Red Hat Enterprise Linux 9

Managing, monitoring, and updating the kernel

A guide to managing the Linux kernel on Red Hat Enterprise Linux 9

Last Updated: 2025-06-09

Red Hat Enterprise Linux 9 Managing, monitoring, and updating the kernel

A guide to managing the Linux kernel on Red Hat Enterprise Linux 9

Legal Notice

Abstract

As a system administrator, you can configure the Linux kernel to optimize the operating system. Changes to the Linux kernel can improve system performance, security, and stability, as well as your ability to audit the system and troubleshoot problems.

Table of Contents

PROVIDING FEEDBACK ON RED HAT DOCUMENTATION

We appreciate your feedback on our documentation. Let us know how we can improve it.

Submitting feedback through Jira (account required)

1. Log in to the Jira website.
2. Click **Create** in the top navigation bar
3. Enter a descriptive title in the **Summary** field.
4. Enter your suggestion for improvement in the **Description** field. Include links to the relevant parts of the documentation.
5. Click **Create** at the bottom of the dialogue.

CHAPTER 1. THE LINUX KERNEL

Learn about the Linux kernel and the Linux kernel RPM package provided and maintained by Red Hat (Red Hat kernel). Keep the Red Hat kernel updated, which ensures the operating system has all the latest bug fixes, performance enhancements, and patches, and is compatible with new hardware.

1.1. WHAT THE KERNEL IS

The kernel is a core part of a Linux operating system that manages the system resources and provides interface between hardware and software applications.

The Red Hat kernel is a custom-built kernel based on the upstream Linux mainline kernel that Red Hat engineers further develop and harden with a focus on stability and compatibility with the latest technologies and hardware.

Before Red Hat releases a new kernel version, the kernel needs to pass a set of rigorous quality assurance tests.

The Red Hat kernels are packaged in the RPM format so that they are easily upgraded and verified by the **DNF** package manager.

> **WARNING**
>
> Kernels that are not compiled by Red Hat are **not** supported by Red Hat.

1.2. RPM PACKAGES

An RPM package consists of an archive of files and metadata used to install and erase these files. Specifically, the RPM package contains the following parts:

GPG signature

The GPG signature is used to verify the integrity of the package.

Header (package metadata)

The RPM package manager uses this metadata to determine package dependencies, where to install files, and other information.

Payload

The payload is a **cpio** archive that contains files to install to the system.

There are two types of RPM packages. Both types share the file format and tooling, but have different contents and serve different purposes:

- Source RPM (SRPM)
  An SRPM contains source code and a **spec** file, which describes how to build the source code into a binary RPM. Optionally, the SRPM can contain patches to source code.

- Binary RPM
  A binary RPM contains the binaries built from the sources and patches.

1.3. THE LINUX KERNEL RPM PACKAGE OVERVIEW

The **kernel** RPM is a meta package that does not contain any files, but rather ensures that the following required sub-packages are properly installed:

kernel-core

Provides the binary image of the Linux kernel (**vmlinuz**).

kernel-modules-core

Provides the basic kernel modules to ensure core functionality. This includes the modules essential for the proper functioning of the most commonly used hardware.

kernel-modules

Provides the remaining kernel modules that are not present in **kernel-core**.

The **kernel-core** and **kernel-modules-core** sub-packages together can be used in virtualized and cloud environments to provide a RHEL 9 kernel with a quick boot time and a small disk size footprint. **kernel-modules** sub-package is usually unnecessary for such deployments.

Optional kernel packages are for example:

kernel-modules-extra

Provides kernel modules for rare hardware. Loading of the module is disabled by default.

kernel-debug

Provides a kernel with many debugging options enabled for kernel diagnosis, at the expense of reduced performance.

kernel-tools

Provides tools for manipulating the Linux kernel and supporting documentation.

kernel-devel

Provides the kernel headers and makefiles that are enough to build modules against the **kernel** package.

kernel-abi-stablelists

Provides information pertaining to the RHEL kernel ABI, including a list of kernel symbols required by external Linux kernel modules and a **dnf** plug-in to aid enforcement.

kernel-headers

Includes the C header files that specify the interface between the Linux kernel and user-space libraries and programs. The header files define structures and constants required for building most standard programs.

kernel-uki-virt

Contains the Unified Kernel Image (UKI) of the RHEL kernel.
UKI combines the Linux kernel, **initramfs**, and the kernel command line into a single signed binary which can be booted directly from the UEFI firmware.

kernel-uki-virt contains the required kernel modules to run in virtualized and cloud environments and can be used instead of the **kernel-core** sub-package.

Additional resources

- *What are the kernel-core, kernel-modules, and kernel-modules-extras packages?*

1.4. DISPLAYING CONTENTS OF A KERNEL PACKAGE

By querying the repository, you can see if a kernel package provides a specific file, such as a module. It is not necessary to download or install the package to display the file list.

Use the **dnf** utility to query the file list, for example, of the **kernel-core**, **kernel-modules-core**, or **kernel-modules** package. Note that the **kernel** package is a meta package that does not contain any files.

Procedure

1. List the available versions of a package:

```
$ dnf repoquery <package_name>
```

2. Display the list of files in a package:

```
$ dnf repoquery -l <package_name>
```

Additional resources

- Packaging and distributing software

1.5. INSTALLING SPECIFIC KERNEL VERSIONS

Install new kernels using the **dnf** package manager.

Procedure

- To install a specific kernel version, enter the following command:

```
# dnf install kernel-5.14.0
```

Additional resources

- *Red Hat Enterprise Linux Release Dates*

1.6. UPDATING THE KERNEL

Update the kernel using the **dnf** package manager.

Procedure

1. To update the kernel, enter the following command:

```
# dnf update kernel
```

This command updates the kernel along with all dependencies to the latest available version.

2. Reboot your system for the changes to take effect.

Additional resources

- package manager
- The **dnf(8)** manual page

1.7. SETTING A KERNEL AS DEFAULT

Set a specific kernel as default by using the **grubby** command-line tool and GRUB.

Procedure

- Setting the kernel as default by using the **grubby** tool.
  - Enter the following command to set the kernel as default using the **grubby** tool:

    ```
    # grubby --set-default $kernel_path
    ```

    The command uses a machine ID without the **.conf** suffix as an argument.

    > **NOTE**
    >
    > The machine ID is located in the **/boot/loader/entries/** directory.

- Setting the kernel as default by using the **id** argument.
  - List the boot entries using the **id** argument and then set an intended kernel as default:

    ```
    # grubby --info ALL | grep id
    # grubby --set-default /boot/vmlinuz-<version>.<architecture>
    ```

    > **NOTE**
    >
    > To list the boot entries using the **title** argument, execute the **# grubby --info=ALL | grep title** command.

- Setting the default kernel for only the next boot.
  - Execute the following command to set the default kernel for only the next reboot using the **grub2-reboot** command:

    ```
    # grub2-reboot <index|title|id>
    ```

    > **WARNING**
    >
    > Set the default kernel for only the next boot with care. Installing new kernel RPMs, self-built kernels, and manually adding the entries to the **/boot/loader/entries/** directory might change the index values.

CHAPTER 2. THE 64K PAGE SIZE KERNEL

kernel-64k is an additional, optional 64-bit ARM architecture kernel package that supports 64k pages. This additional kernel exists alongside the RHEL 9 for ARM kernel which supports 4k pages.

Optimal system performance directly relates to different memory configuration requirements. These requirements are addressed by the two variants of kernel, each suitable for different workloads. RHEL 9 on 64-bit ARM hardware thus offers two MMU page sizes:

- 4k pages kernel for efficient memory usage in smaller environments,
- **kernel-64k** for workloads with large, contiguous memory working sets.

The 4k pages kernel and **kernel-64k** do not differ in the user experience as the user space is the same. You can choose the variant that addresses your situation the best.

4k pages kernel

Use 4k pages for more efficient memory usage in smaller environments, such as those in Edge and lower-cost, small cloud instances. In these environments, increasing the physical system memory amounts is not practical due to space, power, and cost constraints. Also, not all 64-bit ARM architecture processors support a 64k page size.
The 4k pages kernel supports graphical installation using Anaconda, system or cloud image-based installations, as well as advanced installations using Kickstart.

kernel-64k

The 64k page size kernel is a useful option for large datasets on ARM platforms. **kernel-64k** is suitable for memory-intensive workloads as it has significant gains in overall system performance, namely in large database, HPC, and high network performance.
You must choose page size on 64-bit ARM architecture systems at the time of installation. You can install **kernel-64k** only by Kickstart by adding the **kernel-64k** package to the package list in the **Kickstart** file.

Additional resources

- Installing Kernel-64k on ARM

CHAPTER 3. MANAGING KERNEL MODULES

Learn about kernel modules, how to display their information, and how to perform basic administrative tasks with kernel modules.

3.1. INTRODUCTION TO KERNEL MODULES

The Red Hat Enterprise Linux kernel can be extended with kernel modules, which provide optional additional pieces of functionality, without having to reboot the system. On RHEL 9, kernel modules are extra kernel code built into compressed **<KERNEL_MODULE_NAME>.ko.xz** object files.

The most common functionality enabled by kernel modules are:

- Device driver which adds support for new hardware
- Support for a file system such as GFS2 or NFS
- System calls

On modern systems, kernel modules are automatically loaded when needed. However, in some cases it is necessary to load or unload modules manually.

Similarly to the kernel, modules accept parameters that customize their behavior.

You can use the kernel tools to perform the following actions on modules:

- Inspect modules that are currently running.
- Inspect modules that are available to load into the kernel.
- Inspect parameters that a module accepts.
- Enable a mechanism to load and unload kernel modules into the running kernel.

3.2. KERNEL MODULE DEPENDENCIES

Certain kernel modules sometimes depend on one or more other kernel modules. The **/lib/modules/<KERNEL_VERSION>/modules.dep** file contains a complete list of kernel module dependencies for the corresponding kernel version.

depmod

The dependency file is generated by the **depmod** program, included in the **kmod** package. Many utilities provided by **kmod** consider module dependencies when performing operations. Therefore, **manual** dependency-tracking is rarely necessary.

> **WARNING**
>
> The code of kernel modules executes in kernel-space in the unrestricted mode. Be mindful of what modules you are loading.

weak-modules

In addition to **depmod**, Red Hat Enterprise Linux provides the **weak-modules** script, which is a part of the **kmod** package. **weak-modules** determines the modules that are kABI-compatible with installed kernels. While checking modules kernel compatibility, **weak-modules** processes modules symbol dependencies from higher to lower release of kernel for which they were built. It processes each module independently of the kernel release.

Additional resources

- The **modules.dep(5)** manual page
- The **depmod(8)** manual page
- What is the purpose of weak-modules script shipped with Red Hat Enterprise Linux?
- What is Kernel Application Binary Interface (kABI)? (Red Hat Knowledgebase)

3.3. LISTING INSTALLED KERNEL MODULES

The **grubby --info=ALL** command displays an indexed list of installed kernels on **!BLS** and **BLS** installs.

Procedure

- List the installed kernels using the following command:

  ```
  # grubby --info=ALL | grep title
  ```

  The list of all installed kernels is displayed as follows:

  ```
  title="Red Hat Enterprise Linux (5.14.0-1.el9.x86_64) 9.0 (Plow)"
  title="Red Hat Enterprise Linux (0-rescue-0d772916a9724907a5d1350bcd39ac92) 9.0
  (Plow)"
  ```

This is the list of installed kernels of grubby-8.40-17 from the GRUB menu.

3.4. LISTING CURRENTLY LOADED KERNEL MODULES

View the currently loaded kernel modules.

Prerequisites

- The **kmod** package is installed.

Procedure

- To list all currently loaded kernel modules, enter:

  ```
  $ lsmod

  Module                  Size  Used by
  fuse                  126976  3
  uinput                 20480  1
  xt_CHECKSUM            16384  1
  ```

```
ipt_MASQUERADE        16384  1
xt_conntrack          16384  1
ipt_REJECT            16384  1
nft_counter           16384  16
nf_nat_tftp           16384  0
nf_conntrack_tftp     16384  1 nf_nat_tftp
tun                   49152  1
bridge                192512  0
stp                   16384  1 bridge
llc                   16384  2 bridge,stp
nf_tables_set         32768  5
nft_fib_inet          16384  1
…
```

In the example above:

a. The **Module** column provides the **names** of currently loaded modules.

b. The **Size** column displays the amount of **memory** per module in kilobytes.

c. The **Used by** column shows the number, and optionally the names of modules that are **dependent** on a particular module.

Additional resources

- The **/usr/share/doc/kmod/README** file
- The **lsmod(8)** manual page

3.5. DISPLAYING INFORMATION ABOUT KERNEL MODULES

Use the **modinfo** command to display some detailed information about the specified kernel module.

Prerequisites

- The **kmod** package is installed.

Procedure

- To display information about any kernel module, enter:

```
$ modinfo <KERNEL_MODULE_NAME>
```

For example:

```
$ modinfo virtio_net

filename:       /lib/modules/5.14.0-1.el9.x86_64/kernel/drivers/net/virtio_net.ko.xz
license:        GPL
description:    Virtio network driver
rhelversion:    9.0
srcversion:     8809CDDBE7202A1B00B9F1C
alias:          virtio:d00000001v*
depends:        net_failover
retpoline:      Y
```

```
intree:         Y
name:           virtio_net
vermagic:       5.14.0-1.el9.x86_64 SMP mod_unload modversions
...
parm:           napi_weight:int
parm:           csum:bool
parm:           gso:bool
parm:           napi_tx:bool
```

You can query information about all available modules, regardless of whether they are loaded. The **parm** entries show parameters the user is able to set for the module, and what type of value they expect.

> **NOTE**
>
> When entering the name of a kernel module, do not append the **.ko.xz** extension to the end of the name. Kernel module names do not have extensions; their corresponding files do.

Additional resources

- The **modinfo(8)** manual page

3.6. LOADING KERNEL MODULES AT SYSTEM RUNTIME

The optimal way to expand the functionality of the Linux kernel is by loading kernel modules. Use the **modprobe** command to find and load a kernel module into the currently running kernel.

> **IMPORTANT**
>
> The changes described in this procedure **will not persist** after rebooting the system. For information about how to load kernel modules to **persist** across system reboots, see Loading kernel modules automatically at system boot time .

Prerequisites

- Root permissions
- The **kmod** package is installed.
- The respective kernel module is not loaded. To ensure this is the case, list the Listing currently loaded kernel modules.

Procedure

1. Select a kernel module you want to load.
   The modules are located in the **/lib/modules/$(uname -r)/kernel/<SUBSYSTEM>/** directory.
2. Load the relevant kernel module:

```
# modprobe <MODULE_NAME>
```

NOTE

When entering the name of a kernel module, do not append the **.ko.xz** extension to the end of the name. Kernel module names do not have extensions; their corresponding files do.

Verification

- Optionally, verify the relevant module was loaded:

```
$ lsmod | grep <MODULE_NAME>
```

If the module was loaded correctly, this command displays the relevant kernel module. For example:

```
$ lsmod | grep serio_raw
serio_raw          16384  0
```

Additional resources

- The **modprobe(8)** manual page

3.7. UNLOADING KERNEL MODULES AT SYSTEM RUNTIME

To unload certain kernel modules from the running kernel, use the **modprobe** command to find and unload a kernel module at system runtime from the currently loaded kernel.

WARNING

You must not unload the kernel modules that are used by the running system because it can lead to an unstable or non-operational system.

IMPORTANT

After finishing the unloading of inactive kernel modules, the modules that are defined to be automatically loaded on boot, will not remain unloaded after rebooting the system. For information about how to prevent this outcome, see Preventing kernel modules from being automatically loaded at system boot time.

Prerequisites

- You have root permissions.
- The **kmod** package is installed.

Procedure

1. List all the loaded kernel modules:

```
# lsmod
```

2. Select the kernel module you want to unload.
   If a kernel module has dependencies, unload those prior to unloading the kernel module. For details on identifying modules with dependencies, see Listing currently loaded kernel modules and Kernel module dependencies.

3. Unload the relevant kernel module:

   ```
   # modprobe -r <MODULE_NAME>
   ```

   When entering the name of a kernel module, do not append the **.ko.xz** extension to the end of the name. Kernel module names do not have extensions; their corresponding files do.

Verification

- Optionally, verify the relevant module was unloaded:

  ```
  $ lsmod | grep <MODULE_NAME>
  ```

  If the module is unloaded successfully, this command does not display any output.

Additional resources

- **modprobe(8)** manual page

3.8. UNLOADING KERNEL MODULES AT EARLY STAGES OF THE BOOT PROCESS

In certain situations, for example, when the kernel module has a code that causes the system to become unresponsive, and the user is not able to reach the stage to permanently disable the rogue kernel module, you might need to unload a kernel module early in the booting process. To temporarily block the loading of the kernel module, you can use a boot loader.

You can edit the relevant boot loader entry to unload the required kernel module before the booting sequence continues.

> **IMPORTANT**
>
> The changes described in this procedure **will not persist** after the next reboot. For information about how to add a kernel module to a denylist so that it will not be automatically loaded during the boot process, see Preventing kernel modules from being automatically loaded at system boot time.

Prerequisites

- You have a loadable kernel module that you want to prevent from loading for some reason.

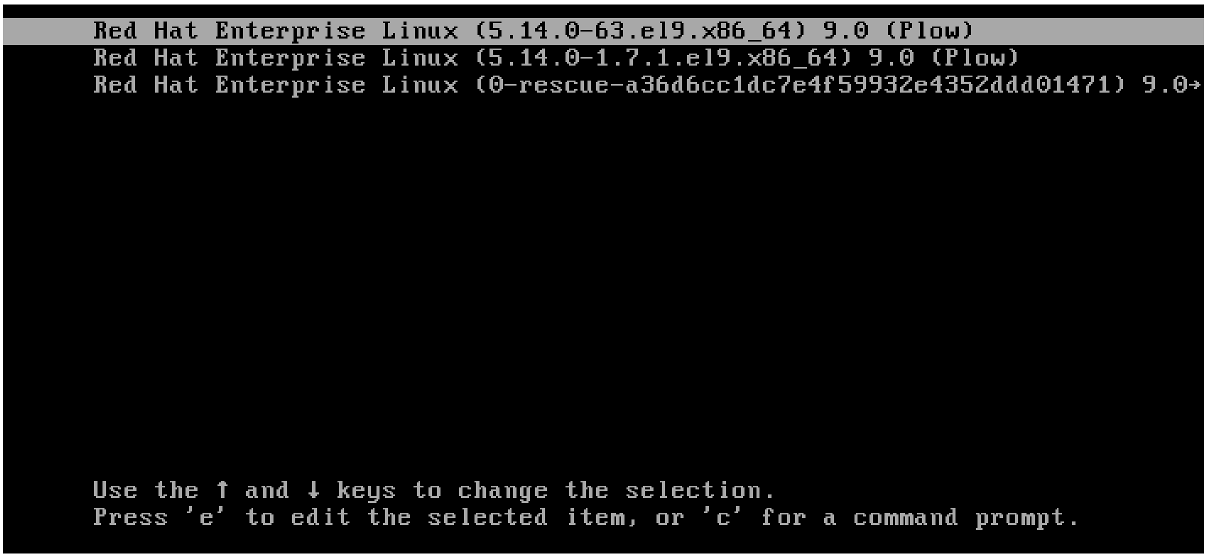
Procedure

1. Boot the system into the boot loader.

2. Use the cursor keys to highlight the relevant boot loader entry.

3. Press the **e** key to edit the entry.

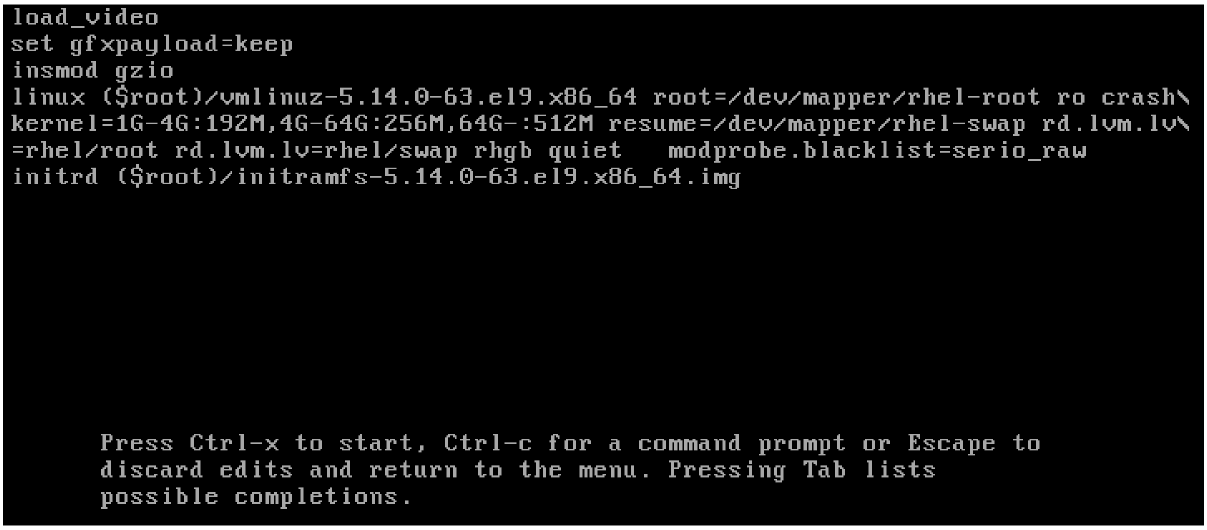
Figure 3.1. Kernel boot menu



4. Use the cursor keys to navigate to the line that starts with **linux**.

5. Append **modprobe.blacklist=*module_name*** to the end of the line.

Figure 3.2. Kernel boot entry



The **serio_raw** kernel module illustrates a rogue module to be unloaded early in the boot process.

6. Press **Ctrl**+**X** to boot using the modified configuration.

Verification

- After the system boots, verify that the relevant kernel module is not loaded:

```
# lsmod | grep serio_raw
```

Additional resources

- Managing kernel modules

3.9. LOADING KERNEL MODULES AUTOMATICALLY AT SYSTEM BOOT TIME

Configure a kernel module to load it automatically during the boot process.

Prerequisites

- Root permissions
- The **kmod** package is installed.

Procedure

1. Select a kernel module you want to load during the boot process.
   The modules are located in the **/lib/modules/$(uname -r)/kernel/<SUBSYSTEM>/** directory.
2. Create a configuration file for the module:

   ```
   # echo <MODULE_NAME> > /etc/modules-load.d/<MODULE_NAME>.conf
   ```

   > **NOTE**
   >
   > When entering the name of a kernel module, do not append the **.ko.xz** extension to the end of the name. Kernel module names do not have extensions; their corresponding files do.

Verification

1. After reboot, verify the relevant module is loaded:

   ```
   $ lsmod | grep <MODULE_NAME>
   ```

> **IMPORTANT**
>
> The changes described in this procedure **will persist** after rebooting the system.

Additional resources

- **modules-load.d(5)** manual page

3.10. PREVENTING KERNEL MODULES FROM BEING AUTOMATICALLY LOADED AT SYSTEM BOOT TIME

You can prevent the system from loading a kernel module automatically during the boot process by listing the module in **modprobe** configuration file with a corresponding command.

Prerequisites

- The commands in this procedure require root privileges. Either use **su -** to switch to the root user or preface the commands with **sudo**.
- The **kmod** package is installed.

- Ensure that your current system configuration does not require a kernel module you plan to deny.

Procedure

1. List modules loaded to the currently running kernel by using the **lsmod** command:

```
$ lsmod
Module                  Size  Used by
tls                   131072  0
uinput                 20480  1
snd_seq_dummy          16384  0
snd_hrtimer            16384  1
…
```

In the output, identify the module you want to prevent from getting loaded.

- Alternatively, identify an unloaded kernel module you want to prevent from potentially loading in the **/lib/modules/*<KERNEL-VERSION>*/kernel/*<SUBSYSTEM>*/** directory, for example:

```
$ ls /lib/modules/4.18.0-477.20.1.el8_8.x86_64/kernel/crypto/
ansi_cprng.ko.xz        chacha20poly1305.ko.xz  md4.ko.xz
serpent_generic.ko.xz
anubis.ko.xz            cmac.ko.xz…
```

2. Create a configuration file serving as a denylist:

```
# touch /etc/modprobe.d/denylist.conf
```

3. In a text editor of your choice, combine the names of modules you want to exclude from automatic loading to the kernel with the **blacklist** configuration command, for example:

```
# Prevents <KERNEL-MODULE-1> from being loaded
blacklist <MODULE-NAME-1>
install <MODULE-NAME-1> /bin/false

# Prevents <KERNEL-MODULE-2> from being loaded
blacklist <MODULE-NAME-2>
install <MODULE-NAME-2> /bin/false
…
```

Because the **blacklist** command does not prevent the module from getting loaded as a dependency for another kernel module that is not in a denylist, you must also define the **install** line. In this case, the system runs **/bin/false** instead of installing the module. The lines starting with a hash sign are comments you can use to make the file more readable.

> **NOTE**
>
> When entering the name of a kernel module, do not append the **.ko.xz** extension to the end of the name. Kernel module names do not have extensions; their corresponding files do.

4. Create a backup copy of the current initial RAM disk image before rebuilding:

```
# cp /boot/initramfs-$(uname -r).img /boot/initramfs-$(uname -r).bak.$(date +%m-%d-%H%M%S).img
```

- Alternatively, create a backup copy of an initial RAM disk image which corresponds to the kernel version for which you want to prevent kernel modules from automatic loading:

```
# cp /boot/initramfs-<VERSION>.img /boot/initramfs-<VERSION>.img.bak.$(date +%m-%d-%H%M%S)
```

5. Generate a new initial RAM disk image to apply the changes:

```
# dracut -f -v
```

- If you build an initial RAM disk image for a different kernel version than your system currently uses, specify both target **initramfs** and kernel version:

```
# dracut -f -v /boot/initramfs-<TARGET-VERSION>.img <CORRESPONDING-TARGET-KERNEL-VERSION>
```

6. Restart the system:

```
$ reboot
```

IMPORTANT

The changes described in this procedure **will take effect and persist**after rebooting the system. If you incorrectly list a key kernel module in the denylist, you can switch the system to an unstable or non-operational state.

Additional resources

- How do I prevent a kernel module from loading automatically? (Red Hat Knowledgebase)
- **modprobe.d(5)** and **dracut(8)** man pages on your system

3.11. COMPILING CUSTOM KERNEL MODULES

You can build a sampling kernel module as requested by various configurations at hardware and software level.

Prerequisites

- You installed the **kernel-devel**, **gcc**, and **elfutils-libelf-devel** packages.

```
# dnf install kernel-devel-$(uname -r) gcc elfutils-libelf-devel
```

- You have root permissions.
- You created the **/root/testmodule/** directory where you compile the custom kernel module.

Procedure

1. Create the **/root/testmodule/test.c** file with the following content.

   ```
   #include <linux/module.h>
   #include <linux/kernel.h>

   int init_module(void)
      { printk("Hello World\n This is a test\n"); return 0; }

   void cleanup_module(void)
      { printk("Good Bye World"); }

   MODULE_LICENSE("GPL");
   ```

   The **test.c** file is a source file that provides the main functionality to the kernel module. The file has been created in a dedicated **/root/testmodule/** directory for organizational purposes. After the module compilation, the **/root/testmodule/** directory will contain multiple files.

   The **test.c** file includes from the system libraries:

   - The **linux/kernel.h** header file is necessary for the **printk()** function in the example code.
   - The **linux/module.h** file contains function declarations and macro definitions that are shared across several source files written in C programming language.

2. Follow the **init_module()** and **cleanup_module()** functions to start and end the kernel logging function **printk()**, which prints text.

3. Create the **/root/testmodule/Makefile** file with the following content.

   ```
   obj-m := test.o
   ```

   The Makefile contains instructions for the compiler to produce an object file named **test.o**. The **obj-m** directive specifies that the resulting **test.ko** file is going to be compiled as a loadable kernel module. Alternatively, the **obj-y** directive can instruct to build **test.ko** as a built-in kernel module.

4. Compile the kernel module.

   ```
   # make -C /lib/modules/$(uname -r)/build M=/root/testmodule modules
   make: Entering directory '/usr/src/kernels/5.14.0-70.17.1.el9_0.x86_64'
     CC [M]  /root/testmodule/test.o
     MODPOST /root/testmodule/Module.symvers
     CC [M]  /root/testmodule/test.mod.o
     LD [M]  /root/testmodule/test.ko
     BTF [M] /root/testmodule/test.ko
   Skipping BTF generation for /root/testmodule/test.ko due to unavailability of vmlinux
   make: Leaving directory '/usr/src/kernels/5.14.0-70.17.1.el9_0.x86_64'
   ```

   The compiler creates an object file (**test.o**) for each source file (**test.c**) as an intermediate step before linking them together into the final kernel module (**test.ko**).

   After a successful compilation, **/root/testmodule/** contains additional files that relate to the compiled custom kernel module. The compiled module itself is represented by the **test.ko** file.

Verification

1. Optional: check the contents of the **/root/testmodule/** directory:

```
# ls -l /root/testmodule/
total 152
-rw-r—r--. 1 root root    16 Jul 26 08:19 Makefile
-rw-r—r--. 1 root root    25 Jul 26 08:20 modules.order
-rw-r—r--. 1 root root     0 Jul 26 08:20 Module.symvers
-rw-r—r--. 1 root root   224 Jul 26 08:18 test.c
-rw-r—r--. 1 root root 62176 Jul 26 08:20 test.ko
-rw-r—r--. 1 root root    25 Jul 26 08:20 test.mod
-rw-r—r--. 1 root root   849 Jul 26 08:20 test.mod.c
-rw-r—r--. 1 root root 50936 Jul 26 08:20 test.mod.o
-rw-r—r--. 1 root root 12912 Jul 26 08:20 test.o
```

2. Copy the kernel module to the **/lib/modules/$(uname -r)/** directory:

```
# cp /root/testmodule/test.ko /lib/modules/$(uname -r)/
```

3. Update the modular dependency list:

```
# depmod -a
```

4. Load the kernel module:

```
# modprobe -v test
insmod /lib/modules/5.14.0-1.el9.x86_64/test.ko
```

5. Verify that the kernel module was successfully loaded:

```
# lsmod | grep test
test                  16384  0
```

6. Read the latest messages from the kernel ring buffer:

```
# dmesg
[74422.545004] Hello World
               This is a test
```

CHAPTER 4. CONFIGURING KERNEL COMMAND-LINE PARAMETERS

With kernel command-line parameters, you can change the behavior of certain aspects of the Red Hat Enterprise Linux kernel at boot time. As a system administrator, you control which options get set at boot. Note that certain kernel behaviors can only be set at boot time.

IMPORTANT

Changing the behavior of the system by modifying kernel command-line parameters can have negative effects on your system. Always test changes before deploying them in production. For further guidance, contact Red Hat Support.

4.1. WHAT ARE KERNEL COMMAND-LINE PARAMETERS

With kernel command-line parameters, you can overwrite default values and set specific hardware settings. At boot time, you can configure the following features:

- The Red Hat Enterprise Linux kernel
- The initial RAM disk
- The user space features

By default, the kernel command-line parameters for systems using the GRUB boot loader are defined in the boot entry configuration file for each kernel boot entry.

You can manipulate boot loader configuration files by using the **grubby** utility. With **grubby**, you can perform these actions:

- Change the default boot entry.
- Add or remove arguments from a GRUB menu entry.

Additional resources

- **kernel-command-line(7)**, **bootparam(7)** and **dracut.cmdline(7)** manual pages
- How to install and boot custom kernels in Red Hat Enterprise Linux 8
- The **grubby(8)** manual page

4.2. UNDERSTANDING BOOT ENTRIES

A boot entry is a collection of options stored in a configuration file and tied to a particular kernel version. In practice, you have at least as many boot entries as your system has installed kernels. The boot entry configuration file is located in the **/boot/loader/entries/** directory:

```
d8712ab6d4f14683c5625e87b52b6b6e-5.14.0-1.el9.x86_64.conf
```

The file name above consists of a machine ID stored in the **/etc/machine-id** file, and a kernel version.

The boot entry configuration file contains information about the kernel version, the initial ramdisk image, and the kernel command-line parameters. The example contents of a boot entry config can be seen below:

```
title Red Hat Enterprise Linux (5.14.0-1.el9.x86_64) 9.0 (Plow)
version 5.14.0-1.el9.x86_64
linux /vmlinuz-5.14.0-1.el9.x86_64
initrd /initramfs-5.14.0-1.el9.x86_64.img
options root=/dev/mapper/rhel_kvm--02--guest08-root ro crashkernel=1G-4G:192M,4G-64G:256M,64G-:512M resume=/dev/mapper/rhel_kvm--02--guest08-swap rd.lvm.lv=rhel_kvm-02-guest08/root rd.lvm.lv=rhel_kvm-02-guest08/swap console=ttyS0,115200
grub_users $grub_users
grub_arg --unrestricted
grub_class kernel
```

4.3. CHANGING KERNEL COMMAND-LINE PARAMETERS FOR ALL BOOT ENTRIES

Change kernel command-line parameters for all boot entries on your system.

> **IMPORTANT**
>
> When installing a newer version of the kernel in RHEL 9 systems, the **grubby** tool passes the kernel command-line arguments from the previous kernel version.
>
> However, this does not apply to RHEL version 9.0 in which newly installed kernels lose previous command-line options. You must run the **grub2-mkconfig** command on the newly installed kernel to pass the parameters to your new kernel. For more information about this known issue, see Boot loader.

Prerequisites

- **grubby** utility is installed on your system.
- **zipl** utility is installed on your IBM Z system.

Procedure

- To add a parameter:

  ```
  # grubby --update-kernel=ALL --args="<NEW_PARAMETER>"
  ```

  For systems that use the GRUB boot loader and, on IBM Z that use the zIPL boot loader, the command adds a new kernel parameter to each **/boot/loader/entries/<*ENTRY*>.conf** file.

  - On IBM Z, update the boot menu:

    ```
    # zipl
    ```

- To remove a parameter:

  ```
  # grubby --update-kernel=ALL --remove-args="<PARAMETER_TO_REMOVE>"
  ```

- On IBM Z, update the boot menu:

```
# zipl
```

Additional resources

- What are kernel command-line parameters
- **grubby(8)** and **zipl(8)** manual pages

4.4. CHANGING KERNEL COMMAND-LINE PARAMETERS FOR A SINGLE BOOT ENTRY

Make changes in kernel command-line parameters for a single boot entry on your system.

Prerequisites

- **grubby** and **zipl** utilities are installed on your system.

Procedure

- To add a parameter:

```
# grubby --update-kernel=/boot/vmlinuz-$(uname -r) --args="<NEW_PARAMETER>"
```

  - On IBM Z, update the boot menu:

```
# zipl
```

- To remove a parameter:

```
# grubby --update-kernel=/boot/vmlinuz-$(uname -r) --remove-args="
<PARAMETER_TO_REMOVE>"
```

  - On IBM Z, update the boot menu:

```
# zipl
```

IMPORTANT

- **grubby** modifies and stores the kernel command-line parameters of an individual kernel boot entry in the **/boot/loader/entries/<*ENTRY*>.conf** file.

4.5. CHANGING KERNEL COMMAND-LINE PARAMETERS TEMPORARILY AT BOOT TIME

Make temporary changes to a Kernel Menu Entry by changing the kernel parameters only during a single boot process.

NOTE

This procedure applies only for a single boot and does not persistently make the changes.

Procedure

1. Boot into the GRUB boot menu.
2. Select the kernel you want to start.
3. Press the **e** key to edit the kernel parameters.
4. Find the kernel command line by moving the cursor down. The kernel command line starts with **linux** on 64-Bit IBM Power Series and x86-64 BIOS-based systems, or **linuxefi** on UEFI systems.
5. Move the cursor to the end of the line.

   NOTE

   Press **Ctrl**+**a** to jump to the start of the line and **Ctrl**+**e** to jump to the end of the line. On some systems, **Home** and **End** keys might also work.

6. Edit the kernel parameters as required. For example, to run the system in emergency mode, add the **emergency** parameter at the end of the **linux** line:

   ```
   linux   ($root)/vmlinuz-5.14.0-63.el9.x86_64 root=/dev/mapper/rhel-root ro crashkernel=1G-4G:192M,4G-64G:256M,64G-:512M resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rhel/swap rhgb quiet emergency
   ```

   To enable the system messages, remove the **rhgb** and **quiet** parameters.

7. Press **Ctrl**+**x** to boot with the selected kernel and the modified command line parameters.

IMPORTANT

If you press the **Esc** key to leave command line editing, it will drop all the user made changes.

4.6. CONFIGURING GRUB SETTINGS TO ENABLE SERIAL CONSOLE CONNECTION

The serial console is beneficial when you need to connect to a headless server or an embedded system and the network is down. Or when you need to avoid security rules and obtain login access on a different system.

You need to configure some default GRUB settings to use the serial console connection.

Prerequisites

- You have root permissions.

Procedure

1. Add the following two lines to the **/etc/default/grub** file:

```
GRUB_TERMINAL="serial"
GRUB_SERIAL_COMMAND="serial --speed=9600 --unit=0 --word=8 --parity=no --stop=1"
```

   The first line disables the graphical terminal. The **GRUB_TERMINAL** key overrides values of **GRUB_TERMINAL_INPUT** and **GRUB_TERMINAL_OUTPUT** keys.

   The second line adjusts the baud rate (**--speed**), parity and other values to fit your environment and hardware. Note that a much higher baud rate, for example 115200, is preferable for tasks such as following log files.

2. Update the GRUB configuration file.
   - On BIOS-based machines:

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

   - On UEFI-based machines:

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

3. Reboot the system for the changes to take effect.

4.7. CHANGING BOOT ENTRIES WITH THE GRUB CONFIGURATION FILE

The **/etc/default/grub** GRUB configuration file contains the **GRUB_CMDLINE_LINUX** key, which lists kernel command-line arguments to add to boot entries for the Linux kernel. For example:

```
GRUB_CMDLINE_LINUX="crashkernel=1G-4G:192M,4G-64G:256M,64G-:512M
resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rhel/swap"
```

To change the boot entries, overwrite Boot Loader Specification (BLS) snippets with the contents of the **GRUB_CMDLINE_LINUX** values.

Prerequisites

- A fresh RHEL 9 installation.

Procedure

1. Add or remove a kernel parameter for individual kernels in a post installation script with **grubby**:

```
# grubby --update-kernel <PATH_TO_KERNEL> --args "<NEW_ARGUMENTS>"
```

   For example, add the **noapic** parameter to the chosen kernel:

```
# grubby --update-kernel /boot/vmlinuz-5.14.0-362.8.1.el9_3.x86_64 --args "noapic"
```

   The parameter is propagated into the BLS snippets, but not into the **/etc/default/grub** file.

2. Overwrite BLS snippets with the contents of the **GRUB_CMDLINE_LINUX** values present in the **/etc/default/grub** file:

```
# grub2-mkconfig -o /boot/grub2/grub.cfg --update-bls-cmdline
Generating grub configuration file …
Adding boot menu entry for UEFI Firmware Settings …
done
```

> **NOTE**
>
> Other changes, such as changes made to **GRUB_TIMEOUT** key (also included in the **/etc/default/grub** GRUB configuration file), do get propagated to the new **grub.cfg** by default.

Verification

1. Reboot your operating system.
2. Verify that the parameters are included in the **/proc/cmdline** file.
   For example, **/proc/cmdline** contains the **noapic** kernel parameter:

```
BOOT_IMAGE=(hd0,gpt2)/vmlinuz-4.18.0-425.3.1.el8.x86_64 root=/dev/mapper/RHELCSB-Root ro vconsole.keymap=us crashkernel=auto rd.lvm.lv=RHELCSB/Root rd.luks.uuid=luks-d8a28c4c-96aa-4319-be26-96896272151d rhgb quiet noapic rd.luks.key=d8a28c4c-96aa-4319-be26-96896272151d=/keyfile:UUID=c47d962e-4be8-41d6-8216-8cf7a0d3b911 ipv6.disable=1
```

CHAPTER 5. CONFIGURING KERNEL PARAMETERS AT RUNTIME

As a system administrator, you can modify many facets of the Red Hat Enterprise Linux kernel's behavior at runtime. Configure kernel parameters at runtime by using the **sysctl** command and by modifying the configuration files in the **/etc/sysctl.d/** and **/proc/sys/** directories.

IMPORTANT

Configuring kernel parameters on a production system requires careful planning. Unplanned changes can render the kernel unstable, requiring a system reboot. Verify that you are using valid options before changing any kernel values.

For more information about tuning kernel on IBM DB2, see Tuning Red Hat Enterprise Linux for IBM DB2.

5.1. WHAT ARE KERNEL PARAMETERS

Kernel parameters are tunable values that you can adjust while the system is running. Note that for changes to take effect, you do not need to reboot the system or recompile the kernel.

It is possible to address the kernel parameters through:

- The **sysctl** command
- The virtual file system mounted at the **/proc/sys/** directory
- The configuration files in the **/etc/sysctl.d/** directory

Tunables are divided into classes by the kernel subsystem. Red Hat Enterprise Linux has the following tunable classes:

Table 5.1. Table of sysctl classes

Tunable class	Subsystem
abi	Execution domains and personalities
crypto	Cryptographic interfaces
debug	Kernel debugging interfaces
dev	Device-specific information
fs	Global and specific file system tunables
kernel	Global kernel tunables
net	Network tunables
sunrpc	Sun Remote Procedure Call (NFS)

Tunable class	Subsystem
user	User Namespace limits
vm	Tuning and management of memory, buffers, and cache

Additional resources

- **sysctl(8)**, and **sysctl.d(5)** manual pages

5.2. CONFIGURING KERNEL PARAMETERS TEMPORARILY WITH SYSCTL

Use the **sysctl** command to temporarily set kernel parameters at runtime. The command is also useful for listing and filtering tunables.

Prerequisites

- Root permissions

Procedure

1. List all parameters and their values.

```
# sysctl -a
```

> **NOTE**
>
> The **# sysctl -a** command displays kernel parameters, which can be adjusted at runtime and at boot time.

2. To configure a parameter temporarily, enter:

```
# sysctl <TUNABLE_CLASS>.<PARAMETER>=<TARGET_VALUE>
```

The sample command above changes the parameter value while the system is running. The changes take effect immediately, without a need for restart.

> **NOTE**
>
> The changes return back to default after your system reboots.

Additional resources

- The **sysctl(8)** manual page
- Using configuration files in /etc/sysctl.d/ to adjust kernel parameters

5.3. CONFIGURING KERNEL PARAMETERS PERMANENTLY WITH SYSCTL

Use the **sysctl** command to permanently set kernel parameters.

Prerequisites

- Root permissions

Procedure

1. List all parameters.

   ```
   # sysctl -a
   ```

   The command displays all kernel parameters that can be configured at runtime.

2. Configure a parameter permanently:

   ```
   # sysctl -w <TUNABLE_CLASS>.<PARAMETER>=<TARGET_VALUE> >> /etc/sysctl.conf
   ```

   The sample command changes the tunable value and writes it to the **/etc/sysctl.conf** file, which overrides the default values of kernel parameters. The changes take effect immediately and persistently, without a need for restart.

> **NOTE**
>
> To permanently modify kernel parameters, you can also make manual changes to the configuration files in the **/etc/sysctl.d/** directory.

Additional resources

- The **sysctl(8)** and **sysctl.conf(5)** manual pages
- Using configuration files in /etc/sysctl.d/ to adjust kernel parameters

5.4. USING CONFIGURATION FILES IN /ETC/SYSCTL.D/ TO ADJUST KERNEL PARAMETERS

You must modify the configuration files in the **/etc/sysctl.d/** directory manually to permanently set kernel parameters.

Prerequisites

- You have root permissions.

Procedure

1. Create a new configuration file in **/etc/sysctl.d/**:

   ```
   # vim /etc/sysctl.d/<some_file.conf>
   ```

2. Include kernel parameters, one per line:

```
<TUNABLE_CLASS>.<PARAMETER>=<TARGET_VALUE>
<TUNABLE_CLASS>.<PARAMETER>=<TARGET_VALUE>
```

3. Save the configuration file.

4. Reboot the machine for the changes to take effect.

   - Alternatively, apply changes without rebooting:

     ```
     # sysctl -p /etc/sysctl.d/<some_file.conf>
     ```

     The command enables you to read values from the configuration file, which you created earlier.

Additional resources

- **sysctl(8)**, **sysctl.d(5)** manual pages

5.5. CONFIGURING KERNEL PARAMETERS TEMPORARILY THROUGH /PROC/SYS/

Set kernel parameters temporarily through the files in the **/proc/sys/** virtual file system directory.

Prerequisites

- Root permissions

Procedure

1. Identify a kernel parameter you want to configure.

   ```
   # ls -l /proc/sys/<TUNABLE_CLASS>/
   ```

   The writable files returned by the command can be used to configure the kernel. The files with read-only permissions provide feedback on the current settings.

2. Assign a target value to the kernel parameter.

   ```
   # echo <TARGET_VALUE> > /proc/sys/<TUNABLE_CLASS>/<PARAMETER>
   ```

   The configuration changes applied by using a command are not permanent and will disappear once the system is restarted.

Verification

1. Verify the value of the newly set kernel parameter.

   ```
   # cat /proc/sys/<TUNABLE_CLASS>/<PARAMETER>
   ```

CHAPTER 6. CONFIGURING KERNEL PARAMETERS PERMANENTLY BY USING RHEL SYSTEM ROLES

You can use the **kernel_settings** RHEL system role to configure kernel parameters on multiple clients simultaneously. Simultaneous configuration has the following advantages:

- Provides a friendly interface with efficient input setting.
- Keeps all intended kernel parameters in one place.

After you run the **kernel_settings** role from the control machine, the kernel parameters are applied to the managed systems immediately and persist across reboots.

> **IMPORTANT**
>
> Note that RHEL system role delivered over RHEL channels are available to RHEL customers as an RPM package in the default AppStream repository. RHEL system role are also available as a collection to customers with Ansible subscriptions over Ansible Automation Hub.

6.1. APPLYING SELECTED KERNEL PARAMETERS BY USING THE KERNEL_SETTINGS RHEL SYSTEM ROLE

You can use the **kernel_settings** RHEL system role to remotely configure various kernel parameters across multiple managed operating systems with persistent effects. For example, you can configure:

- Transparent hugepages to increase performance by reducing the overhead of managing smaller pages.
- The largest packet sizes to be transmitted over the network with the loopback interface.
- Limits on files to be opened simultaneously.

Prerequisites

- You have prepared the control node and the managed nodes
- You are logged in to the control node as a user who can run playbooks on the managed nodes.
- The account you use to connect to the managed nodes has **sudo** permissions on them.

Procedure

1. Create a playbook file, for example **~/playbook.yml**, with the following content:

```
---
- name: Configuring kernel settings
  hosts: managed-node-01.example.com
  tasks:
    - name: Configure hugepages, packet size for loopback device, and limits on
simultaneously open files.
      ansible.builtin.include_role:
        name: redhat.rhel_system_roles.kernel_settings
      vars:
```

```
kernel_settings_sysctl:
  - name: fs.file-max
    value: 400000
  - name: kernel.threads-max
    value: 65536
kernel_settings_sysfs:
  - name: /sys/class/net/lo/mtu
    value: 65000
kernel_settings_transparent_hugepages: madvise
kernel_settings_reboot_ok: true
```

The settings specified in the example playbook include the following:

kernel_settings_sysfs: *<list_of_sysctl_settings>*
: A YAML list of **sysctl** settings and the values you want to assign to these settings.

kernel_settings_transparent_hugepages: *<value>*
: Controls the memory subsystem Transparent Huge Pages (THP) setting. You can disable THP support (**never**), enable it system wide (**always**) or inside **MAD_HUGEPAGE** regions (**madvise**).

kernel_settings_reboot_ok: *<true|false>*
: The default is **false**. If set to **true**, the system role will determine if a reboot of the managed host is necessary for the requested changes to take effect and reboot it. If set to **false**, the role will return the variable **kernel_settings_reboot_required** with a value of **true**, indicating that a reboot is required. In this case, a user must reboot the managed node manually.

For details about all variables used in the playbook, see the **/usr/share/ansible/roles/rhel-system-roles.kdump/README.md** file on the control node.

1. Validate the playbook syntax:

```
$ ansible-playbook --syntax-check ~/playbook.yml
```

Note that this command only validates the syntax and does not protect against a wrong but valid configuration.

2. Run the playbook:

```
$ ansible-playbook ~/playbook.yml
```

Verification

- Verify the affected kernel parameters:

```
# ansible managed-node-01.example.com -m command -a 'sysctl fs.file-max
kernel.threads-max net.ipv6.conf.lo.mtu'
# ansible managed-node-01.example.com -m command -a 'cat
/sys/kernel/mm/transparent_hugepage/enabled'
```

Additional resources

- **/usr/share/ansible/roles/rhel-system-roles.kernel_settings/README.md** file
- **/usr/share/doc/rhel-system-roles/kernel_settings/** directory

CHAPTER 7. CONFIGURING THE GRUB BOOT LOADER BY USING RHEL SYSTEM ROLES

By using the **bootloader** RHEL system role, you can automate the configuration and management tasks related to the GRUB boot loader.

This role currently supports configuring the GRUB boot loader, which runs on the following CPU architectures:

- AMD and Intel 64-bit architectures (x86-64)
- The 64-bit ARM architecture (ARMv8.0)
- IBM Power Systems, Little Endian (POWER9)

7.1. UPDATING THE EXISTING BOOT LOADER ENTRIES BY USING THE BOOTLOADER RHEL SYSTEM ROLE

You can use the **bootloader** RHEL system role to update the existing entries in the GRUB boot menu in an automated fashion. This way you can efficiently pass specific kernel command-line parameters that can optimize the performance or behavior of your systems.

For example, if you leverage systems, where detailed boot messages from the kernel and init system are not necessary, use **bootloader** to apply the **quiet** parameter to your existing boot loader entries on your managed nodes to achieve a cleaner, less cluttered, and more user-friendly booting experience.

Prerequisites

- You have prepared the control node and the managed nodes
- You are logged in to the control node as a user who can run playbooks on the managed nodes.
- The account you use to connect to the managed nodes has **sudo** permissions on them.
- You identified the kernel that corresponds to the boot loader entry you want to update.

Procedure

1. Create a playbook file, for example **~/playbook.yml**, with the following content:

```
---
- name: Configuration and management of GRUB boot loader
  hosts: managed-node-01.example.com
  tasks:
    - name: Update existing boot loader entries
      ansible.builtin.include_role:
        name: redhat.rhel_system_roles.bootloader
      vars:
        bootloader_settings:
          - kernel:
              path: /boot/vmlinuz-5.14.0-362.24.1.el9_3.aarch64
            options:
```

```
          - name: quiet
            state: present
      bootloader_reboot_ok: true
```

The settings specified in the example playbook include the following:

kernel

Specifies the kernel connected with the boot loader entry that you want to update.

options

Specifies the kernel command-line parameters to update for your chosen boot loader entry (kernel).

bootloader_reboot_ok: *true*

The role detects that a reboot is required for the changes to take effect and performs a restart of the managed node.

For details about all variables used in the playbook, see the **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file on the control node.

2. Validate the playbook syntax:

```
$ ansible-playbook --syntax-check ~/playbook.yml
```

Note that this command only validates the syntax and does not protect against a wrong but valid configuration.

3. Run the playbook:

```
$ ansible-playbook ~/playbook.yml
```

Verification

- Check that your specified boot loader entry has updated kernel command-line parameters:

```
# ansible managed-node-01.example.com -m ansible.builtin.command -a 'grubby --
info=ALL'
managed-node-01.example.com | CHANGED | rc=0 >>
...
index=1
kernel="/boot/vmlinuz-5.14.0-362.24.1.el9_3.aarch64"
args="ro crashkernel=1G-4G:256M,4G-64G:320M,64G-:576M rd.lvm.lv=rhel/root
rd.lvm.lv=rhel/swap $tuned_params quiet"
root="/dev/mapper/rhel-root"
initrd="/boot/initramfs-5.14.0-362.24.1.el9_3.aarch64.img $tuned_initrd"
title="Red Hat Enterprise Linux (5.14.0-362.24.1.el9_3.aarch64) 9.4 (Plow)"
id="2c9ec787230141a9b087f774955795ab-5.14.0-362.24.1.el9_3.aarch64"
...
```

Additional resources

- **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file
- **/usr/share/doc/rhel-system-roles/bootloader/** directory

- Working With Playbooks
- Using Variables
- Roles
- Configuring kernel command-line parameters

7.2. SECURING THE BOOT MENU WITH PASSWORD BY USING THE BOOTLOADER RHEL SYSTEM ROLE

You can use the **bootloader** RHEL system role to set a password to the GRUB boot menu in an automated fashion. This way you can efficiently prevent unauthorized users from modifying boot parameters, and to have better control over the system boot.

Prerequisites

- You have prepared the control node and the managed nodes
- You are logged in to the control node as a user who can run playbooks on the managed nodes.
- The account you use to connect to the managed nodes has **sudo** permissions on them.

Procedure

1. Store your sensitive variables in an encrypted file:
   a. Create the vault:

   ```
   $ ansible-vault create ~/vault.yml
   New Vault password: <vault_password>
   Confirm New Vault password: <vault_password>
   ```

   b. After the **ansible-vault create** command opens an editor, enter the sensitive data in the ***<key>*: *<value>*** format:

   ```
   pwd: <password>
   ```

   c. Save the changes, and close the editor. Ansible encrypts the data in the vault.
2. Create a playbook file, for example ~/**playbook.yml**, with the following content:

```
---
- name: Configuration and management of GRUB boot loader
  hosts: managed-node-01.example.com
  vars_files:
    - ~/vault.yml
  tasks:
    - name: Set the bootloader password
      ansible.builtin.include_role:
        name: redhat.rhel_system_roles.bootloader
      vars:
        bootloader_password: "{{ pwd }}"
        bootloader_reboot_ok: true
```

The settings specified in the example playbook include the following:

bootloader_password: *"{{ pwd }}"*

The variable ensures protection of boot parameters with a password.

bootloader_reboot_ok: *true*

The role detects that a reboot is required for the changes to take effect and performs a restart of the managed node.

> **IMPORTANT**
>
> Changing the boot loader password is not an idempotent transaction. This means that if you apply the same Ansible playbook again, the result will not be the same, and the state of the managed node will change.

For details about all variables used in the playbook, see the **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file on the control node.

3. Validate the playbook syntax:

```
$ ansible-playbook --syntax-check --ask-vault-pass ~/playbook.yml
```

Note that this command only validates the syntax and does not protect against a wrong but valid configuration.

4. Run the playbook:

```
$ ansible-playbook --ask-vault-pass ~/playbook.yml
```

Verification

1. On your managed node during the GRUB boot menu screen, press the **e** key for edit.

2. You are prompted for a username and a password:

Enter username: root

The boot loader username is always **root** and you do not need to specify it in your Ansible playbook.

Enter password: *<password>*

The boot loader password corresponds to the **pwd** variable that you defined in the **vault.yml** file.

3. You can view or edit configuration of the particular boot loader entry:

Additional resources

- **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file
- **/usr/share/doc/rhel-system-roles/bootloader/** directory

7.3. SETTING A TIMEOUT FOR THE BOOT LOADER MENU BY USING THE BOOTLOADER RHEL SYSTEM ROLE

You can use the **bootloader** RHEL system role to configure a timeout for the GRUB boot loader menu in an automated way. You can update a period of time to intervene and select a non-default boot entry for various purposes.

Prerequisites

- You have prepared the control node and the managed nodes
- You are logged in to the control node as a user who can run playbooks on the managed nodes.
- The account you use to connect to the managed nodes has **sudo** permissions on them.

Procedure

1. Create a playbook file, for example **~/playbook.yml**, with the following content:

```
---
- name: Configuration and management of the GRUB boot loader
  hosts: managed-node-01.example.com
  tasks:
    - name: Update the boot loader timeout
      ansible.builtin.include_role:
        name: redhat.rhel_system_roles.bootloader
      vars:
        bootloader_timeout: 10
```

The settings specified in the example playbook include the following:

bootloader_timeout: 10
: Input an integer to control for how long the GRUB boot loader menu is displayed before booting the default entry.

For details about all variables used in the playbook, see the **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file on the control node.

2. Validate the playbook syntax:

```
$ ansible-playbook --syntax-check ~/playbook.yml
```

Note that this command only validates the syntax and does not protect against a wrong but valid configuration.

3. Run the playbook:

```
$ ansible-playbook ~/playbook.yml
```

Verification

1. Remotely restart your managed node:

```
# ansible managed-node-01.example.com -m ansible.builtin.reboot
managed-node-01.example.com | CHANGED => {
    "changed": true,
    "elapsed": 21,
    "rebooted": true
}
```

2. On the managed node, observe the GRUB boot menu screen.

The highlighted entry will be executed automatically in 10s

For how long this boot menu is displayed before GRUB automatically uses the default entry.

- Alternative: you can remotely query for the "timeout" settings in the **/boot/grub2/grub.cfg** file of your managed node:

```
# ansible managed-node-01.example.com -m ansible.builtin.command -a "grep 'timeout' /boot/grub2/grub.cfg"
managed-node-01.example.com | CHANGED | rc=0 >>
if [ x$feature_timeout_style = xy ] ; then
  set timeout_style=menu
  set timeout=10
# Fallback normal timeout code in case the timeout_style feature is
  set timeout=10
if [ x$feature_timeout_style = xy ] ; then
    set timeout_style=menu
    set timeout=10
    set orig_timeout_style=${timeout_style}
    set orig_timeout=${timeout}
      # timeout_style=menu + timeout=0 avoids the countdown code keypress check
      set timeout_style=menu
      set timeout=10
      set timeout_style=hidden
      set timeout=10
if [ x$feature_timeout_style = xy ]; then
  if [ "${menu_show_once_timeout}" ]; then
    set timeout_style=menu
    set timeout=10
    unset menu_show_once_timeout
    save_env menu_show_once_timeout
```

Additional resources

- **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file
- **/usr/share/doc/rhel-system-roles/bootloader/** directory

7.4. COLLECTING THE BOOT LOADER CONFIGURATION INFORMATION BY USING THE BOOTLOADER RHEL SYSTEM ROLE

You can use the **bootloader** RHEL system role to gather information about the GRUB boot loader entries in an automated fashion. You can use this information to verify the correct configuration of system boot parameters, such as kernel and initial RAM disk image paths.

As a result, you can for example:

- Prevent boot failures.
- Revert to a known good state when troubleshooting.
- Be sure that security-related kernel command-line parameters are correctly configured.

Prerequisites

- You have prepared the control node and the managed nodes
- You are logged in to the control node as a user who can run playbooks on the managed nodes.
- The account you use to connect to the managed nodes has **sudo** permissions on them.

Procedure

1. Create a playbook file, for example **~/playbook.yml**, with the following content:

```
---
- name: Configuration and management of GRUB boot loader
  hosts: managed-node-01.example.com
  tasks:
    - name: Gather information about the boot loader configuration
      ansible.builtin.include_role:
        name: redhat.rhel_system_roles.bootloader
      vars:
        bootloader_gather_facts: true

    - name: Display the collected boot loader configuration information
      debug:
        var: bootloader_facts
```

For details about all variables used in the playbook, see the **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file on the control node.

2. Validate the playbook syntax:

```
$ ansible-playbook --syntax-check ~/playbook.yml
```

Note that this command only validates the syntax and does not protect against a wrong but valid configuration.

3. Run the playbook:

```
$ ansible-playbook ~/playbook.yml
```

Verification

- After you run the preceding playbook on the control node, you will see a similar command-line output as in the following example:

```
...
    "bootloader_facts": [
        {
            "args": "ro crashkernel=1G-4G:256M,4G-64G:320M,64G-:576M rd.lvm.lv=rhel/root
rd.lvm.lv=rhel/swap $tuned_params quiet",
            "default": true,
            "id": "2c9ec787230141a9b087f774955795ab-5.14.0-362.24.1.el9_3.aarch64",
            "index": "1",
            "initrd": "/boot/initramfs-5.14.0-362.24.1.el9_3.aarch64.img $tuned_initrd",
            "kernel": "/boot/vmlinuz-5.14.0-362.24.1.el9_3.aarch64",
            "root": "/dev/mapper/rhel-root",
            "title": "Red Hat Enterprise Linux (5.14.0-362.24.1.el9_3.aarch64) 9.4 (Plow)"
        }
    ]
...
```

The command-line output shows the following notable configuration information about the boot entry:

args

Command-line parameters passed to the kernel by the GRUB2 boot loader during the boot process. They configure various settings and behaviors of the kernel, initramfs, and other boot-time components.

id

Unique identifier assigned to each boot entry in a boot loader menu. It consists of machine ID and the kernel version.

root

The root filesystem for the kernel to mount and use as the primary filesystem during the boot.

Additional resources

- **/usr/share/ansible/roles/rhel-system-roles.bootloader/README.md** file
- **/usr/share/doc/rhel-system-roles/bootloader/** directory
- Understanding boot entries

CHAPTER 8. APPLYING PATCHES WITH KERNEL LIVE PATCHING

You can use the Red Hat Enterprise Linux kernel live patching solution to patch a running kernel without rebooting or restarting any processes.

With this solution, system administrators:

- Can immediately apply critical security patches to the kernel.
- Do not have to wait for long-running tasks to complete, for users to log off, or for scheduled downtime.
- Control the system's uptime more and do not sacrifice security or stability.

By using the kernel live patching, you can reduce the number of reboots required for security patches. However, note that you cannot address all critical or important CVEs. For more details about the scope of live patching, see the Red Hat Knowledgebase solution Is live kernel patch (kpatch) supported in Red Hat Enterprise Linux?.

> **WARNING**
>
> Some incompatibilities exist between kernel live patching and other kernel subcomponents. Read the Limitations of kpatch carefully before using kernel live patching.

> **NOTE**
>
> For details about the support cadence of kernel live patching updates, see:
>
> - Kernel Live Patch Support Cadence Update
> - Kernel Live Patch life cycles

8.1. LIMITATIONS OF KPATCH

- By using the **kpatch** feature, you can apply simple security and bug fix updates that do not require an immediate system reboot.
- You must not use the **SystemTap** or **kprobe** tool during or after loading a patch. The patch might not take effect until the probes are removed.

8.2. SUPPORT FOR THIRD-PARTY LIVE PATCHING

The **kpatch** utility is the only kernel live patching utility supported by Red Hat with the RPM modules provided by Red Hat repositories. Red Hat does not support live patches provided by a third party.

For more information about third-party software support policies, see As a customer how does Red Hat support me when I use third party components?

8.3. ACCESS TO KERNEL LIVE PATCHES

A kernel module (**kmod**) implements kernel live patching capability and is provided as an RPM package.

All customers have access to kernel live patches, which are delivered through the usual channels. However, customers who do not subscribe to an extended support offering will lose access to new patches for the current minor release once the next minor release becomes available. For example, customers with standard subscriptions will only be able to live patch RHEL 9.1 kernel until the RHEL 9.2 kernel is released.

The components of kernel live patching are as follows:

Kernel patch module

- The delivery mechanism for kernel live patches.
- A kernel module built specifically for the kernel being patched.
- The patch module contains the code of the required fixes for the kernel.
- Patch modules register with the **livepatch** kernel subsystem and specify the original functions to replace, along with pointers to the replacement functions. Kernel patch modules are delivered as RPMs.
- The naming convention is **kpatch_<kernel version>_<kpatch version>_<kpatch release>**. The "kernel version" part of the name has *dots* replaced with *underscores*.

The kpatch utility

A command-line utility for managing patch modules.

The kpatch service

A **systemd** service required by **multiuser.target**. This target loads the kernel patch module at boot time.

The kpatch-dnf package

A DNF plugin delivered in the form of an RPM package. This plugin manages automatic subscription to kernel live patches.

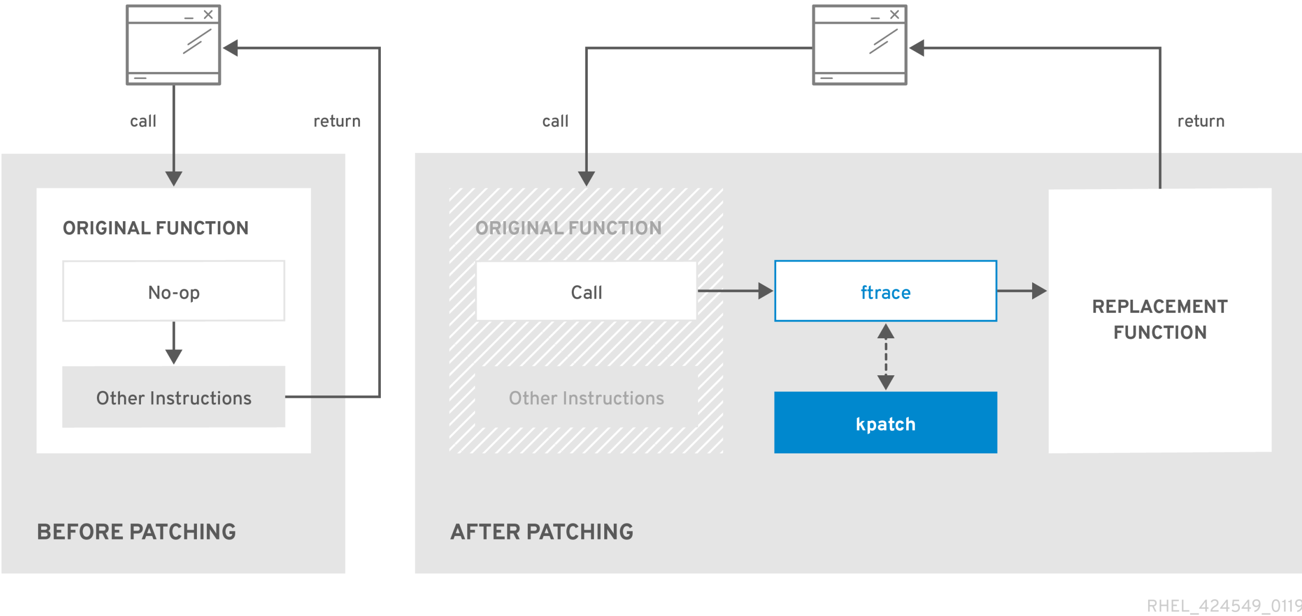
8.4. THE PROCESS OF LIVE PATCHING KERNELS

The **kpatch** kernel patching solution uses the **livepatch** kernel subsystem to redirect outdated functions to updated ones. Applying a live kernel patch to a system triggers the following processes:

1. The kernel patch module is copied to the **/var/lib/kpatch/** directory and registered for re-application to the kernel by **systemd** on next boot.
2. The **kpatch** module loads into the running kernel and the new functions are registered to the **ftrace** mechanism with a pointer to the location in memory of the new code.

When the kernel accesses the patched function, the **ftrace** mechanism redirects it, bypassing the original functions and leading the kernel to the patched version of the function.

Figure 8.1. How kernel live patching works



8.5. SUBSCRIBING THE CURRENTLY INSTALLED KERNELS TO THE LIVE PATCHING STREAM

A kernel patch module is delivered in an RPM package, specific to the version of the kernel being patched. Each RPM package will be cumulatively updated over time.

The following procedure explains how to subscribe to all future cumulative live patching updates for a given kernel. Because live patches are cumulative, you cannot select which individual patches are deployed for a given kernel.

> **WARNING**
>
> Red Hat does not support any third party live patches applied to a Red Hat supported system.

Prerequisites

- You have root permissions.

Procedure

1. Optional: Check your kernel version:

```
# uname -r
5.14.0-1.el9.x86_64
```

2. Search for a live patching package that corresponds to the version of your kernel:

```
# dnf search $(uname -r)
```

3. Install the live patching package:

```
# dnf install "kpatch-patch = $(uname -r)"
```

The command above installs and applies the latest cumulative live patches for that specific kernel only.

If the version of a live patching package is 1-1 or higher, the package will contain a patch module. In that case the kernel will be automatically patched during the installation of the live patching package.

The kernel patch module is also installed into the **/var/lib/kpatch/** directory to be loaded by the **systemd** system and service manager during the future reboots.

NOTE

An empty live patching package will be installed when there are no live patches available for a given kernel. An empty live patching package will have a *kpatch_version-kpatch_release* of 0-0, for example **kpatch-patch-5_14_0-1-0-0.x86_64.rpm**. The installation of the empty RPM subscribes the system to all future live patches for the given kernel.

Verification

- Verify that all installed kernels have been patched:

```
# kpatch list
Loaded patch modules:
kpatch_5_14_0_1_0_1 [enabled]

Installed patch modules:
kpatch_5_14_0_1_0_1 (5.14.0-1.el9.x86_64)
…
```

The output shows that the kernel patch module has been loaded into the kernel that is now patched with the latest fixes from the **kpatch-patch-5_14_0-1-0-1.el9.x86_64.rpm** package.

NOTE

Entering the **kpatch list** command does not return an empty live patching package. Use the **rpm -qa | grep kpatch** command instead.

```
# rpm -qa | grep kpatch
kpatch-dnf-0.4-3.el9.noarch
kpatch-0.9.7-2.el9.noarch
kpatch-patch-5_14_0-284_25_1-0-0.el9_2.x86_64
```

Additional resources

- **kpatch(1)** manual page

- Installing RHEL 9 content

8.6. AUTOMATICALLY SUBSCRIBING ANY FUTURE KERNEL TO THE LIVE PATCHING STREAM

You can use the **kpatch-dnf** DNF plugin to subscribe your system to fixes delivered by the kernel patch module, also known as kernel live patches. The plugin enables **automatic** subscription for any kernel the system currently uses, and also for kernels **to-be-installed in the future**

Prerequisites

- You have root permissions.

Procedure

1. Optional: Check all installed kernels and the kernel you are currently running:

```
# dnf list installed | grep kernel
Updating Subscription Management repositories.
Installed Packages
...
kernel-core.x86_64         5.14.0-1.el9          @beaker-BaseOS
kernel-core.x86_64         5.14.0-2.el9          @@commandline
...

# uname -r
5.14.0-2.el9.x86_64
```

2. Install the **kpatch-dnf** plugin:

```
# dnf install kpatch-dnf
```

3. Enable automatic subscription to kernel live patches:

```
# dnf kpatch auto
Updating Subscription Management repositories.
Last metadata expiration check: 1:38:21 ago on Fri 17 Sep 2021 07:29:53 AM EDT.
Dependencies resolved.
==================================================
 Package                    Architecture
==================================================
Installing:
 kpatch-patch-5_14_0-1            x86_64
 kpatch-patch-5_14_0-2            x86_64

Transaction Summary
===================================================
Install  2 Packages
…
```

This command subscribes all currently installed kernels to receiving kernel live patches. The command also installs and applies the latest cumulative live patches, if any, for all installed kernels.

When you update the kernel, live patches are installed automatically during the new kernel installation process.

The kernel patch module is also installed into the **/var/lib/kpatch/** directory to be loaded by the **systemd** system and service manager during future reboots.

NOTE

An empty live patching package will be installed when there are no live patches available for a given kernel. An empty live patching package will have a *kpatch_version-kpatch_release* of 0-0, for example **kpatch-patch-5_14_0-1-0-0.el9.x86_64.rpm**. The installation of the empty RPM subscribes the system to all future live patches for the given kernel.

Verification

- Verify that all installed kernels are patched:

```
# kpatch list
Loaded patch modules:
kpatch_5_14_0_2_0_1 [enabled]

Installed patch modules:
kpatch_5_14_0_1_0_1 (5.14.0-1.el9.x86_64)
kpatch_5_14_0_2_0_1 (5.14.0-2.el9.x86_64)
```

The output shows that both the kernel you are running, and the other installed kernel have been patched with fixes from **kpatch-patch-5_14_0-1-0-1.el9.x86_64.rpm** and **kpatch-patch-5_14_0-2-0-1.el9.x86_64.rpm** packages respectively.

NOTE

Entering the **kpatch list** command does not return an empty live patching package. Use the **rpm -qa | grep kpatch** command instead.

```
# rpm -qa | grep kpatch
kpatch-dnf-0.4-3.el9.noarch
kpatch-0.9.7-2.el9.noarch
kpatch-patch-5_14_0-284_25_1-0-0.el9_2.x86_64
```

Additional resources

- **kpatch(1)** and **dnf-kpatch(8)** manual pages

8.7. DISABLING AUTOMATIC SUBSCRIPTION TO THE LIVE PATCHING STREAM

When you subscribe your system to fixes delivered by the kernel patch module, your subscription is **automatic**. You can disable this feature, to disable automatic installation of **kpatch-patch** packages.

Prerequisites

- You have root permissions.

Procedure

1. Optional: Check all installed kernels and the kernel you are currently running:

```
# dnf list installed | grep kernel
Updating Subscription Management repositories.
Installed Packages
...
kernel-core.x86_64          5.14.0-1.el9          @beaker-BaseOS
kernel-core.x86_64          5.14.0-2.el9          @@commandline
...

# uname -r
5.14.0-2.el9.x86_64
```

2. Disable automatic subscription to kernel live patches:

```
# dnf kpatch manual
Updating Subscription Management repositories.
```

Verification

- You can check for the successful outcome:

```
# yum kpatch status
...
Updating Subscription Management repositories.
Last metadata expiration check: 0:30:41 ago on Tue Jun 14 15:59:26 2022.
Kpatch update setting: manual
```

Additional resources

- **kpatch(1)** and **dnf-kpatch(8)** manual pages

8.8. UPDATING KERNEL PATCH MODULES

The kernel patch modules are delivered and applied through RPM packages. The process of updating a cumulative kernel patch module is similar to updating any other RPM package.

Prerequisites

- The system is subscribed to the live patching stream, as described in Subscribing the currently installed kernels to the live patching stream.

Procedure

- Update to a new cumulative version for the current kernel:

```
# dnf update "kpatch-patch = $(uname -r)"
```

  The command above automatically installs and applies any updates that are available for the currently running kernel. Including any future released cumulative live patches.

- Alternatively, update all installed kernel patch modules:

  ```
  # dnf update "kpatch-patch"
  ```

> **NOTE**
>
> When the system reboots into the same kernel, the kernel is automatically live patched again by the **kpatch.service** systemd service.

Additional resources

- *Updating software packages* in RHEL

8.9. REMOVING THE LIVE PATCHING PACKAGE

Disable the Red Hat Enterprise Linux kernel live patching solution by removing the live patching package.

Prerequisites

- Root permissions
- The live patching package is installed.

Procedure

1. Select the live patching package.

   ```
   # dnf list installed | grep kpatch-patch
   kpatch-patch-5_14_0-1.x86_64        0-1.el9        @@commandline
   …
   ```

   The example output lists live patching packages that you installed.

2. Remove the live patching package.

   ```
   # dnf remove kpatch-patch-5_14_0-1.x86_64
   ```

   When a live patching package is removed, the kernel remains patched until the next reboot, but the kernel patch module is removed from disk. On future reboot, the corresponding kernel will no longer be patched.

3. Reboot your system.

4. Verify the live patching package is removed:

   ```
   # dnf list installed | grep kpatch-patch
   ```

   The command displays no output if the package has been successfully removed.

Verification

1. Verify the kernel live patching solution is disabled:

```
# kpatch list
Loaded patch modules:
```

The example output shows that the kernel is not patched and the live patching solution is not active because there are no patch modules that are currently loaded.

IMPORTANT

Currently, Red Hat does not support reverting live patches without rebooting your system. In case of any issues, contact our support team.

Additional resources

- The **kpatch(1)** manual page
- *Removing installed packages* in RHEL

8.10. UNINSTALLING THE KERNEL PATCH MODULE

Prevent the Red Hat Enterprise Linux kernel live patching solution from applying a kernel patch module on subsequent boots.

Prerequisites

- Root permissions
- A live patching package is installed.
- A kernel patch module is installed and loaded.

Procedure

1. Select a kernel patch module:

```
# kpatch list
Loaded patch modules:
kpatch_5_14_0_1_0_1 [enabled]

Installed patch modules:
kpatch_5_14_0_1_0_1 (5.14.0-1.el9.x86_64)
…
```

2. Uninstall the selected kernel patch module.

```
# kpatch uninstall kpatch_5_14_0_1_0_1
uninstalling kpatch_5_14_0_1_0_1 (5.14.0-1.el9.x86_64)
```

- Note that the uninstalled kernel patch module is still loaded:

```
# kpatch list
Loaded patch modules:
kpatch_5_14_0_1_0_1 [enabled]
```

```
Installed patch modules:
<NO_RESULT>
```

When the selected module is uninstalled, the kernel remains patched until the next reboot, but the kernel patch module is removed from disk.

3. Reboot your system.

Verification

1. Verify that the kernel patch module is uninstalled:

   ```
   # kpatch list
   Loaded patch modules:
   …
   ```

   This example output shows no loaded or installed kernel patch modules, therefore the kernel is not patched and the kernel live patching solution is not active.

Additional resources

- The **kpatch(1)** manual page

8.11. DISABLING KPATCH.SERVICE

Prevent the Red Hat Enterprise Linux kernel live patching solution from applying all kernel patch modules globally on subsequent boots.

Prerequisites

- Root permissions
- A live patching package is installed.
- A kernel patch module is installed and loaded.

Procedure

1. Verify **kpatch.service** is enabled.

   ```
   # systemctl is-enabled kpatch.service
   enabled
   ```

2. Disable **kpatch.service**:

   ```
   # systemctl disable kpatch.service
   Removed /etc/systemd/system/multi-user.target.wants/kpatch.service.
   ```

   - Note that the applied kernel patch module is still loaded:

     ```
     # kpatch list
     Loaded patch modules:
     kpatch_5_14_0_1_0_1 [enabled]
     ```

```
Installed patch modules:
kpatch_5_14_0_1_0_1 (5.14.0-1.el9.x86_64)
```

3. Reboot your system.

4. Optional: Verify the status of **kpatch.service**.

```
# systemctl status kpatch.service
● kpatch.service - "Apply kpatch kernel patches"
  Loaded: loaded (/usr/lib/systemd/system/kpatch.service; disabled; vendor preset: disabled)
  Active: inactive (dead)
```

   The example output testifies that **kpatch.service** is disabled. Thereby, the kernel live patching solution is not active.

5. Verify that the kernel patch module has been unloaded.

```
# kpatch list
Loaded patch modules:

Installed patch modules:
kpatch_5_14_0_1_0_1 (5.14.0-1.el9.x86_64)
```

   The example output above shows that a kernel patch module is still installed but the kernel is not patched.

IMPORTANT

Currently, Red Hat does not support reverting live patches without rebooting your system. In case of any issues, contact our support team.

Additional resources

- The **kpatch(1)** manual page.
- Managing systemd

CHAPTER 9. KEEPING KERNEL PANIC PARAMETERS DISABLED IN VIRTUALIZED ENVIRONMENTS

When configuring a Virtual Machine in RHEL 9, do not enable the **softlockup_panic** and **nmi_watchdog** kernel parameters, because the Virtual Machine might suffer from a spurious soft lockup. And that should not require a kernel panic.

Find the reasons behind this advice in the following sections.

9.1. WHAT IS A SOFT LOCKUP

A soft lockup is a situation usually caused by a bug, when a task is executing in kernel space on a CPU without rescheduling. The task also does not allow any other task to execute on that particular CPU. As a result, a warning is displayed to a user through the system console. This problem is also referred to as the soft lockup firing.

Additional resources

- *What is a CPU soft lockup?*

9.2. PARAMETERS CONTROLLING KERNEL PANIC

The following kernel parameters can be set to control a system's behavior when a soft lockup is detected.

softlockup_panic

Controls whether or not the kernel will panic when a soft lockup is detected.

Type	Value	Effect
Integer	0	kernel does not panic on soft lockup
Integer	1	kernel panics on soft lockup

By default, on RHEL 8, this value is 0.

The system needs to detect a hard lockup first to be able to panic. The detection is controlled by the **nmi_watchdog** parameter.

nmi_watchdog

Controls whether lockup detection mechanisms (**watchdogs**) are active or not. This parameter is of integer type.

Value	Effect
0	disables lockup detector
1	enables lockup detector

The hard lockup detector monitors each CPU for its ability to respond to interrupts.

watchdog_thresh

Controls frequency of watchdog **hrtimer**, NMI events, and soft or hard lockup thresholds.

Default threshold	Soft lockup threshold
10 seconds	2 * **watchdog_thresh**

Setting this parameter to zero disables lockup detection altogether.

Additional resources

- *Softlockup detector and hardlockup detector*
- *Kernel sysctl*

9.3. SPURIOUS SOFT LOCKUPS IN VIRTUALIZED ENVIRONMENTS

The soft lockup firing on physical hosts usually represents a kernel or a hardware bug. The same phenomenon happening on guest operating systems in virtualized environments might represent a false warning.

Heavy workload on a host or high contention over some specific resource, such as memory, can cause a spurious soft lockup firing because the host might schedule out the guest CPU for a period longer than 20 seconds. When the guest CPU is again scheduled to run on the host, it experiences a *time jump* that triggers the due timers. The timers also include the **hrtimer** watchdog that can report a soft lockup on the guest CPU.

Soft lockup in a virtualized environment can be false. You must not enable the kernel parameters that trigger a system panic when a soft lockup reports to a guest CPU.

IMPORTANT

To understand soft lockups in guests, it is essential to know that the host schedules the guest as a task, and the guest then schedules its own tasks.

Additional resources

- *Virtual machine components and their interaction*

CHAPTER 10. ADJUSTING KERNEL PARAMETERS FOR DATABASE SERVERS

To ensure efficient operation of database servers and databases, you must configure the required sets of kernel parameters.

10.1. INTRODUCTION TO DATABASE SERVERS

A database server is a service that provides features of a database management system (DBMS). DBMS provides utilities for database administration and interacts with end users, applications, and databases.

Red Hat Enterprise Linux 9 provides the following database management systems:

- **MariaDB 10.5**
- **MariaDB 10.11** - available since RHEL 9.4
- **MySQL 8.0**
- **PostgreSQL 13**
- **PostgreSQL 15** - available since RHEL 9.2
- **PostgreSQL 16** - available since RHEL 9.4
- **Redis 6**

10.2. PARAMETERS AFFECTING PERFORMANCE OF DATABASE APPLICATIONS

The following kernel parameters affect performance of database applications.

fs.aio-max-nr

Defines the maximum number of asynchronous I/O operations the system can handle on the server.

> **NOTE**
>
> Raising the **fs.aio-max-nr** parameter produces no additional changes beyond increasing the aio limit.

fs.file-max

Defines the maximum number of file handles (temporary file names or IDs assigned to open files) the system supports at any instance.
The kernel dynamically allocates file handles whenever a file handle is requested by an application. However, the kernel does not free these file handles when they are released by the application. It recycles these file handles instead. The total number of allocated file handles will increase over time even though the number of currently used file handles might be low.

kernel.shmall

Defines the total number of shared memory pages that can be used system-wide. To use the entire main memory, the value of the **kernel.shmall** parameter should be ≤ total main memory size.

kernel.shmmax

Defines the maximum size in bytes of a single shared memory segment that a Linux process can allocate in its virtual address space.

kernel.shmmni

Defines the maximum number of shared memory segments the database server is able to handle.

net.ipv4.ip_local_port_range

The system uses this port range for programs that connect to a database server without specifying a port number.

net.core.rmem_default

Defines the default receive socket memory through Transmission Control Protocol (TCP).

net.core.rmem_max

Defines the maximum receive socket memory through Transmission Control Protocol (TCP).

net.core.wmem_default

Defines the default send socket memory through Transmission Control Protocol (TCP).

net.core.wmem_max

Defines the maximum send socket memory through Transmission Control Protocol (TCP).

vm.dirty_bytes / vm.dirty_ratio

Defines a threshold in bytes / in percentage of dirty-able memory at which a process generating dirty data is started in the **write()** function.

NOTE

Either **vm.dirty_bytes** or **vm.dirty_ratio** can be specified at a time.

vm.dirty_background_bytes / vm.dirty_background_ratio

Defines a threshold in bytes / in percentage of dirty-able memory at which the kernel tries to actively write dirty data to hard-disk.

NOTE

Either **vm.dirty_background_bytes** or **vm.dirty_background_ratio** can be specified at a time.

vm.dirty_writeback_centisecs

Defines a time interval between periodic wake-ups of the kernel threads responsible for writing dirty data to hard-disk.
This kernel parameters measures in 100th's of a second.

vm.dirty_expire_centisecs

Defines the time of dirty data that becomes old to be written to hard-disk.
This kernel parameters measures in 100th's of a second.

Additional resources

- *Dirty pagecache writeback and vm.dirty parameters*

CHAPTER 11. GETTING STARTED WITH KERNEL LOGGING

Log files provide messages about the system, including the kernel, services, and applications running on it. The logging system in Red Hat Enterprise Linux is provided by the built-in **syslog** protocol. Various utilities use this system to record events and organize them into log files. These files are useful when auditing the operating system or troubleshooting problems.

11.1. WHAT IS THE KERNEL RING BUFFER

During the boot process, the console provides important information about the initial phase of the system startup. To avoid loss of the early messages the kernel utilizes a ring buffer. This buffer stores all messages, including boot messages, generated by the **printk()** function within the kernel code. The messages from the kernel ring buffer are then read and stored in log files on permanent storage, for example, by the **syslog** service.

The ring buffer is a cyclic data structure that has a fixed size, and is hard-coded into the kernel. Users can display data stored in the kernel ring buffer through the **dmesg** command or the **/var/log/boot.log** file. When the ring buffer is full, the new data overwrites the old.

Additional resources

- **syslog(2)** and **dmesg(1)** manual page

11.2. ROLE OF PRINTK ON LOG-LEVELS AND KERNEL LOGGING

Each message the kernel reports has a log-level associated with it that defines the importance of the message. The kernel ring buffer, as described in What is the kernel ring buffer , collects kernel messages of all log-levels. It is the **kernel.printk** parameter that defines what messages from the buffer are printed to the console.

The log-level values break down in this order:

0
: Kernel emergency. The system is unusable.

1
: Kernel alert. Action must be taken immediately.

2
: Condition of the kernel is considered critical.

3
: General kernel error condition.

4
: General kernel warning condition.

5
: Kernel notice of a normal but significant condition.

6
: Kernel informational message.

7
: Kernel debug-level messages.

By default, **kernel.printk** in RHEL 9 has the following values:

```
# sysctl kernel.printk
kernel.printk = 7 4 1 7
```

The four values define the following, in order:

1. Console log-level, defines the lowest priority of messages printed to the console.
2. Default log-level for messages without an explicit log-level attached to them.
3. Sets the lowest possible log-level configuration for the console log-level.
4. Sets default value for the console log-level at boot time.
   Each of these values defines a different rule for handling error messages.

IMPORTANT

The default **7 4 1 7 printk** value allows for better debugging of kernel activity. However, when coupled with a serial console, this **printk** setting might cause intense I/O bursts that might lead to a RHEL system becoming temporarily unresponsive. To avoid these situations, setting a **printk** value of **4 4 1 7** typically works, but at the expense of losing the extra debugging information.

Also note that certain kernel command line parameters, such as **quiet** or **debug**, change the default **kernel.printk** values.

Additional resources

- **syslog(2)** manual page

CHAPTER 12. REINSTALLING GRUB

You can reinstall the GRUB boot loader to fix certain problems, usually caused by an incorrect installation of GRUB, missing files, or a broken system. You can resolve these issues by restoring the missing files and updating the boot information.

Reasons to reinstall GRUB:

- Upgrading the GRUB boot loader packages.
- Adding the boot information to another drive.
- The user requires the GRUB boot loader to control installed operating systems. However, some operating systems are installed with their own boot loaders and reinstalling GRUB returns control to the desired operating system.

> **NOTE**
>
> GRUB restores files only if they are not corrupted.

12.1. REINSTALLING GRUB ON BIOS-BASED MACHINES

You can reinstall the GRUB boot loader on your BIOS-based system. Always reinstall GRUB after updating the GRUB packages.

> **IMPORTANT**
>
> This overwrites the existing GRUB to install the new GRUB. Ensure that the system does not cause data corruption or boot crash during the installation.

Procedure

1. Reinstall GRUB on the device where it is installed. For example, if **sda** is your device:

```
# grub2-install /dev/sda
```

2. Reboot your system for the changes to take effect:

```
# reboot
```

Additional resources

- **grub-install(1)** man page on your system

12.2. REINSTALLING GRUB ON UEFI-BASED MACHINES

You can reinstall the GRUB boot loader on your UEFI-based system.

> **IMPORTANT**
>
> Ensure that the system does not cause data corruption or boot crash during the installation.

Procedure

1. Reinstall the **grub2-efi** and **shim** boot loader files:

```
# yum reinstall grub2-efi shim
```

2. Reboot your system for the changes to take effect:

```
# reboot
```

12.3. REINSTALLING GRUB ON IBM POWER MACHINES

You can reinstall the GRUB boot loader on the Power PC Reference Platform (PReP) boot partition of your IBM Power system. Always reinstall GRUB after updating the GRUB packages.

> **IMPORTANT**
>
> This overwrites the existing GRUB to install the new GRUB. Ensure that the system does not cause data corruption or boot crash during the installation.

Procedure

1. Determine the disk partition that stores GRUB:

```
# bootlist -m normal -o
sda1
```

2. Reinstall GRUB on the disk partition:

```
# grub2-install partition
```

Replace ***partition*** with the identified GRUB partition, such as **/dev/sda1**.

3. Reboot your system for the changes to take effect:

```
# reboot
```

Additional resources

- **grub-install(1)** man page on your system

12.4. RESETTING GRUB

Resetting GRUB completely removes all GRUB configuration files and system settings, and reinstalls the boot loader. You can reset all the configuration settings to their default values, and therefore fix failures caused by corrupted files and invalid configuration.

> **IMPORTANT**
>
> The following procedure will remove all the customization made by the user.

Procedure

1. Remove the configuration files:

```
# rm /etc/grub.d/*
# rm /etc/sysconfig/grub
```

2. Reinstall packages.

   - On BIOS-based machines:

   ```
   # yum reinstall grub2-tools
   ```

   - On UEFI-based machines:

   ```
   # yum reinstall grub2-efi shim grub2-tools grub2-common
   ```

3. Rebuild the **grub.cfg** file for the changes to take effect.

   - On BIOS-based machines:

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

   - On UEFI-based machines:

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

   > **WARNING**
   >
   > The path to rebuild **grub.cfg** is same for both BIOS and UEFI based machines. Actual **grub.cfg** is present at BIOS path only. The UEFI path has a stub file that must not be modified or recreated using **grub2-mkconfig** command.

4. Follow Reinstalling GRUB procedure to restore GRUB on the **/boot/** partition.

CHAPTER 13. INSTALLING KDUMP

The **kdump** service is installed and activated by default on the new versions of RHEL 9 installations.

13.1. WHAT IS KDUMP

kdump is a service that provides a crash dumping mechanism and generates a crash dump or a **vmcore** dump file. **vmcore** includes the contents of the system memory for analysis and troubleshooting. **kdump** uses the **kexec** system call to boot into the second kernel, *capture kernel*, without a reboot. This kernel captures the contents of the crashed kernel's memory and saves it into a file. The second kernel is available in a reserved part of the system memory.

IMPORTANT

A kernel crash dump can be the only information available if a system failure occur. Therefore, operational **kdump** is important in mission-critical environments. Red Hat advises to regularly update and test **kexec-tools** in your normal kernel update cycle. This is important when you install new kernel features.

If you have multiple kernels on a machine, you can enable **kdump** for all installed kernels or for specified kernels only. When you install **kdump**, the system creates a default **/etc/kdump.conf** file. **/etc/kdump.conf** includes the default minimum **kdump** configuration, which you can edit to customize the **kdump** configuration.

13.2. INSTALLING KDUMP USING ANACONDA

The **Anaconda** installer provides a graphical interface screen for **kdump** configuration during an interactive installation. You can enable **kdump** and reserve the required amount of memory.

Procedure

1. On the Anaconda installer, click **KDUMP** and enable **kdump**:
2. In **Kdump Memory Reservation**, select **Manual**` if you must customize the memory reserve.
3. In **KDUMP > Memory To Be Reserved (MB)**, set the required memory reserve for **kdump**.
   = Installing kdump on the command line

Installation options such as custom **Kickstart** installations, in some cases does **not** install or enable **kdump** by default. The following procedure helps you enable **kdump** in this case.

Prerequisites

- An active RHEL subscription.
- A repository containing the **kexec-tools** package for your system CPU architecture.
- Fulfilled requirements for **kdump** configurations and targets. For details, see Supported kdump configurations and targets.

Procedure

1. Check if **kdump** is installed on your system:

```
# rpm -q kexec-tools
```

Output if the package is installed:

```
# kexec-tools-2.0.22-13.el9.x86_64
```

Output if the package is not installed:

```
package kexec-tools is not installed
```

2. Install **kdump** and other necessary packages:

```
# dnf install kexec-tools
```

CHAPTER 14. CONFIGURING KDUMP ON THE COMMAND LINE

The memory for **kdump** is reserved during the system boot. You can configure the memory size in the system's Grand Unified Bootloader (GRUB) configuration file. The memory size depends on the **crashkernel=** value specified in the configuration file and the size of the physical memory of system.

14.1. ESTIMATING THE KDUMP SIZE

When planning and building your **kdump** environment, it is important to know the space required by the crash dump file.

The **makedumpfile --mem-usage** command estimates the space required by the crash dump file. It generates a memory usage report. The report helps you decide the dump level and the pages that are safe to exclude.

Procedure

- Enter the following command to generate a memory usage report:

```
# makedumpfile --mem-usage /proc/kcore


TYPE        PAGES    EXCLUDABLE    DESCRIPTION
-------------------------------------------------------------
ZERO          501635      yes        Pages filled with zero
CACHE          51657       yes        Cache pages
CACHE_PRIVATE 5442        yes        Cache pages + private
USER          16301       yes        User process pages
FREE          77738211    yes        Free pages
KERN_DATA     1333192     no         Dumpable kernel data
```

IMPORTANT

The **makedumpfile --mem-usage** command reports required memory in pages. This means that you must calculate the size of memory in use against the kernel page size.

By default the RHEL kernel uses 4 KB sized pages on AMD64 and Intel 64 CPU architectures, and 64 KB sized pages on IBM POWER architectures.

14.2. CONFIGURING KDUMP MEMORY USAGE ON RHEL 9

The **kexec-tools** package maintains the default **crashkernel=** memory reservation values. The **kdump** service uses the default value to reserve the crash kernel memory for each kernel. The default value can also serve as the reference base value to estimate the required memory size when you set the **crashkernel=** value manually. The minimum size of the crash kernel can vary depending on the hardware and machine specifications.

The automatic memory allocation for **kdump** also varies based on the system hardware architecture and available memory size. For example, on AMD64 and Intel 64-bit architectures, the default value for the **crashkernel=** parameter will work only when the available memory is more than 1 GB. The **kexec-tools** utility configures the following default memory reserves on AMD64 and Intel 64-bit architecture:

```
crashkernel=1G-4G:192M,4G-64G:256M,64G:512M
```

You can also run **kdumpctl estimate** to get an approximate value without triggering a crash. The estimated **crashkernel=** value might not be an exact one but can serve as a reference to set an appropriate **crashkernel=** value.

NOTE

The **crashkernel=auto** option in the boot command line is no longer supported on RHEL 9 and later releases.

Prerequisites

- You have root permissions on the system.
- You have fulfilled **kdump** requirements for configurations and targets. For details, see Supported kdump configurations and targets .
- You have installed the **zipl** utility if it is the IBM Z system.

Procedure

1. Configure the default value for crash kernel:

   ```
   # kdumpctl reset-crashkernel --kernel=ALL
   ```

   When configuring the **crashkernel=** value, test the configuration by rebooting the system with **kdump** enabled. If the **kdump** kernel fails to boot, increase the memory size gradually to set an acceptable value.

2. To use a custom **crashkernel=** value:

   a. Configure the required memory reserve.

      ```
      crashkernel=192M
      ```

      Optionally, you can set the amount of reserved memory to a variable depending on the total amount of installed memory by using the syntax **crashkernel=*<range1>:<size1>,<range2>:<size2>***. For example:

      ```
      crashkernel=1G-4G:192M,2G-64G:256M
      ```

      The example reserves 192 MB of memory if the total amount of system memory is 1 GB or higher and lower than 4 GB. If the total amount of memory is more than 4 GB, 256 MB is reserved for **kdump**.

   b. Optional: Offset the reserved memory.
      Some systems require to reserve memory with a certain fixed offset since **crashkernel** reservation is very early, and it wants to reserve some area for special usage. If the offset is set, the reserved memory begins there. To offset the reserved memory, use the following syntax:

      ```
      crashkernel=192M@16M
      ```

The example reserves 192 MB of memory starting at 16 MB (physical address 0x01000000). If you offset to 0 or do not specify a value, **kdump** offsets the reserved memory automatically. You can also offset memory when setting a variable memory reservation by specifying the offset as the last value. For example, **crashkernel=1G-4G:192M,2G-64G:256M@16M**.

c. Update the boot loader configuration:

```
# grubby --update-kernel ALL --args "crashkernel=<custom-value>"
```

The ***<custom-value>*** must contain the custom **crashkernel=** value that you have configured for the crash kernel.

3. Reboot for changes to take effect:

```
# reboot
```

> **VERIFICATION**
>
> The commands to test **kdump** configuration will cause the kernel to crash with data loss. Follow the instructions with care. You must not use an active production system to test the kdump configuration.

Cause the kernel to crash by activating the **sysrq** key. The **address-YYYY-MM-DD-HH:MM:SS/vmcore** file is saved to the target location as specified in the **/etc/kdump.conf** file. If you select the default target location, the **vmcore** file is saved in the partition mounted under **/var/crash/**.

1. Activate the **sysrq** key to boot into the **kdump** kernel:

```
# echo c > /proc/sysrq-trigger
```

The command causes kernel to crash and reboots the kernel if required.

2. Display the **/etc/kdump.conf** file and check if the **vmcore** file is saved in the target destination.

Additional resources

- How to manually modify the boot parameter in grub before the system boots .
- **grubby(8)** man page on your system.

14.3. CONFIGURING THE KDUMP TARGET

The crash dump is usually stored as a file in a local file system, written directly to a device. Optionally, you can send crash dump over a network by using the **NFS** or **SSH** protocols. Only one of these options to preserve a crash dump file can be set at a time. The default behavior is to store it in the **/var/crash/** directory of the local file system.

Prerequisites

- You have root permissions on the system.
- Fulfilled requirements for **kdump** configurations and targets. For details, see Supported kdump configurations and targets.

Procedure

- To store the crash dump file in **/var/crash/** directory of the local file system, edit the **/etc/kdump.conf** file and specify the path:

```
path /var/crash
```

The option **path /var/crash** represents the path to the file system in which **kdump** saves the crash dump file.

NOTE

  - When you specify a dump target in the **/etc/kdump.conf** file, then the path is **relative** to the specified dump target.
  - When you do not specify a dump target in the **/etc/kdump.conf** file, then the path represents the **absolute** path from the root directory.

Depending on the file system mounted in the current system, the dump target and the adjusted dump path are configured automatically.

- To secure the crash dump file and the accompanying files produced by **kdump**, you should set up proper attributes for the target destination directory, such as user permissions and SELinux contexts. Additionally, you can define a script, for example **kdump_post.sh** in the **kdump.conf** file as follows:

```
kdump_post <path_to_kdump_post.sh>
```

The **kdump_post** directive specifies a shell script or a command that executes **after kdump** has completed capturing and saving a crash dump to the specified destination. You can use this mechanism to extend the functionality of **kdump** to perform actions including the adjustments in file permissions.

- The **kdump** target configuration

```
# *grep -v ^# /etc/kdump.conf | grep -v ^$*
ext4 /dev/mapper/vg00-varcrashvol
path /var/crash
core_collector makedumpfile -c --message-level 1 -d 31
```

The dump target is specified (**ext4 /dev/mapper/vg00-varcrashvol**), and, therefore, it is mounted at **/var/crash**. The **path** option is also set to **/var/crash**. Therefore, the **kdump** saves the **vmcore** file in the **/var/crash/var/crash** directory.

- To change the local directory for saving the crash dump, edit the **/etc/kdump.conf** configuration file as a **root** user:
  a. Remove the hash sign (**#**) from the beginning of the **#path /var/crash** line.
  b. Replace the value with the intended directory path. For example:

```
path /usr/local/cores
```

> **IMPORTANT**
>
> In RHEL 9, the directory defined as the **kdump** target using the **path** directive must exist when the **kdump systemd** service starts to avoid failures. Unlike in earlier versions of RHEL, the directory is no longer created automatically if it does not exist when the service starts.

- To write the file to a different partition, edit the **/etc/kdump.conf** configuration file:
  a. Remove the hash sign (**#**) from the beginning of the **#ext4** line, depending on your choice.
     - device name (the **#ext4 /dev/vg/lv_kdump** line)
     - file system label (the **#ext4 LABEL=/boot** line)
     - UUID (the **#ext4 UUID=03138356-5e61-4ab3-b58e-27507ac41937** line)

  b. Change the file system type and the device name, label or UUID, to the required values. The correct syntax for specifying UUID values is both **UUID="correct-uuid"** and **UUID=correct-uuid**. For example:

     ```
     ext4 UUID=03138356-5e61-4ab3-b58e-27507ac41937
     ```

> **IMPORTANT**
>
> It is recommended to specify storage devices by using a **LABEL=** or **UUID=**. Disk device names such as **/dev/sda3** are not guaranteed to be consistent across reboot.
>
> When you use Direct Access Storage Device (DASD) on IBM Z hardware, ensure the dump devices are correctly specified in **/etc/dasd.conf** before proceeding with **kdump**.

- To write the crash dump directly to a device, edit the **/etc/kdump.conf** configuration file:
  a. Remove the hash sign (**#**) from the beginning of the **#raw /dev/vg/lv_kdump** line.
  b. Replace the value with the intended device name. For example:

     ```
     raw /dev/sdb1
     ```

- To store the crash dump to a remote machine by using the **NFS** protocol:
  a. Remove the hash sign (**#**) from the beginning of the **#nfs my.server.com:/export/tmp** line.
  b. Replace the value with a valid hostname and directory path. For example:

     ```
     nfs penguin.example.com:/export/cores
     ```

  c. Restart the **kdump** service for the changes to take effect:

     ```
     sudo systemctl restart kdump.service
     ```

> **NOTE**
>
> While using the NFS directive to specify the NFS target, **kdump.service** automatically attempts to mount the NFS target to check the disk space. There is no need to mount the NFS target in advance. To prevent **kdump.service** from mounting the target, use the **dracut_args --mount** directive in **kdump.conf**. This will enable **kdump.service** to call the **dracut** utility with the **--mount** argument to specify the NFS target.

- To store the crash dump to a remote machine by using the SSH protocol:
  a. Remove the hash sign (**#**) from the beginning of the **#ssh user@my.server.com** line.
  b. Replace the value with a valid username and hostname.
  c. Include your SSH key in the configuration.
     i. Remove the hash sign from the beginning of the **#sshkey /root/.ssh/kdump_id_rsa** line.
     ii. Change the value to the location of a key valid on the server you are trying to dump to. For example:

```
ssh john@penguin.example.com
sshkey /root/.ssh/mykey
```

Additional resources

Files produced by kdump after system crash .

14.4. CONFIGURING THE KDUMP CORE COLLECTOR

The **kdump** service uses a **core_collector** program to capture the crash dump image. In RHEL, the **makedumpfile** utility is the default core collector. It helps shrink the dump file by:

- Compressing the size of a crash dump file and copying only necessary pages by using various dump levels.
- Excluding unnecessary crash dump pages.
- Filtering the page types to be included in the crash dump.

> **NOTE**
>
> Crash dump file compression is enabled by default in the RHEL 7 and above.

If you need to customize the crash dump file compression, follow this procedure.

Syntax

```
core_collector makedumpfile -l --message-level 1 -d 31
```

Options

- **-c**, **-l** or **-p**: specify compress dump file format by each page using either, **zlib** for **-c** option, **lzo** for **-l** option or **snappy** for **-p** option.
- **-d (dump_level)**: excludes pages so that they are not copied to the dump file.
- **--message-level** : specify the message types. You can restrict outputs printed by specifying **message_level** with this option. For example, specifying 7 as **message_level** prints common messages and error messages. The maximum value of **message_level** is 31.

Prerequisites

- You have root permissions on the system.
- Fulfilled requirements for **kdump** configurations and targets. For details, see Supported kdump configurations and targets.

Procedure

1. As a **root**, edit the **/etc/kdump.conf** configuration file and remove the hash sign ("#") from the beginning of the **#core_collector makedumpfile -l --message-level 1 -d 31**.
2. Enter the following command to enable crash dump file compression:

```
core_collector makedumpfile -l --message-level 1 -d 31
```

The **-l** option specifies the **dump** compressed file format. The **-d** option specifies dump level as 31. The **--message-level** option specifies message level as 1.

Also, consider following examples with the **-c** and **-p** options:

- To compress a crash dump file by using **-c**:

  ```
  core_collector makedumpfile -c -d 31 --message-level 1
  ```

- To compress a crash dump file by using **-p**:

  ```
  core_collector makedumpfile -p -d 31 --message-level 1
  ```

Additional resources

- **makedumpfile(8)** man page on your system
- Configuration file for kdump

14.5. CONFIGURING THE KDUMP DEFAULT FAILURE RESPONSES

By default, when **kdump** fails to create a crash dump file at the configured target location, the system reboots and the dump is lost in the process. You can change the default failure response and configure **kdump** to perform a different operation when it fails to save the core dump to the primary target. The additional actions are:

dump_to_rootfs

Saves the core dump to the **root** file system.

reboot

Reboots the system, losing the core dump in the process.

halt

Stops the system, losing the core dump in the process.

poweroff

Power the system off, losing the core dump in the process.

shell

Runs a shell session from within the **initramfs**, you can record the core dump manually.

final_action

Enables additional operations such as **reboot**, **halt**, and **poweroff** after a successful **kdump** or when shell or **dump_to_rootfs** failure action completes. The default is **reboot**.

failure_action

Specifies the action to perform when a dump might fail in a kernel crash. The default is **reboot**.

Prerequisites

- Root permissions.
- Fulfilled requirements for **kdump** configurations and targets. For details, see Supported kdump configurations and targets.

Procedure

1. As a **root** user, remove the hash sign (**#**) from the beginning of the **#failure_action** line in the **/etc/kdump.conf** configuration file.
2. Replace the value with a required action.

```
failure_action poweroff
```

Additional resources

- Configuring the kdump target

14.6. CONFIGURATION FILE FOR KDUMP

The configuration file for **kdump** kernel is **/etc/sysconfig/kdump**. This file controls the **kdump** kernel command line parameters. For most configurations, use the default options. However, in some scenarios you might need to modify certain parameters to control the **kdump** kernel behavior. For example, modifying the **KDUMP_COMMANDLINE_APPEND** option to append the **kdump** kernel command-line to obtain a detailed debugging output or the **KDUMP_COMMANDLINE_REMOVE** option to remove arguments from the **kdump** command line.

KDUMP_COMMANDLINE_REMOVE

This option removes arguments from the current **kdump** command line. It removes parameters that can cause **kdump** errors or **kdump** kernel boot failures. These parameters might have been parsed from the previous **KDUMP_COMMANDLINE** process or inherited from the **/proc/cmdline** file. When this variable is not configured, it inherits all values from the **/proc/cmdline** file. Configuring this option also provides information that is helpful in debugging an issue.

To remove certain arguments, add them to **KDUMP_COMMANDLINE_REMOVE** as follows:

```
# KDUMP_COMMANDLINE_REMOVE="hugepages hugepagesz slub_debug quiet log_buf_len
swiotlb"
```

KDUMP_COMMANDLINE_APPEND

This option appends arguments to the current command line. These arguments might have been parsed by the previous **KDUMP_COMMANDLINE_REMOVE** variable.
For the **kdump** kernel, disabling certain modules such as **mce**, **cgroup**, **numa**, **hest_disable** can help prevent kernel errors. These modules can consume a significant part of the kernel memory reserved for **kdump** or cause **kdump** kernel boot failures.

To disable memory **cgroups** on the **kdump** kernel command line, run the command as follows:

```
KDUMP_COMMANDLINE_APPEND="cgroup_disable=memory"
```

Additional resources

- The **Documentation/admin-guide/kernel-parameters.txt** file
- The **/etc/sysconfig/kdump** file

14.7. TESTING THE KDUMP CONFIGURATION

After configuring **kdump**, you must manually test a system crash and ensure that the **vmcore** file is generated in the defined **kdump** target. The **vmcore** file is captured from the context of the freshly booted kernel. Therefore, **vmcore** has critical information for debugging a kernel crash.

WARNING

Do not test **kdump** on active production systems. The commands to test **kdump** will cause the kernel to crash with loss of data. Depending on your system architecture, ensure that you schedule significant maintenance time because **kdump** testing might require several reboots with a long boot time.

If the **vmcore** file is not generated during the **kdump** test, identify and fix issues before you run the test again for a successful **kdump** testing.

If you make any manual system modifications, you must test the **kdump** configuration at the end of any system modification. For example, if you make any of the following changes, ensure that you test the **kdump** configuration for an optimal **kdump** performances for:

- Package upgrades.
- Hardware level changes, for example, storage or networking changes.
- Firmware upgrades.

- New installation and application upgrades that include third party modules.
- If you use the hot-plugging mechanism to add more memory on hardware that support this mechanism.
- After you make changes in the **/etc/kdump.conf** or **/etc/sysconfig/kdump** file.

Prerequisites

- You have root permissions on the system.
- You have saved all important data. The commands to test **kdump** cause the kernel to crash with loss of data.
- You have scheduled significant machine maintenance time depending on the system architecture.

Procedure

1. Enable the **kdump** service:

```
# kdumpctl restart
```

2. Check the status of the **kdump** service with the **kdumpctl**:

```
# kdumpctl status
  kdump:Kdump is operational
```

   Optionally, if you use the **systemctl** command, the output prints in the **systemd** journal.

3. Start a kernel crash to test the **kdump** configuration. The **sysrq-trigger** key combination causes the kernel to crash and might reboot the system if required.

```
# echo c > /proc/sysrq-trigger
```

   On a kernel reboot, the ***address-YYYY-MM-DD-HH:MM:SS*/vmcore** file is created at the location you have specified in the **/etc/kdump.conf** file. The default is **/var/crash/**.

Additional resources

- Configuring the kdump target

14.8. FILES PRODUCED BY KDUMP AFTER SYSTEM CRASH

After your system crashes, the **kdump** service captures the kernel memory in a dump file (**vmcore**) and it also generates additional diagnostic files to aid in troubleshooting and postmortem analysis.

Files produced by **kdump**:

- **vmcore** - main kernel memory dump file containing system memory at the time of the crash. It includes data as per the configuration of the **core_collector** program specified in **kdump** configuration. By default the kernel data structures, process information, stack traces, and other diagnostic information.

- **vmcore-dmesg.txt** - contents of the kernel ring buffer log (**dmesg**) from the primary kernel that panicked.
- **kexec-dmesg.log** - has kernel and system log messages from the execution of the secondary **kexec** kernel that collects the **vmcore** data.

Additional resources

- What is the kernel ring buffer

14.9. ENABLING AND DISABLING THE KDUMP SERVICE

You can configure to enable or disable the **kdump** functionality on a specific kernel or on all installed kernels. You must routinely test the **kdump** functionality and validate its operates correctly.

Prerequisites

- You have root permissions on the system.
- You have completed **kdump** requirements for configurations and targets. See Supported kdump configurations and targets.
- All configurations for installing **kdump** are set up as required.

Procedure

1. Enable the **kdump** service for **multi-user.target**:

```
# systemctl enable kdump.service
```

2. Start the service in the current session:

```
# systemctl start kdump.service
```

3. Stop the **kdump** service:

```
# systemctl stop kdump.service
```

4. Disable the **kdump** service:

```
# systemctl disable kdump.service
```

> **WARNING**
>
> It is recommended to set **kptr_restrict=1** as default. When **kptr_restrict** is set to (1) as default, the **kdumpctl** service loads the crash kernel regardless of whether the Kernel Address Space Layout (**KASLR**) is enabled.
>
> If **kptr_restrict** is not set to **1** and KASLR is enabled, the contents of **/proc/kore** file are generated as all zeros. The **kdumpctl** service fails to access the **/proc/kcore** file and load the crash kernel. The **kexec-kdump-howto.txt** file displays a warning message, which recommends you to set **kptr_restrict=1**. Verify for the following in the **sysctl.conf** file to ensure that **kdumpctl** service loads the crash kernel:
>
> - Kernel **kptr_restrict=1** in the **sysctl.conf** file.

14.10. PREVENTING KERNEL DRIVERS FROM LOADING FOR KDUMP

You can control the capture kernel from loading certain kernel drivers by adding the **KDUMP_COMMANDLINE_APPEND=** variable in the **/etc/sysconfig/kdump** configuration file. By using this method, you can prevent the **kdump** initial RAM disk image **initramfs** from loading the specified kernel module. This helps to prevent the out-of-memory (OOM) killer errors or other crash kernel failures.

You can append the **KDUMP_COMMANDLINE_APPEND=** variable by using one of the following configuration options:

- **rd.driver.blacklist=*<modules>***
- **modprobe.blacklist=*<modules>***

Prerequisites

- You have root permissions on the system.

Procedure

1. Display the list of modules that are loaded to the currently running kernel. Select the kernel module that you intend to block from loading:

```
$ lsmod

Module                  Size  Used by
fuse                  126976  3
xt_CHECKSUM            16384  1
ipt_MASQUERADE         16384  1
uinput                 20480  1
xt_conntrack           16384  1
```

2. Update the **KDUMP_COMMANDLINE_APPEND=** variable in the **/etc/sysconfig/kdump** file. For example:

```
KDUMP_COMMANDLINE_APPEND="rd.driver.blacklist=hv_vmbus,hv_storvsc,hv_utils,hv_net
vsc,hid-hyperv"
```

Also, consider the following example by using the **modprobe.blacklist=*<modules>*** configuration option:

```
KDUMP_COMMANDLINE_APPEND="modprobe.blacklist=emcp modprobe.blacklist=bnx2fc
modprobe.blacklist=libfcoe modprobe.blacklist=fcoe"
```

3. Restart the **kdump** service:

```
# systemctl restart kdump
```

Additional resources

- **dracut.cmdline** man page on your system.

14.11. RUNNING KDUMP ON SYSTEMS WITH ENCRYPTED DISK

When you run a LUKS encrypted partition, systems require certain amount of available memory. If the system has less than the required amount of available memory, the **cryptsetup** utility fails to mount the partition. As a result, capturing the **vmcore** file to an encrypted target location fails in the second kernel (capture kernel).

The **kdumpctl estimate** command helps you estimate the amount of memory you need for **kdump**. **kdumpctl estimate** prints the recommended **crashkernel** value, which is the most suitable memory size required for **kdump**.

The recommended **crashkernel** value is calculated based on the current kernel size, kernel module, initramfs, and the LUKS encrypted target memory requirement.

If you are using the custom **crashkernel=** option, **kdumpctl estimate** prints the **LUKS required size** value. The value is the memory size required for LUKS encrypted target.

Procedure

1. Print the estimate **crashkernel=** value:

```
# *kdumpctl estimate*

Encrypted kdump target requires extra memory, assuming using the keyslot with minimum
memory requirement
   Reserved crashkernel:    256M
   Recommended crashkernel: 652M

   Kernel image size:   47M
   Kernel modules size: 8M
   Initramfs size:      20M
   Runtime reservation: 64M
   LUKS required size:  512M
   Large modules: <none>
   WARNING: Current crashkernel size is lower than recommended size 652M.
```

2. Configure the amount of required memory by increasing the **crashkernel=** value.

3. Reboot the system.

NOTE

If the **kdump** service still fails to save the dump file to the encrypted target, increase the **crashkernel=** value as required.

CHAPTER 15. CONFIGURING KDUMP IN THE WEB CONSOLE

You can set up and test the **kdump** configuration by using the RHEL 9 web console. The web console can enable the **kdump** service at boot time. With the web console, you can configure the reserved memory for **kdump** and to select the **vmcore** saving location in an uncompressed or compressed format.

15.1. CONFIGURING KDUMP MEMORY USAGE AND TARGET LOCATION IN WEB CONSOLE

You can configure the memory reserve for the **kdump** kernel and also specify the target location to capture the **vmcore** dump file with the RHEL web console interface.

Prerequisites

- The web console must be installed and accessible. For details, see Installing the web console.

Procedure

1. In the web console, open the **Kernel dump** tab and start the **kdump** service by setting the **Kernel crash dump** switch to on.
2. Configure the **kdump** memory usage in the terminal, for example:

   ```
   $ sudo grubby --update-kernel ALL --args crashkernel=512M
   ```

   Restart the system to apply the changes.
3. In the **Kernel dump** tab, click **Edit** at the end of the **Crash dump location** field.
4. Specify the target directory for saving the **vmcore** dump file:
   - For a local filesystem, select **Local Filesystem** from the drop-down menu.
   - For a remote system by using the SSH protocol, select **Remote over SSH** from the drop-down menu and specify the following fields:
     - In the **Server** field, enter the remote server address.
     - In the **SSH key** field, enter the SSH key location.
     - In the **Directory** field, enter the target directory.
   - For a remote system by using the NFS protocol, select **Remote over NFS** from the drop-down menu and specify the following fields:
     - In the **Server** field, enter the remote server address.
     - In the **Export** field, enter the location of the shared folder of an NFS server.
     - In the **Directory** field, enter the target directory.

> **NOTE**
>
> You can reduce the size of the **vmcore** file by selecting the **Compression** checkbox.

5. Optional: Display the automation script by clicking **View automation script**
   A window with the generated script opens. You can browse a shell script and an Ansible playbook generation options tab.

6. Optional: Copy the script by clicking **Copy to clipboard**
   You can use this script to apply the same configuration on multiple machines.

Verification

1. Click **Test configuration**.

2. Click **Crash system** under **Test kdump settings**.

   > **WARNING**
   >
   > When you start the system crash, the kernel operation stops and results in a system crash with data loss.

Additional resources

- Supported kdump targets

CHAPTER 16. ENABLING KDUMP

For your RHEL 9 systems, you can configure enabling or disabling the **kdump** functionality on a specific kernel or on all installed kernels. However, you must routinely test the **kdump** functionality and validate its working status.

16.1. ENABLING KDUMP FOR ALL INSTALLED KERNELS

The **kdump** service starts by enabling **kdump.service** after the **kexec** tool is installed. You can enable and start the **kdump** service for all kernels installed on the machine.

Prerequisites

- You have administrator privileges.

Procedure

1. Add the **crashkernel=** command-line parameter to all installed kernels:

```
# grubby --update-kernel=ALL --args="crashkernel=xxM"
```

   xxM is the required memory in megabytes.

2. Reboot the system:

```
# reboot
```

3. Enable the **kdump** service:

```
# systemctl enable --now kdump.service
```

Verification

- Check that the **kdump** service is running:

```
# systemctl status kdump.service

○ kdump.service - Crash recovery kernel arming
    Loaded: loaded (/usr/lib/systemd/system/kdump.service; enabled; vendor preset:
disabled)
    Active: active (live)
```

16.2. ENABLING KDUMP FOR A SPECIFIC INSTALLED KERNEL

You can enable the **kdump** service for a specific kernel on the machine.

Prerequisites

- You have administrator privileges.

Procedure

1. List the kernels installed on the machine.

```
# ls -a /boot/vmlinuz-*
/boot/vmlinuz-0-rescue-2930657cd0dc43c2b75db480e5e5b4a9
/boot/vmlinuz-4.18.0-330.el8.x86_64
/boot/vmlinuz-4.18.0-330.rt7.111.el8.x86_64
```

2. Add a specific **kdump** kernel to the system's Grand Unified Bootloader (GRUB) configuration. For example:

```
# grubby --update-kernel=vmlinuz-4.18.0-330.el8.x86_64 --args="crashkernel=xxM"
```

xxM is the required memory reserve in megabytes.

3. Enable the **kdump** service.

```
# systemctl enable --now kdump.service
```

Verification

- Check that the **kdump** service is running.

```
# systemctl status kdump.service

○ kdump.service - Crash recovery kernel arming
    Loaded: loaded (/usr/lib/systemd/system/kdump.service; enabled; vendor preset:
disabled)
    Active: active (live)
```

16.3. DISABLING THE KDUMP SERVICE

You can stop the **kdump.service** and disable the service from starting on your RHEL 9 systems.

Prerequisites

- Fulfilled requirements for **kdump** configurations and targets. For details, see Supported kdump configurations and targets.
- All configurations for installing **kdump** are set up according to your needs. For details, see Installing kdump.

Procedure

1. To stop the **kdump** service in the current session:

```
# systemctl stop kdump.service
```

2. To disable the **kdump** service:

```
# systemctl disable kdump.service
```

> **WARNING**
>
> It is recommended to set **kptr_restrict=1** as default. When **kptr_restrict** is set to (1) as default, the **kdumpctl** service loads the crash kernel regardless of whether the Kernel Address Space Layout (**KASLR**) is enabled.
>
> If **kptr_restrict** is not set to **1** and **KASLR** is enabled, the contents of **/proc/kore** file are generated as all zeros. The **kdumpctl** service fails to access the **/proc/kcore** file and load the crash kernel. The **kexec-kdump-howto.txt** file displays a warning message, which recommends you to set **kptr_restrict=1**. Verify for the following in the **sysctl.conf** file to ensure that **kdumpctl** service loads the crash kernel:
>
> - Kernel **kptr_restrict=1** in the **sysctl.conf** file.

Additional resources

- Managing systemd

CHAPTER 17. SUPPORTED KDUMP CONFIGURATIONS AND TARGETS

The **kdump** mechanism is a feature of the Linux kernel that generates a crash dump file when a kernel crash occurs. The kernel dump file has critical information that helps to analyze and determine the root cause of a kernel crash. The crash can be because of various factors, hardware issues or third-party kernel modules problems, to name a few.

By using the provided information and procedures, you can perform the following actions:

- Identify the supported configurations and targets for your RHEL 9 systems.
- Configure kdump.
- Verify kdump operation.

17.1. MEMORY REQUIREMENTS FOR KDUMP

For **kdump** to capture a kernel crash dump and save it for further analysis, a part of the system memory should be permanently reserved for the capture kernel. When reserved, this part of the system memory is not available to the main kernel.

The memory requirements vary based on certain system parameters. One of the major factors is the system's hardware architecture. To identify the exact machine architecture, such as Intel 64 and AMD64, also known as x86_64, and print it to standard output, use the following command:

```
$ uname -m
```

With the stated list of minimum memory requirements, you can set the appropriate memory size to automatically reserve a memory for **kdump** on the latest available versions. The memory size depends on the system's architecture and total available physical memory.

Table 17.1. Minimum amount of reserved memory required for kdump

Architecture	Available Memory	Minimum Reserved Memory
AMD64 and Intel 64 (**x86_64**)	1 GB to 4 GB	192 MB of RAM
	4 GB to 64 GB	256 MB of RAM
	64 GB and more	512 MB of RAM
64-bit ARM (4k pages)	1 GB to 4 GB	256 MB of RAM
	4 GB to 64 GB	320 MB of RAM
	64 GB and more	576 MB of RAM
64-bit ARM (64k pages)	1 GB to 4 GB	356 MB of RAM
	4 GB to 64 GB	420 MB of RAM

Architecture	Available Memory	Minimum Reserved Memory
	64 GB and more	676 MB of RAM
IBM Power Systems (**ppc64le**)	2 GB to 4 GB	384 MB of RAM
	4 GB to 16 GB	512 MB of RAM
	16 GB to 64 GB	1 GB of RAM
	64 GB to 128 GB	2 GB of RAM
	128 GB and more	4 GB of RAM
IBM Z (**s390x**)	1 GB to 4 GB	192 MB of RAM
	4 GB to 64 GB	256 MB of RAM
	64 GB and more	512 MB of RAM

On many systems, **kdump** is able to estimate the amount of required memory and reserve it automatically. This behavior is enabled by default, but only works on systems that have more than a certain amount of total available memory, which varies based on the system architecture.

IMPORTANT

The automatic configuration of reserved memory based on the total amount of memory in the system is a best effort estimation. The actual required memory might vary due to other factors such as I/O devices. Using not enough of memory might cause debug kernel unable to boot as a capture kernel in the case of kernel panic. To avoid this problem, increase the crash kernel memory sufficiently.

Additional resources

- Red Hat Enterprise Linux Technology Capabilities and Limits

17.2. MINIMUM THRESHOLD FOR AUTOMATIC MEMORY RESERVATION

By default, the **kexec-tools** utility configures the **crashkernel** command line parameter and reserves a certain amount of memory for **kdump**. On some systems however, it is still possible to assign memory for **kdump** either by using the **crashkernel=auto** parameter in the boot loader configuration file, or by enabling this option in the graphical configuration utility. For this automatic reservation to work, a certain amount of total memory needs to be available in the system. The memory requirement varies based on the system's architecture. If the system memory is less than the specified threshold value, you must configure the memory manually.

Table 17.2. Minimum amount of memory required for automatic memory reservation

Architecture	Required Memory
AMD64 and Intel 64 (**x86_64**)	1 GB
IBM Power Systems (**ppc64le**)	2 GB
IBM Z (**s390x**)	1 GB
64-bit ARM	1 GB

NOTE

The **crashkernel=auto** option in the boot command line is no longer supported on RHEL 9 and later releases.

17.3. SUPPORTED KDUMP TARGETS

When a kernel crash occurs, the operating system saves the dump file on the configured or default target location. You can save the dump file either directly to a device, store as a file on a local file system, or send the dump file over a network. With the following list of dump targets, you can know the targets that are currently supported or not supported by **kdump**.

Table 17.3. kdump targets on RHEL 9

Target type	Supported Targets	Unsupported Targets

Target type	Supported Targets	Unsupported Targets
Physical Storage	• Logical Volume Manager (LVM). • Thin provisioning volume. • Fibre Channel (FC) disks such as **qla2xxx**, **lpfc**, **bnx2fc**, and **bfa**. • An **iSCSI** software-configured logical device on a networked storage server. • The **mdraid** subsystem as a software **RAID** solution. • Hardware RAID such as **smartpqi**, **hpsa**, **megaraid**, **mpt3sas**, **aacraid**, and **mpi3mr**. • **SCSI** and **SATA** disks. • **iSCSI** and **HBA** offloads. • Hardware **FCoE** such as **qla2xxx** and **lpfc**. • Software **FCoE** such as **bnx2fc**. For software **FCoE** to function, additional memory configuration might be required.	• BIOS RAID. • Software **iSCSI** with **iBFT**. Currently supported transports are **bnx2i**, **cxgb3i**, and **cxgb4i**. • Software iSCSI with hybrid device driver such as **be2iscsi**. • Fibre Channel over Ethernet (**FCoE**). • Legacy IDE. • **GlusterFS** servers. • **GFS2** file system. • Clustered Logical Volume Manager (CLVM). • High availability LVM volumes (HA-LVM).
Network	• Hardware using kernel modules such as **igb**, **ixgbe**, **ice**, **i40e**, **e1000e**, **igc**, **tg3**, **bnx2x**, **bnxt_en**, **qede**, **cxgb4**, **be2net**, **enic**, **sfc**, **mlx4_en**, **mlx5_core**, **r8169**, **atlantic**, **nfp**, and **nicvf** on 64-bit ARM architecture only.	• Hardware using kernel modules such as **sfc SRIOV**, **cxgb4vf**, and **pch_gbe**. • IPv6 protocol. • Wireless connections. • InfiniBand networks. • VLAN network over bridge and team.

Target type	Supported Targets	Unsupported Targets
Hypervisor	• Kernel-based virtual machines (KVM). • Xen hypervisor in certain configurations only. • ESXi 6.6, 6.7, 7.0. • Hyper-V 2012 R2 on RHEL Gen1 UP Guest only and later version.	
Filesystem	The **ext[234]fs**, **XFS**, **virtiofs**, and NFS file systems.	The **Btrfs** file system.
Firmware	• BIOS-based systems. • UEFI Secure Boot.	

Additional resources

- Configuring the kdump target

17.4. SUPPORTED KDUMP FILTERING LEVELS

To reduce the size of the dump file, **kdump** uses the **makedumpfile** core collector to compress the data and also exclude unwanted information, for example, you can remove **hugepages** and **hugetlbfs** pages by using the **-8** level. The levels that **makedumpfile** currently supports can be seen in the table for *Filtering levels for `kdump`* .

Table 17.4. Filtering levels forkdump

Option	Description
1	Zero pages
2	Cache pages
4	Cache private
8	User pages
16	Free pages

Additional resources

- Configuring the kdump core collector

17.5. SUPPORTED DEFAULT FAILURE RESPONSES

By default, when **kdump** fails to create a core dump, the operating system reboots. However, you can configure **kdump** to perform a different operation in case it fails to save the core dump to the primary target.

dump_to_rootfs
: Attempt to save the core dump to the root file system. This option is especially useful in combination with a network target: if the network target is unreachable, this option configures kdump to save the core dump locally. The system is rebooted afterwards.

reboot
: Reboot the system, losing the core dump in the process.

halt
: Halt the system, losing the core dump in the process.

poweroff
: Power off the system, losing the core dump in the process.

shell
: Run a shell session from within the initramfs, allowing the user to record the core dump manually.

final_action
: Enable additional operations such as **reboot**, **halt**, and **poweroff** actions after a successful **kdump** or when **shell** or **dump_to_rootfs** failure action completes. The default **final_action** option is **reboot**.

failure_action
: Specifies the action to perform when a dump might fail in the event of a kernel crash. The default **failure_action** option is **reboot**.

Additional resources

- Configuring the kdump default failure responses

17.6. USING FINAL_ACTION PARAMETER

When **kdump** succeeds or if **kdump** fails to save the **vmcore** file at the configured target, you can perform additional operations like **reboot**, **halt**, and **poweroff** by using the **final_action** parameter. If the **final_action** parameter is not specified, **reboot** is the default response.

Procedure

1. To configure **final_action**, edit the **/etc/kdump.conf** file and add one of the following options:
   - **final_action reboot**
   - **final_action halt**
   - **final_action poweroff**
2. Restart the **kdump** service for the changes to take effect.

```
# kdumpctl restart
```

17.7. USING FAILURE_ACTION PARAMETER

The **failure_action** parameter specifies the action to perform when a dump fails in the event of a kernel crash. The default action for **failure_action** is **reboot** that reboots the system.

The parameter recognizes the following actions to take:

reboot
: Reboots the system after a dump failure.

dump_to_rootfs
: Saves the dump file on a root file system when a non-root dump target is configured.

halt
: Halts the system.

poweroff
: Stops the running operations on the system.

shell
: Starts a shell session inside **initramfs**, from which you can manually perform additional recovery actions.

Procedure

1. To configure an action to take if the dump fails, edit the **/etc/kdump.conf** file and specify one of the **failure_action** options:
   - **failure_action reboot**
   - **failure_action halt**
   - **failure_action poweroff**
   - **failure_action shell**
   - **failure_action dump_to_rootfs**
2. Restart the **kdump** service for the changes to take effect.

```
# kdumpctl restart
```

CHAPTER 18. FIRMWARE ASSISTED DUMP MECHANISMS

Firmware assisted dump (fadump) is a dump capturing mechanism, provided as an alternative to the **kdump** mechanism on IBM POWER systems. The **kexec** and **kdump** mechanisms are useful for capturing core dumps on AMD64 and Intel 64 systems. However, some hardware, such as mini systems and mainframe computers, uses the onboard firmware to isolate regions of memory and prevent any accidental overwriting of data that is important to the crash analysis. The **fadump** utility is optimized for the **fadump** mechanisms and their integration with RHEL on IBM POWER systems.

18.1. FIRMWARE ASSISTED DUMP ON IBM POWERPC HARDWARE

The **fadump** utility captures the **vmcore** file from a fully-reset system with PCI and I/O devices. This mechanism uses firmware to preserve memory regions during a crash and then reuses the **kdump** userspace scripts to save the **vmcore** file. The memory regions consist of all system memory contents, except the boot memory, system registers, and hardware Page Table Entries (PTEs).

The **fadump** mechanism offers improved reliability over the traditional dump type, by rebooting the partition and using a new kernel to dump the data from the previous kernel crash. The **fadump** requires an IBM POWER6 processor-based or later version hardware platform.

For further details about the **fadump** mechanism, including PowerPC specific methods of resetting hardware, see the **/usr/share/doc/kexec-tools/fadump-howto.txt** file.

NOTE

The area of memory that is not preserved, known as boot memory, is the amount of RAM required to successfully boot the kernel after a crash event. By default, the boot memory size is 256MB or 5% of total system RAM, whichever is larger.

Unlike **kexec-initiated** event, the **fadump** mechanism uses the production kernel to recover a crash dump. When booting after a crash, PowerPC hardware makes the device node **/proc/device-tree/rtas/ibm.kernel-dump** available to the **proc** filesystem (**procfs**). The **fadump-aware kdump** scripts, check for the stored **vmcore**, and then complete the system reboot cleanly.

18.2. ENABLING FIRMWARE ASSISTED DUMP MECHANISM

You can enhance the crash dumping capabilities of IBM POWER systems by enabling the firmware assisted dump (**fadump**) mechanism.

In the Secure Boot environment, the GRUB boot loader allocates a boot memory region, known as the Real Mode Area (RMA). The RMA has a size of 512 MB, divided among the boot components. If a component exceeds its size allocation, **GRUB** fails with an out-of-memory (**OOM**) error.

> **WARNING**
>
> Do not enable firmware assisted dump (**fadump**) mechanism in the Secure Boot environment on RHEL 9.1 and earlier versions. The GRUB boot loader fails with the following error:
>
> ```
> error: ../../grub-core/kern/mm.c:376:out of memory.
> Press any key to continue…
> ```
>
> The system is recoverable only if you increase the default **initramfs** size due to the **fadump** configuration.
>
> For information about workaround methods to recover the system, see the System boot ends in GRUB Out of Memory (OOM) article.

Prerequisites

- You have root permissions on the system.

Procedure

1. Install the **kexec-tools** package.
2. Configure the default value for **crashkernel**.

   ```
   # kdumpctl reset-crashkernel --fadump=on --kernel=ALL
   ```

3. Optional: Reserve boot memory instead of the default value.

   ```
   # grubby --update-kernel ALL --args="fadump=on crashkernel=xxM"
   ```

   xxM is the required memory size in megabytes.

   > **NOTE**
   >
   > When specifying boot configuration options, test the configurations by rebooting the kernel with **kdump** enabled. If the **kdump** kernel fails to boot, increase the **crashkernel** value gradually to set an appropriate value.

4. Reboot for changes to take effect.

   ```
   # reboot
   ```

18.3. FIRMWARE ASSISTED DUMP MECHANISMS ON IBM Z HARDWARE

IBM Z systems support the following firmware assisted dump mechanisms:

- **Stand-alone dump (sadump)**
- **VMDUMP**

The **kdump** infrastructure is supported and utilized on IBM Z systems. However, using one of the firmware assisted dump (fadump) methods for IBM Z has the following benefits:

- The system console initiates and controls the **sadump** mechanism, and stores it on an **IPL** bootable device.
- The **VMDUMP** mechanism is similar to **sadump**. This tool is also initiated from the system console, but retrieves the resulting dump from hardware and copies it to the system for analysis.
- These methods (similarly to other hardware based dump mechanisms) have the ability to capture the state of a machine in the early boot phase, before the **kdump** service starts.
- Although **VMDUMP** contains a mechanism to receive the dump file into a Red Hat Enterprise Linux system, the configuration and control of **VMDUMP** is managed from the IBM Z Hardware console.

Additional resources

- Using the Dump Tools on Red Hat Enterprise Linux 8.5
- Stand-alone dump
- Creating dumps on z/VM with VMDUMP

18.4. USING SADUMP ON FUJITSU PRIMEQUEST SYSTEMS

The Fujitsu **sadump** mechanism provides a **fallback** dump capture when **kdump** is unable to complete successfully. You can manually invoke **sadump** from the system Management Board (MMB) interface. Using MMB, configure **kdump** like for an Intel 64 or AMD64 server and then proceed to enable **sadump**.

Procedure

1. Add or edit the following lines in the **/etc/sysctl.conf** file to ensure that **kdump** starts as expected for **sadump**:

```
kernel.panic=0
kernel.unknown_nmi_panic=1
```

> **WARNING**
>
> In particular, ensure that after **kdump**, the system does not reboot. If the system reboots after **kdump** has failed to save the **vmcore** file, then it is not possible to invoke the **sadump**.

2. Set the **failure_action** parameter in **/etc/kdump.conf** appropriately as **halt** or **shell**.

```
failure_action shell
```

Additional resources

- The FUJITSU Server PRIMEQUEST 2000 Series Installation Manual

CHAPTER 19. ANALYZING A CORE DUMP

To identify the cause of the system crash, you can use the **crash** utility, which provides an interactive prompt similar to the GNU Debugger (GDB). By using **crash**, you can analyze a core dump created by **kdump**, **netdump**, **diskdump**, or **xendump** and a running Linux system. Alternatively, you can use the Kernel Oops Analyzer or the Kdump Helper tool.

19.1. INSTALLING THE CRASH UTILITY

With the provided information, understand the required packages and the procedure to install the **crash** utility. The **crash** utility might not be installed by default on your RHEL 9 systems. **crash** is a tool to interactively analyze a system's state while it is running or after a kernel crash occurs and a core dump file is created. The core dump file is also known as the **vmcore** file.

Procedure

1. Enable the relevant repositories:

```
# subscription-manager repos --enable baseos repository
```

```
# subscription-manager repos --enable appstream repository
```

```
# subscription-manager repos --enable rhel-9-for-x86_64-baseos-debug-rpms
```

2. Install the **crash** package:

```
# dnf install crash
```

3. Install the **kernel-debuginfo** package:

```
# dnf install kernel-debuginfo
```

The package **kernel-debuginfo** will correspond to the running kernel and provides the data necessary for the dump analysis.

19.2. RUNNING AND EXITING THE CRASH UTILITY

The **crash** utility is a powerful tool for analyzing **kdump**. By running **crash** on a crash dump file, you can gain insights into the system's state at the time of the crash, identify the root cause of the issue, and troubleshoot kernel-related problems.

Prerequisites

- Identify the currently running kernel (for example **5.14.0-1.el9.x86_64**).

Procedure

1. To start the **crash** utility, two necessary parameters need to be passed to the command:

   - The debug-info (a decompressed vmlinuz image), for example **/usr/lib/debug/lib/modules/5.14.0-1.el9.x86_64/vmlinux** provided through a specific **kernel-debuginfo** package.

- The actual vmcore file, for example **/var/crash/127.0.0.1-2021-09-13-14:05:33/vmcore**
  The resulting **crash** command then looks:

  ```
  # crash /usr/lib/debug/lib/modules/5.14.0-1.el9.x86_64/vmlinux /var/crash/127.0.0.1-2021-09-13-14:05:33/vmcore
  ```

  Use the same *<kernel>* version that was captured by **kdump**.

2. Running the crash utility.
   The following example shows analyzing a core dump created on September 13 2021 at 14:05 PM, using the 5.14.0-1.el9.x86_64 kernel.

   ```
   ...
   WARNING: kernel relocated [202MB]: patching 90160 gdb minimal_symbol values

         KERNEL: /usr/lib/debug/lib/modules/5.14.0-1.el9.x86_64/vmlinux
       DUMPFILE: /var/crash/127.0.0.1-2021-09-13-14:05:33/vmcore  [PARTIAL DUMP]
           CPUS: 2
           DATE: Mon Sep 13 14:05:16 2021
         UPTIME: 01:03:57
   LOAD AVERAGE: 0.00, 0.00, 0.00
          TASKS: 586
       NODENAME: localhost.localdomain
        RELEASE: 5.14.0-1.el9.x86_64
        VERSION: #1 SMP Wed Aug 29 11:51:55 UTC 2018
        MACHINE: x86_64  (2904 Mhz)
         MEMORY: 2.9 GB
          PANIC: "sysrq: SysRq : Trigger a crash"
            PID: 10635
        COMMAND: "bash"
           TASK: ffff8d6c84271800  [THREAD_INFO: ffff8d6c84271800]
            CPU: 1
          STATE: TASK_RUNNING (SYSRQ)

   crash>
   ```

3. To exit the interactive prompt and stop **crash**, type **exit** or **q**.

   ```
   crash> exit
   ~]#
   ```

> **NOTE**
>
> The **crash** command is also utilized as a powerful tool for debugging a live system. However, you must use it with caution to avoid system-level issues.

Additional resources

- A Guide to Unexpected System Restarts

19.3. DISPLAYING VARIOUS INDICATORS IN THE CRASH UTILITY

Use the **crash** utility to display various indicators, such as a kernel message buffer, a backtrace, a process status, virtual memory information and open files.

Displaying the message buffer

- To display the kernel message buffer, type the **log** command at the interactive prompt:

```
crash> log
... several lines omitted ...
EIP: 0060:[<c068124f>] EFLAGS: 00010096 CPU: 2
EIP is at sysrq_handle_crash+0xf/0x20
EAX: 00000063 EBX: 00000063 ECX: c09e1c8c EDX: 00000000
ESI: c0a09ca0 EDI: 00000286 EBP: 00000000 ESP: ef4dbf24
 DS: 007b ES: 007b FS: 00d8 GS: 00e0 SS: 0068
Process bash (pid: 5591, ti=ef4da000 task=f196d560 task.ti=ef4da000)
Stack:
 c068146b c0960891 c0968653 00000003 00000000 00000002 efade5c0 c06814d0
<0> fffffffb c068150f b7776000 f2600c40 c0569ec4 ef4dbf9c 00000002 b7776000
<0> efade5c0 00000002 b7776000 c0569e60 c051de50 ef4dbf9c f196d560 ef4dbfb4
Call Trace:
 [<c068146b>] ? __handle_sysrq+0xfb/0x160
 [<c06814d0>] ? write_sysrq_trigger+0x0/0x50
 [<c068150f>] ? write_sysrq_trigger+0x3f/0x50
 [<c0569ec4>] ? proc_reg_write+0x64/0xa0
 [<c0569e60>] ? proc_reg_write+0x0/0xa0
 [<c051de50>] ? vfs_write+0xa0/0x190
 [<c051e8d1>] ? sys_write+0x41/0x70
 [<c0409adc>] ? syscall_call+0x7/0xb
Code: a0 c0 01 0f b6 41 03 19 d2 f7 d2 83 e2 03 83 e0 cf c1 e2 04 09 d0 88 41 03 f3 c3 90 c7
05 c8 1b 9e c0 01 00 00 00 0f ae f8 89 f6 <c6> 05 00 00 00 00 01 c3 89 f6 8d bc 27 00 00 00
00 8d 50 d0 83
EIP: [<c068124f>] sysrq_handle_crash+0xf/0x20 SS:ESP 0068:ef4dbf24
CR2: 0000000000000000
```

Type **help log** for more information about the command usage.

> **NOTE**
>
> The kernel message buffer includes the most essential information about the system crash. It is always dumped first in to the **vmcore-dmesg.txt** file. If you fail to obtain the full **vmcore** file, for example, due to insufficient space on the target location, you can obtain the required information from the kernel message buffer. By default, **vmcore-dmesg.txt** is placed in the **/var/crash/** directory.

Displaying a backtrace

- To display the kernel stack trace, use the **bt** command.

```
crash> bt
PID: 5591   TASK: f196d560  CPU: 2   COMMAND: "bash"
 #0 [ef4dbdcc] crash_kexec at c0494922
 #1 [ef4dbe20] oops_end at c080e402
 #2 [ef4dbe34] no_context at c043089d
 #3 [ef4dbe58] bad_area at c0430b26
 #4 [ef4dbe6c] do_page_fault at c080fb9b
```

```
 #5 [ef4dbee4] error_code (via page_fault) at c080d809
    EAX: 00000063  EBX: 00000063  ECX: c09e1c8c  EDX: 00000000  EBP: 00000000
    DS:  007b      ESI: c0a09ca0  ES:  007b      EDI: 00000286  GS:  00e0
    CS:  0060      EIP: c068124f  ERR: ffffffff  EFLAGS: 00010096
 #6 [ef4dbf18] sysrq_handle_crash at c068124f
 #7 [ef4dbf24] __handle_sysrq at c0681469
 #8 [ef4dbf48] write_sysrq_trigger at c068150a
 #9 [ef4dbf54] proc_reg_write at c0569ec2
#10 [ef4dbf74] vfs_write at c051de4e
#11 [ef4dbf94] sys_write at c051e8cc
#12 [ef4dbfb0] system_call at c0409ad5
    EAX: ffffffda  EBX: 00000001  ECX: b7776000  EDX: 00000002
    DS:  007b      ESI: 00000002  ES:  007b      EDI: b7776000
    SS:  007b      ESP: bfcb2088  EBP: bfcb20b4  GS:  0033
    CS:  0073      EIP: 00edc416  ERR: 00000004  EFLAGS: 00000246
```

Type **bt *<pid>*** to display the backtrace of a specific process or type **help bt** for more information about **bt** usage.

Displaying a process status

- To display the status of processes in the system, use the **ps** command.

```
crash> ps
   PID    PPID  CPU   TASK    ST  %MEM     VSZ    RSS  COMM
>     0      0   0  c09dc560  RU   0.0       0      0  [swapper]
>     0      0   1  f7072030  RU   0.0       0      0  [swapper]
      0      0   2  f70a3a90  RU   0.0       0      0  [swapper]
>     0      0   3  f70ac560  RU   0.0       0      0  [swapper]
      1      0   1  f705ba90  IN   0.0    2828   1424  init
... several lines omitted ...
   5566      1   1  f2592560  IN   0.0   12876    784  auditd
   5567      1   2  ef427560  IN   0.0   12876    784  auditd
   5587   5132   0  f196d030  IN   0.0   11064   3184  sshd
>  5591   5587   2  f196d560  RU   0.0    5084   1648  bash
```

Use **ps *<pid>*** to display the status of a single specific process. Use *help ps* for more information about **ps** usage.

Displaying virtual memory information

- To display basic virtual memory information, type the **vm** command at the interactive prompt.

```
crash> vm
PID: 5591   TASK: f196d560  CPU: 2   COMMAND: "bash"
   MM       PGD      RSS    TOTAL_VM
f19b5900  ef9c6000  1648k    5084k
  VMA       START      END    FLAGS  FILE
f1bb0310    242000    260000 8000875  /lib/ld-2.12.so
f26af0b8    260000    261000 8100871  /lib/ld-2.12.so
efbc275c    261000    262000 8100873  /lib/ld-2.12.so
efbc2a18    268000    3ed000 8000075  /lib/libc-2.12.so
efbc23d8    3ed000    3ee000 8000070  /lib/libc-2.12.so
efbc2888    3ee000    3f0000 8100071  /lib/libc-2.12.so
efbc2cd4    3f0000    3f1000 8100073  /lib/libc-2.12.so
```

```
efbc243c    3f1000    3f4000 100073
efbc28ec    3f6000    3f9000 8000075  /lib/libdl-2.12.so
efbc2568    3f9000    3fa000 8100071  /lib/libdl-2.12.so
efbc2f2c    3fa000    3fb000 8100073  /lib/libdl-2.12.so
f26af888    7e6000    7fc000 8000075  /lib/libtinfo.so.5.7
f26aff2c    7fc000    7ff000 8100073  /lib/libtinfo.so.5.7
efbc211c    d83000    d8f000 8000075  /lib/libnss_files-2.12.so
efbc2504    d8f000    d90000 8100071  /lib/libnss_files-2.12.so
efbc2950    d90000    d91000 8100073  /lib/libnss_files-2.12.so
f26afe00    edc000    edd000 4040075
f1bb0a18   8047000   8118000 8001875  /bin/bash
f1bb01e4   8118000   811d000 8101873  /bin/bash
f1bb0c70   811d000   8122000 100073
f26afae0   9fd9000   9ffa000 100073
... several lines omitted ...
```

Use **vm** ***<pid>*** to display information about a single specific process, or use **help vm** for more information about **vm** usage.

Displaying open files

- To display information about open files, use the **files** command.

```
crash> files
PID: 5591   TASK: f196d560  CPU: 2   COMMAND: "bash"
ROOT: /    CWD: /root
 FD    FILE     DENTRY    INODE    TYPE  PATH
  0  f734f640  eedc2c6c  eecd6048  CHR   /pts/0
  1  efade5c0  eee14090  f00431d4  REG   /proc/sysrq-trigger
  2  f734f640  eedc2c6c  eecd6048  CHR   /pts/0
 10  f734f640  eedc2c6c  eecd6048  CHR   /pts/0
255  f734f640  eedc2c6c  eecd6048  CHR   /pts/0
```

Use **files** ***<pid>*** to display files opened by only one selected process, or use **help files** for more information about **files** usage.

19.4. USING KERNEL OOPS ANALYZER

The Kernel Oops Analyzer tool analyzes the crash dump by comparing the **oops** messages with known issues in the knowledge base.

Prerequisites

- An **oops** message is secured to feed the Kernel Oops Analyzer.

Procedure

1. Access the Kernel Oops Analyzer tool.
2. To diagnose a kernel crash issue, upload a kernel oops log generated in **vmcore**.
    - Alternatively, you can diagnose a kernel crash issue by providing a text message or a **vmcore-dmesg.txt** as an input.

3. Click **DETECT** to compare the **oops** message based on information from the **makedumpfile** against known solutions.

Additional resources

- The Kernel Oops Analyzer article

19.5. THE KDUMP HELPER TOOL

The Kdump Helper tool helps to set up the **kdump** using the provided information. Kdump Helper generates a configuration script based on your preferences. Initiating and running the script on your server sets up the **kdump** service.

Additional resources

- Kdump Helper

CHAPTER 20. USING EARLY KDUMP TO CAPTURE BOOT TIME CRASHES

Early kdump is a feature of the **kdump** mechanism that captures the **vmcore** file if a system or kernel crash occurs during the early phases of the boot process before the system services start. Early kdump loads the crash kernel and the **initramfs** of crash kernel in the memory much earlier.

A kernel crash can sometimes occur during the early boot phase before the **kdump** service starts and is able to capture and save the contents of the crashed kernel memory. Therefore, crucial information related to the crash that is important for troubleshooting is lost. To address this problem, you can use the **early kdump** feature, which is a part of the **kdump** service.

20.1. ENABLING EARLY KDUMP

The **early kdump** feature sets up the crash kernel and the initial RAM disk image (**initramfs**) to load early enough to capture the **vmcore** information for an early crash. This helps to eliminate the risk of losing information about the early boot kernel crashes.

Prerequisites

- An active RHEL subscription.
- A repository containing the **kexec-tools** package for your system CPU architecture.
- Fulfilled **kdump** configuration and targets requirements. For more information see, Supported kdump configurations and targets.

Procedure

1. Verify that the **kdump** service is enabled and active:

```
# systemctl is-enabled kdump.service && systemctl is-active kdump.service
enabled
active
```

   If **kdump** is not enabled and running, set all required configurations and verify that **kdump** service is enabled.

2. Rebuild the **initramfs** image of the booting kernel with the **early kdump** functionality:

```
# dracut -f --add earlykdump
```

3. Add the **rd.earlykdump** kernel command line parameter:

```
# grubby --update-kernel=/boot/vmlinuz-$(uname -r) --args="rd.earlykdump"
```

4. Reboot the system to reflect the changes:

```
# reboot
```

Verification

- Verify that **rd.earlykdump** is successfully added and **early kdump** feature is enabled:

```
# cat /proc/cmdline
BOOT_IMAGE=(hd0,msdos1)/vmlinuz-5.14.0-1.el9.x86_64 root=/dev/mapper/rhel-root ro
crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rhel/swap
rhgb quiet rd.earlykdump

# journalctl -x | grep early-kdump
Sep 13 15:46:11 redhat dracut-cmdline[304]: early-kdump is enabled.
Sep 13 15:46:12 redhat dracut-cmdline[304]: kexec: loaded early-kdump kernel
```

Additional resources

- The **/usr/share/doc/kexec-tools/early-kdump-howto.txt** file
- What is early kdump support and how do I configure it? (Red Hat Knowledgebase)

CHAPTER 21. SIGNING A KERNEL AND MODULES FOR SECURE BOOT

You can enhance the security of your system by using a signed kernel and signed kernel modules. On UEFI-based build systems where Secure Boot is enabled, you can self-sign a privately built kernel or kernel modules. Furthermore, you can import your public key into a target system where you want to deploy your kernel or kernel modules.

If Secure Boot is enabled, all of the following components have to be signed with a private key and authenticated with the corresponding public key:

- UEFI operating system boot loader
- The Red Hat Enterprise Linux kernel
- All kernel modules

If any of these components are not signed and authenticated, the system cannot finish the booting process.

RHEL 9 includes:

- Signed boot loaders
- Signed kernels
- Signed kernel modules

In addition, the signed first-stage boot loader and the signed kernel include embedded Red Hat public keys. These signed executable binaries and embedded keys enable RHEL 9 to install, boot, and run with the Microsoft UEFI Secure Boot Certification Authority keys. These keys are provided by the UEFI firmware on systems that support UEFI Secure Boot.

NOTE

- Not all UEFI-based systems include support for Secure Boot.
- The build system, where you build and sign your kernel module, does not need to have UEFI Secure Boot enabled and does not even need to be a UEFI-based system.

21.1. PREREQUISITES

- To be able to sign externally built kernel modules, install the utilities from the following packages:

```
# dnf install pesign openssl kernel-devel mokutil keyutils
```

Table 21.1. Required utilities

Utility	Provided by package	Used on	Purpose
efikeygen	**pesign**	Build system	Generates public and private X.509 key pair

Utility	Provided by package	Used on	Purpose
openssl	**openssl**	Build system	Exports the unencrypted private key
sign-file	**kernel-devel**	Build system	Executable file used to sign a kernel module with the private key
mokutil	**mokutil**	Target system	Optional utility used to manually enroll the public key
keyctl	**keyutils**	Target system	Optional utility used to display public keys in the system keyring

21.2. WHAT IS UEFI SECURE BOOT

With the *Unified Extensible Firmware Interface* (UEFI) Secure Boot technology, you can prevent the execution of the kernel-space code that is not signed by a trusted key. The system boot loader is signed with a cryptographic key. The database of public keys in the firmware authorizes the process of signing the key. You can subsequently verify a signature in the next-stage boot loader and the kernel.

UEFI Secure Boot establishes a chain of trust from the firmware to the signed drivers and kernel modules as follows:

- An UEFI private key signs, and a public key authenticates the **shim** first-stage boot loader. A *certificate authority* (CA) in turn signs the public key. The CA is stored in the firmware database.
- The **shim** file contains the Red Hat public key **Red Hat Secure Boot (CA key 1)** to authenticate the GRUB boot loader and the kernel.
- The kernel in turn contains public keys to authenticate drivers and modules.

Secure Boot is the boot path validation component of the UEFI specification. The specification defines:

- Programming interface for cryptographically protected UEFI variables in non-volatile storage.
- Storing the trusted X.509 root certificates in UEFI variables.
- Validation of UEFI applications such as boot loaders and drivers.
- Procedures to revoke known-bad certificates and application hashes.

UEFI Secure Boot helps in the detection of unauthorized changes but does **not**:

- Prevent installation or removal of second-stage boot loaders.
- Require explicit user confirmation of such changes.
- Stop boot path manipulations. Signatures are verified during booting but, not when the boot loader is installed or updated.

If the boot loader or the kernel are not signed by a system trusted key, Secure Boot prevents them from starting.

21.3. UEFI SECURE BOOT SUPPORT

You can install and run RHEL 9 on systems with enabled UEFI Secure Boot if the kernel and all the loaded drivers are signed with a trusted key. Red Hat provides kernels and drivers that are signed and authenticated by the relevant Red Hat keys.

If you want to load externally built kernels or drivers, you must sign them as well.

Restrictions imposed by UEFI Secure Boot

- The system only runs the kernel-mode code after its signature has been properly authenticated.
- GRUB module loading is disabled because there is no infrastructure for signing and verification of GRUB modules. Allowing module loading would run untrusted code within the security perimeter defined by Secure Boot.
- Red Hat provides a signed GRUB binary that has all supported modules on RHEL 9.

Additional resources

- Restrictions Imposed by UEFI Secure Boot

21.4. REQUIREMENTS FOR AUTHENTICATING KERNEL MODULES WITH X.509 KEYS

In RHEL 9, when a kernel module is loaded, the kernel checks the signature of the module against the public X.509 keys from the kernel system keyring (**.builtin_trusted_keys**) and the kernel platform keyring (**.platform**). The **.platform** keyring provides keys from third-party platform providers and custom public keys. The keys from the kernel system **.blacklist** keyring are excluded from verification.

You need to meet certain conditions to load kernel modules on systems with enabled UEFI Secure Boot functionality:

- If UEFI Secure Boot is enabled or if the **module.sig_enforce** kernel parameter has been specified:
  - You can only load those signed kernel modules whose signatures were authenticated against keys from the system keyring (**.builtin_trusted_keys**) and the platform keyring (**.platform**).
  - The public key must not be on the system revoked keys keyring (**.blacklist**).
- If UEFI Secure Boot is disabled and the **module.sig_enforce** kernel parameter has not been specified:
  - You can load unsigned kernel modules and signed kernel modules without a public key.
- If the system is not UEFI-based or if UEFI Secure Boot is disabled:
  - Only the keys embedded in the kernel are loaded onto **.builtin_trusted_keys** and **.platform**.
  - You have no ability to augment that set of keys without rebuilding the kernel.

Table 21.2. Kernel module authentication requirements for loading

Module signed	Public key found and signature valid	UEFI Secure Boot state	sig_enforce	Module load	Kernel tainted
Unsigned	-	Not enabled	Not enabled	Succeeds	Yes
		Not enabled	Enabled	Fails	-
		Enabled	-	Fails	-
Signed	No	Not enabled	Not enabled	Succeeds	Yes
		Not enabled	Enabled	Fails	-
		Enabled	-	Fails	-
Signed	Yes	Not enabled	Not enabled	Succeeds	No
		Not enabled	Enabled	Succeeds	No
		Enabled	-	Succeeds	No

21.5. SOURCES FOR PUBLIC KEYS

During boot, the kernel loads X.509 keys from a set of persistent key stores into the following keyrings:

- The system keyring (**.builtin_trusted_keys**)
- The **.platform** keyring
- The system **.blacklist** keyring

Table 21.3. Sources for system keyrings

Source of X.509 keys	User can add keys	UEFI Secure Boot state	Keys loaded during boot
Embedded in kernel	No	-	**.builtin_trusted_keys**
UEFI **db**	Limited	Not enabled	No
		Enabled	**.platform**
Embedded in the **shim** boot loader	No	Not enabled	No
		Enabled	**.platform**

Source of X.509 keys	User can add keys	UEFI Secure Boot state	Keys loaded during boot
Machine Owner Key (MOK) list	Yes	Not enabled	No
		Enabled	**.platform**

.builtin_trusted_keys

- A keyring that is built on boot.
- Provides trusted public keys.
- **root** privileges are required to view the keys.

.platform

- A keyring that is built on boot.
- Provides keys from third-party platform providers and custom public keys.
- **root** privileges are required to view the keys.

.blacklist

- A keyring with X.509 keys which have been revoked.
- A module signed by a key from **.blacklist** will fail authentication even if your public key is in **.builtin_trusted_keys**.

UEFI Secure Boot**db**

- A signature database.
- Stores keys (hashes) of UEFI applications, UEFI drivers, and boot loaders.
- The keys can be loaded on the machine.

UEFI Secure Boot**dbx**

- A revoked signature database.
- Prevents keys from getting loaded.
- The revoked keys from this database are added to the **.blacklist** keyring.

21.6. GENERATING A PUBLIC AND PRIVATE KEY PAIR

To use a custom kernel or custom kernel modules on a Secure Boot-enabled system, you must generate a public and private X.509 key pair. You can use the generated private key to sign the kernel or the kernel modules. You can also validate the signed kernel or kernel modules by adding the corresponding public key to the Machine Owner Key (MOK) for Secure Boot.

> **WARNING**
>
> Apply strong security measures and access policies to guard the contents of your private key. In the wrong hands, the key could be used to compromise any system which is authenticated by the corresponding public key.

Procedure

- Create an X.509 public and private key pair:
  - If you only want to sign custom kernel *modules*:

    ```
    # efikeygen --dbdir /etc/pki/pesign \
             --self-sign \
             --module \
             --common-name 'CN=Organization signing key' \
             --nickname 'Custom Secure Boot key'
    ```

  - If you want to sign custom *kernel*:

    ```
    # efikeygen --dbdir /etc/pki/pesign \
             --self-sign \
             --kernel \
             --common-name 'CN=Organization signing key' \
             --nickname 'Custom Secure Boot key'
    ```

  - When the RHEL system is running FIPS mode:

    ```
    # efikeygen --dbdir /etc/pki/pesign \
             --self-sign \
             --kernel \
             --common-name 'CN=Organization signing key' \
             --nickname 'Custom Secure Boot key'
             --token 'NSS FIPS 140-2 Certificate DB'
    ```

    > **NOTE**
    >
    > In FIPS mode, you must use the **--token** option so that **efikeygen** finds the default "NSS Certificate DB" token in the PKI database.

    The public and private keys are now stored in the **/etc/pki/pesign/** directory.

> **IMPORTANT**
>
> It is a good security practice to sign the kernel and the kernel modules within the validity period of its signing key. However, the **sign-file** utility does not warn you and the key will be usable in RHEL 9 regardless of the validity dates.

Additional resources

- **openssl(1)** manual page
- Enrolling public key on target system by adding the public key to the MOK list

21.7. EXAMPLE OUTPUT OF SYSTEM KEYRINGS

You can display information about the keys on the system keyrings using the **keyctl** utility from the **keyutils** package.

Prerequisites

- You have root permissions.
- You have installed the **keyctl** utility from the **keyutils** package.

Example 21.1. Keyrings output

The following is a shortened example output of **.builtin_trusted_keys**, **.platform**, and **.blacklist** keyrings from a RHEL 9 system where UEFI Secure Boot is enabled.

```
# keyctl list %:.builtin_trusted_keys
6 keys in keyring:
...asymmetric: Red Hat Enterprise Linux Driver Update Program (key 3): bf57f3e87...
...asymmetric: Red Hat Secure Boot (CA key 1): 4016841644ce3a810408050766e8f8a29...
...asymmetric: Microsoft Corporation UEFI CA 2011: 13adbf4309bd82709c8cd54f316ed...
...asymmetric: Microsoft Windows Production PCA 2011: a92902398e16c49778cd90f99e...
...asymmetric: Red Hat Enterprise Linux kernel signing key: 4249689eefc77e95880b...
...asymmetric: Red Hat Enterprise Linux kpatch signing key: 4d38fd864ebe18c5f0b7...

# keyctl list %:.platform
4 keys in keyring:
...asymmetric: VMware, Inc.: 4ad8da0472073...
...asymmetric: Red Hat Secure Boot CA 5: cc6fafe72...
...asymmetric: Microsoft Windows Production PCA 2011: a929f298e1...
...asymmetric: Microsoft Corporation UEFI CA 2011: 13adbf4e0bd82...

# keyctl list %:.blacklist
4 keys in keyring:
...blacklist: bin:f5ff83a...
...blacklist: bin:0dfdbec...
...blacklist: bin:38f1d22...
...blacklist: bin:51f831f...
```

The **.builtin_trusted_keys** keyring in the example shows the addition of two keys from the UEFI Secure Boot **db** keys as well as the **Red Hat Secure Boot (CA key 1)**, which is embedded in the **shim** boot loader.

Example 21.2. Kernel console output

The following example shows the kernel console output. The messages identify the keys with an UEFI Secure Boot related source. These include UEFI Secure Boot **db**, embedded **shim**, and MOK list.

```
# dmesg | egrep 'integrity.*cert'
[1.512966] integrity: Loading X.509 certificate: UEFI:db
[1.513027] integrity: Loaded X.509 cert 'Microsoft Windows Production PCA 2011: a929023...
[1.513028] integrity: Loading X.509 certificate: UEFI:db
[1.513057] integrity: Loaded X.509 cert 'Microsoft Corporation UEFI CA 2011: 13adbf4309...
[1.513298] integrity: Loading X.509 certificate: UEFI:MokListRT (MOKvar table)
[1.513549] integrity: Loaded X.509 cert 'Red Hat Secure Boot CA 5: cc6fa5e72868ba494e93...
```

Additional resources

- **keyctl(1)**, **dmesg(1)** manual pages

21.8. ENROLLING PUBLIC KEY ON TARGET SYSTEM BY ADDING THE PUBLIC KEY TO THE MOK LIST

You must authenticate your public key on a system for kernel or kernel module access and enroll it in the platform keyring (**.platform**) of the target system. When RHEL 9 boots on a UEFI-based system with Secure Boot enabled, the kernel imports public keys from the **db** key database and excludes revoked keys from the **dbx** database.

The Machine Owner Key (MOK) facility allows expanding the UEFI Secure Boot key database. When booting RHEL 9 on UEFI-enabled systems with Secure Boot enabled, keys on the MOK list are added to the platform keyring (**.platform**), along with the keys from the Secure Boot database. The list of MOK keys is stored securely and persistently in the same way, but it is a separate facility from the Secure Boot databases.

The MOK facility is supported by **shim**, **MokManager**, **GRUB**, and the **mokutil** utility that enables secure key management and authentication for UEFI-based systems.

> **NOTE**
>
> To get the authentication service of your kernel module on your systems, consider requesting your system vendor to incorporate your public key into the UEFI Secure Boot key database in their factory firmware image.

Prerequisites

- You have generated a public and private key pair and know the validity dates of your public keys. For details, see Generating a public and private key pair .

Procedure

1. Export your public key to the **sb_cert.cer** file:

```
# certutil -d /etc/pki/pesign \
        -n 'Custom Secure Boot key' \
        -Lr \
        > sb_cert.cer
```

2. Import your public key into the MOK list:

```
# mokutil --import sb_cert.cer
```

3. Enter a new password for this MOK enrollment request.

4. Reboot the machine.
   The **shim** boot loader notices the pending MOK key enrollment request and it launches **MokManager.efi** to enable you to complete the enrollment from the UEFI console.

5. Choose **Enroll MOK**, enter the password you previously associated with this request when prompted, and confirm the enrollment.
   Your public key is added to the MOK list, which is persistent.

   Once a key is on the MOK list, it will be automatically propagated to the **.platform** keyring on this and subsequent boots when UEFI Secure Boot is enabled.

21.9. SIGNING A KERNEL WITH THE PRIVATE KEY

You can obtain enhanced security benefits on your system by loading a signed kernel if the UEFI Secure Boot mechanism is enabled.

Prerequisites

- You have generated a public and private key pair and know the validity dates of your public keys. For details, see Generating a public and private key pair .
- You have enrolled your public key on the target system. For details, see Enrolling public key on target system by adding the public key to the MOK list.
- You have a kernel image in the ELF format available for signing.

Procedure

- On the x64 architecture:

  a. Create a signed image:

  ```
  # pesign --certificate 'Custom Secure Boot key' \
          --in vmlinuz-version \
          --sign \
          --out vmlinuz-version.signed
  ```

  Replace ***version*** with the version suffix of your **vmlinuz** file, and ***Custom Secure Boot key*** with the name that you chose earlier.

  b. Optional: Check the signatures:

  ```
  # pesign --show-signature \
          --in vmlinuz-version.signed
  ```

  c. Overwrite the unsigned image with the signed image:

  ```
  # mv vmlinuz-version.signed vmlinuz-version
  ```

- On the 64-bit ARM architecture:

  a. Decompress the **vmlinuz** file:

```
# zcat vmlinuz-version > vmlinux-version
```

b. Create a signed image:

```
# pesign --certificate 'Custom Secure Boot key' \
        --in vmlinux-version \
        --sign \
        --out vmlinux-version.signed
```

c. Optional: Check the signatures:

```
# pesign --show-signature \
        --in vmlinux-version.signed
```

d. Compress the **vmlinux** file:

```
# gzip --to-stdout vmlinux-version.signed > vmlinuz-version
```

e. Remove the uncompressed **vmlinux** file:

```
# rm vmlinux-version*
```

21.10. SIGNING A GRUB BUILD WITH THE PRIVATE KEY

On a system where the UEFI Secure Boot mechanism is enabled, you can sign a GRUB build with a custom existing private key. You must do this if you are using a custom GRUB build, or if you have removed the Microsoft trust anchor from your system.

Prerequisites

- You have generated a public and private key pair and know the validity dates of your public keys. For details, see Generating a public and private key pair .
- You have enrolled your public key on the target system. For details, see Enrolling public key on target system by adding the public key to the MOK list.
- You have a GRUB EFI binary available for signing.

Procedure

- On the x64 architecture:

a. Create a signed GRUB EFI binary:

```
# pesign --in /boot/efi/EFI/redhat/grubx64.efi \
        --out /boot/efi/EFI/redhat/grubx64.efi.signed \
        --certificate 'Custom Secure Boot key' \
        --sign
```

Replace ***Custom Secure Boot key*** with the name that you chose earlier.

b. Optional: Check the signatures:

```
# pesign --in /boot/efi/EFI/redhat/grubx64.efi.signed \
      --show-signature
```

c. Overwrite the unsigned binary with the signed binary:

```
# mv /boot/efi/EFI/redhat/grubx64.efi.signed \
   /boot/efi/EFI/redhat/grubx64.efi
```

- On the 64-bit ARM architecture:

  a. Create a signed GRUB EFI binary:

```
# pesign --in /boot/efi/EFI/redhat/grubaa64.efi \
      --out /boot/efi/EFI/redhat/grubaa64.efi.signed \
      --certificate 'Custom Secure Boot key' \
      --sign
```

  Replace ***Custom Secure Boot key*** with the name that you chose earlier.

  b. Optional: Check the signatures:

```
# pesign --in /boot/efi/EFI/redhat/grubaa64.efi.signed \
      --show-signature
```

  c. Overwrite the unsigned binary with the signed binary:

```
# mv /boot/efi/EFI/redhat/grubaa64.efi.signed \
   /boot/efi/EFI/redhat/grubaa64.efi
```

21.11. SIGNING KERNEL MODULES WITH THE PRIVATE KEY

You can enhance the security of your system by loading signed kernel modules if the UEFI Secure Boot mechanism is enabled.

Your signed kernel module is also loadable on systems where UEFI Secure Boot is disabled or on a non-UEFI system. As a result, you do not need to provide both, a signed and unsigned version of your kernel module.

Prerequisites

- You have generated a public and private key pair and know the validity dates of your public keys. For details, see Generating a public and private key pair .
- You have enrolled your public key on the target system. For details, see Enrolling public key on target system by adding the public key to the MOK list.
- You have a kernel module in ELF image format available for signing.

Procedure

1. Export your public key to the **sb_cert.cer** file:

```
# certutil -d /etc/pki/pesign \
```

```
        -n 'Custom Secure Boot key' \
        -Lr \
        > sb_cert.cer
```

2. Extract the key from the NSS database as a PKCS #12 file:

```
# pk12util -o sb_cert.p12 \
        -n 'Custom Secure Boot key' \
        -d /etc/pki/pesign
```

3. When the previous command prompts, enter a new password that encrypts the private key.

4. Export the unencrypted private key:

```
# openssl pkcs12 \
      -in sb_cert.p12 \
      -out sb_cert.priv \
      -nocerts \
      -noenc
```

> **IMPORTANT**
>
> Keep the unencrypted private key secure.

5. Sign your kernel module. The following command appends the signature directly to the ELF image in your kernel module file:

```
# /usr/src/kernels/$(uname -r)/scripts/sign-file \
       sha256 \
       sb_cert.priv \
       sb_cert.cer \
       my_module.ko
```

Your kernel module is now ready for loading.

> **IMPORTANT**
>
> In RHEL 9, the validity dates of the key pair matter. The key does not expire, but the kernel module must be signed within the validity period of its signing key. The **sign-file** utility will not warn you of this. For example, a key that is only valid in 2021 can be used to authenticate a kernel module signed in 2021 with that key. However, users cannot use that key to sign a kernel module in 2022.

Verification

1. Display information about the kernel module's signature:

```
# modinfo my_module.ko | grep signer
  signer:        Your Name Key
```

Check that the signature lists your name as entered during generation.

> **NOTE**
>
> The appended signature is not contained in an ELF image section and is not a formal part of the ELF image. Therefore, utilities such as **readelf** cannot display the signature on your kernel module.

2. Load the module:

```
# insmod my_module.ko
```

3. Remove (unload) the module:

```
# modprobe -r my_module.ko
```

Additional resources

- Displaying information about kernel modules

21.12. LOADING SIGNED KERNEL MODULES

After enrolling your public key in the system keyring (**.builtin_trusted_keys**) and the MOK list, and signing kernel modules with your private key, you can load them using the **modprobe** command.

Prerequisites

- You have generated the public and private key pair. For details, see Generating a public and private key pair.
- You have enrolled the public key into the system keyring. For details, see Enrolling public key on target system by adding the public key to the MOK list.
- You have signed a kernel module with the private key. For details, see Signing kernel modules with the private key.
- Install the **kernel-modules-extra** package, which creates the **/lib/modules/$(uname -r)/extra/** directory:

```
# dnf -y install kernel-modules-extra
```

Procedure

1. Verify that your public keys are on the system keyring:

```
# keyctl list %:.platform
```

2. Copy the kernel module into the **extra/** directory of the kernel that you want:

```
# cp my_module.ko /lib/modules/$(uname -r)/extra/
```

3. Update the modular dependency list:

```
# depmod -a
```

4. Load the kernel module:

```
# modprobe -v my_module
```

5. Optional: To load the module on boot, add it to the **/etc/modules-loaded.d/*my_module*.conf** file:

```
# echo "my_module" > /etc/modules-load.d/my_module.conf
```

Verification

- Verify that the module was successfully loaded:

```
# lsmod | grep my_module
```

Additional resources

- Managing kernel modules

CHAPTER 22. UPDATING THE SECURE BOOT REVOCATION LIST

You can update the UEFI Secure Boot Revocation List on your system so that Secure Boot identifies software with known security issues and prevents it from compromising your boot process.

22.1. THE SECURE BOOT REVOCATION LIST

The UEFI Secure Boot Revocation List, or the Secure Boot Forbidden Signature Database (**dbx**), is a list that identifies software that Secure Boot no longer allows to run.

When a security issue or a stability problem is found in software that interfaces with Secure Boot, such as in the GRUB boot loader, the Revocation List stores its hash signature. Software with such a recognized signature cannot run during boot, and the system boot fails to prevent compromising the system.

For example, a certain version of GRUB might contain a security issue that allows an attacker to bypass the Secure Boot mechanism. When the issue is found, the Revocation List adds hash signatures of all GRUB versions that contain the issue. As a result, only secure GRUB versions can boot on the system.

The Revocation List requires regular updates to recognize newly found issues. When updating the Revocation List, make sure to use a safe update method that does not cause your currently installed system to no longer boot.

22.2. APPLYING AN ONLINE REVOCATION LIST UPDATE

You can update the Secure Boot Revocation List on your system so that Secure Boot prevents known security issues. This procedure is safe and ensures that the update does not prevent your system from booting.

Prerequisites

- Secure Boot is enabled on your system.
- Your system can access the internet for updates.

Procedure

1. Determine the current version of the Revocation List:

   ```
   # fwupdmgr get-devices
   ```

   See the **Current version** field under **UEFI dbx**.

2. Enable the LVFS Revocation List repository:

   ```
   # fwupdmgr enable-remote lvfs
   ```

3. Refresh the repository metadata:

   ```
   # fwupdmgr refresh
   ```

4. Apply the Revocation List update:

- On the command line:

```
# fwupdmgr update
```

- In the graphical interface:

    i. Open the **Software** application

    ii. Navigate to the **Updates** tab.

    iii. Find the **Secure Boot dbx Configuration Update**entry.

    iv. Click **Update**.

5. At the end of the update, **fwupdmgr** or **Software** asks you to reboot the system. Confirm the reboot.

Verification

- After the reboot, check the current version of the Revocation List again:

```
# fwupdmgr get-devices
```

22.3. APPLYING AN OFFLINE REVOCATION LIST UPDATE

On a system with no internet connection, you can update the Secure Boot Revocation List from RHEL so that Secure Boot prevents known security issues. This procedure is safe and ensures that the update does not prevent your system from booting.

Procedure

1. Determine the current version of the Revocation List:

```
# fwupdmgr get-devices
```

   See the **Current version** field under **UEFI dbx**.

2. List the updates available from RHEL:

```
# ls /usr/share/dbxtool/
```

3. Select the most recent update file for your architecture. The file names use the following format:

```
DBXUpdate-date-architecture.cab
```

4. Install the selected update file:

```
# fwupdmgr install /usr/share/dbxtool/DBXUpdate-date-architecture.cab
```

5. At the end of the update, **fwupdmgr** asks you to reboot the system. Confirm the reboot.

Verification

- After the reboot, check the current version of the Revocation List again:

```
# fwupdmgr get-devices
```

CHAPTER 23. ENHANCING SECURITY WITH THE KERNEL INTEGRITY SUBSYSTEM

You can improve the protection of your system by using components of the kernel integrity subsystem. Learn more about the relevant components and their configuration.

> **NOTE**
>
> Red Hat products distributed through methods such as RPMs, ISOs, and zip files are signed with cryptographic signatures. The RHEL Kernel keyring system includes certificates for Red Hat product signing keys only. Therefore, to ensure kernels are tamper-proof, you must not use other hash features.

23.1. THE KERNEL INTEGRITY SUBSYSTEM

The integrity subsystem is the kernel component that maintains the overall integrity of system data. This subsystem helps in maintaining the system in the same state from the time it was built. Using this subsystem, you can protect executable files, libraries, and configuration files.

The kernel integrity subsystem consists of two major components:

Integrity Measurement Architecture (IMA)

- IMA measures file content whenever it is executed or accessed by cryptographically hashing or signing with cryptographic keys. The keys are stored in the kernel keyring subsystem.
- IMA places the measured values within the kernel's memory space. This prevents users of the system from modifying the measured values.
- IMA allows local and remote parties to verify the measured values.
- IMA provides local validation of the current content of files against the values previously stored in the measurement list within the kernel memory. This extension forbids performing any operation on a specific file in case the current and the previous measures do not match.

Extended Verification Module (EVM)

- EVM protects extended attributes of files (also known as *xattr*) related to system security, such as IMA measurements and SELinux attributes. EVM cryptographically hashes their corresponding values or signs them with cryptographic keys. The keys are stored in the kernel keyring subsystem.

The kernel integrity subsystem can use the Trusted Platform Module (TPM) to further harden system security.

A TPM is a hardware, firmware, or virtual component with integrated cryptographic keys that are built according to the TPM specification by the Trusted Computing Group (TCG) for important cryptographic functions. By providing cryptographic functions from a protected and tamper-proof area of the hardware chip, TPMs are protected from software-based attacks. TPMs provide the following features:

- Random-number generator
- Generator and secure storage for cryptographic keys

- Hashing generator
- Remote attestation

Additional resources

- Security hardening
- Basic and advanced configuration of Security-Enhanced Linux (SELinux)

23.2. TRUSTED AND ENCRYPTED KEYS

Trusted keys and *encrypted keys* are an important part of enhancing system security.

Trusted and encrypted keys are variable-length symmetric keys generated by the kernel that use the kernel keyring service. You can verify the integrity of the keys, for example, to allow the extended verification module (EVM) to verify and confirm the integrity of a running system. User-level programs can only access the keys in the form of encrypted *blobs*.

Trusted keys

Trusted keys need the Trusted Platform Module (TPM) chip, which is used to both create and encrypt (seal) the keys. Each TPM has a master wrapping key, called the storage root key, which is stored within the TPM itself.

> **NOTE**
>
> RHEL 9 supports only TPM 2.0. If you must use TPM 1.2, use RHEL 8. For more information, see the Red Hat Knowledgebase solution Is Trusted Platform Module (TPM) supported by Red Hat?.

You can verify the status of TPM 2.0 chip:

```
$ cat /sys/class/tpm/tpm0/tpm_version_major
2
```

You can also enable a TPM 2.0 chip and manage the TPM 2.0 device through settings in the machine firmware.

In addition to that, you can seal the trusted keys with a specific set of the TPM's *platform configuration register* (PCR) values. PCR contains a set of integrity-management values that reflect the firmware, boot loader, and operating system. PCR-sealed keys can only be decrypted by the TPM on the system where they were encrypted. However, when you load a PCR-sealed trusted key to a keyring, its associated PCR values are verified. After verification, you can update the key with new or future PCR values, for example, to support booting a new kernel. Also, you can save a single key as multiple blobs, each with a different PCR value.

Encrypted keys

Encrypted keys do not require a TPM, because they use the kernel Advanced Encryption Standard (AES), which makes them faster than trusted keys. Encrypted keys are created using kernel-generated random numbers and encrypted by a *master key* when they are exported into user-space blobs.

The master key is either a trusted key or a user key. If the master key is not trusted, the security of the encrypted key depends on the user key that was used to encrypt it.

23.3. WORKING WITH TRUSTED KEYS

You can improve system security by using the **keyctl** utility to create, export, load and update trusted keys.

Prerequisites

- Trusted Platform Module (TPM) is enabled and active. See The kernel integrity subsystem and Trusted and encrypted keys.
  You can verify that your system has a TPM by entering the **tpm2_pcrread** command. If the output from this command displays several hashes, you have a TPM.

Procedure

1. Create a 2048-bit RSA key with an SHA-256 primary storage key with a persistent handle of, for example, *81000001*, by using one of the following utilities:

   a. By using the **tss2** package:

   ```
   # TPM_DEVICE=/dev/tpm0 tsscreateprimary -hi o -st
   Handle 80000000
   # TPM_DEVICE=/dev/tpm0 tssevictcontrol -hi o -ho 80000000 -hp 81000001
   ```

   b. By using the **tpm2-tools** package:

   ```
   # tpm2_createprimary --key-algorithm=rsa2048 --key-context=key.ctxt
   name-alg:
     value: sha256
     raw: 0xb
   …
   sym-keybits: 128
   rsa: xxxxxx…

   # tpm2_evictcontrol -c key.ctxt 0x81000001
   persistentHandle: 0x81000001
   action: persisted
   ```

2. Create a trusted key by using a TPM 2.0 with the syntax of **keyctl add trusted *<NAME>* "new *<KEY_LENGTH>* keyhandle=*<PERSISTENT-HANDLE>* [options]" *<KEYRING>***. In this example, the persistent handle is *81000001*.

   ```
   # keyctl add trusted kmk "new 32 keyhandle=0x81000001" @u
   642500861
   ```

   The command creates a trusted key called **kmk** with the length of **32** bytes (256 bits) and places it in the user keyring (**@u**). The keys may have a length of 32 to 128 bytes (256 to 1024 bits).

3. List the current structure of the kernel keyrings:

   ```
   # keyctl show
   Session Keyring
          -3 --alswrv    500   500  keyring: ses 97833714 --alswrv 500 -1 \ keyring: uid.1000
   642500861 --alswrv 500 500 \ trusted: kmk
   ```

4. Export the key to a user-space blob by using the serial number of the trusted key:

   ```
   # keyctl pipe 642500861 > kmk.blob
   ```

   The command uses the **pipe** subcommand and the serial number of **kmk**.

5. Load the trusted key from the user-space blob:

   ```
   # keyctl add trusted kmk "load `cat kmk.blob`" @u
   268728824
   ```

6. Create secure encrypted keys that use the TPM-sealed trusted key (**kmk**). Follow this syntax: *keyctl add encrypted <NAME> "new [FORMAT] <KEY_TYPE>:<PRIMARY_KEY_NAME> <KEY_LENGTH>" <KEYRING>*:

   ```
   # keyctl add encrypted encr-key "new trusted:kmk 32" @u
   159771175
   ```

Additional resources

- the **keyctl(1)** manual page

23.4. WORKING WITH ENCRYPTED KEYS

You can improve system security on systems where a Trusted Platform Module (TPM) is not available by managing encrypted keys.

Encrypted keys, unless sealed by a trusted primary key, inherit the security level of the user primary key (random-number key) used for encryption. Therefore, it is highly recommended to load the primary user key securely, ideally early in the boot process.

Procedure

1. Generate a user key by using a random sequence of numbers:

   ```
   # keyctl add user kmk-user "$(dd if=/dev/urandom bs=1 count=32 2>/dev/null)" @u
   427069434
   ```

   The command generates a user key called **kmk-user** which acts as a *primary key* and is used to seal the actual encrypted keys.

2. Generate an encrypted key using the primary key from the previous step:

   ```
   # keyctl add encrypted encr-key "new user:kmk-user 32" @u
   1012412758
   ```

Verification

1. List all keys in the specified user keyring:

   ```
   # keyctl list @u
   2 keys in keyring:
   427069434: --alswrv  1000  1000 user: kmk-user
   ```

```
1012412758: --alswrv  1000  1000 encrypted: encr-key
```

Additional resources

- The **keyctl(1)** manual page

23.5. ENABLING IMA AND EVM

You can enable and configure Integrity measurement architecture (IMA) and extended verification module (EVM) to improve the security of the operating system.

> **IMPORTANT**
>
> Always enable EVM together with IMA.
>
> Although you can enable EVM alone, EVM appraisal is only triggered by an IMA appraisal rule. Therefore, EVM does not protect file metadata such as SELinux attributes. If file metadata is tampered with offline, EVM can only prevent file metadata changes. It does not prevent file access, such as executing the file.

Prerequisites

- Secure Boot is temporarily disabled.

  > **NOTE**
  >
  > When Secure Boot is enabled, the **ima_appraise=fix** kernel command-line parameter does not work.

- The **securityfs** file system is mounted on the **/sys/kernel/security/** directory and the **/sys/kernel/security/integrity/ima/** directory exists. You can verify where **securityfs** is mounted by using the **mount** command:

  ```
  # mount
  ...
  securityfs on /sys/kernel/security type securityfs (rw,nosuid,nodev,noexec,relatime)
  ...
  ```

- The **systemd** service manager is patched to support IMA and EVM on boot time. Verify by using the following command:

  ```
  # grep <options> pattern <files>
  ```

  For example:

  ```
  # dmesg | grep -i -e EVM -e IMA -w
  [ 0.943873] ima: No TPM chip found, activating TPM-bypass!
  [ 0.944566] ima: Allocated hash algorithm: sha256
  [ 0.944579] ima: No architecture policies found
  [ 0.944601] evm: Initialising EVM extended attributes:
  [ 0.944602] evm: security.selinux
  [ 0.944604] evm: security.SMACK64 (disabled)
  [ 0.944605] evm: security.SMACK64EXEC (disabled)
  ```

```
[ 0.944607] evm: security.SMACK64TRANSMUTE (disabled)
[ 0.944608] evm: security.SMACK64MMAP (disabled)
[ 0.944609] evm: security.apparmor (disabled)
[ 0.944611] evm: security.ima
[ 0.944612] evm: security.capability
[ 0.944613] evm: HMAC attrs: 0x1
[ 1.314520] systemd[1]: systemd 252-18.el9 running in system mode (+PAM +AUDIT
+SELINUX -APPARMOR +IMA +SMACK +SECCOMP +GCRYPT +GNUTLS +OPENSSL
+ACL +BLKID +CURL +ELFUTILS -FIDO2 +IDN2 -IDN -IPTC +KMOD +LIBCRYPTSETUP
+LIBFDISK +PCRE2 -PWQUALITY +P11KIT -QRENCODE +TPM2 +BZIP2 +LZ4 +XZ
+ZLIB +ZSTD -BPF_FRAMEWORK +XKBCOMMON +UTMP +SYSVINIT default-
hierarchy=unified)
[ 1.717675] device-mapper: core: CONFIG_IMA_DISABLE_HTABLE is disabled. Duplicate
IMA measurements will not be recorded in the IMA log.
[ 4.799436] systemd[1]: systemd 252-18.el9 running in system mode (+PAM +AUDIT
+SELINUX -APPARMOR +IMA +SMACK +SECCOMP +GCRYPT +GNUTLS +OPENSSL
+ACL +BLKID +CURL +ELFUTILS -FIDO2 +IDN2 -IDN -IPTC +KMOD +LIBCRYPTSETUP
+LIBFDISK +PCRE2 -PWQUALITY +P11KIT -QRENCODE +TPM2 +BZIP2 +LZ4 +XZ
+ZLIB +ZSTD -BPF_FRAMEWORK +XKBCOMMON +UTMP +SYSVINIT default-
hierarchy=unified)
```

Procedure

1. Enable IMA and EVM in the *fix* mode for the current boot entry and allow users to gather and update the IMA measurements by adding the following kernel command-line parameters:

   ```
   # grubby --update-kernel=/boot/vmlinuz-$(uname -r) --args="ima_policy=appraise_tcb
   ima_appraise=fix evm=fix"
   ```

   The command enables IMA and EVM in the *fix* mode for the current boot entry to gather and update the IMA measurements.

   The **ima_policy=appraise_tcb** kernel command-line parameter ensures that the kernel uses the default Trusted Computing Base (TCB) measurement policy and the appraisal step. The appraisal step forbids access to files whose prior and current measures do not match.

2. Reboot to make the changes come into effect.

3. Optional: Verify the parameters added to the kernel command line:

   ```
   # cat /proc/cmdline
   BOOT_IMAGE=(hd0,msdos1)/vmlinuz-5.14.0-1.el9.x86_64 root=/dev/mapper/rhel-root ro
   crashkernel=1G-4G:192M,4G-64G:256M,64G-:512M resume=/dev/mapper/rhel-swap
   rd.lvm.lv=rhel/root rd.lvm.lv=rhel/swap rhgb quiet ima_policy=appraise_tcb ima_appraise=fix
   evm=fix
   ```

4. Create a kernel master key to protect the EVM key:

   ```
   # keyctl add user kmk "$(dd if=/dev/urandom bs=1 count=32 2> /dev/null)" @u
   748544121
   ```

   The **kmk** is kept entirely in the kernel space memory. The 32-byte long value of the **kmk** is generated from random bytes from the **/dev/urandom** file and placed in the user (**@u**) keyring. The key serial number is on the first line of the previous output.

5. Create an encrypted EVM key based on the **kmk**:

```
# keyctl add encrypted evm-key "new user:kmk 64" @u
641780271
```

The command uses the **kmk** to generate and encrypt a 64-byte long user key (named **evm-key**) and places it in the user (**@u**) keyring. The key serial number is on the first line of the previous output.

> **IMPORTANT**
>
> It is necessary to name the user key as **evm-key** because that is the name the EVM subsystem is expecting and is working with.

6. Create a directory for exported keys.

```
# mkdir -p /etc/keys/
```

7. Search for the **kmk** and export its unencrypted value into the new directory.

```
# keyctl pipe $(keyctl search @u user kmk) > /etc/keys/kmk
```

8. Search for the **evm-key** and export its encrypted value into the new directory.

```
# keyctl pipe $(keyctl search @u encrypted evm-key) > /etc/keys/evm-key
```

The **evm-key** has been encrypted by the kernel master key earlier.

9. Optional: View the newly created keys:

```
# keyctl show
Session Keyring
974575405   --alswrv     0       0      keyring: ses 299489774 --alswrv 0 65534 \ keyring: uid.0
748544121 --alswrv 0 0 \ user: kmk
641780271   --alswrv     0       0          \_ encrypted: evm-key

# ls -l /etc/keys/
total 8
-rw-r--r--. 1 root root 246 Jun 24 12:44 evm-key
-rw-r--r--. 1 root root  32 Jun 24 12:43 kmk
```

10. Optional: If the keys are removed from the keyring, for example after system reboot, you can import the already exported **kmk** and **evm-key** instead of creating new ones.

    a. Import the **kmk**.

    ```
    # keyctl add user kmk "$(cat /etc/keys/kmk)" @u
    451342217
    ```

    b. Import the **evm-key**.

    ```
    # keyctl add encrypted evm-key "load $(cat /etc/keys/evm-key)" @u
    924537557
    ```

11. Activate EVM.

```
# echo 1 > /sys/kernel/security/evm
```

12. Relabel the whole system.

```
# find / -fstype xfs -type f -uid 0 -exec head -n 1 '{}' >/dev/null \;
```

> **WARNING**
>
> Enabling IMA and EVM without relabeling the system might make the majority of the files on the system inaccessible.

Verification

- Verify that EVM has been initialized:

```
# dmesg | tail -1
[…] evm: key initialized
```

23.6. COLLECTING FILE HASHES WITH INTEGRITY MEASUREMENT ARCHITECTURE

In the *measurement* phase, you can create file hashes and store them as extended attributes (*xattrs*) of those files. With the file hashes, you can generate either an RSA-based digital signature or a Hash-based Message Authentication Code (HMAC-SHA1) and prevent offline tampering attacks on the extended attributes.

Prerequisites

- IMA and EVM are enabled. For more information, see Enabling integrity measurement architecture and extended verification module.
- A valid trusted key or encrypted key is stored in the kernel keyring.
- The **ima-evm-utils**, **attr**, and **keyutils** packages are installed.

Procedure

1. Create a test file:

```
# echo <Test_text> > test_file
```

IMA and EVM ensure that the **test_file** example file has assigned hash values that are stored as its extended attributes.

2. Inspect the file's extended attributes:

```
# getfattr -m . -d test_file
# file: test_file
security.evm=0sAnDIy4VPA0HArpPO/EqiutnNyBql
security.ima=0sAQOEDeuUnWzwwKYk+n66h/vby3eD
```

The example output shows extended attributes with the IMA and EVM hash values and SELinux context. EVM adds a **security.evm** extended attribute related to the other attributes. At this point, you can use the **evmctl** utility on **security.evm** to generate either an RSA-based digital signature or a Hash-based Message Authentication Code (HMAC-SHA1).

Additional resources

- Security hardening

23.7. ADDING IMA SIGNATURES TO PACKAGE FILES

To allow the kernel, Keylime, **fapolicyd**, and **debuginfo** packages to perform their integrity checks, you need to add IMA signatures to RPM files. After installing the **rpm-plugin-ima** plug-in, newly installed RPM files automatically have IMA signatures placed in the **security.ima** extended file attribute. However, you need to reinstall existing packages to obtain IMA signatures.

Procedure

1. Install the **rpm-plugin-ima** plug-in:

```
# dnf install rpm-plugin-ima -y
```

2. Reinstall all packages:

```
# dnf reinstall '*' -y
```

Verification

1. Confirm that the reinstalled package file has a valid IMA signature. For example, to check the IMA signature of the **/usr/bin/bash** file, run the following command:

```
# getfattr -m security.ima -d /usr/bin/bash
```

```
'security.ima=0sAwIE0zIESQBnMGUCMFhf0iBeM7NjjhCCHVt4/ORx1eCegjrWSHzFbJMCsAh
R9bYU2hNGjiWUYT2IlqWaaAIxALFGUkqGP5vDLuxQXibO9g7HFcfyZzRBY4rbKPsXcAIZRtD
HVS5dQBZqM3hyS5v1MA=='
```

2. Verify the IMA signature of a file with a specified certificate. For example, to check that the IMA signature of **/usr/bin/bash** is accessible by **/usr/share/doc/kernel-keys/$(uname -r)/ima.cer**, run the following command:".

```
# evmctl ima_verify -k /usr/share/doc/kernel-keys/$(uname -r)/ima.cer /usr/bin/bash
```

```
'key 1: d3320449 /usr/share/doc/kernel-keys/5.14.0-359.el9.x86-64/ima.cer
/usr/bin/bash:' verification is OK
```

23.8. ENABLING KERNEL RUNTIME INTEGRITY MONITORING

You can enable kernel runtime integrity monitoring that IMA appraisal provides.

Prerequisites

- The **kernel** installed on your system has version **5.14.0-359** or higher.
- The **dracut** package has version **057-43.git20230816** or higher.
- The **keyutils** package is installed.
- The **ima-evm-utils** package is installed.
- The files covered by the policy have valid signatures. For instructions, see Adding IMA signatures to package files.

Procedure

1. To copy the Red Hat IMA code signing key to the **/etc/ima/keys** file, run:

```
$ mkdir -p /etc/keys/ima
$ cp /usr/share/doc/kernel-keys/$(uname -r)/ima.cer /etc/ima/keys
```

2. To add the IMA code signing key to the **.ima** keyring, run:

```
# keyctl padd asymmetric RedHat-IMA %:.ima < /etc/ima/keys/ima.cer
```

3. Depending on your threat model, define an IMA policy in the **/etc/sysconfig/ima-policy** file. For example, the following IMA policy checks the integrity of both executables and involved memory mapping library files:

```
# PROC_SUPER_MAGIC = 0x9fa0
dont_appraise fsmagic=0x9fa0
# SYSFS_MAGIC = 0x62656572
dont_appraise fsmagic=0x62656572
# DEBUGFS_MAGIC = 0x64626720
dont_appraise fsmagic=0x64626720
# TMPFS_MAGIC = 0x01021994
dont_appraise fsmagic=0x1021994
# RAMFS_MAGIC
dont_appraise fsmagic=0x858458f6
# DEVPTS_SUPER_MAGIC=0x1cd1
dont_appraise fsmagic=0x1cd1
# BINFMTFS_MAGIC=0x42494e4d
dont_appraise fsmagic=0x42494e4d
# SECURITYFS_MAGIC=0x73636673
dont_appraise fsmagic=0x73636673
# SELINUX_MAGIC=0xf97cff8c
dont_appraise fsmagic=0xf97cff8c
# SMACK_MAGIC=0x43415d53
dont_appraise fsmagic=0x43415d53
# NSFS_MAGIC=0x6e736673
dont_appraise fsmagic=0x6e736673
# EFIVARFS_MAGIC
```

```
dont_appraise fsmagic=0xde5e81e4
# CGROUP_SUPER_MAGIC=0x27e0eb
dont_appraise fsmagic=0x27e0eb
# CGROUP2_SUPER_MAGIC=0x63677270
dont_appraise fsmagic=0x63677270
appraise func=BPRM_CHECK
appraise func=FILE_MMAP mask=MAY_EXEC
```

4. To load the IMA policy to make sure the kernel accepts this IMA policy, run:

```
# echo /etc/sysconfig/ima-policy > /sys/kernel/security/ima/policy
# echo $?
0
```

5. To enable the **dracut** integrity module to automatically load the IMA code signing key and the IMA policy, run:

```
# echo 'add_dracutmodules+=" integrity "' > /etc/dracut.conf.d/98-integrity.conf
# dracut -f
```

23.9. CREATING CUSTOM IMA KEYS USING OPENSSL

You can use **OpenSSL** to generate a CSR for your digital certificates to secure your code.

The kernel searches the **.ima** keyring for a code signing key to verify an IMA signature. Before you add a code signing key to the **.ima** keyring, you need to ensure that IMA CA key signed this key in the **.builtin_trusted_keys** or **.secondary_trusted_keys** keyrings.

Prerequisites

- The custom IMA CA key has the following extensions:
  - the basic constraints extension with the CA boolean asserted.
  - the **KeyUsage** extension with the **keyCertSign** bit asserted but **without** the **digitalSignature** asserted.
- The custom IMA code signing key falls under the following criteria:
  - The IMA CA key signed this custom IMA code signing key.
  - The custom key includes the **subjectKeyIdentifier** extension.

Procedure

1. To generate a custom IMA CA key pair, run:

```
# openssl req -new -x509 -utf8 -sha256 -days 3650 -batch -config ima_ca.conf -outform DER -out custom_ima_ca.der -keyout custom_ima_ca.priv
```

2. Optional: To check the content of the **ima_ca.conf** file, run:

```
# cat ima_ca.conf
[ req ]
```

```
default_bits = 2048
distinguished_name = req_distinguished_name
prompt = no
string_mask = utf8only
x509_extensions = ca

[ req_distinguished_name ]
O = YOUR_ORG
CN =  YOUR_COMMON_NAME IMA CA
emailAddress = YOUR_EMAIL

[ ca ]
basicConstraints=critical,CA:TRUE
subjectKeyIdentifier=hash
authorityKeyIdentifier=keyid:always,issuer
keyUsage=critical,keyCertSign,cRLSign
```

3. To generate a private key and a certificate signing request (CSR) for the IMA code signing key, run:

```
# openssl req -new -utf8 -sha256 -days 365 -batch -config ima.conf -out
custom_ima.csr -keyout custom_ima.priv
```

4. Optional: To check the content of the **ima.conf** file, run:

```
# cat ima.conf
[ req ]
default_bits = 2048
distinguished_name = req_distinguished_name
prompt = no
string_mask = utf8only
x509_extensions = code_signing

[ req_distinguished_name ]
O = YOUR_ORG
CN = YOUR_COMMON_NAME IMA signing key
emailAddress = YOUR_EMAIL

[ code_signing ]
basicConstraints=critical,CA:FALSE
keyUsage=digitalSignature
subjectKeyIdentifier=hash
authorityKeyIdentifier=keyid:always,issuer
```

5. Use the IMA CA private key to sign the CSR to create the IMA code signing certificate:

```
# openssl x509 -req -in custom_ima.csr -days 365 -extfile ima.conf -extensions
code_signing -CA custom_ima_ca.der -CAkey custom_ima_ca.priv -CAcreateserial -
outform DER -out ima.der
```

23.10. DEPLOYING A CUSTOM SIGNED IMA POLICY FOR UEFI SYSTEMS

In the Secure Boot environment, you may want to only load a signed IMA policy signed by your custom IMA key.

Prerequisites

- The MOK list contains the custom IMA key. For guidance, see Enrolling public key on target system by adding the public key to the MOK list.
- The kernel installed on your system has version 5.14.0-335 or higher.

Procedure

1. Enable Secure Boot.
2. Permanently add the **ima_policy=secure_boot** kernel parameter.
   For instructions, see Configuring kernel parameters permanently with sysctl .
3. Prepare your IMA policy by running the command:

```
# evmctl ima_sign /etc/sysconfig/ima-policy -k
<PATH_TO_YOUR_CUSTOM_IMA_KEY>
Place your public certificate under /etc/keys/ima/ and add it to the .ima keyring
```

4. Sign the policy with your custom IMA code signing key by running the command:

```
# keyctl padd asymmetric CUSTOM_IMA1 %:.ima < /etc/ima/keys/my_ima.cer
```

5. Load the IMA policy by running the command:

```
# echo /etc/sysconfig/ima-policy > /sys/kernel/security/ima/policy
# echo $?
0
```

CHAPTER 24. USING SYSTEMD TO MANAGE RESOURCES USED BY APPLICATIONS

RHEL 9 moves the resource management settings from the process level to the application level by binding the system of **cgroup** hierarchies with the **systemd** unit tree. Therefore, you can manage the system resources with the **systemctl** command, or by modifying the **systemd** unit files.

To achieve this, **systemd** takes various configuration options from the unit files or directly via the **systemctl** command. Then **systemd** applies those options to specific process groups by using the Linux kernel system calls and features like **cgroups** and **namespaces**.

NOTE

You can review the full set of configuration options for **systemd** in the following manual pages:

- **systemd.resource-control(5)**
- **systemd.exec(5)**

24.1. ROLE OF SYSTEMD IN RESOURCE MANAGEMENT

The core function of **systemd** is service management and supervision. The **systemd** system and service manager :

- ensures that managed services start at the right time and in the correct order during the boot process.
- ensures that managed services run smoothly to use the underlying hardware platform optimally.
- provides capabilities to define resource management policies.
- provides capabilities to tune various options, which can improve the performance of the service.

IMPORTANT

In general, Red Hat recommends you use **systemd** for controlling the usage of system resources. You should manually configure the **cgroups** virtual file system only in special cases. For example, when you need to use **cgroup-v1** controllers that have no equivalents in **cgroup-v2** hierarchy.

24.2. DISTRIBUTION MODELS OF SYSTEM SOURCES

To modify the distribution of system resources, you can apply one or more of the following distribution models:

Weights

You can distribute the resource by adding up the weights of all sub-groups and giving each sub-group the fraction matching its ratio against the sum.
For example, if you have 10 cgroups, each with weight of value 100, the sum is 1000. Each cgroup receives one tenth of the resource.

Weight is usually used to distribute stateless resources. For example the *CPUWeight=* option is an implementation of this resource distribution model.

Limits

A cgroup can consume up to the configured amount of the resource. The sum of sub-group limits can exceed the limit of the parent cgroup. Therefore it is possible to overcommit resources in this model.
For example the *MemoryMax=* option is an implementation of this resource distribution model.

Protections

You can set up a protected amount of a resource for a cgroup. If the resource usage is below the protection boundary, the kernel will try not to penalize this cgroup in favor of other cgroups that compete for the same resource. An overcommit is also possible.
For example the *MemoryLow=* option is an implementation of this resource distribution model.

Allocations

Exclusive allocations of an absolute amount of a finite resource. An overcommit is not possible. An example of this resource type in Linux is the real-time budget.

unit file option

A setting for resource control configuration.
For example, you can configure CPU resource with options like *CPUAccounting=*, or *CPUQuota=*. Similarly, you can configure memory or I/O resources with options like *AllowedMemoryNodes=* and *IOAccounting=*.

24.3. ALLOCATING SYSTEM RESOURCES USING SYSTEMD

Allocating system resources by using systemd involves creating, managing systemd services and units. This can be configured to start, stop, or restart at specific times or in response to certain system events.

Procedure

To change the required value of the unit file option of your service, you can adjust the value in the unit file, or use the **systemctl** command:

1. Check the assigned values for the service of your choice.

```
# systemctl show --property <unit file option> <service name>
```

2. Set the required value of the CPU time allocation policy option:

```
# systemctl set-property <service name> <unit file option>=<value>
```

Verification

- Check the newly assigned values for the service of your choice.

```
# systemctl show --property <unit file option> <service name>
```

Additional resources

- **systemd.resource-control(5)** and **systemd.exec(5)** man pages on your system

24.4. OVERVIEW OF SYSTEMD HIERARCHY FOR CGROUPS

On the backend, the **systemd** system and service manager uses the **slice**, the **scope**, and the **service** units to organize and structure processes in the control groups. You can further modify this hierarchy by creating custom unit files or using the **systemctl** command. Also, **systemd** automatically mounts hierarchies for important kernel resource controllers at the **/sys/fs/cgroup/** directory.

For resource control, you can use the following three **systemd** unit types:

Service

A process or a group of processes, which **systemd** started according to a unit configuration file. Services encapsulate the specified processes so that they can be started and stopped as one set. Services are named in the following way:

```
<name>.service
```

Scope

A group of externally created processes. Scopes encapsulate processes that are started and stopped by the arbitrary processes through the **fork()** function and then registered by **systemd** at runtime. For example, user sessions, containers, and virtual machines are treated as scopes. Scopes are named as follows:

```
<name>.scope
```

Slice

A group of hierarchically organized units. Slices organize a hierarchy in which scopes and services are placed.
The actual processes are contained in scopes or in services. Every name of a slice unit corresponds to the path to a location in the hierarchy.

The dash (**-**) character acts as a separator of the path components to a slice from the **-.slice** root slice. In the following example:

```
<parent-name>.slice
```

parent-name.slice is a sub-slice of **parent.slice**, which is a sub-slice of the **-.slice** root slice. **parent-name.slice** can have its own sub-slice named **parent-name-name2.slice**, and so on.

The **service**, the **scope**, and the **slice** units directly map to objects in the control group hierarchy. When these units are activated, they map directly to control group paths built from the unit names.

The following is an abbreviated example of a control group hierarchy:

```
Control group /:
-.slice
├─user.slice
│ ├─user-42.slice
│ │ ├─session-c1.scope
│ │ │ ├─ 967 gdm-session-worker [pam/gdm-launch-environment]
│ │ │ ├─1035 /usr/libexec/gdm-x-session gnome-session --autostart
/usr/share/gdm/greeter/autostart
│ │ │ ├─1054 /usr/libexec/Xorg vt1 -displayfd 3 -auth /run/user/42/gdm/Xauthority -background none
-noreset -keeptty -verbose 3
│ │ │ ├─1212 /usr/libexec/gnome-session-binary --autostart /usr/share/gdm/greeter/autostart
```

```
│ │ │ ├─1369 /usr/bin/gnome-shell
│ │ │ ├─1732 ibus-daemon --xim --panel disable
│ │ │ ├─1752 /usr/libexec/ibus-dconf
│ │ │ ├─1762 /usr/libexec/ibus-x11 --kill-daemon
│ │ │ ├─1912 /usr/libexec/gsd-xsettings
│ │ │ ├─1917 /usr/libexec/gsd-a11y-settings
│ │ │ ├─1920 /usr/libexec/gsd-clipboard
…
├─init.scope
│ └─1 /usr/lib/systemd/systemd --switched-root --system --deserialize 18
└─system.slice
  ├─rngd.service
  │ └─800 /sbin/rngd -f
  ├─systemd-udevd.service
  │ └─659 /usr/lib/systemd/systemd-udevd
  ├─chronyd.service
  │ └─823 /usr/sbin/chronyd
  ├─auditd.service
  │ ├─761 /sbin/auditd
  │ └─763 /usr/sbin/sedispatch
  ├─accounts-daemon.service
  │ └─876 /usr/libexec/accounts-daemon
  ├─example.service
  │ ├─ 929 /bin/bash /home/jdoe/example.sh
  │ └─4902 sleep 1
  …
```

The example above shows that services and scopes contain processes and are placed in slices that do not contain processes of their own.

Additional resources

- *Managing system services with systemctl* in Red Hat Enterprise Linux
- What are kernel resource controllers
- The **systemd.resource-control(5)**, **systemd.exec(5)**, **cgroups(7)**, **fork()**, **fork(2)** manual pages
- Understanding cgroups

24.5. LISTING SYSTEMD UNITS

Use the **systemd** system and service manager to list its units.

Procedure

- List all active units on the system with the **systemctl** utility. The terminal returns an output similar to the following example:

```
# systemctl
UNIT                       LOAD   ACTIVE SUB     DESCRIPTION
…
init.scope                 loaded active running System and Service Manager
session-2.scope            loaded active running Session 2 of user jdoe
abrt-ccpp.service          loaded active exited  Install ABRT coredump hook
```

```
abrt-oops.service                          loaded active running   ABRT kernel log watcher
abrt-vmcore.service                         loaded active exited    Harvest vmcores for ABRT
abrt-xorg.service                          loaded active running   ABRT Xorg log watcher
…
-.slice                              loaded active active    Root Slice
machine.slice                           loaded active active    Virtual Machine and Container
Slice system-getty.slice                                              loaded active active
system-getty.slice
system-lvm2\x2dpvscan.slice                    loaded active active    system-
lvm2\x2dpvscan.slice
system-sshd\x2dkeygen.slice                    loaded active active    system-
sshd\x2dkeygen.slice
system-systemd\x2dhibernate\x2dresume.slice         loaded active active    system-
systemd\x2dhibernate\x2dresume>
system-user\x2druntime\x2ddir.slice               loaded active active    system-
user\x2druntime\x2ddir.slice
system.slice                          loaded active active    System Slice
user-1000.slice                         loaded active active    User Slice of UID 1000
user-42.slice                          loaded active active    User Slice of UID 42
user.slice                           loaded active active    User and Session Slice
…
```

UNIT

A name of a unit that also reflects the unit position in a control group hierarchy. The units relevant for resource control are a *slice*, a *scope*, and a *service*.

LOAD

Indicates whether the unit configuration file was properly loaded. If the unit file failed to load, the field provides the state *error* instead of *loaded*. Other unit load states are: *stub*, *merged*, and *masked*.

ACTIVE

The high-level unit activation state, which is a generalization of **SUB**.

SUB

The low-level unit activation state. The range of possible values depends on the unit type.

DESCRIPTION

The description of the unit content and functionality.

- List all active and inactive units:

```
# systemctl --all
```

- Limit the amount of information in the output:

```
# systemctl --type service,masked
```

The **--type** option requires a comma-separated list of unit types such as a *service* and a *slice*, or unit load states such as *loaded* and *masked*.

Additional resources

- *Managing system services with systemctl* in RHEL
- The **systemd.resource-control(5)**, **systemd.exec(5)** manual pages

24.6. VIEWING SYSTEMD CGROUPS HIERARCHY

Display control groups (**cgroups**) hierarchy and processes running in specific **cgroups**.

Procedure

- Display the whole **cgroups** hierarchy on your system with the **systemd-cgls** command.

```
# systemd-cgls
Control group /:
-.slice
├─user.slice
│ ├─user-42.slice
│ │ ├─session-c1.scope
│ │ │ ├─ 965 gdm-session-worker [pam/gdm-launch-environment]
│ │ │ ├─1040 /usr/libexec/gdm-x-session gnome-session --autostart
/usr/share/gdm/greeter/autostart
…
├─init.scope
│ └─1 /usr/lib/systemd/systemd --switched-root --system --deserialize 18
└─system.slice
 …
 ├─example.service
 │ ├─6882 /bin/bash /home/jdoe/example.sh
 │ └─6902 sleep 1
 ├─systemd-journald.service
   └─629 /usr/lib/systemd/systemd-journald
 …
```

The example output returns the entire **cgroups** hierarchy, where the highest level is formed by *slices*.

- Display the **cgroups** hierarchy filtered by a resource controller with the **systemd-cgls *<resource_controller>*** command.

```
# systemd-cgls memory
Controller memory; Control group /:
├─1 /usr/lib/systemd/systemd --switched-root --system --deserialize 18
├─user.slice
│ ├─user-42.slice
│ │ ├─session-c1.scope
│ │ │ ├─ 965 gdm-session-worker [pam/gdm-launch-environment]
…
└─system.slice
 |
 …
 ├─chronyd.service
 │ └─844 /usr/sbin/chronyd
 ├─example.service
 │ ├─8914 /bin/bash /home/jdoe/example.sh
 │ └─8916 sleep 1
 …
```

The example output lists the services that interact with the selected controller.

- Display detailed information about a certain unit and its part of the **cgroups** hierarchy with the **systemctl status <*system_unit*>** command.

```
# systemctl status example.service
● example.service - My example service
  Loaded: loaded (/usr/lib/systemd/system/example.service; enabled; vendor preset:
disabled)
  Active: active (running) since Tue 2019-04-16 12:12:39 CEST; 3s ago
 Main PID: 17737 (bash)
   Tasks: 2 (limit: 11522)
  Memory: 496.0K (limit: 1.5M)
  CGroup: /system.slice/example.service
          ├─17737 /bin/bash /home/jdoe/example.sh
          └─17743 sleep 1
Apr 16 12:12:39 redhat systemd[1]: Started My example service.
Apr 16 12:12:39 redhat bash[17737]: The current time is Tue Apr 16 12:12:39 CEST 2019
Apr 16 12:12:40 redhat bash[17737]: The current time is Tue Apr 16 12:12:40 CEST 2019
```

Additional resources

- **systemd.resource-control(5)** and **cgroups(7)** man pages on your system

24.7. VIEWING CGROUPS OF PROCESSES

You can learn which *control group* (**cgroup**) a process belongs to. Then you can check the **cgroup** to find which controllers and controller-specific configurations it uses.

Procedure

1. To view which **cgroup** a process belongs to, run the **# cat proc/<*PID*>/cgroup** command:

```
# cat /proc/2467/cgroup
0::/system.slice/example.service
```

   The example output relates to a process of interest. In this case, it is a process identified by **PID 2467**, which belongs to the **example.service** unit. You can determine whether the process was placed in a correct control group as defined by the **systemd** unit file specifications.

2. To display what controllers and respective configuration files the **cgroup** uses, check the **cgroup** directory:

```
# cat /sys/fs/cgroup/system.slice/example.service/cgroup.controllers
memory pids

# ls /sys/fs/cgroup/system.slice/example.service/
cgroup.controllers
cgroup.events
…
cpu.pressure
cpu.stat
io.pressure
memory.current
memory.events
…
```

```
pids.current
pids.events
pids.max
```

> **NOTE**
>
> The version 1 hierarchy of **cgroups** uses a per-controller model. Therefore the output from the **/proc/*PID*/cgroup** file shows, which **cgroups** under each controller the PID belongs to. You can find the respective **cgroups** under the controller directories at **/sys/fs/cgroup/*<controller_name>*/**.

Additional resources

- The **cgroups(7)** manual page
- What are kernel resource controllers
- Documentation in the **/usr/share/doc/kernel-doc-<kernel_version>/Documentation/admin-guide/cgroup-v2.rst** file (after installing the **kernel-doc** package)

24.8. MONITORING RESOURCE CONSUMPTION

View a list of currently running control groups (**cgroups**) and their resource consumption in real-time.

Procedure

1. Display a dynamic account of currently running **cgroups** with the **systemd-cgtop** command.

```
# systemd-cgtop
Control Group                              Tasks   %CPU   Memory  Input/s Output/s
/                                         607   29.8     1.5G        -        -
/system.slice                             125      -   428.7M        -        -
/system.slice/ModemManager.service          3      -     8.6M        -        -
/system.slice/NetworkManager.service        3      -    12.8M        -        -
/system.slice/accounts-daemon.service       3      -     1.8M        -        -
/system.slice/boot.mount                    -      -    48.0K        -        -
/system.slice/chronyd.service               1      -     2.0M        -        -
/system.slice/cockpit.socket                -      -     1.3M        -        -
/system.slice/colord.service                3      -     3.5M        -        -
/system.slice/crond.service                 1      -     1.8M        -        -
/system.slice/cups.service                  1      -     3.1M        -        -
/system.slice/dev-hugepages.mount           -      -   244.0K        -        -
/system.slice/dev-mapper-rhel\x2dswap.swap  -      -   912.0K        -        -
/system.slice/dev-mqueue.mount              -      -    48.0K        -        -
/system.slice/example.service               2      -     2.0M        -        -
/system.slice/firewalld.service             2      -    28.8M        -        -
...
```

The example output displays currently running **cgroups** ordered by their resource usage (CPU, memory, disk I/O load). The list refreshes every 1 second by default. Therefore, it offers a dynamic insight into the actual resource usage of each control group.

Additional resources

- The **systemd-cgtop(1)** manual page

24.9. USING SYSTEMD UNIT FILES TO SET LIMITS FOR APPLICATIONS

The **systemd** service manager supervises each existing or running unit and creates control groups for them. The units have configuration files in the **/usr/lib/systemd/system/** directory.

You can manually modify the unit files to:

- set limits.
- prioritize.
- control access to hardware resources for groups of processes.

Prerequisites

- You have the **root** privileges.

Procedure

1. Edit the **/usr/lib/systemd/system/example.service** file to limit the memory usage of a service:

```
…
[Service]
MemoryMax=1500K
…
```

   The configuration limits the maximum memory that the processes in a control group cannot exceed. The **example.service** service is part of such a control group which has imposed limitations. You can use suffixes K, M, G, or T to identify Kilobyte, Megabyte, Gigabyte, or Terabyte as a unit of measurement.

2. Reload all unit configuration files:

```
# systemctl daemon-reload
```

3. Restart the service:

```
# systemctl restart example.service
```

Verification

1. Check that the changes took effect:

```
# cat /sys/fs/cgroup/system.slice/example.service/memory.max
1536000
```

   The example output shows that the memory consumption was limited at around 1,500 KB.

Additional resources

- Understanding cgroups
- *Managing system services with systemctl* in Red Hat Enterprise Linux
- **systemd.resource-control(5)**, **systemd.exec(5)**, and **cgroups(7)** man pages on your system

24.10. USING SYSTEMCTL COMMAND TO SET LIMITS TO APPLICATIONS

CPU affinity settings help you restrict the access of a particular process to some CPUs. Effectively, the CPU scheduler never schedules the process to run on the CPU that is not in the affinity mask of the process.

The default CPU affinity mask applies to all services managed by **systemd**.

To configure CPU affinity mask for a particular **systemd** service, **systemd** provides **CPUAffinity=** both as:

- a unit file option.
- a configuration option in the [Manager] section of the **/etc/systemd/system.conf** file.

The **CPUAffinity=** unit file option sets a list of CPUs or CPU ranges that are merged and used as the affinity mask.

Procedure

To set CPU affinity mask for a particular **systemd** service using the **CPUAffinity** unit file option:

1. Check the values of the **CPUAffinity** unit file option in the service of your choice:

```
$ systemctl show --property <CPU affinity configuration option> <service name>
```

2. As the root user, set the required value of the **CPUAffinity** unit file option for the CPU ranges used as the affinity mask:

```
# systemctl set-property <service name> CPUAffinity=<value>
```

3. Restart the service to apply the changes.

```
# systemctl restart <service name>
```

Additional resources

- **systemd.resource-control(5)**, **systemd.exec(5)**, **cgroups(7)** man pages on your system

24.11. SETTING GLOBAL DEFAULT CPU AFFINITY THROUGH MANAGER CONFIGURATION

The **CPUAffinity** option in the **/etc/systemd/system.conf** file defines an affinity mask for the process identification number (PID) 1 and all processes forked off of PID1. You can then override the **CPUAffinity** on a per-service basis.

To set the default CPU affinity mask for all **systemd** services using the **/etc/systemd/system.conf** file:

1. Set the CPU numbers for the **CPUAffinity=** option in the [Manager] section of the **/etc/systemd/system.conf** file.

2. Save the edited file and reload the **systemd** service:

```
# systemctl daemon-reload
```

3. Reboot the server to apply the changes.

Additional resources

- The **systemd.resource-control(5)** and **systemd.exec(5)** man pages.

24.12. CONFIGURING NUMA POLICIES USING SYSTEMD

Non-uniform memory access (NUMA) is a computer memory subsystem design, in which the memory access time depends on the physical memory location relative to the processor.

Memory close to the CPU has lower latency (local memory) than memory that is local for a different CPU (foreign memory) or is shared between a set of CPUs.

In terms of the Linux kernel, NUMA policy governs where (for example, on which NUMA nodes) the kernel allocates physical memory pages for the process.

systemd provides unit file options **NUMAPolicy** and **NUMAMask** to control memory allocation policies for services.

Procedure

To set the NUMA memory policy through the **NUMAPolicy** unit file option:

1. Check the values of the **NUMAPolicy** unit file option in the service of your choice:

```
$ systemctl show --property <NUMA policy configuration option> <service name>
```

2. As a root, set the required policy type of the **NUMAPolicy** unit file option:

```
# systemctl set-property <service name> NUMAPolicy=<value>
```

3. Restart the service to apply the changes.

```
# systemctl restart <service name>
```

To set a global **NUMAPolicy** setting using the [Manager] configuration option:

1. Search in the **/etc/systemd/system.conf** file for the **NUMAPolicy** option in the [Manager] section of the file.

2. Edit the policy type and save the file.

3. Reload the **systemd** configuration:

```
# systemd daemon-reload
```

4. Reboot the server.

> **IMPORTANT**
>
> When you configure a strict NUMA policy, for example **bind**, make sure that you also appropriately set the **CPUAffinity=** unit file option.

Additional resources

- Using systemctl command to set limits to applications
- The **systemd.resource-control(5)**, **systemd.exec(5)**, and **set_mempolicy(2)** man pages.

24.13. NUMA POLICY CONFIGURATION OPTIONS FOR SYSTEMD

Systemd provides the following options to configure the NUMA policy:

NUMAPolicy

Controls the NUMA memory policy of the executed processes. You can use these policy types:

- default
- preferred
- bind
- interleave
- local

NUMAMask

Controls the NUMA node list that is associated with the selected NUMA policy.
Note that you do not have to specify the **NUMAMask** option for the following policies:

- default
- local

For the preferred policy, the list specifies only a single NUMA node.

Additional resources

- **systemd.resource-control(5)**, **systemd.exec(5)**, and **set_mempolicy(2)** man pages on your system

24.14. CREATING TRANSIENT CGROUPS USING SYSTEMD-RUN COMMAND

The transient **cgroups** set limits on resources consumed by a unit (service or scope) during its runtime.

Procedure

- To create a transient control group, use the **systemd-run** command in the following format:

  ```
  # systemd-run --unit=<name> --slice=<name>.slice <command>
  ```

  This command creates and starts a transient service or a scope unit and runs a custom command in such a unit.

  - The **--unit=<name>** option gives a name to the unit. If **--unit** is not specified, the name is generated automatically.
  - The **--slice=<*name*>.slice** option makes your service or scope unit a member of a specified slice. Replace **<*name*>.slice** with the name of an existing slice (as shown in the output of **systemctl -t slice**), or create a new slice by passing a unique name. By default, services and scopes are created as members of the **system.slice**.
  - Replace **<*command*>** with the command you want to enter in the service or the scope unit. The following message is displayed to confirm that you created and started the service or the scope successfully:

    ```
    # Running as unit <name>.service
    ```

- *Optional*: Keep the unit running after its processes finished to collect runtime information:

  ```
  # systemd-run --unit=<name> --slice=<name>.slice --remain-after-exit <command>
  ```

  The command creates and starts a transient service unit and runs a custom command in the unit. The **--remain-after-exit** option ensures that the service keeps running after its processes have finished.

Additional resources

- The **systemd-run(1)** manual page

24.15. REMOVING TRANSIENT CONTROL GROUPS

You can use the **systemd** system and service manager to remove transient control groups (**cgroups**) if you no longer need to limit, prioritize, or control access to hardware resources for groups of processes.

Transient **cgroups** are automatically released when all the processes that a service or a scope unit contains finish.

Procedure

- To stop the service unit with all its processes, enter:

  ```
  # systemctl stop <name>.service
  ```

- To terminate one or more of the unit processes, enter:

  ```
  # systemctl kill <name>.service --kill-who=PID,... --signal=<signal>
  ```

  The command uses the **--kill-who** option to select process(es) from the control group you want to terminate. To kill multiple processes at the same time, pass a comma-separated list of PIDs.

The **--signal** option determines the type of POSIX signal to be sent to the specified processes. The default signal is *SIGTERM*.

Additional resources

- What are control groups
- What are kernel resource controllers
- **systemd.resource-control(5)** and **cgroups(7)** man pages on your system
- Understanding control groups
- *Managing systemd* in RHEL

CHAPTER 25. UNDERSTANDING CONTROL GROUPS

Using the control groups (**cgroups**) kernel functionality, you can control resource usage of applications to use them more efficiently.

You can use **cgroups** for the following tasks:

- Setting limits for system resource allocation.
- Prioritizing the allocation of hardware resources to specific processes.
- Isolating certain processes from obtaining hardware resources.

25.1. INTRODUCING CONTROL GROUPS

Using the *control groups* Linux kernel feature, you can organize processes into hierarchically ordered groups - **cgroups**. You define the hierarchy (control groups tree) by providing structure to **cgroups** virtual file system, mounted by default on the **/sys/fs/cgroup/** directory.

The **systemd** service manager uses **cgroups** to organize all units and services that it governs. Manually, you can manage the hierarchies of **cgroups** by creating and removing sub-directories in the **/sys/fs/cgroup/** directory.

The resource controllers in the kernel then modify the behavior of processes in **cgroups** by limiting, prioritizing or allocating system resources, of those processes. These resources include the following:

- CPU time
- Memory
- Network bandwidth
- Combinations of these resources

The primary use case of **cgroups** is aggregating system processes and dividing hardware resources among applications and users. This makes it possible to increase the efficiency, stability, and security of your environment.

Control groups version 1

Control groups version 1 (**cgroups-v1**) provide a per-resource controller hierarchy. Each resource, such as CPU, memory, or I/O, has its own control group hierarchy. You can combine different control group hierarchies in a way that one controller can coordinate with another in managing their respective resources. However, when the two controllers belong to different process hierarchies, the coordination is limited.
The **cgroups-v1** controllers were developed across a large time span, resulting in inconsistent behavior and naming of their control files.

Control groups version 2

Control groups version 2 (**cgroups-v2**) provide a single control group hierarchy against which all resource controllers are mounted.
The control file behavior and naming is consistent among different controllers.

IMPORTANT

RHEL 9, by default, mounts and uses **cgroups-v2**.

Additional resources

- Introducing kernel resource controllers
- The **cgroups(7)** manual page
- cgroups-v1
- cgroups-v2

25.2. INTRODUCING KERNEL RESOURCE CONTROLLERS

Kernel resource controllers enable the functionality of control groups. RHEL 9 supports various controllers for *control groups version 1* (**cgroups-v1**) and *control groups version 2* (**cgroups-v2**).

A resource controller, also called a control group subsystem, is a kernel subsystem that represents a single resource, such as CPU time, memory, network bandwidth or disk I/O. The Linux kernel provides a range of resource controllers that are mounted automatically by the **systemd** service manager. You can find a list of the currently mounted resource controllers in the **/proc/cgroups** file.

Controllers available forcgroups-v1:

blkio
: Sets limits on input/output access to and from block devices.

cpu
: Adjusts the parameters of the Completely Fair Scheduler (CFS) for a control group's tasks. The **cpu** controller is mounted together with the **cpuacct** controller on the same mount.

cpuacct
: Creates automatic reports on CPU resources used by tasks in a control group. The **cpuacct** controller is mounted together with the **cpu** controller on the same mount.

cpuset
: Restricts control group tasks to run only on a specified subset of CPUs and to direct the tasks to use memory only on specified memory nodes.

devices
: Controls access to devices for tasks in a control group.

freezer
: Suspends or resumes tasks in a control group.

memory
: Sets limits on memory use by tasks in a control group and generates automatic reports on memory resources used by those tasks.

net_cls
: Tags network packets with a class identifier (**classid**) that enables the Linux traffic controller (the **tc** command) to identify packets that originate from a particular control group task. A subsystem of **net_cls**, the **net_filter** (iptables), can also use this tag to perform actions on such packets. The **net_filter** tags network sockets with a firewall identifier (**fwid**) that allows the Linux firewall to identify packets that originate from a particular control group task (by using the **iptables** command).

net_prio

Sets the priority of network traffic.

pids

Sets limits for multiple processes and their children in a control group.

perf_event

Groups tasks for monitoring by the **perf** performance monitoring and reporting utility.

rdma

Sets limits on Remote Direct Memory Access/InfiniBand specific resources in a control group.

hugetlb

Limits the usage of large size virtual memory pages by tasks in a control group.

Controllers available for **cgroups-v2**:

io

Sets limits on input/output access to and from block devices.

memory

Sets limits on memory use by tasks in a control group and generates automatic reports on memory resources used by those tasks.

pids

Sets limits for multiple processes and their children in a control group.

rdma

Sets limits on Remote Direct Memory Access/InfiniBand specific resources in a control group.

cpu

Adjusts the parameters of the Completely Fair Scheduler (CFS) for a control group's tasks and creates automatic reports on CPU resources used by tasks in a control group.

cpuset

Restricts control group tasks to run only on a specified subset of CPUs and to direct the tasks to use memory only on specified memory nodes. Supports only the core functionality (**cpus{,.effective}**, **mems{,.effective}**) with a new partition feature.

perf_event

Groups tasks for monitoring by the **perf** performance monitoring and reporting utility. **perf_event** is enabled automatically on the v2 hierarchy.

> **IMPORTANT**
>
> A resource controller can be used either in a **cgroups-v1** hierarchy or a **cgroups-v2** hierarchy, not simultaneously in both.

Additional resources

- The **cgroups(7)** manual page
- Documentation in **/usr/share/doc/kernel-doc-<kernel_version>/Documentation/cgroups-v1/** directory (after installing the **kernel-doc** package).

25.3. INTRODUCING NAMESPACES

Namespaces create separate spaces for organizing and identifying software objects. This keeps them from affecting each other. As a result, each software object contains its own set of resources, for example, a mount point, a network device, or a a hostname, even though they are sharing the same system.

One of the most common technologies that use namespaces are containers.

Changes to a particular global resource are visible only to processes in that namespace and do not affect the rest of the system or other namespaces.

To inspect which namespaces a process is a member of, you can check the symbolic links in the **/proc/<*PID*>/ns/** directory.

Table 25.1. Supported namespaces and resources which they isolate:

Namespace	Isolates
Mount	Mount points
UTS	Hostname and NIS domain name
IPC	System V IPC, POSIX message queues
PID	Process IDs
Network	Network devices, stacks, ports, etc
User	User and group IDs
Control groups	Control group root directory

Additional resources

- The **namespaces(7)** and **cgroup_namespaces(7)** manual pages

CHAPTER 26. USING CGROUPFS TO MANUALLY MANAGE CGROUPS

You can manage **cgroup** hierarchies on your system by creating directories on the **cgroupfs** virtual file system. The file system is mounted by default on the **/sys/fs/cgroup/** directory and you can specify desired configurations in dedicated control files.

> **IMPORTANT**
>
> In general, Red Hat recommends you use **systemd** for controlling the usage of system resources. You should manually configure the **cgroups** virtual file system only in special cases. For example, when you need to use **cgroup-v1** controllers that have no equivalents in **cgroup-v2** hierarchy.

26.1. CREATING CGROUPS AND ENABLING CONTROLLERS IN CGROUPS-V2 FILE SYSTEM

You can manage the *control groups* (**cgroups**) by creating or removing directories and by writing to files in the **cgroups** virtual file system. The file system is by default mounted on the **/sys/fs/cgroup/** directory. To use settings from the **cgroups** controllers, you also need to enable the desired controllers for child **cgroups**. The root **cgroup** has, by default, enabled the **memory** and **pids** controllers for its child **cgroups**. Therefore, Red Hat recommends to create at least two levels of child **cgroups** inside the **/sys/fs/cgroup/** root **cgroup**. This way you optionally remove the **memory** and **pids** controllers from the child **cgroups** and maintain better organizational clarity of **cgroup** files.

Prerequisites

- You have root permissions.

Procedure

1. Create the **/sys/fs/cgroup/Example/** directory:

   ```
   # mkdir /sys/fs/cgroup/Example/
   ```

   The **/sys/fs/cgroup/Example/** directory defines a child group. When you create the **/sys/fs/cgroup/Example/** directory, some **cgroups-v2** interface files are automatically created in the directory. The **/sys/fs/cgroup/Example/** directory contains also controller-specific files for the **memory** and **pids** controllers.

2. Optional: Inspect the newly created child control group:

   ```
   # ll /sys/fs/cgroup/Example/
   -r—r—r--. 1 root root 0 Jun  1 10:33 cgroup.controllers
   -r—r—r--. 1 root root 0 Jun  1 10:33 cgroup.events
   -rw-r—r--. 1 root root 0 Jun  1 10:33 cgroup.freeze
   -rw-r--r--. 1 root root 0 Jun  1 10:33 cgroup.procs
   …
   -rw-r—r--. 1 root root 0 Jun  1 10:33 cgroup.subtree_control
   -r—r—r--. 1 root root 0 Jun  1 10:33 memory.events.local
   -rw-r—r--. 1 root root 0 Jun  1 10:33 memory.high
   -rw-r—r--. 1 root root 0 Jun  1 10:33 memory.low
   …
   ```

```
-r—r—r--. 1 root root 0 Jun  1 10:33 pids.current
-r—r—r--. 1 root root 0 Jun  1 10:33 pids.events
-rw-r—r--. 1 root root 0 Jun  1 10:33 pids.max
```

The example output shows general **cgroup** control interface files such as **cgroup.procs** or **cgroup.controllers**. These files are common to all control groups, regardless of enabled controllers.

The files such as **memory.high** and **pids.max** relate to the **memory** and **pids** controllers, which are in the root control group (**/sys/fs/cgroup/**), and are enabled by default by **systemd**.

By default, the newly created child group inherits all settings from the parent **cgroup**. In this case, there are no limits from the root **cgroup**.

3. Verify that the desired controllers are available in the **/sys/fs/cgroup/cgroup.controllers** file:

```
# cat /sys/fs/cgroup/cgroup.controllers
cpuset cpu io memory hugetlb pids rdma
```

4. Enable the desired controllers. In this example it is **cpu** and **cpuset** controllers:

```
# echo "+cpu" >> /sys/fs/cgroup/cgroup.subtree_control
# echo "+cpuset" >> /sys/fs/cgroup/cgroup.subtree_control
```

These commands enable the **cpu** and **cpuset** controllers for the immediate child groups of the **/sys/fs/cgroup/** root control group. Including the newly created **Example** control group. A *child group* is where you can specify processes and apply control checks to each of the processes based on your criteria.

Users can read the contents of the **cgroup.subtree_control** file at any level to get an idea of what controllers are going to be available for enablement in the immediate child group.

NOTE

By default, the **/sys/fs/cgroup/cgroup.subtree_control** file in the root control group contains **memory** and **pids** controllers.

5. Enable the desired controllers for child **cgroups** of the **Example** control group:

```
# echo "+cpu +cpuset" >> /sys/fs/cgroup/Example/cgroup.subtree_control
```

This command ensures that the immediate child control group will *only* have controllers relevant to regulate the CPU time distribution - not to **memory** or **pids** controllers.

6. Create the **/sys/fs/cgroup/Example/tasks/** directory:

```
# mkdir /sys/fs/cgroup/Example/tasks/
```

The **/sys/fs/cgroup/Example/tasks/** directory defines a child group with files that relate purely to **cpu** and **cpuset** controllers. You can now assign processes to this control group and utilize **cpu** and **cpuset** controller options for your processes.

7. Optional: Inspect the child control group:

```
# ll /sys/fs/cgroup/Example/tasks
-r—r—r--. 1 root root 0 Jun  1 11:45 cgroup.controllers
-r—r—r--. 1 root root 0 Jun  1 11:45 cgroup.events
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.freeze
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.max.depth
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.max.descendants
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.procs
-r—r—r--. 1 root root 0 Jun  1 11:45 cgroup.stat
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.subtree_control
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.threads
-rw-r—r--. 1 root root 0 Jun  1 11:45 cgroup.type
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpu.max
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpu.pressure
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpuset.cpus
-r—r—r--. 1 root root 0 Jun  1 11:45 cpuset.cpus.effective
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpuset.cpus.partition
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpuset.mems
-r—r—r--. 1 root root 0 Jun  1 11:45 cpuset.mems.effective
-r—r—r--. 1 root root 0 Jun  1 11:45 cpu.stat
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpu.weight
-rw-r—r--. 1 root root 0 Jun  1 11:45 cpu.weight.nice
-rw-r—r--. 1 root root 0 Jun  1 11:45 io.pressure
-rw-r—r--. 1 root root 0 Jun  1 11:45 memory.pressure
```

IMPORTANT

The **cpu** controller is only activated if the relevant child control group has at least 2 processes which compete for time on a single CPU.

Verification

- Optional: confirm that you have created a new **cgroup** with only the desired controllers active:

```
# cat /sys/fs/cgroup/Example/tasks/cgroup.controllers
cpuset cpu
```

Additional resources

- What are kernel resource controllers
- Mounting cgroups-v1
- **cgroups(7)**, **sysfs(5)** manual pages

26.2. CONTROLLING DISTRIBUTION OF CPU TIME FOR APPLICATIONS BY ADJUSTING CPU WEIGHT

You need to assign values to the relevant files of the **cpu** controller to regulate distribution of the CPU time to applications under the specific cgroup tree.

Prerequisites

- You have root permissions.

- You have applications for which you want to control distribution of CPU time.
- You created a two level hierarchy of *child control groups* inside the **/sys/fs/cgroup/** *root control group* as in the following example:

```
…
  ├── Example
  │   ├── g1
  │   ├── g2
  │   └── g3
…
```

- You enabled the **cpu** controller in the parent control group and in child control groups similarly as described in Creating cgroups and enabling controllers in cgroups-v2 file system .

Procedure

1. Configure desired CPU weights to achieve resource restrictions within the control groups:

```
# echo "150" > /sys/fs/cgroup/Example/g1/cpu.weight
# echo "100" > /sys/fs/cgroup/Example/g2/cpu.weight
# echo "50" > /sys/fs/cgroup/Example/g3/cpu.weight
```

2. Add the applications' PIDs to the **g1**, **g2**, and **g3** child groups:

```
# echo "33373" > /sys/fs/cgroup/Example/g1/cgroup.procs
# echo "33374" > /sys/fs/cgroup/Example/g2/cgroup.procs
# echo "33377" > /sys/fs/cgroup/Example/g3/cgroup.procs
```

The example commands ensure that desired applications become members of the **Example/g*/** child cgroups and will get their CPU time distributed as per the configuration of those cgroups.

The weights of the children cgroups (**g1**, **g2**, **g3**) that have running processes are summed up at the level of the parent cgroup (**Example**). The CPU resource is then distributed proportionally based on the respective weights.

As a result, when all processes run at the same time, the kernel allocates to each of them the proportionate CPU time based on their respective cgroup's **cpu.weight** file:

Child cgroup	**cpu.weight** file	CPU time allocation
g1	150	~50% (150/300)
g2	100	~33% (100/300)
g3	50	~16% (50/300)

The value of the **cpu.weight** controller file is not a percentage.

If one process stopped running, leaving cgroup **g2** with no running processes, the calculation would omit the cgroup **g2** and only account weights of cgroups **g1** and **g3**:

Child cgroup	**cpu.weight** file	CPU time allocation
g1	150	~75% (150/200)
g3	50	~25% (50/200)

> **IMPORTANT**
>
> If a child cgroup has multiple running processes, the CPU time allocated to the cgroup is distributed equally among its member processes.

Verification

1. Verify that the applications run in the specified control groups:

```
# cat /proc/33373/cgroup /proc/33374/cgroup /proc/33377/cgroup
0::/Example/g1
0::/Example/g2
0::/Example/g3
```

The command output shows the processes of the specified applications that run in the **Example/g*/** child cgroups.

2. Inspect the current CPU consumption of the throttled applications:

```
# top
top - 05:17:18 up 1 day, 18:25,  1 user,  load average: 3.03, 3.03, 3.00
Tasks:  95 total,   4 running,  91 sleeping,   0 stopped,   0 zombie
%Cpu(s): 18.1 us, 81.6 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.3 hi,  0.0 si,  0.0 st
MiB Mem :   3737.0 total,   3233.7 free,    132.8 used,    370.5 buff/cache
MiB Swap:   4060.0 total,   4060.0 free,      0.0 used.   3373.1 avail Mem

    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
  33373 root      20   0   18720   1748   1460 R  49.5   0.0 415:05.87 sha1sum
  33374 root      20   0   18720   1756   1464 R  32.9   0.0 412:58.33 sha1sum
  33377 root      20   0   18720   1860   1568 R  16.3   0.0 411:03.12 sha1sum
    760 root      20   0  416620  28540  15296 S   0.3   0.7   0:10.23 tuned
      1 root      20   0  186328  14108   9484 S   0.0   0.4   0:02.00 systemd
      2 root      20   0       0      0      0 S   0.0   0.0   0:00.01 kthread
...
```

> **NOTE**
>
> All processes run on a single CPU for clear illustration. The CPU weight applies the same principles when used on multiple CPUs.

Notice that the CPU resource for the **PID 33373**, **PID 33374**, and **PID 33377** was allocated based on the 150, 100, and 50 weights you assigned to the respective child cgroups. The weights correspond to around 50%, 33%, and 16% allocation of CPU time for each application.

26.3. MOUNTING CGROUPS-V1

During the boot process, RHEL 9 mounts the **cgroup-v2** virtual filesystem by default. To utilize **cgroup-v1** functionality in limiting resources for your applications, manually configure the system.

> **NOTE**
>
> Both **cgroup-v1** and **cgroup-v2** are fully enabled in the kernel. There is no default control group version from the kernel point of view, and is decided by **systemd** to mount at startup.

Prerequisites

- You have root permissions.

Procedure

1. Configure the system to mount **cgroups-v1** by default during system boot by the **systemd** system and service manager:

   ```
   # grubby --update-kernel=/boot/vmlinuz-$(uname -r) --args="systemd.unified_cgroup_hierarchy=0 systemd.legacy_systemd_cgroup_controller"
   ```

   This adds the necessary kernel command-line parameters to the current boot entry.

   To add the same parameters to all kernel boot entries:

   ```
   # grubby --update-kernel=ALL --args="systemd.unified_cgroup_hierarchy=0 systemd.legacy_systemd_cgroup_controller"
   ```

2. Reboot the system for the changes to take effect.

Verification

1. Verify that the **cgroups-v1** filesystem was mounted:

   ```
   # mount -l | grep cgroup
   tmpfs on /sys/fs/cgroup type tmpfs (ro,nosuid,nodev,noexec,seclabel,size=4096k,nr_inodes=1024,mode=755,inode64)
   cgroup on /sys/fs/cgroup/systemd type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,xattr,release_agent=/usr/lib/systemd/systemd-cgroups-agent,name=systemd)
   cgroup on /sys/fs/cgroup/perf_event type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,perf_event)
   cgroup on /sys/fs/cgroup/cpu,cpuacct type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,cpu,cpuacct)
   cgroup on /sys/fs/cgroup/pids type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,pids)
   cgroup on /sys/fs/cgroup/cpuset type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,cpuset)
   cgroup on /sys/fs/cgroup/net_cls,net_prio type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,net_cls,net_prio)
   cgroup on /sys/fs/cgroup/hugetlb type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,hugetlb)
   cgroup on /sys/fs/cgroup/memory type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,memory)
   ```

```
cgroup on /sys/fs/cgroup/blkio type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,blkio)
cgroup on /sys/fs/cgroup/devices type cgroup
(rw,nosuid,nodev,noexec,relatime,seclabel,devices)
cgroup on /sys/fs/cgroup/misc type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,misc)
cgroup on /sys/fs/cgroup/freezer type cgroup
(rw,nosuid,nodev,noexec,relatime,seclabel,freezer)
cgroup on /sys/fs/cgroup/rdma type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,rdma)
```

The **cgroups-v1** filesystems that correspond to various **cgroup-v1** controllers, were successfully mounted on the **/sys/fs/cgroup/** directory.

2. Inspect the contents of the **/sys/fs/cgroup/** directory:

```
# ll /sys/fs/cgroup/
dr-xr-xr-x. 10 root root  0 Mar 16 09:34 blkio
lrwxrwxrwx.  1 root root 11 Mar 16 09:34 cpu → cpu,cpuacct
lrwxrwxrwx.  1 root root 11 Mar 16 09:34 cpuacct → cpu,cpuacct
dr-xr-xr-x. 10 root root  0 Mar 16 09:34 cpu,cpuacct
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 cpuset
dr-xr-xr-x. 10 root root  0 Mar 16 09:34 devices
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 freezer
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 hugetlb
dr-xr-xr-x. 10 root root  0 Mar 16 09:34 memory
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 misc
lrwxrwxrwx.  1 root root 16 Mar 16 09:34 net_cls → net_cls,net_prio
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 net_cls,net_prio
lrwxrwxrwx.  1 root root 16 Mar 16 09:34 net_prio → net_cls,net_prio
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 perf_event
dr-xr-xr-x. 10 root root  0 Mar 16 09:34 pids
dr-xr-xr-x.  2 root root  0 Mar 16 09:34 rdma
dr-xr-xr-x. 11 root root  0 Mar 16 09:34 systemd
```

The **/sys/fs/cgroup/** directory, also called the *root control group*, by default, contains controller-specific directories such as **cpuset**. In addition, there are some directories related to **systemd**.

Additional resources

- What are kernel resource controllers
- **cgroups(7)**, **sysfs(5)** manual pages
- cgroup-v2 enabled by default in RHEL 9

26.4. SETTING CPU LIMITS TO APPLICATIONS USING CGROUPS-V1

To configure CPU limits to an application by using *control groups version 1* (**cgroups-v1**), use the **/sys/fs/** virtual file system.

Prerequisites

- You have root permissions.
- You have an application to restrict its CPU consumption installed on your system.

- You configured the system to mount **cgroups-v1** by default during system boot by the **systemd** system and service manager:

  ```
  # grubby --update-kernel=/boot/vmlinuz-$(uname -r) --
  args="systemd.unified_cgroup_hierarchy=0
  systemd.legacy_systemd_cgroup_controller"
  ```

  This adds the necessary kernel command-line parameters to the current boot entry.

Procedure

1. Identify the process ID (PID) of the application that you want to restrict in CPU consumption:

   ```
   # top
   top - 11:34:09 up 11 min,  1 user,  load average: 0.51, 0.27, 0.22
   Tasks: 267 total,   3 running, 264 sleeping,   0 stopped,   0 zombie
   %Cpu(s): 49.0 us,  3.3 sy,  0.0 ni, 47.5 id,  0.0 wa,  0.2 hi,  0.0 si,  0.0 st
   MiB Mem :   1826.8 total,    303.4 free,   1046.8 used,    476.5 buff/cache
   MiB Swap:   1536.0 total,   1396.0 free,    140.0 used.    616.4 avail Mem

     PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
    6955 root      20   0  228440   1752   1472 R  99.3   0.1   0:32.71 sha1sum
    5760 jdoe      20   0 3603868 205188  64196 S   3.7  11.0   0:17.19 gnome-shell
    6448 jdoe      20   0  743648  30640  19488 S   0.7   1.6   0:02.73 gnome-terminal-
       1 root      20   0  245300   6568   4116 S   0.3   0.4   0:01.87 systemd
     505 root      20   0       0      0      0 I   0.3   0.0   0:00.75 kworker/u4:4-events_unbound
   ...
   ```

   The **sha1sum** example application with **PID 6955** consumes a large amount of CPU resources.

2. Create a sub-directory in the **cpu** resource controller directory:

   ```
   # mkdir /sys/fs/cgroup/cpu/Example/
   ```

   This directory represents a control group, where you can place specific processes and apply certain CPU limits to the processes. At the same time, a number of **cgroups-v1** interface files and **cpu** controller-specific files will be created in the directory.

3. Optional: Inspect the newly created control group:

   ```
   # ll /sys/fs/cgroup/cpu/Example/
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cgroup.clone_children
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cgroup.procs
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.stat
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage_all
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage_percpu
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage_percpu_sys
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage_percpu_user
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage_sys
   -r—r—r--. 1 root root 0 Mar 11 11:42 cpuacct.usage_user
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cpu.cfs_period_us
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cpu.cfs_quota_us
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cpu.rt_period_us
   -rw-r—r--. 1 root root 0 Mar 11 11:42 cpu.rt_runtime_us
   ```

```
-rw-r—r--. 1 root root 0 Mar 11 11:42 cpu.shares
-r—r—r--. 1 root root 0 Mar 11 11:42 cpu.stat
-rw-r—r--. 1 root root 0 Mar 11 11:42 notify_on_release
-rw-r—r--. 1 root root 0 Mar 11 11:42 tasks
```

Files, such as **cpuacct.usage**, **cpu.cfs._period_us** represent specific configurations and/or limits, which can be set for processes in the **Example** control group. Note that the file names are prefixed with the name of the control group controller they belong to.

By default, the newly created control group inherits access to the system's entire CPU resources without a limit.

4. Configure CPU limits for the control group:

```
# echo "1000000" > /sys/fs/cgroup/cpu/Example/cpu.cfs_period_us
# echo "200000" > /sys/fs/cgroup/cpu/Example/cpu.cfs_quota_us
```

- The **cpu.cfs_period_us** file represents how frequently a control group's access to CPU resources must be reallocated. The time period is in microseconds (µs, "us"). The upper limit is 1 000 000 microseconds and the lower limit is 1000 microseconds.
- The **cpu.cfs_quota_us** file represents the total amount of time in microseconds for which all processes in a control group can collectively run during one period, as defined by **cpu.cfs_period_us**. When processes in a control group use up all the time specified by the quota during a single period, they are throttled for the remainder of the period and not allowed to run until the next period. The lower limit is 1000 microseconds.
  The example commands above set the CPU time limits so that all processes collectively in the **Example** control group will be able to run only for 0.2 seconds (defined by **cpu.cfs_quota_us**) out of every 1 second (defined by **cpu.cfs_period_us**).

5. Optional: Verify the limits:

```
# cat /sys/fs/cgroup/cpu/Example/cpu.cfs_period_us
/sys/fs/cgroup/cpu/Example/cpu.cfs_quota_us
1000000
200000
```

6. Add the application's PID to the **Example** control group:

```
# echo "6955" > /sys/fs/cgroup/cpu/Example/cgroup.procs
```

This command ensures that a specific application becomes a member of the **Example** control group and does not exceed the CPU limits configured for the **Example** control group. The PID must represent an existing process in the system. The **PID 6955** here was assigned to the **sha1sum /dev/zero &** process, used to illustrate the use case of the **cpu** controller.

Verification

1. Verify that the application runs in the specified control group:

```
# cat /proc/6955/cgroup
12:cpuset:/
11:hugetlb:/
10:net_cls,net_prio:/
9:memory:/user.slice/user-1000.slice/user@1000.service
```

```
8:devices:/user.slice
7:blkio:/
6:freezer:/
5:rdma:/
4:pids:/user.slice/user-1000.slice/user@1000.service
3:perf_event:/
2:cpu,cpuacct:/Example
1:name=systemd:/user.slice/user-1000.slice/user@1000.service/gnome-terminal-
server.service
```

The process of an application runs in the **Example** control group applying CPU limits to the application's process.

2. Identify the current CPU consumption of your throttled application:

```
# top
top - 12:28:42 up  1:06,  1 user,  load average: 1.02, 1.02, 1.00
Tasks: 266 total,   6 running, 260 sleeping,   0 stopped,   0 zombie
%Cpu(s): 11.0 us,  1.2 sy,  0.0 ni, 87.5 id,  0.0 wa,  0.2 hi,  0.0 si,  0.2 st
MiB Mem :   1826.8 total,    287.1 free,   1054.4 used,    485.3 buff/cache
MiB Swap:   1536.0 total,   1396.7 free,    139.2 used.    608.3 avail Mem

  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
 6955 root      20   0  228440   1752   1472 R  20.6   0.1  47:11.43 sha1sum
 5760 jdoe      20   0 3604956 208832  65316 R   2.3  11.2   0:43.50 gnome-shell
 6448 jdoe      20   0  743836  31736  19488 S   0.7   1.7   0:08.25 gnome-terminal-
  505 root      20   0       0      0      0 I   0.3   0.0   0:03.39 kworker/u4:4-events_unbound
 4217 root      20   0   74192   1612   1320 S   0.3   0.1   0:01.19 spice-vdagentd
...
```

Note that the CPU consumption of the **PID 6955** has decreased from 99% to 20%.

> **NOTE**
>
> The **cgroups-v2** counterpart for **cpu.cfs_period_us** and **cpu.cfs_quota_us** is the **cpu.max** file. The **cpu.max** file is available through the **cpu** controller.

Additional resources

- Introducing kernel resource controllers
- **cgroups(7)**, **sysfs(5)** manual pages

CHAPTER 27. ANALYZING SYSTEM PERFORMANCE WITH BPF COMPILER COLLECTION

The BPF Compiler Collection (BCC) analyzes system performance by combining the capabilities of Berkeley Packet Filter (BPF). With BPF, you can safely run the custom programs within the kernel to access system events and data for performance monitoring, tracing, and debugging. BCC simplifies the development and deployment of BPF programs with tools and libraries for users to extract important insights from their systems.

27.1. INSTALLING THE BCC-TOOLS PACKAGE

Install the **bcc-tools** package, which also installs the BPF Compiler Collection (BCC) library as a dependency.

Procedure

- Install **bcc-tools**.

```
# dnf install bcc-tools
```

  The BCC tools are installed in the **/usr/share/bcc/tools/** directory.

Verification

- Inspect the installed tools:

```
# ls -l /usr/share/bcc/tools/
...
-rwxr-xr-x. 1 root root  4198 Dec 14 17:53 dcsnoop
-rwxr-xr-x. 1 root root  3931 Dec 14 17:53 dcstat
-rwxr-xr-x. 1 root root 20040 Dec 14 17:53 deadlock_detector
-rw-r--r--. 1 root root  7105 Dec 14 17:53 deadlock_detector.c
drwxr-xr-x. 3 root root  8192 Mar 11 10:28 doc
-rwxr-xr-x. 1 root root  7588 Dec 14 17:53 execsnoop
-rwxr-xr-x. 1 root root  6373 Dec 14 17:53 ext4dist
-rwxr-xr-x. 1 root root 10401 Dec 14 17:53 ext4slower
...
```

  The **doc** directory in the listing provides documentation for each tool.

27.2. USING SELECTED BCC-TOOLS FOR PERFORMANCE ANALYSES

Use certain pre-created programs from the BPF Compiler Collection (BCC) library to efficiently and securely analyze the system performance on the per-event basis. The set of pre-created programs in the BCC library can serve as examples for creation of additional programs.

Prerequisites

- Installed bcc-tools package
- Root permissions

Procedure

Using **execsnoop** to examine the system processes

1. Run the **execsnoop** program in one terminal:

```
# /usr/share/bcc/tools/execsnoop
```

1. To create a short-lived process of the **ls** command, in another terminal, enter:

   ```
   $ ls /usr/share/bcc/tools/doc/
   ```

2. The terminal running **execsnoop** shows the output similar to the following:

   ```
   PCOMM PID    PPID   RET ARGS
   ls    8382   8287     0 /usr/bin/ls --color=auto /usr/share/bcc/tools/doc/
   ...
   ```

   The **execsnoop** program prints a line of output for each new process that consume system resources. It even detects processes of programs that run very shortly, such as **ls**, and most monitoring tools would not register them.

   The **execsnoop** output displays the following fields:

PCOMM
: The parent process name. (**ls**)

PID
: The process ID. (**8382**)

PPID
: The parent process ID. (**8287**)

RET
: The return value of the **exec()** system call (**0**), which loads program code into new processes.

ARGS
: The location of the started program with arguments.

To see more details, examples, and options for **execsnoop**, see **/usr/share/bcc/tools/doc/execsnoop_example.txt** file.

For more information about **exec()**, see **exec(3)** manual pages.

Using **opensnoop** to track what files a command opens

1. In one terminal, run the **opensnoop** program to print the output for files opened only by the process of the **uname** command:

```
# /usr/share/bcc/tools/opensnoop -n uname
```

1. In another terminal, enter the command to open certain files:

   ```
   $ uname
   ```

2. The terminal running **opensnoop** shows the output similar to the following:

```
PID    COMM  FD ERR PATH
8596   uname  3  0   /etc/ld.so.cache
8596   uname  3  0   /lib64/libc.so.6
8596   uname  3  0   /usr/lib/locale/locale-archive
...
```

The **opensnoop** program watches the **open()** system call across the whole system, and prints a line of output for each file that **uname** tried to open along the way.

The **opensnoop** output displays the following fields:

PID

The process ID. (**8596**)

COMM

The process name. (**uname**)

FD

The file descriptor - a value that **open()** returns to refer to the open file. (**3**)

ERR

Any errors.

PATH

The location of files that **open()** tried to open.

If a command tries to read a non-existent file, then the **FD** column returns **-1** and the **ERR** column prints a value corresponding to the relevant error. As a result, **opensnoop** can help you identify an application that does not behave properly.

To see more details, examples, and options for **opensnoop**, see **/usr/share/bcc/tools/doc/opensnoop_example.txt** file.

For more information about **open()**, see **open(2)** manual pages.

Use the biotop to monitor the top processes performing I/O operations on the disk

1. Run the **biotop** program in one terminal with argument **30** to produce 30 second summary:

```
# /usr/share/bcc/tools/biotop 30
```

NOTE

When no argument provided, the output screen by default refreshes every 1 second.

1. In another terminal, enter command to read the content from the local hard disk device and write the output to the **/dev/zero** file:

```
# dd if=/dev/vda of=/dev/zero
```

This step generates certain I/O traffic to illustrate **biotop**.

2. The terminal running **biotop** shows the output similar to the following:

```
PID    COMM             D MAJ MIN DISK       I/O  Kbytes     AVGms
9568   dd               R 252 0   vda      16294 14440636.0  3.69
48     kswapd0          W 252 0   vda       1763 120696.0    1.65
7571   gnome-shell      R 252 0   vda        834 83612.0     0.33
1891   gnome-shell      R 252 0   vda       1379 19792.0     0.15
7515   Xorg             R 252 0   vda        280  9940.0     0.28
7579   llvmpipe-1       R 252 0   vda        228  6928.0     0.19
9515   gnome-control-c  R 252 0   vda         62  6444.0     0.43
8112   gnome-terminal-  R 252 0   vda         67  2572.0     1.54
7807   gnome-software   R 252 0   vda         31  2336.0     0.73
9578   awk              R 252 0   vda         17  2228.0     0.66
7578   llvmpipe-0       R 252 0   vda        156  2204.0     0.07
9581   pgrep            R 252 0   vda         58  1748.0     0.42
7531   InputThread      R 252 0   vda         30  1200.0     0.48
7504   gdbus            R 252 0   vda          3  1164.0     0.30
1983   llvmpipe-1       R 252 0   vda         39   724.0     0.08
1982   llvmpipe-0       R 252 0   vda         36   652.0     0.06
...
```

The **biotop** output displays the following fields:

PID
: The process ID. (**9568**)

COMM
: The process name. (**dd**)

DISK
: The disk performing the read operations. (**vda**)

I/O
: The number of read operations performed. (16294)

Kbytes
: The amount of Kbytes reached by the read operations. (14,440,636)

AVGms
: The average I/O time of read operations. (3.69)

For more details, examples, and options for **biotop**, see the **/usr/share/bcc/tools/doc/biotop_example.txt** file.

For more information about **dd**, see **dd(1)** manual pages.

Using xfsslower to expose unexpectedly slow file system operations

The **xfsslower** measures the time spent by XFS file system in performing read, write, open or sync (**fsync**) operations. The **1** argument ensures that the program shows only the operations that are slower than 1 ms.

1. Run the **xfsslower** program in one terminal:

```
# /usr/share/bcc/tools/xfsslower 1
```

NOTE

When no arguments provided, **xfsslower** by default displays operations slower than 10 ms.

2. In another terminal, enter the command to create a text file in the **vim** editor to start interaction with the XFS file system:

```
$ vim text
```

3. The terminal running **xfsslower** shows something similar upon saving the file from the previous step:

```
TIME     COMM           PID    T BYTES   OFF_KB   LAT(ms) FILENAME
13:07:14 b'bash'       4754   R 256     0          7.11 b'vim'
13:07:14 b'vim'        4754   R 832     0          4.03 b'libgpm.so.2.1.0'
13:07:14 b'vim'        4754   R 32      20         1.04 b'libgpm.so.2.1.0'
13:07:14 b'vim'        4754   R 1982    0          2.30 b'vimrc'
13:07:14 b'vim'        4754   R 1393    0          2.52 b'getscriptPlugin.vim'
13:07:45 b'vim'        4754   S 0       0          6.71 b'text'
13:07:45 b'pool'       2588   R 16      0          5.58 b'text'
...
```

Each line represents an operation in the file system, which took more time than a certain threshold. **xfsslower** detects possible file system problems, which can take form of unexpectedly slow operations.

The **xfsslower** output displays the following fields:

COMM
: The process name. (**b'bash'**)

T
: The operation type. (**R**)

- **R**ead
- **W**rite
- **S**ync

OFF_KB
: The file offset in KB. (0)

FILENAME
: The file that is read, written, or synced.

To see more details, examples, and options for **xfsslower**, see **/usr/share/bcc/tools/doc/xfsslower_example.txt** file.

For more information about **fsync**, see **fsync(2)** manual pages.