers are moved to their appropriate cgroups (around time 75), I/O throughput is divided among both servers with the ratio of 10:1.

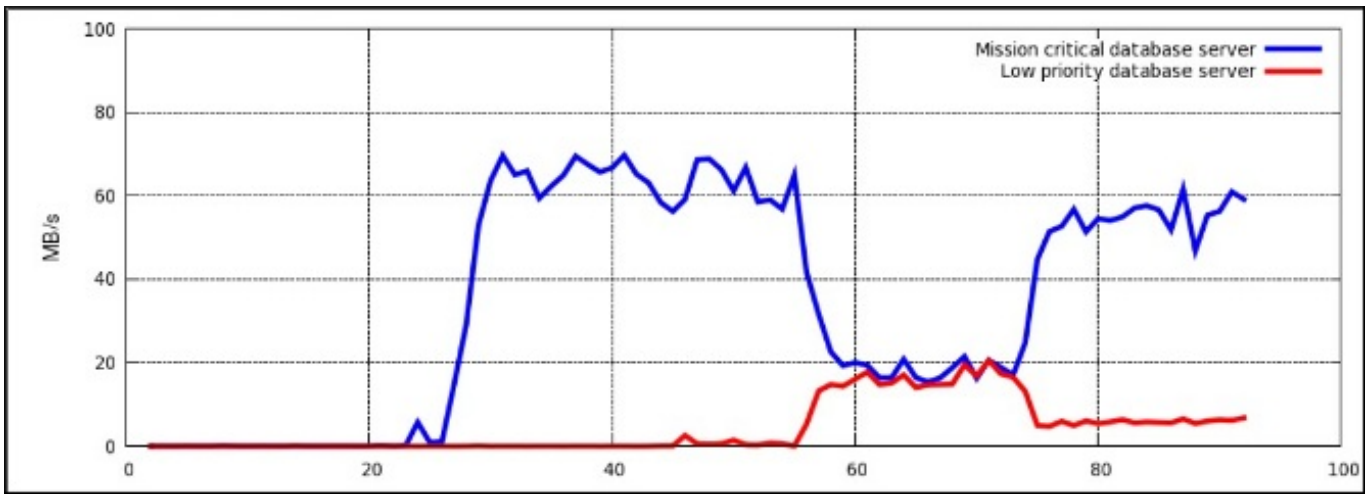


Figure 4.2. I/O throughput with resource allocation

Alternatively, block device I/O throttling can be used for the low priority database to limit its number of read and write operation. For more information on the **blkio** subsystem, refer to Section 3.1, “blkio”.

4.2. Prioritizing Network Traffic

When running multiple network-related services on a single server system, it is important to define network priorities between these services. Defining these priorities ensures that packets originating from certain services have a higher priority than packets originating from other services. For example, such priorities are useful when a server system simultaneously functions as an NFS and Samba server. The NFS traffic must be of high priority as users expect high throughput. The Samba traffic can be deprioritized to allow better performance of the NFS server.

The **net_prio** subsystem can be used to set network priorities for processes in cgroups. These priorities are then translated into Type Of Service (TOS) bits and embedded into every packet. Follow the steps in Procedure 4.2, “Setting Network Priorities for File Sharing Services” to configure prioritization of two file sharing services (NFS and Samba).

Procedure 4.2. Setting Network Priorities for File Sharing Services

1. The **net_prio** subsystem is not compiled in the kernel, it is a module that must be loaded manually. To do so, type:

```
~]# modprobe net_prio
```

2. Attach the **net_prio** subsystem to the **/cgroup/net_prio** cgroup:

```
~]# mkdir /cgroup/net_prio
~]# mount -t cgroup -o net_prio net_prio /cgroup/net_prio
```

3. Create two cgroups, one for each service:

```
~]# mkdir /cgroup/net_prio/nfs_high
~]# mkdir /cgroup/net_prio/samba_low
```

4. To automatically move the **nfs** services to the **nfs_high** cgroup, add the following line to the **/etc/sysconfig/nfs** file:

```
CGROUP_DAEMON="net_prio:nfs_high"
```

This configuration ensures that **nfs** service processes are moved to the **nfs_high** cgroup when the **nfs** service is started or restarted. For more information about moving service processes to cgroups, refer to Section 2.9.1, “Starting a Service in a Control Group”.

5. The **smbd** daemon does not have a configuration file in the **/etc/sysconfig** directory. To automatically move the **smbd** daemon to the **samba_low** cgroup, add the following line to the **/etc/cgrules.conf** file:

```
*:smbd                  net_prio                samba_low
```

Note that this rule moves every **smbd** daemon, not only **/usr/sbin/smbd**, into the **samba_low** cgroup.

You can define rules for the **nmbd** and **winbindd** daemons to be moved to the **samba_low** cgroup in a similar way.

6. Start the **cgred** service to load the configuration from the previous step:

```
~]# service cgred start
Starting CGroup Rules Engine Daemon:                       [  OK  ]
```

7. For the purposes of this example, let us assume both services use the **eth1** network interface. Define network priorities for each cgroup, where **1** denotes low priority and **10** denotes high priority:

```
~]# echo "eth1 1" > /cgroup/net_prio/samba_low
~]# echo "eth1 10" > /cgroup/net_prio/nfs_high
```

8. Start the **nfs** and **smb** services and check whether their processes have been moved into the correct cgroups:

```
~]# service smb start
```

```
Starting SMB services:                                     [  OK  ]
~]# cat /cgroup/net_prio/samba_low
16122
16124
~]# service nfs start
Starting NFS services:                                     [  OK  ]
Starting NFS quotas:                                       [  OK  ]
Starting NFS mountd:                                       [  OK  ]
Stopping RPC idmapd:                                       [  OK  ]
Starting RPC idmapd:                                       [  OK  ]
Starting NFS daemon:                                       [  OK  ]
~]# cat /cgroup/net_prio/nfs_high
16321
16325
16376
```

Network traffic originating from NFS now has higher priority than traffic originating from Samba.

Similar to Procedure 4.2, “Setting Network Priorities for File Sharing Services”, the **net_prio** subsystem can be used to set network priorities for client applications, for example, Firefox.

4.3. Per-group Division of CPU and Memory Resources

When a large amount of users use a single system, it is practical to provide certain users with more resources than others. Consider the following example: in a hypothetical company, there are three departments — finance, sales, and engineering. Because engineers use the system and its resources for more tasks than the other departments, it is logical that they have more resources available in case all departments are running CPU and memory intensive tasks.

Cgroups provide a way to limit the resources per each system group of users. For this example, assume that the following users have been created on the system:

```
~]$ grep home /etc/passwd
martin:x:500:500::/home/martin:/bin/bash
john:x:501:501::/home/john:/bin/bash
mark:x:502:502::/home/mark:/bin/bash
peter:x:503:503::/home/peter:/bin/bash
jenn:x:504:504::/home/jenn:/bin/bash
mike:x:505:505::/home/mike:/bin/bash
```

These users have been assigned to the following system groups:

```
~]$ grep -e "50[678]" /etc/group
finance:x:506:jenn,john
sales:x:507:mark,martin
engineering:x:508:peter,mike
```

For this example to work properly, you must have the *libcgroup* package installed. Using the **/etc/cgconfig.conf** and **/etc/cgrules.conf** files, you can create a hierarchy and a set of rules which determine the amount of resources for each user. To achieve this, follow the steps in Procedure 4.3, “Per-group CPU and memory resource management”.

Procedure 4.3. Per-group CPU and memory resource management

1. In the **/etc/cgconfig.conf** file, configure the following subsystems to be mounted and cgroups to be created:

```
mount {
    cpu     = /cgroup/cpu_and_mem;
    cpuacct = /cgroup/cpu_and_mem;
    memory  = /cgroup/cpu_and_mem;
}

group finance {
        cpu {
                cpu.shares="250";
        }
        cpuacct {
                cpuacct.usage="0";
        }
        memory {
                memory.limit_in_bytes="2G";
                memory.memsw.limit_in_bytes="3G";
        }
}

group sales {
        cpu {
                cpu.shares="250";
        }
        cpuacct {
                cpuacct.usage="0";
        }
        memory {
                memory.limit_in_bytes="4G";
                memory.memsw.limit_in_bytes="6G";
        }
}

group engineering {
        cpu {
                cpu.shares="500";
        }
        cpuacct {
                cpuacct.usage="0";
        }
        memory {
                memory.limit_in_bytes="8G";
                memory.memsw.limit_in_bytes="16G";
        }
}
```

When loaded, the above configuration file mounts the **cpu**, **cpuacct**, and **memory** subsystems to a single **cpu_and_mem** cgroup. For more information on these subsystems, refer to Chapter 3, *Subsystems and Tunable Parameters*. Next, it creates a hierarchy in **cpu_and_mem** which contains three cgroups: sales, finance, and engineering. In each of these cgroups, custom parameters are set for each subsystem:

- **cpu** — the ***cpu.shares*** parameter determines the share of CPU resources available to each process in all cgroups. Setting the parameter to **250**, **250**, and **500** in the finance,

sales, and engineering cgroups respectively means that processes started in these groups will split the resources with a 1:1:2 ratio. Note that when a single process is running, it consumes as much CPU as necessary no matter which cgroup it is placed in. The CPU limitation only comes into effect when two or more processes compete for CPU resources.

- **cpuacct** — the ***cpuacct.usage="0"*** parameter is used to reset values stored in the **cpuacct.usage** and **cpuacct.usage_percpu** files. These files report total CPU time (in nanoseconds) consumed by all processes in a cgroup.

- **memory** — the ***memory.limit_in_bytes*** parameter represents the amount of memory that is made available to all processes within a certain cgroup. In our example, processes started in the finance cgroup have 2 GB of memory available, processes in the sales group have 4 GB of memory available, and processes in the engineering group have 8 GB of memory available. The ***memory.memsw.limit_in_bytes*** parameter specifies the total amount of memory and swap space processes may use. Should a process in the finance cgroup hit the 2 GB memory limit, it is allowed to use another 1 GB of swap space, thus totaling the configured 3 GB.

2. To define the rules which the **cgrulesengd** daemon uses to move processes to specific cgroups, configure the **/etc/cgrules.conf** in the following way:

```
#<user/group>          <controller(s)>          <cgroup>
@finance               cpu,cpuacct,memory       finance
@sales                 cpu,cpuacct,memory       sales
@engineering           cpu,cpuacct,memory       engineering
```

   The above configuration creates rules that assign a specific system group (for example, ***@finance***) the resource controllers it may use (for example, **cpu**, **cpuacct**, **memory**) and a cgroup (for example, **finance**) which contains all processes originating from that system group.

   In our example, when the **cgrulesengd** daemon, started via the **service cgred start** command, detects a process that is started by a user that belongs to the finance system group (for example, **jenn**), that process is automatically moved to the **/cgroup/cpu_and_mem/finance/tasks** file and is subjected to the resource limitations set in the finance cgroup.

3. Start the **cgconfig** service to create the hierarchy of cgroups and set the needed parameters in all created cgroups:

```
~]# service cgconfig start
Starting cgconfig service:                                 [  OK  ]
```

   Start the **cgred** service to let the **cgrulesengd** daemon detect any processes started in system groups configured in the **/etc/cgrules.conf** file:

```
~]# service cgred start
Starting CGroup Rules Engine Daemon:                       [  OK  ]
```

   Note that **cgred** is the name of the service that starts the **cgrulesengd** daemon.

4. To make all of the changes above persistent across reboots, configure the **cgconfig** and **cgred** services to be started by default:

```
~]# chkconfig cgconfig on
~]# chkconfig cgred on
```

To test whether this setup works, execute a CPU or memory intensive process and observe the results, for example, using the **top** utility. To test the CPU resource management, execute the following **dd** command under each user:

```
~]$ dd if=/dev/zero of=/dev/null bs=1024k
```

The above command reads the **/dev/zero** and outputs it to the **/dev/null** in chunks of 1024 KB. When the **top** utility is launched, you can see results similar to these:

```
 PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
8201 peter     20   0  103m 1676  556 R 24.9  0.2   0:04.18 dd
8202 mike      20   0  103m 1672  556 R 24.9  0.2   0:03.47 dd
8199 jenn      20   0  103m 1676  556 R 12.6  0.2   0:02.87 dd
8200 john      20   0  103m 1676  556 R 12.6  0.2   0:02.20 dd
8197 martin    20   0  103m 1672  556 R 12.6  0.2   0:05.56 dd
8198 mark      20   0  103m 1672  556 R 12.3  0.2   0:04.28 dd
⋮
```

All processes have been correctly assigned to their cgroups and are only allowed to consume CPU resource made available to them. If all but two processes, which belong to the finance and engineering cgroups, are stopped, the remaining resources are evenly split between both processes:

```
  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
8202 mike      20   0  103m 1676  556 R 66.4  0.2   0:06.35 dd
8200 john      20   0  103m 1672  556 R 33.2  0.2   0:05.08 dd
⋮
```

Alternative method

Because the **cgrulesengd** daemon moves a process to a cgroup only after the appropriate conditions set by the rules in **/etc/cgrules.conf** have been fulfilled, that process may be running for a few milliseconds in an incorrect cgroup. An alternative way to move processes to their specified cgroups is to use the **pam_cgroup.so** PAM module. This module moves processes to available cgroups according to rules defined in the **/etc/cgrules.conf** file. Follow the steps in Procedure 4.4, “Using a PAM module to move processes to cgroups” to configure the **pam_cgroup.so** PAM module. Note that the *libcgroup-pam* package that provides this module is available form the Optional subscription channel. Before subscribing to this channel please see the Scope of Coverage Details. If you decide to install packages from the channel, follow the steps documented in the article called How to access Optional and Supplementary channels, and -devel packages using Red Hat Subscription Manager (RHSM)? on Red Hat Customer Portal.

Procedure 4.4. Using a PAM module to move processes to cgroups

1. Install the *libcgroup-pam* package from the optional Red Hat Enterprise Linux Yum repository:

```
~]# yum install libcgroup-pam --enablerepo=rhel-6-server-
optional-rpms
```

2. Ensure that the PAM module has been installed and exists:

```
~]# ls /lib64/security/pam_cgroup.so
/lib64/security/pam_cgroup.so
```

Note that on 32-bit systems, the module is placed in the **/lib/security** directory.

3. Add the following line to the **/etc/pam.d/su** file to use the **pam_cgroup.so** module each time the **su** command is executed:

```
session         optional        pam_cgroup.so
```

4. Configure the **/etc/cgconfig.conf** and **/etc/cgrules.conf** files as in Procedure 4.3, “Per-group CPU and memory resource management”.

5. Log out all users that are affected by the cgroup settings in the **/etc/cgrules.conf** file to apply the above configuration.

When using the **pam_cgroup.so** PAM module, you may disable the **cgred** service.

Appendix A. Revision History

Revision 1.0-32 **Thu Jul 16 2015** **Laura Bailey**

Publishing for RHEL 6.7 GA.

Revision 1.0-30 **Tue May 12 2015** **Radek Bíba**

Fixed an incorrect link in section Per-group Division of CPU and Memory Resources.

Revision 1.0-29 **Mon Apr 20 2015** **Radek Bíba**

Red Hat Enterprise Linux 6.7 Beta release of the Resource Management Guide.

Revision 1.0-26 **Thu Oct 10 2014** **Peter Ondrejka**

Red Hat Enterprise Linux 6.6 GA release of the Resource Management Guide. Includes various fixes and new content:
- Subsystem reference updated and clarified
- New tunable parameters of the memory subsystem added
- A note on disabling the memory subsystem permanently added

Revision 1.0-16 **Thu Feb 21 2013** **Martin Prpič**

Red Hat Enterprise Linux 6.4 GA release of the *Resource Management Guide*. Includes various fixes and new content:
- Final use case scenarios — 584631
- Documentation for the **perf_event** controller — 807326
- Documentation for common cgroup files — 807329
- Documentation for OOM control and the notification API — 822400, 822401
- CPU ceiling enforcement documentation — 828991

Revision 1.0-7 **Wed Jun 20 2012** **Martin Prpič**

Red Hat Enterprise Linux 6.3 GA release of the *Resource Management Guide*.
- Added two use cases.
- Added documentation for the **net_prio** subsystem.

Revision 1.0-6 **Tue Dec 6 2011** **Martin Prpič**

Red Hat Enterprise Linux 6.2 GA release of the *Resource Management Guide*.

Revision 1.0-5 **Thu May 19 2011** **Martin Prpič**

Red Hat Enterprise Linux 6.1 GA release of the *Resource Management Guide*.

Revision 1.0-4 **Tue Mar 1 2011** **Martin Prpič**

- Fixed multiple examples — BZ#667623, BZ#667676, BZ#667699
- Clarification of the cgclear command — BZ#577101
- Clarification of the lssubsystem command — BZ#678517
- Freezing a process — BZ#677548

Revision 1.0-3 **Wed Nov 17 2010** **Rüdiger Landmann**

Correct remount example — BZ#612805

Revision 1.0-2 **Thu Nov 11 2010** **Rüdiger Landmann**

Remove pre-release feedback instructions

Revision 1.0-1 **Wed Nov 10 2010** **Rüdiger Landmann**

Corrections from QE — BZ#581702 and BZ#612805

Revision 1.0-0 **Tue Nov 9 2010** **Rüdiger Landmann**

Feature-complete version for GA