Red Hat Enterprise Linux 8

Managing, monitoring, and updating the kernel

A guide to managing the Linux kernel on Red Hat Enterprise Linux 8

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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.

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MAKING OPEN SOURCE MORE INCLUSIVE

Red Hat is committed to replacing problematic language in our code, documentation, and web properties. We are beginning with these four terms: master, slave, blacklist, and whitelist. Because of the enormity of this endeavor, these changes will be implemented gradually over several upcoming releases. For more details, see our CTO Chris Wright's message .

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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 **YUM** package manager.

> **WARNING**
>
> Kernels that have not been 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

Contains the binary image of the kernel, all **initramfs**-related objects to bootstrap the system, and a minimal number of kernel modules to ensure core functionality. This sub-package alone could be used in virtualized and cloud environments to provide a Red Hat Enterprise Linux 8 kernel with a quick boot time and a small disk size footprint.

kernel-modules

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

The small set of **kernel** sub-packages above aims to provide a reduced maintenance surface to system administrators especially in virtualized and cloud environments.

Optional kernel packages are for example:

kernel-modules-extra

Contains kernel modules for rare hardware and modules which loading is disabled by default.

kernel-debug

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

kernel-tools

Contains tools for manipulating the Linux kernel and supporting documentation.

kernel-devel

Contains the kernel headers and makefiles sufficient to build modules against the **kernel** package.

kernel-abi-stablelists

Contains information pertaining to the RHEL kernel ABI, including a list of kernel symbols that are needed by external Linux kernel modules and a **yum** 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 that are needed for building most standard programs.

Additional resources

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

1.4. DISPLAYING CONTENTS OF A KERNEL PACKAGE

To determine if a kernel package provides a specific file, such as a module, you can display the file list of the package for your architecture by querying the repository. 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:

```
$ yum repoquery <package_name>
```

For example, list the available versions of the **kernel-core** package:

```
$ yum repoquery kernel-core
kernel-core-0:4.18.0-147.0.2.el8_1.x86_64
kernel-core-0:4.18.0-147.0.3.el8_1.x86_64
kernel-core-0:4.18.0-147.3.1.el8_1.x86_64
kernel-core-0:4.18.0-147.5.1.el8_1.x86_64
kernel-core-0:4.18.0-147.8.1.el8_1.x86_64
kernel-core-0:4.18.0-147.el8.x86_64
…
```

2. Display the list of files in a package:

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

For example, display the list of files in the **kernel-core-0:5.14.0-162.23.1.el9_1.x86_64** package.

```
$ yum repoquery -l kernel-core-0:4.18.0-147.8.1.el8_1.x86_64
/boot/.vmlinuz-4.18.0-147.8.1.el8_1.x86_64.hmac
/boot/System.map-4.18.0-147.8.1.el8_1.x86_64
/boot/config-4.18.0-147.8.1.el8_1.x86_64
/boot/initramfs-4.18.0-147.8.1.el8_1.x86_64.img
/boot/symvers-4.18.0-147.8.1.el8_1.x86_64.gz
/boot/vmlinuz-4.18.0-147.8.1.el8_1.x86_64
/etc/ld.so.conf.d/kernel-4.18.0-147.8.1.el8_1.x86_64.conf
/lib/modules
/lib/modules/4.18.0-147.8.1.el8_1.x86_64
...
```

Additional resources

- Packaging and distributing software

1.5. INSTALLING SPECIFIC KERNEL VERSIONS

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

Procedure

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

```
# yum install kernel-{version}
```

Additional resources

- *Red Hat Code Browser*
- *Red Hat Enterprise Linux Release Dates*

1.6. UPDATING THE KERNEL

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

Procedure

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

   ```
   # yum 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.

> **NOTE**
>
> When upgrading from RHEL 7 to RHEL 8, follow relevant sections of the *Upgrading from RHEL 7 to RHEL 8* document.

Additional resources

- Managing software packages

1.7. SETTING A KERNEL AS DEFAULT

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

Procedure

- Setting the kernel as default, 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, 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 RPM's, self-built kernels, and manually adding the entries to the **/boot/loader/entries/** directory may change the index values.

CHAPTER 2. MANAGING KERNEL MODULES

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

2.1. INTRODUCTION TO KERNEL MODULES

The Red Hat Enterprise Linux kernel can be extended with optional, additional pieces of functionality, called kernel modules, without having to reboot the system. On RHEL 8, kernel modules are extra kernel code which is 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.

Like the kernel itself, the modules can take parameters that customize their behavior if needed.

Tooling is provided to inspect which modules are currently running, which modules are available to load into the kernel and which parameters a module accepts. The tooling also provides a mechanism to load and unload kernel modules into the running kernel.

2.2. 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 respective kernel version.

depmod

The dependency file is generated by the **depmod** program, which is a part of the **kmod** package. Many of the utilities provided by **kmod** take module dependencies into account when performing operations so that **manual** dependency-tracking is rarely necessary.

> **WARNING**
>
> The code of kernel modules is executed in kernel-space in the unrestricted mode. Because of this, you should be mindful of what modules you are loading.

weak-modules

In addition to **depmod**, Red Hat Enterprise Linux provides the **weak-modules** script shipped also with the **kmod** package. **weak-modules** determines which modules 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. This means that **weak-modules** processes each module independently of kernel release they were built against.

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)?

2.3. 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 (4.18.0-20.el8.x86_64) 8.0 (Ootpa)
title=Red Hat Enterprise Linux (4.18.0-19.el8.x86_64) 8.0 (Ootpa)
title=Red Hat Enterprise Linux (4.18.0-12.el8.x86_64) 8.0 (Ootpa)
title=Red Hat Enterprise Linux (4.18.0) 8.0 (Ootpa)
title=Red Hat Enterprise Linux (0-rescue-2fb13ddde2e24fde9e6a246a942caed1) 8.0 (Ootpa)
```

The above example displays the installed kernels list of grubby-8.40-17, from the GRUB menu.

2.4. 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

2.5. LISTING ALL INSTALLED KERNELS

Use the **grubby** utility to list all installed kernels on your system.

Prerequisites

- You have root permissions.

Procedure

- To list all installed kernels, enter:

```
# grubby --info=ALL | grep ^kernel

kernel="/boot/vmlinuz-4.18.0-305.10.2.el8_4.x86_64"
kernel="/boot/vmlinuz-4.18.0-240.el8.x86_64"
kernel="/boot/vmlinuz-0-rescue-41eb2e172d7244698abda79a51778f1b"
```

The output displays path to all the installed kernels, and displays also their respective versions.

2.6. 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/4.18.0-94.el8.x86_64/kernel/drivers/net/virtio_net.ko.xz
  license:        GPL
  description:    Virtio network driver
  rhelversion:    8.1
  srcversion:     2E9345B281A898A91319773
  alias:          virtio:d00000001v*
  depends:        net_failover
  intree:         Y
  name:           virtio_net
  vermagic:       4.18.0-94.el8.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 or not. 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

2.7. 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 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

2.8. UNLOADING KERNEL MODULES AT SYSTEM RUNTIME

At times, you find that you need 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**
>
> Do not unload kernel modules when they are used by the running system. Doing so can lead to an unstable or non-operational system.

IMPORTANT

After finishing this procedure, the kernel modules that are defined to be automatically loaded on boot, **will not stay unloaded** after rebooting the system. For information about how to counter this outcome, see Preventing kernel modules from being automatically loaded at system boot time.

Prerequisites

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

Procedure

1. List all 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 was unloaded successfully, this command does not display any output.

Additional resources

- **modprobe(8)** manual page

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

In certain situations, it is necessary to unload a kernel module very early in the booting process. For example, when the kernel module contains a code, which causes the system to become unresponsive, and the user is not able to reach the stage to permanently disable the rogue kernel module. In that case it is possible to temporarily block the loading of the kernel module using a boot loader.

You can edit the relevant boot loader entry to unload the desired 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.

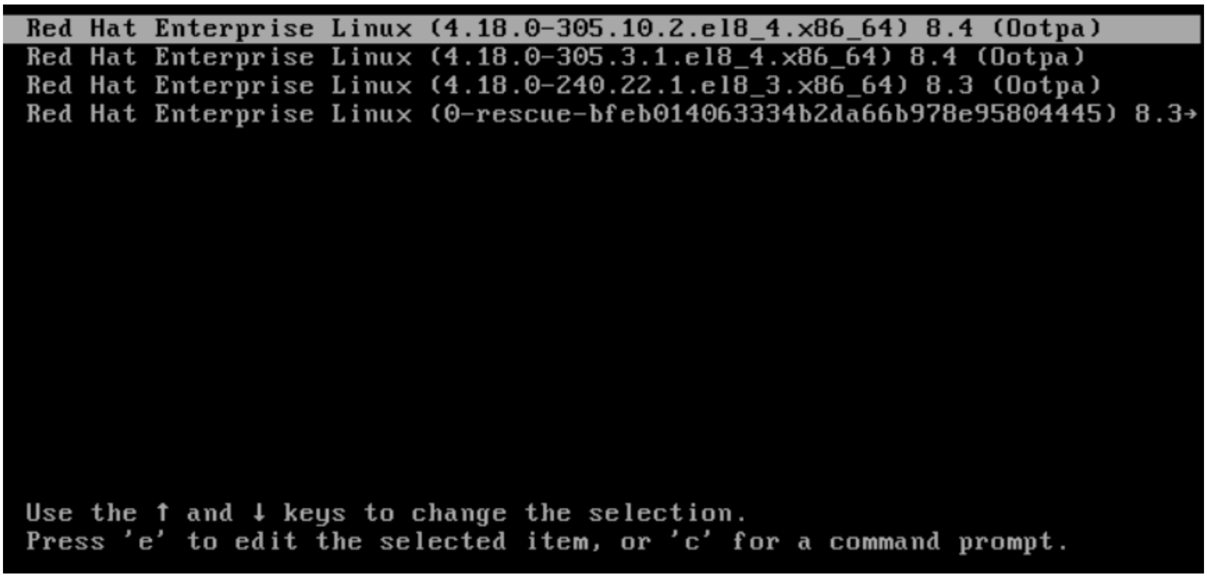
Prerequisites

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

Procedure

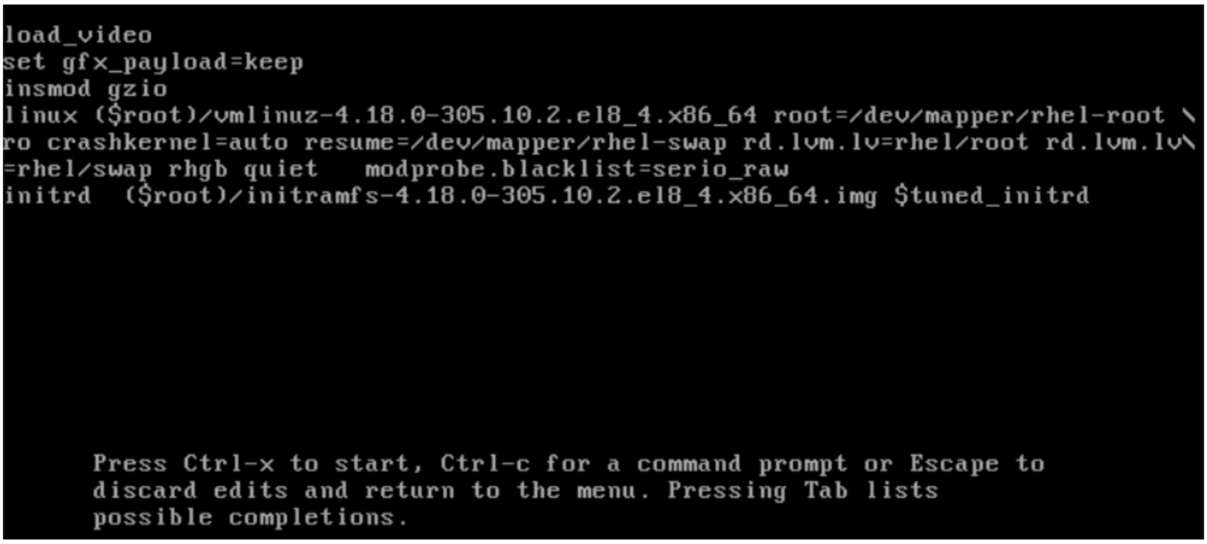
1. Boot the system into the boot loader.
2. Use the cursor keys to highlight the relevant boot loader entry.
3. Press the **e** key to edit the entry.

Figure 2.1. 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 2.2. 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

- Once the system fully boots, verify that the relevant kernel module is not loaded.

```
# lsmod | grep serio_raw
```

Additional resources

- Managing kernel modules

2.10. LOADING KERNEL MODULES AUTOMATICALLY AT SYSTEM BOOT TIME

Configure a kernel module so that it is loaded 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.

3. Optionally, after reboot, verify the relevant module was loaded:

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

   The example command above should succeed and display the relevant kernel module.

IMPORTANT

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

Additional resources

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

2.11. 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 being 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 being 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? solution article
- **modprobe.d(5)** and **dracut(8)** man pages

2.12. 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"); }
```

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 to be shared between 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 that the compiler has to produce an object file specifically 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 would 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/4.18.0-305.el8.x86_64'
  CC [M]  /root/testmodule/test.o
  Building modules, stage 2.
  MODPOST 1 modules
WARNING: modpost: missing MODULE_LICENSE() in /root/testmodule/test.o
see include/linux/module.h for more information
  CC      /root/testmodule/test.mod.o
  LD [M]  /root/testmodule/test.ko
make: Leaving directory '/usr/src/kernels/4.18.0-305.el8.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/4.18.0-305.el8.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
```

Additional resources

- Managing kernel modules

CHAPTER 3. 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 8 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 8 to install, boot, and run with the Microsoft UEFI Secure Boot Certification Authority keys that 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.

3.1. PREREQUISITES

- To be able to sign externally built kernel modules, install the utilities from the following packages:

```
# yum install pesign openssl kernel-devel mokutil keyutils
```

Table 3.1. 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

3.2. 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 has not been signed by a trusted key. The system boot loader is signed with a cryptographic key. The database of public keys, which is contained in the firmware, authorizes the signing 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, 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.

3.3. UEFI SECURE BOOT SUPPORT

You can install and run RHEL 8 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 them to be loaded constitutes execution of untrusted code inside the security perimeter that Secure Boot defines.
- Red Hat provides a signed GRUB binary that contains all the supported modules on RHEL 8.

Additional resources

- Restrictions Imposed by UEFI Secure Boot

3.4. REQUIREMENTS FOR AUTHENTICATING KERNEL MODULES WITH X.509 KEYS

In RHEL 8, 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 contains 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 3.2. 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

3.5. 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 3.3. 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

Source of X.509 keys	User can add keys	UEFI Secure Boot state	Keys loaded during boot
		Enabled	**.platform**
Machine Owner Key (MOK) list	Yes	Not enabled	No
		Enabled	**.platform**

.builtin_trusted_keys

- A keyring that is built on boot
- Contains trusted public keys
- **root** privileges are needed to view the keys

.platform

- A keyring that is built on boot
- Contains keys from third-party platform providers and custom public keys
- **root** privileges are needed 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 being loaded
- The revoked keys from this database are added to the **.blacklist** keyring

3.6. 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 8 regardless of the validity dates.

Additional resources

- **openssl(1)** manual page
- *RHEL Security Guide*
- Enrolling public key on target system by adding the public key to the MOK list

3.7. 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 3.1. Keyrings output

The following is a shortened example output of **.builtin_trusted_keys**, **.platform**, and **.blacklist** keyrings from a RHEL 8 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 3.2. 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

3.8. ENROLLING PUBLIC KEY ON TARGET SYSTEM BY ADDING THE PUBLIC KEY TO THE MOK LIST

You must enroll your public key on all systems where you want to authenticate and load your kernel or kernel modules. You can import the public key on a target system in different ways so that the platform keyring (**.platform**) is able to use the public key to authenticate the kernel or kernel modules.

When RHEL 8 boots on a UEFI-based system with Secure Boot enabled, the kernel loads onto the platform keyring (**.platform**) all public keys that are in the Secure Boot **db** key database. At the same time, the kernel excludes the keys in the **dbx** database of revoked keys.

You can use the Machine Owner Key (MOK) facility feature to expand the UEFI Secure Boot key database. When RHEL 8 boots on an UEFI-enabled system with Secure Boot enabled, the keys on the MOK list are also added to the platform keyring (**.platform**) in addition to the keys from the key database. The MOK list keys are also stored persistently and securely in the same fashion as the Secure Boot database keys, but these are two separate facilities. The MOK facility is supported by **shim**, **MokManager**, **GRUB**, and the **mokutil** utility.

> **NOTE**
>
> To facilitate authentication 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.

3.9. 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*
  ```

3.10. 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
```

3.11. 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 you, 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 \
        -nodes
```

IMPORTANT

Handle the unencrypted private key with care.

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 8, 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 2019 can be used to authenticate a kernel module signed in 2019 with that key. However, users cannot use that key to sign a kernel module in 2020.

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

3.12. LOADING SIGNED KERNEL MODULES

Once your public key is enrolled in the system keyring (**.builtin_trusted_keys**) and the MOK list, and after you have signed the respective kernel module with your private key, you can load your signed kernel module with 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:

```
# yum -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. Optionally, 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 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 have full control over what options get set at boot. Certain kernel behaviors can only be set at boot time, so understanding how to make these changes is a key administration skill.

> **IMPORTANT**
>
> Changing the behavior of the system by modifying kernel command-line parameters may have negative effects on your system. Always test changes prior to 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 **kernelopts** variable of the **/boot/grub2/grubenv** file for each kernel boot entry.

> **NOTE**
>
> For IBM Z, the kernel command-line parameters are stored in the boot entry configuration file because the **zipl** boot loader does not support environment variables. Thus, the **kernelopts** environment variable cannot be used.

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 which are 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 and can look like this:

```
6f9cc9cb7d7845d49698c9537337cedc-4.18.0-5.el8.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 **kernelopts** environment variable, which contains the kernel command-line parameters. The example contents of a boot entry config can be seen below:

```
title Red Hat Enterprise Linux (4.18.0-74.el8.x86_64) 8.0 (Ootpa)
version 4.18.0-74.el8.x86_64
linux /vmlinuz-4.18.0-74.el8.x86_64
initrd /initramfs-4.18.0-74.el8.x86_64.img $tuned_initrd
options $kernelopts $tuned_params
id rhel-20190227183418-4.18.0-74.el8.x86_64
grub_users $grub_users
grub_arg --unrestricted
grub_class kernel
```

The **kernelopts** environment variable is defined in the **/boot/grub2/grubenv** file.

Additional resources

- How to install and boot custom kernels in Red Hat Enterprise Linux 8

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

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

Prerequisites

- Verify that the **grubby** utility is installed on your system.
- Verify that the **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, the command updates the **/boot/grub2/grubenv** file by adding a new kernel parameter to the **kernelopts** variable in that 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
```

> **NOTE**
>
> Newly installed kernels inherit the kernel command-line parameters from your previously configured kernels.

Additional resources

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

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

- Verify that the **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
```

> **NOTE**
>
> On systems that use the **grub.cfg** file, there is, by default, the **options** parameter for each kernel boot entry, which is set to the **kernelopts** variable. This variable is defined in the /**boot/grub2/grubenv** configuration file.

IMPORTANT

On GRUB2 systems:

- If the kernel command-line parameters are modified for all boot entries, the **grubby** utility updates the **kernelopts** variable in the **/boot/grub2/grubenv** file.
- If kernel command-line parameters are modified for a single boot entry, the **kernelopts** variable is expanded, the kernel parameters are modified, and the resulting value is stored in the respective boot entry's **/boot/loader/entries/<RELEVANT_KERNEL_BOOT_ENTRY.conf>** file.

On zIPL systems:

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

Additional resources

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

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 2 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-4.18.0-348.12.2.el8_5.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 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/efi/EFI/redhat/grub.cfg
```

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

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 may render the kernel unstable, requiring a system reboot. Verify that you are using valid options before changing any kernel values.

5.1. WHAT ARE KERNEL PARAMETERS

Kernel parameters are tunable values which you can adjust while the system is running. There is no requirement to reboot or recompile the kernel for changes to take effect.

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)
user	User Namespace limits

Tunable class	Subsystem
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
- Configuring kernel parameters permanently with sysctl
- 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

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

Prerequisites

- 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, to apply changes without rebooting, enter:

     ```
     # 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 command makes configuration changes that will disappear once the system is restarted.

3. Optionally, verify the value of the newly set kernel parameter.

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

Additional resources

- Configuring kernel parameters permanently with sysctl
- Using configuration files in /etc/sysctl.d/ to adjust kernel parameters

5.6. ADDITIONAL RESOURCES

- Tuning Red Hat Enterprise Linux for IBM DB2

CHAPTER 6. MAKING TEMPORARY CHANGES TO THE GRUB MENU

You can modify GRUB menu entries or pass arguments to the kernel, which applies only to the current boot. On a selected menu entry in the boot loader menu, you can:

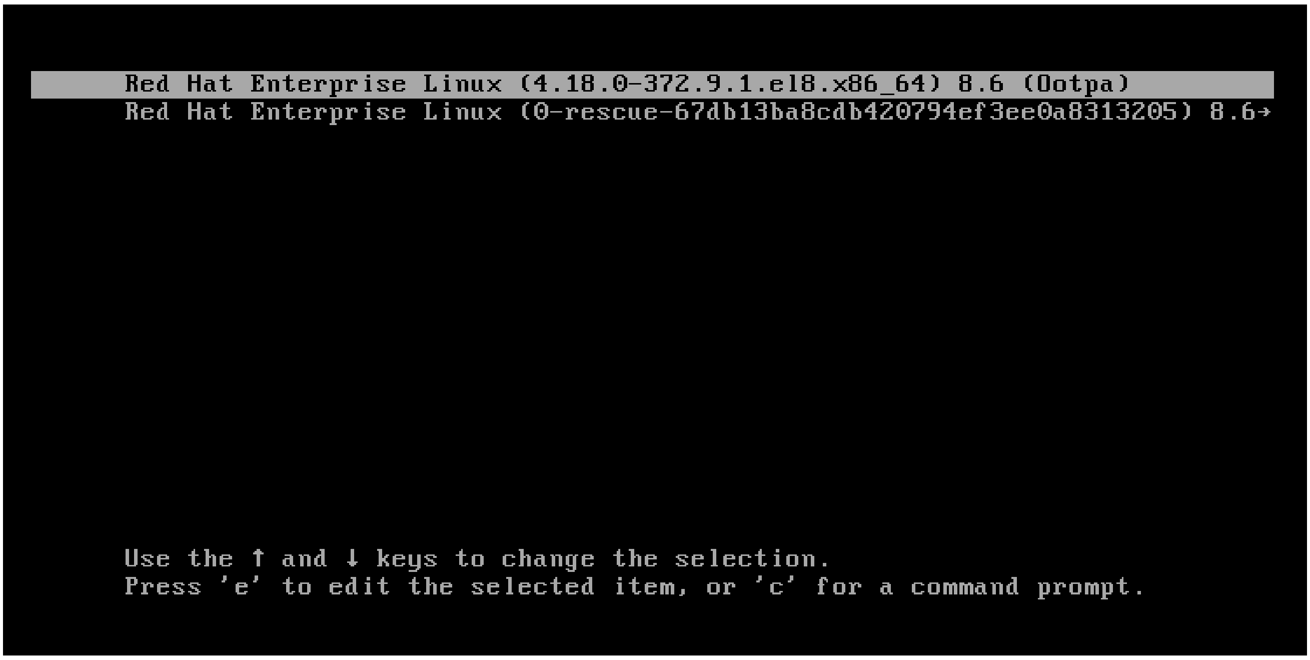
- display the menu entry editor interface by pressing the **e** key.
- discard any changes and reload the standard menu interface by pressing the **Esc** key.
- load the command-line interface by pressing the **c** key.
- type any relevant GRUB commands and enter them by pressing the **Enter** key.
- complete a command based on context by pressing the **Tab** key.
- move to the beginning of a line by pressing the **Ctrl**+**a** key combination.
- move to the end of a line by pressing the **Ctrl**+**e** key combination.

> **IMPORTANT**
>
> The following procedures provide instruction on making changes to a GRUB Menu during a single boot process.

6.1. INTRODUCTION TO GRUB

GRUB stands for the **GNU GRand Unified Bootloader**. With GRUB, you can select an operating system or kernel to be loaded at system boot time. Also, you can pass arguments to the kernel.

When booting with GRUB, you can use either a menu interface or a command-line interface (the **GRUB command shell**). When you start the system, the menu interface appears.



You can switch to the command-line interface by pressing the **c** key.

You can return to the menu interface by typing exit and pressing the Enter key.

GRUB BLS files

The boot loader menu entries are defined as Boot Loader Specification (**BLS**) files. This file format manages boot loader configuration for each boot option in a drop-in directory, without manipulating boot loader configuration files. The **grubby** utility can edit these **BLS** files.

GRUB configuration file

The **/boot/grub2/grub.cfg** configuration file does not define the menu entries.

Additional resources

- Boot menu
- Introduction to bootloader specification

6.2. INTRODUCTION TO BOOTLOADER SPECIFICATION

The BootLoader Specification (BLS) defines a scheme and the file format to manage the bootloader configuration for each boot option in the drop-in directory without the need to manipulate the bootloader configuration files. Unlike earlier approaches, each boot entry is now represented by a separate configuration file in the drop-in directory. The drop-in directory extends its configuration without having the need to edit or regenerate the configuration files. The BLS extends this concept for the boot menu entries.

Using BLS, you can manage the bootloader menu options by adding, removing, or editing individual boot entry files in a directory. This makes the kernel installation process significantly simpler and consistent across the different architectures.

The **grubby** tool is a thin wrapper script around the BLS and it supports the same **grubby** arguments and options. It runs the **dracut** to create an initial ramdisk image. With this setup, the core bootloader configuration files are static and are not modified after kernel installation.

This premise is particularly relevant in RHEL 8, because the same bootloader is not used in all architectures. GRUB is used in most of them such as the 64-bit ARM, but little-endian variants of IBM Power Systems with Open Power Abstraction Layer (OPAL) uses **Petitboot** and the IBM Z architecture uses **zipl**.

Additional Resources

- Section 4.2, “Understanding boot entries”
- the **grubby(8)** manual page

6.3. BOOTING TO RESCUE MODE

Rescue mode provides a convenient single-user environment in which you can repair your system in situations when it is unable to complete a normal booting process. In rescue mode, the system attempts to mount all local file systems and start some important system services. However, it does not activate network interfaces or allow more users to be logged into the system at the same time.

Procedure

1. On the GRUB boot screen, press the **e** key for edit.
2. Add the following parameter at the end of the **linux** line:

```
systemd.unit=rescue.target
```

```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-4.18.0-372.9.1.el8.x86_64 root=/dev/mapper/rhel-root ro \
crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rh\
el/swap  rhgb quiet zswap.enabled=0 systemd.unit=rescue.target_
initrd  ($root)/initramfs-4.18.0-372.9.1.el8.x86_64.img $tuned_initrd
```

3. Press **Ctrl**+**x** to boot to rescue mode.

```
You are in rescue mode. After logging in, type "journalctl -xb" to view
system logs, "systemctl reboot" to reboot, "systemctl default" or "exit"
to boot into default mode.
Give root password for maintenance
(or press Control-D to continue):
```

6.4. BOOTING TO EMERGENCY MODE

Emergency mode provides the most minimal environment possible in which you can repair your system even in situations when the system is unable to enter rescue mode.

In emergency mode, the system:

- mounts the **root** file system only for reading
- starts a few essential services

However, the system **does not**:

- attempt to mount any other local file systems
- activate network interfaces

Procedure

1. On the GRUB boot screen, press the **e** key for edit.
2. Add the following parameter at the end of the **linux** line:

```
systemd.unit=emergency.target
```

```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-4.18.0-372.9.1.el8.x86_64 root=/dev/mapper/rhel-root ro \
crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rh\
el/swap  rhgb quiet zswap.enabled=0 systemd.unit=emergency.target
initrd  ($root)/initramfs-4.18.0-372.9.1.el8.x86_64.img $tuned_initrd
```

3. Press **Ctrl**+**x** to boot to emergency mode.

```
You are in emergency mode. After logging in, type "journalctl -xb" to view
system logs, "systemctl reboot" to reboot, "systemctl default" or "exit"
to boot into default mode.
Give root password for maintenance
(or press Control-D to continue): _
```

6.5. BOOTING TO THE DEBUG SHELL

The **systemd** debug shell provides a shell very early in the start-up process. Once in the debug shell, you can use the **systemctl** commands, such as **systemctl list-jobs** and **systemctl list-units**, to search for the cause of **systemd** related boot-up problems.

Procedure

1. On the GRUB boot screen, press the **e** key for edit.

2. Add the following parameter at the end of the **linux** line:

```
systemd.debug-shell
```

```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-4.18.0-372.9.1.el8.x86_64 root=/dev/mapper/rhel-root ro \
crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root rd.lvm.lv=rh\
el/swap  rhgb quiet systemd.debug-shell_
initrd  ($root)/initramfs-4.18.0-372.9.1.el8.x86_64.img $tuned_initrd
```

3. Optionally add the **debug** option.

> **NOTE**
>
> Adding the **debug** option to the kernel command line increases the number of log messages. For **systemd**, the kernel command-line option **debug** is now a shortcut for **systemd.log_level=debug**.

4. Press **Ctrl**+**x** to boot to the debug shell.

> **WARNING**
>
> Permanently enabling the debug shell is a security risk because no authentication is required to use it. Disable it when the debugging session has ended.

6.6. CONNECTING TO THE DEBUG SHELL

During the boot process, the **systemd-debug-generator** configures the debug shell on TTY9.

Prerequisites

- You have booted to the debug shell successfully. See Booting to the debug shell.

Procedure

1. Press **Ctrl**+**Alt**+**F9** to connect to the debug shell.
   If you work with a virtual machine, sending this key combination requires support from the virtualization application. For example, if you use **Virtual Machine Manager**, select **Send Key → Ctrl+Alt+F9** from the menu.

2. The debug shell does not require authentication, therefore you can see a prompt similar to the following on TTY9:

```
sh-4.4#
```

Verification steps

- Enter a command as follows:

```
sh-4.4# systemctl status $$
```

```
sh-4.4# systemctl status $$
● debug-shell.service - Early root shell on /dev/tty9 FOR DEBUGGING ONLY
   Loaded: loaded (/usr/lib/systemd/system/debug-shell.service; enabled-runtime; vendor preset: disabled)
   Active: active (running) since Tue 2022-08-02 08:40:09 EDT; 45s ago
     Docs: man:systemd-debug-generator(8)
 Main PID: 735 (sh)
    Tasks: 3 (limit: 17257)
   Memory: 2.3M
   CGroup: /system.slice/debug-shell.service
           ├─ 735 /bin/sh
           ├─2092 systemctl status 735
           └─2093 less
sh-4.4#
```

- To return to the default shell, if the boot succeeded, press **Ctrl**+**Alt**+**F1**.

Additional resources

- The **systemd-debug-generator(8)** manual page

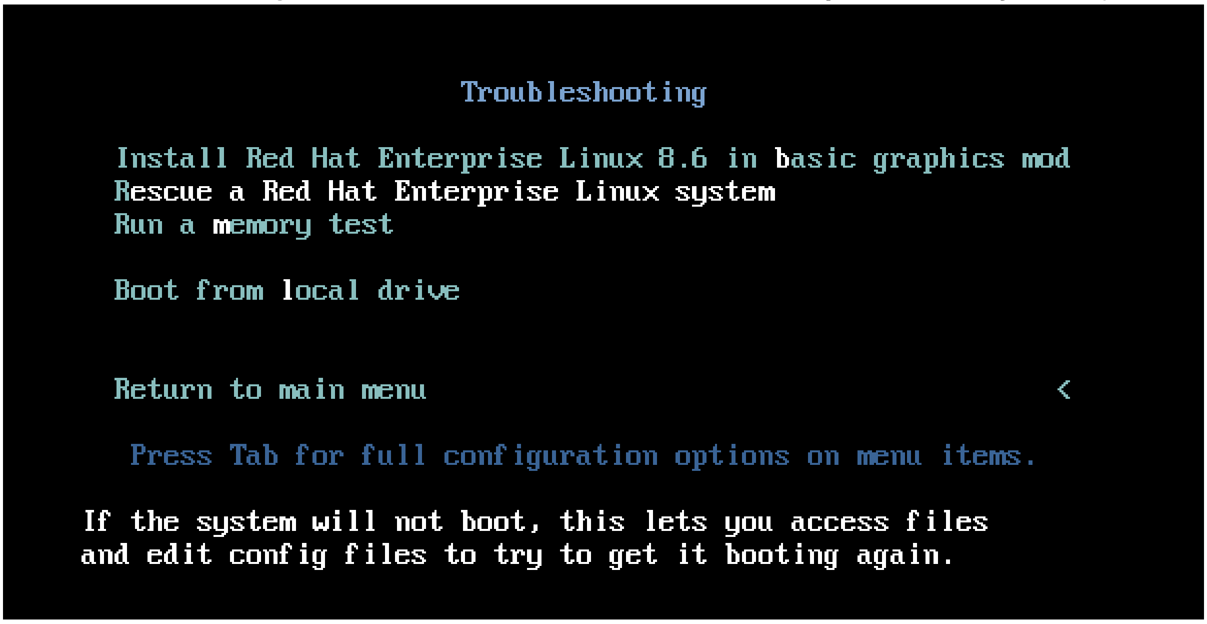
6.7. RESETTING THE ROOT PASSWORD USING AN INSTALLATION DISK

In case you forget or lose the **root** password, you can reset it.

Procedure

1. Boot the host from an installation source.
2. In the boot menu for the installation media, select the **Troubleshooting** option.

3. In the Troubleshooting menu, select the **Rescue a Red Hat Enterprise Linux system** option.



4. At the Rescue menu, select **1** and press the **Enter** key to continue.

```
================================================================================
Rescue

The rescue environment will now attempt to find your Linux installation and
mount it under the directory : /mnt/sysroot.  You can then make any changes
required to your system.  Choose '1' to proceed with this step.
You can choose to mount your file systems read-only instead of read-write by
choosing '2'.
If for some reason this process does not work choose '3' to skip directly to a
shell.

1) Continue
2) Read-only mount
3) Skip to shell
4) Quit (Reboot)

Please make a selection from the above: 1_
```

5. Change the file system **root** as follows:

```
sh-4.4# chroot /mnt/sysimage
```

```
When finished, please exit from the shell and your system will reboot.
Please press ENTER to get a shell:
sh-4.4# chroot /mnt/sysimage
bash-4.4#









[anaconda]1:main* 2:shell  3:log  4:storage-log  5:program-log
```

6. Enter the **passwd** command and follow the instructions displayed on the command line to change the **root** password.

```
bash-4.4# passwd
Changing password for user root.
New password:
Retype new password:
passwd: all authentication tokens updated successfully.
bash-4.4#


[anaconda]1:main* 2:shell  3:log  4:storage-log  5:program-log
```

7. Remove the **autorelable** file to prevent a time consuming SELinux relabel of the disk:

```
sh-4.4# rm -f /.autorelabel
```

8. Enter the **exit** command to exit the **chroot** environment.

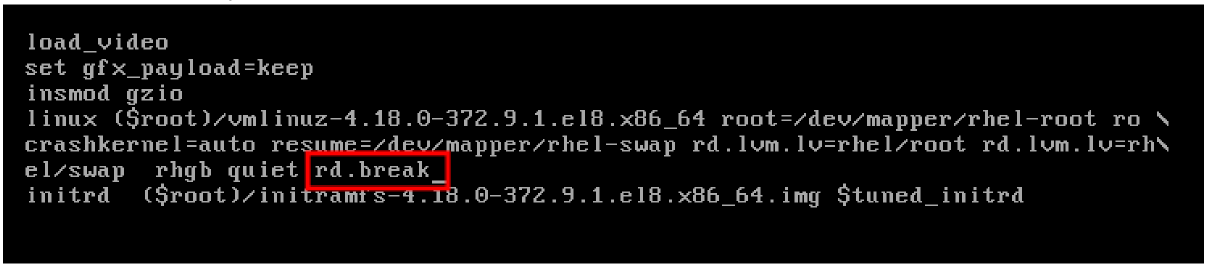
9. Enter the **exit** command again to resume the initialization and finish the system boot.

6.8. RESETTING THE ROOT PASSWORD USING RD.BREAK

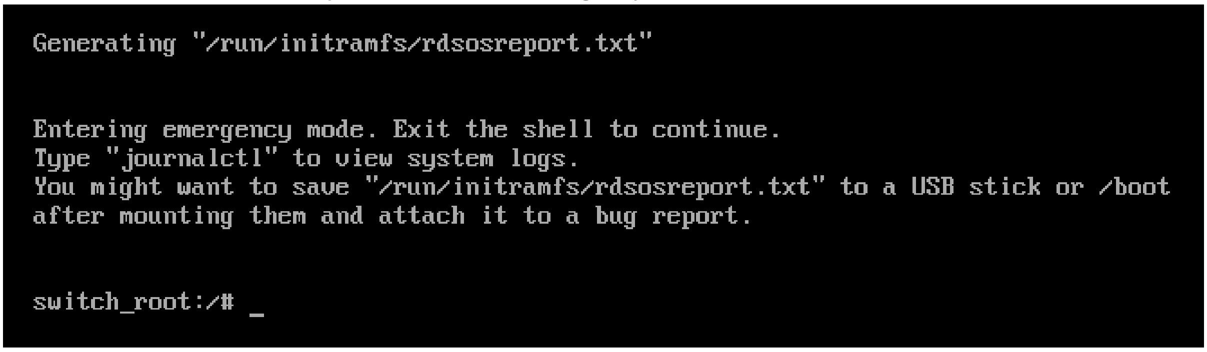
In case you forget or lose the **root** password, you can reset it.

Procedure

1. Start the system and, on the GRUB boot screen, press the **e** key for edit.
2. Add the **rd.break** parameter at the end of the **linux** line:



3. Press **Ctrl**+**x** to boot the system with the changed parameters.



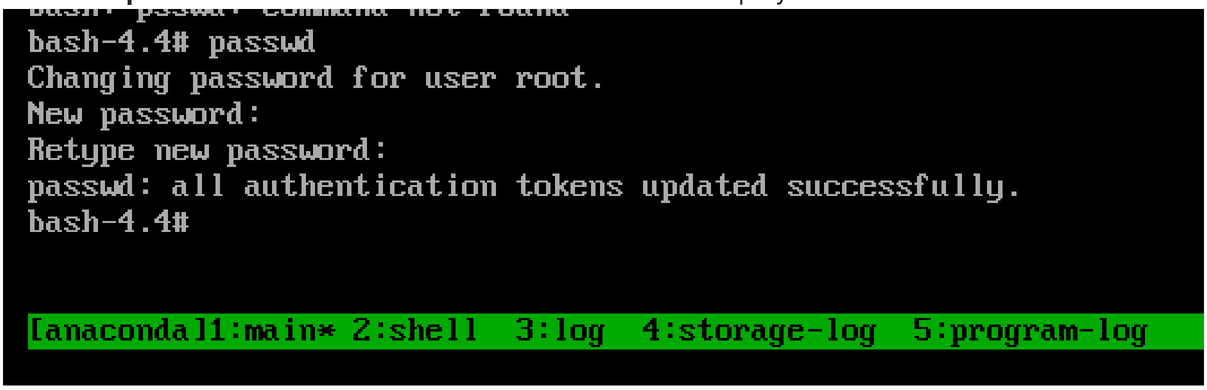
4. Remount the file system as writable.

```
switch_root:/# mount -o remount,rw /sysroot
```

5. Change the file system's **root**.

```
switch_root:/# chroot /sysroot
```

6. Enter the **passwd** command and follow the instructions displayed on the command line.



7. Relabel all files on the next system boot.

```
sh-4.4# touch /.autorelabel
```

8. Remount the file system as **read only**:

```
sh-4.4# mount -o remount,ro /
```

9. Enter the **exit** command to exit the **chroot** environment.

10. Enter the **exit** command again to resume the initialization and finish the system boot.

> **NOTE**
>
> The SELinux relabeling process can take a long time. A system reboot occurs automatically when the process is complete.

TIP

You can omit the time consuming SELinux relabeling process by adding the **enforcing=0** option.

Procedure

1. When adding the **rd.break** parameter at the end of the **linux** line, append **enforcing=0** as well.

```
rd.break enforcing=0
```

2. Restore the **/etc/shadow** file's SELinux security context.

```
# restorecon /etc/shadow
```

3. Turn SELinux policy enforcement back on and verify that it is on.

```
# setenforce 1
# getenforce
Enforcing
```

Note that if you added the **enforcing=0** option in step 3 you can omit entering the **touch /.autorelabel** command in step 8.

6.9. ADDITIONAL RESOURCES

- The **/usr/share/doc/grub2-common** directory.
- The **info grub2** command.

CHAPTER 7. MAKING PERSISTENT CHANGES TO THE GRUB BOOT LOADER

Use the **grubby** tool to make persistent changes in GRUB.

7.1. PREREQUISITES

- You have successfully installed RHEL on your system.
- You have root permission.

7.2. LISTING THE DEFAULT KERNEL

By listing the default kernel, you can find the file name and the index number of the default kernel to make permanent changes to the GRUB boot loader.

Procedure

- To find out the file name of the default kernel, enter:

```
# grubby --default-kernel
/boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
```

- To find out the index number of the default kernel, enter:

```
# grubby --default-index
0
```

7.3. VIEWING THE GRUB MENU ENTRY FOR A KERNEL

You can list all the kernel menu entries or view the GRUB menu entry for a specific kernel.

Procedure

- To list all kernel menu entries, enter:

```
# grubby --info=ALL
index=0
kernel="/boot/vmlinuz-4.18.0-372.9.1.el8.x86_64"
args="ro crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root
rd.lvm.lv=rhel/swap rhgb quiet $tuned_params zswap.enabled=1"
root="/dev/mapper/rhel-root"
initrd="/boot/initramfs-4.18.0-372.9.1.el8.x86_64.img $tuned_initrd"
title="Red Hat Enterprise Linux (4.18.0-372.9.1.el8.x86_64) 8.6 (Ootpa)"
id="67db13ba8cdb420794ef3ee0a8313205-4.18.0-372.9.1.el8.x86_64"
index=1
kernel="/boot/vmlinuz-0-rescue-67db13ba8cdb420794ef3ee0a8313205"
args="ro crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root
rd.lvm.lv=rhel/swap rhgb quiet"
root="/dev/mapper/rhel-root"
initrd="/boot/initramfs-0-rescue-67db13ba8cdb420794ef3ee0a8313205.img"
```

```
title="Red Hat Enterprise Linux (0-rescue-67db13ba8cdb420794ef3ee0a8313205) 8.6
(Ootpa)"
id="67db13ba8cdb420794ef3ee0a8313205-0-rescue"
```

- To view the GRUB menu entry for a specific kernel, enter:

```
# grubby --info /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
grubby --info /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
index=0
kernel="/boot/vmlinuz-4.18.0-372.9.1.el8.x86_64"
args="ro crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root
rd.lvm.lv=rhel/swap rhgb quiet $tuned_params zswap.enabled=1"
root="/dev/mapper/rhel-root"
initrd="/boot/initramfs-4.18.0-372.9.1.el8.x86_64.img $tuned_initrd"
title="Red Hat Enterprise Linux (4.18.0-372.9.1.el8.x86_64) 8.6 (Ootpa)"
id="67db13ba8cdb420794ef3ee0a8313205-4.18.0-372.9.1.el8.x86_64"
```

NOTE

Try tab completion to see available kernels within the **/boot** directory.

7.4. EDITING A KERNEL ARGUMENT

You can change a value in an existing kernel argument. For example, you can change the virtual console (screen) font and size.

Procedure

- Change the virtual console font to **latarcyrheb-sun** with the size of **32**.

```
# grubby --args=vconsole.font=latarcyrheb-sun32 --update-kernel /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
```

7.5. ADDING AND REMOVING ARGUMENTS FROM A GRUB MENU ENTRY

You can add, remove, or simultaneously add and remove arguments from the GRUB Menu.

Procedure

- To add arguments to a GRUB menu entry, use the **--update-kernel** option in combination with **--args**. For example, following command adds a serial console:

```
# grubby --args=console=ttyS0,115200 --update-kernel /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
```

  The console arguments are attached to the end of the line, the new console will take precedence over any other configured consoles.

- To remove arguments from a GRUB menu entry, use the **--update-kernel** option in combination with **--remove-args**. For example:

```
# grubby --remove-args="rhgb quiet" --update-kernel /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
```

This command removes the Red Hat graphical boot argument and enables log messages, that is verbose mode.

- To add and remove arguments simultaneously, enter:

```
# grubby --remove-args="rhgb quiet" --args=console=ttyS0,115200 --update-kernel /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
```

Verification steps

- To review the permanent changes you have made, enter:

```
# grubby --info /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
index=0
kernel="/boot/vmlinuz-4.18.0-372.9.1.el8.x86_64"
args="ro crashkernel=auto resume=/dev/mapper/rhel-swap rd.lvm.lv=rhel/root
rd.lvm.lv=rhel/swap $tuned_params zswap.enabled=1 console=ttyS0,115200"
root="/dev/mapper/rhel-root"
initrd="/boot/initramfs-4.18.0-372.9.1.el8.x86_64.img $tuned_initrd"
title="Red Hat Enterprise Linux (4.18.0-372.9.1.el8.x86_64) 8.6 (Ootpa)"
id="67db13ba8cdb420794ef3ee0a8313205-4.18.0-372.9.1.el8.x86_64"
```

7.6. ADDING A NEW BOOT ENTRY

You can add a new boot entry to the bootloader menu entries.

Procedure

1. Copy all the kernel arguments from your default kernel to this new kernel entry.

```
# grubby --add-kernel=new_kernel --title="entry_title" --initrd="new_initrd" --copy-default
```

2. Get the list of available boot entries.

```
# ls -l /boot/loader/entries/*
-rw-r--r--. 1 root root 408 May 27 06:18
/boot/loader/entries/67db13ba8cdb420794ef3ee0a8313205-0-rescue.conf
-rw-r--r--. 1 root root 536 Jun 30 07:53
/boot/loader/entries/67db13ba8cdb420794ef3ee0a8313205-4.18.0-372.9.1.el8.x86_64.conf
-rw-r--r--  1 root root 336 Aug 15 15:12
/boot/loader/entries/d88fa2c7ff574ae782ec8c4288de4e85-4.18.0-193.el8.x86_64.conf
```

3. Create a new boot entry. For example, for the *4.18.0-193.el8.x86_64* kernel, issue the command as follows:

```
# grubby --grub2 --add-kernel=/boot/vmlinuz-4.18.0-193.el8.x86_64 --title="Red Hat Enterprise 8 Test" --initrd=/boot/initramfs-4.18.0-193.el8.x86_64.img --copy-default
```

Verification

Verification

- Verify that the newly added boot entry is listed among the available boot entries.

```
# ls -l /boot/loader/entries/*
-rw-r--r--. 1 root root 408 May 27 06:18
/boot/loader/entries/67db13ba8cdb420794ef3ee0a8313205-0-rescue.conf
-rw-r--r--. 1 root root 536 Jun 30 07:53
/boot/loader/entries/67db13ba8cdb420794ef3ee0a8313205-4.18.0-372.9.1.el8.x86_64.conf
-rw-r--r-- 1 root root 287 Aug 16 15:17
/boot/loader/entries/d88fa2c7ff574ae782ec8c4288de4e85-4.18.0-
193.el8.x86_64.0~custom.conf
-rw-r--r--  1 root root 287 Aug 16 15:29
/boot/loader/entries/d88fa2c7ff574ae782ec8c4288de4e85-4.18.0-193.el8.x86_64.conf
```

7.7. CHANGING THE DEFAULT BOOT ENTRY WITH GRUBBY

With the **grubby** tool, you can change the default boot entry.

Procedure

- To make a persistent change in the kernel designated as the default kernel, enter:

```
# grubby --set-default /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
The default is /boot/loader/entries/67db13ba8cdb420794ef3ee0a8313205-4.18.0-
372.9.1.el8.x86_64.conf with index 0 and kernel /boot/vmlinuz-4.18.0-372.9.1.el8.x86_64
```

7.8. UPDATING ALL KERNEL MENUS WITH THE SAME ARGUMENTS

You can add the same kernel boot arguments to all the kernel menu entries.

Procedure

- To add the same kernel boot arguments to all the kernel menu entries, attach the **--update-kernel=ALL** parameter. For example, this command adds a serial console to all kernels:

```
# grubby --update-kernel=ALL --args=console=ttyS0,115200
```

> **NOTE**
>
> The **--update-kernel** parameter also accepts **DEFAULT** or a comma-separated list of kernel index numbers.

7.9. CHANGING DEFAULT KERNEL OPTIONS FOR CURRENT AND FUTURE KERNELS

By using the **kernelopts** variable, you can change the default kernel options for both current and future kernels.

Procedure

1. List the kernel parameters from the **kernelopts** variable:

```
# grub2-editenv - list | grep kernelopts
kernelopts=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
```

2. Make the changes to the kernel command-line parameters. You can add, remove or modify a parameter. For example, to add the **debug** parameter, enter:

```
# grub2-editenv - set "$(grub2-editenv - list | grep kernelopts) <debug>"
```

3. *Optional*: verify that the newly added parameter has been added to **kernelopts**:

```
# grub2-editenv - list | grep kernelopts
kernelopts=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 debug
```

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

NOTE

As an alternative, you can use the **grubby** command to pass the arguments to current and future kernels:

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

7.10. ADDITIONAL RESOURCES

- The **/usr/share/doc/grub2-common** directory.
- The **info grub2** command.

CHAPTER 8. BUILDING A CUSTOMIZED BOOT MENU

You can build a boot menu containing specific entries or change the order of the entries. For such a task, you can use GRUB, **grubby**, and Boot Loader Specification (**BLS**) files.

The following sections provide information about using GRUB and **grubby** to do basic customization of the boot menu.

8.1. THE GRUB CONFIGURATION FILE

Learn about the boot loader configuration file that is **/boot/grub2/grub.cfg** on BIOS-based machines and **/boot/efi/EFI/redhat/grub.cfg** on UEFI-based machines.

GRUB scripts search the user's computer and build a boot menu based on what operating systems the scripts find. To reflect the latest system boot options, the boot menu is rebuilt automatically when the kernel is updated or a new kernel is added.

GRUB uses a series of scripts to build the menu; these are located in the **/etc/grub.d/** directory. The following files are included:

- **00_header**, which loads GRUB settings from the **/etc/default/grub** file.
- **01_users**, which reads the root password from the **user.cfg** file.
- **10_linux**, which locates kernels in the default partition of Red Hat Enterprise Linux.
- **30_os-prober**, which builds entries for operating systems found on other partitions.
- **40_custom**, a template, which can be used to create additional menu entries.

GRUB reads scripts from the **/etc/grub.d/** directory in alphabetical order and therefore you can rename them to change the boot order of specific menu entries.

8.2. HIDING THE LIST OF BOOTABLE KERNELS

You can prevent GRUB from displaying the list of bootable kernels when the system starts up.

Procedure

1. Set the **GRUB_TIMEOUT_STYLE** option in the **/etc/default/grub** file as follows:

   ```
   GRUB_TIMEOUT_STYLE=hidden
   ```

2. Rebuild the **grub.cfg** file for the changes to take effect.
   - On BIOS-based machines, enter:

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

   - On UEFI-based machines, enter:

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

3. Press the **Esc** key to display the list of bootable kernels when booting.

IMPORTANT

Do not set **GRUB_TIMEOUT** to *0* in the **/etc/default/grub** file to hide the list of bootable kernels. With such a setting, the system always boots immediately on the default menu entry, and if the default kernel fails to boot, it is not possible to boot any previous kernel.

8.3. CHANGING THE DEFAULT BOOT ENTRY WITH THE GRUB CONFIGURATION FILE

You can specify the default kernel package type, and thus change the default boot entry.

Procedure

1. Specify which operating system or kernel should be loaded by default by passing its index to the **grub2-set-default** command. For example:

```
# grubby --set-default-index=1
The default is /boot/loader/entries/d5151aa93c444ac89e78347a1504d6c6-4.18.0-348.el8.x86_64.conf with index 1 and kernel /boot/vmlinuz-4.18.0-348.el8.x86_64
```

   GRUB supports using a numeric value as the key for the **saved_entry** directive in **/boot/grub2/grubenv** to change the default order in which the operating systems are loaded.

   NOTE

   Index counting starts with zero; therefore, in the previous example, GRUB loads the second entry. With the next installed kernel, the index value will be overwritten.

   NOTE

   You can also use **grubby** to find indices for kernels. For more information, see Viewing the GRUB Menu Entry for a Kernel.

2. *Optional*: Force the system to always use a particular menu entry:

   a. List the available menu entries:

```
# grubby --info=ALL
```

   b. Use the menu entry name or the number of the position of a menu entry in the list as the key to the **GRUB_DEFAULT** directive in the **/etc/default/grub** file. For example:

```
GRUB_DEFAULT=example-gnu-linux
```

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

   - On BIOS-based machines, enter:

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

   - On UEFI-based machines, enter:

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

CHAPTER 9. 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.

9.1. 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

- The **grub-install(1)** man page

9.2. 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
   ```

9.3. 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 GRUB partition that you found in the previous step, such as **/dev/sda1**.

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

   ```
   # reboot
   ```

Additional resources

- The **grub-install(1)** man page

9.4. RESETTING GRUB

Resetting GRUB completely removes all GRUB configuration files and system settings and reinstalls the bootloader. You can reset all the configuration settings to their default values, and thus fix failures caused by corrupted files and incorrect configuration.

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

Procedure

1. Remove the configuration files.

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

2. Reinstall packages.

   - On BIOS-based machines, enter:

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

   - On UEFI-based machines, enter:

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

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

   - On BIOS-based machines, enter:

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

   - On UEFI-based machines, enter:

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

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

CHAPTER 10. PROTECTING GRUB WITH A PASSWORD

You can protect GRUB with a password in two ways:

- Password is required for modifying menu entries but not for booting existing menu entries.
- Password is required for modifying menu entries as well as for booting existing menu entries.

10.1. SETTING PASSWORD PROTECTION ONLY FOR MODIFYING MENU ENTRIES

You can configure GRUB to support password authentication for modifying GRUB menu entries. This procedure creates a **/boot/grub2/user.cfg** file that contains the password in the hash format.

IMPORTANT

Setting a password using the **grub2-setpassword** command prevents menu entries from unauthorized modification but not from unauthorized booting.

Procedure

1. Issue the **grub2-setpassword** command as root.

```
# grub2-setpassword
```

2. Enter the password for the user and press the **Enter** key to confirm the password.

```
Enter password:
Confirm the password:
```

NOTE

The root user is defined in the **/boot/grub2/grub.cfg** file with the password changes. Therefore, modifying a boot entry during booting requires the root user name and password.

10.2. SETTING PASSWORD PROTECTION FOR MODIFYING AND BOOTING MENU ENTRIES

You can configure GRUB to prevent menu entries from unauthorized modification as well as from unauthorized booting.

WARNING

If you forget the GRUB password, you will not be able to boot the entries you have reconfigured.

Procedure

1. Open the Boot Loader Specification (**BLS**) file for boot entry you want to modify from the **/boot/loader/entries/** directory.

2. Find the line beginning with **grub_users**. This parameter passes extra arguments to **menuentry**.

3. Set the **grub_users** attribute to the user name that is allowed to boot the entry besides the superusers, by default this user is **root**. Here is a sample configuration file:

```
title Red Hat Enterprise Linux (4.18.0-221.el8.x86_64) 8.3
(Ootpa)
version 4.18.0-221.el8.x86_64
linux /vmlinuz-4.18.0-221.el8.x86_64
initrd /initramfs-4.18.0-221.el8.x86_64.img $tuned_initrd
options $kernelopts $tuned_params
id rhel-20200625210904-4.18.0-221.el8.x86_64
grub_users root
grub_arg --unrestricted
grub_class kernel
```

4. Save and close the **BLS** file.

> **NOTE**
>
> If you want to protect all the menu entries from booting, you can directly set the **grub_users** attribute. For example, if root is the user:
>
> ```
> # grub2-editenv - set grub_users="root"
> ```

CHAPTER 11. KEEPING KERNEL PANIC PARAMETERS DISABLED IN VIRTUALIZED ENVIRONMENTS

When configuring a Virtual Machine in RHEL 8, you should 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.

11.1. 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?*

11.2. 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 RHEL8 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/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*

11.3. SPURIOUS SOFT LOCKUPS IN VIRTUALIZED ENVIRONMENTS

The soft lockup firing on physical hosts, as described in What is a soft lockup, usually represents a kernel or hardware bug. The same phenomenon happening on guest operating systems in virtualized environments may represent a false warning.

Heavy work-load on a host or high contention over some specific resource such as memory, usually causes a spurious soft lockup firing. This is because the host may schedule out the guest CPU for a period longer than 20 seconds. Then when the guest CPU is again scheduled to run on the host, it experiences a *time jump* which triggers due timers. The timers include also watchdog **hrtimer**, which can consequently report a soft lockup on the guest CPU.

Because a soft lockup in a virtualized environment may be spurious, you should not enable the kernel parameters that would cause a system panic when a soft lockup is reported on 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

- What is a soft lockup
- *Virtual machine components and their interaction*
- *Virtual machine reports a "BUG: soft lockup"*

CHAPTER 12. ADJUSTING KERNEL PARAMETERS FOR DATABASE SERVERS

There are different sets of kernel parameters which can affect performance of specific database applications. To secure efficient operation of database servers and databases, configure the respective kernel parameters accordingly.

12.1. 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 8 provides the following database management systems:

- **MariaDB 10.3**
- **MariaDB 10.5** - available since RHEL 8.4
- **MySQL 8.0**
- **PostgreSQL 10**
- **PostgreSQL 9.6**
- **PostgreSQL 12** - available since RHEL 8.1.1
- **PostgreSQL 13** - available since RHEL 8.4
- **PostgreSQL 15** - available since RHEL 8.8

12.2. 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. The kernel however does not free these file handles when they are released by the application. The kernel recycles these file handles instead. This means that over time the total number of allocated file handles will increase even though the number of currently used file handles may 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

Defines the port range the system can use for programs which want to connect to a database server without a specific 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 after which dirty data is old enough 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 13. GETTING STARTED WITH KERNEL LOGGING

Log files are files that contain messages about the system, including the kernel, services, and applications running on it. The logging system in Red Hat Enterprise Linux is based on 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.

13.1. WHAT IS THE KERNEL RING BUFFER

During the boot process, the console provides a lot of important information about the initial phase of the system startup. To avoid loss of the early messages the kernel utilizes what is called 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 buffer mentioned above is a cyclic data structure which 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

13.2. 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 8 contains the following four 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 above 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 14. INSTALLING KDUMP

The **kdump** service is installed and activated by default on the new versions of RHEL 8 installations. With the provided information and procedures, learn what **kdump** is and how to install if **kdump** is not enabled by default.

14.1. WHAT IS KDUMP

kdump is a service which provides a crash dumping mechanism and generates a dump file, known as crash dump or a **vmcore** file. The **vmcore** file has the contents of the system memory that helps in analysis and troubleshooting. **kdump** uses the **kexec** system call to boot into the second kernel, a *capture kernel* without a reboot and then 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 especially important when you install new kernel features.

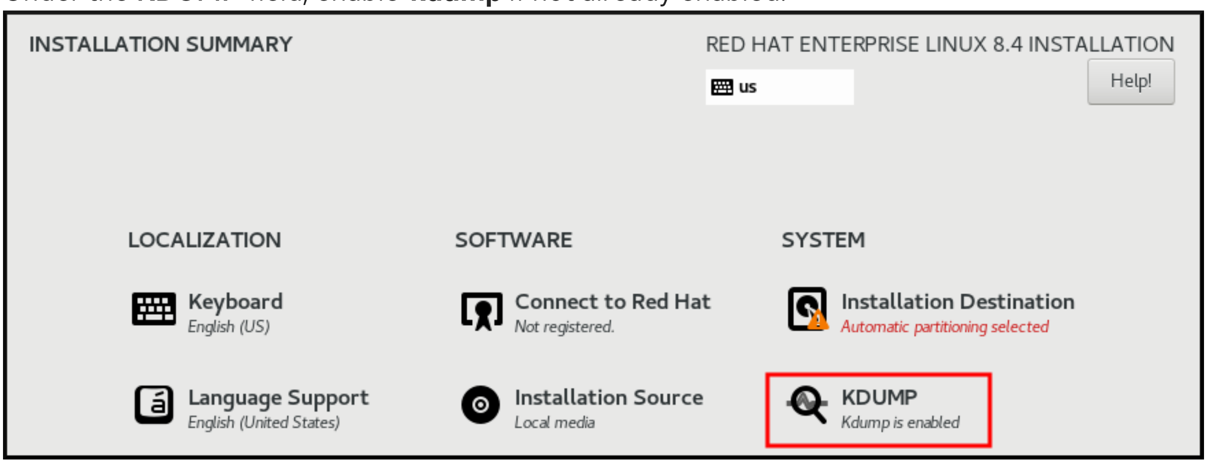
You can enable **kdump** for all installed kernels on a machine or only for specified kernels. This is useful when there are multiple kernels used on a machine, some of which are stable enough that there is no concern that they could crash. When you install **kdump**, a default **/etc/kdump.conf** file is created. The **/etc/kdump.conf** file includes the default minimum **kdump** configuration, which you can edit to customize the **kdump** configuration.

14.2. INSTALLING KDUMP USING ANACONDA

The **Anaconda** installer provides a graphical interface screen for **kdump** configuration during an interactive installation. The installer screen is titled as **KDUMP** and is available from the main **Installation Summary** screen. You can enable **kdump** and reserve the required amount of memory.

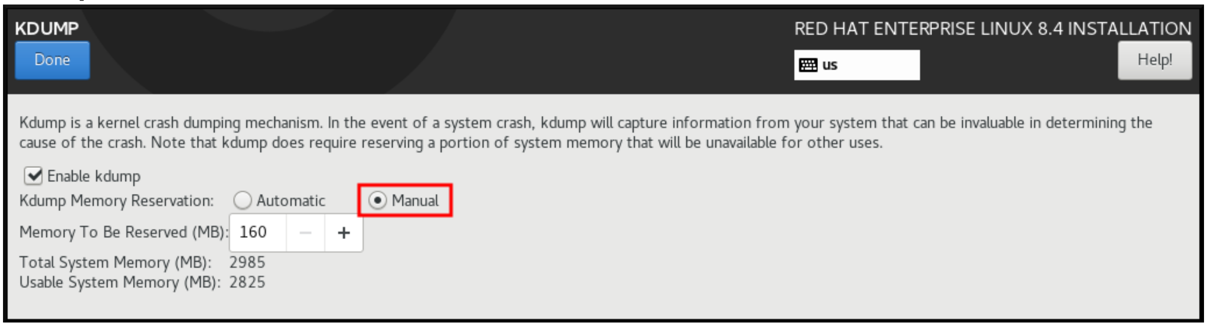
Procedure

1. Under the **KDUMP** field, enable **kdump** if not already enabled.



2. Under **Kdump Memory Reservation**, select **Manual**` if you must customize the memory reserve.

3. Under **KDUMP** field, in **Memory To Be Reserved (MB)**, set the required memory reserve for **kdump**.



14.3. INSTALLING KDUMP ON THE COMMAND LINE

Some installation options, such as custom **Kickstart** installations, in some cases do **not** install or enable **kdump** by default. If this is your case, follow the procedure below.

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 whether **kdump** is installed on your system:

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

Output if the package is installed:

```
kexec-tools-2.0.17-11.el8.x86_64
```

Output if the package is not installed:

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

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

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

IMPORTANT

On **kernel-3.10.0-693.el7** onward, the **Intel IOMMU** driver is supported for **kdump**. For **kernel-3.10.0-514[.XYZ].el7** and early versions, you must ensure that **Intel IOMMU** is disabled to prevent an unresponsive capture kernel.

CHAPTER 15. CONFIGURING KDUMP ON THE COMMAND LINE

The memory for **kdump** is reserved during the system boot. The memory size is configured 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 system's physical memory.

15.1. ESTIMATING THE KDUMP SIZE

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

The **makedumpfile --mem-usage** command estimates how much space the crash dump file requires. It generates a memory usage report. The report helps you determine the dump level and which pages are safe to be excluded.

Procedure

- Execute 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.

15.2. CONFIGURING KDUMP MEMORY USAGE

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

You can define the **crashkernel=** option in many ways. You can specify the **crashkernel=** value or configure the **auto** option. The **crashkernel=auto** parameter reserves memory automatically, based on the total amount of physical memory in the system. When configured, the kernel automatically reserves an appropriate amount of required memory for the capture kernel. This helps to prevent Out-of-Memory (OOM) errors.

> **NOTE**
>
> The automatic memory allocation for **kdump** varies based on system hardware architecture and available memory size.
>
> For example, on AMD64 and Intel 64, the **crashkernel=auto** parameter works only when the available memory is more than 1GB. The 64-bit ARM architecture and IBM Power Systems needs more than 2 GB of available memory.
>
> If the system has less than the minimum memory threshold for automatic allocation, you can configure the amount of reserved memory manually.

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. Prepare the **crashkernel=** option.
   - For example, to reserve 128 MB of memory, use the following:

     ```
     crashkernel=128M
     ```

   - Alternatively, you can set the amount of reserved memory to a variable depending on the total amount of installed memory. The syntax for memory reservation into a variable is **crashkernel=*<range1>*:*<size1>*,*<range2>*:*<size2>***. For example:

     ```
     crashkernel=512M-2G:64M,2G-:128M
     ```

     The command reserves 64 MB of memory if the total amount of system memory is in the range of 512 MB and 2 GB. If the total amount of memory is more than 2 GB, the memory reserve is 128 MB.

   - Offset the reserved memory.
     Some systems require to reserve memory with a certain fixed offset because the **crashkernel** reservation happens early, and you may need to reserve more memory for special usage. When you define an offset, the reserved memory begins there. To offset the reserved memory, use the following syntax:

     ```
     crashkernel=128M@16M
     ```

     In this example, **kdump** reserves 128 MB of memory starting at 16 MB (physical address **0x01000000**). If you set the offset parameter to 0 or omit entirely, **kdump** offsets the reserved memory automatically. You can also use this syntax when setting a variable memory reservation. In that case, the offset is always specified last. For example:

     ```
     crashkernel=512M-2G:64M,2G-:128M@16M
     ```

2. Apply the **crashkernel=** option to your boot loader configuration:

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

Replace ***<value>*** with the value of the **crashkernel=** option that you prepared in the previous step.

Additional resources

- Memory requirements for kdump
- Configuring kernel command-line parameters
- How to manually modify the boot parameter in grub before the system boots
- How to install and boot custom kernels in Red Hat Enterprise Linux 8
- **grubby(8)** manual page

15.3. CONFIGURING THE KDUMP TARGET

The crash dump is usually stored as a file in a local file system, written directly to a device. Alternatively, you can set up for the crash dump to be sent over a network 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 what is mounted in the current system, the dump target and the adjusted dump path are taken 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 is executed **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 adjustment of file permissions.

Example 15.1. 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
```

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

- To change the local directory in which the crash dump is to be saved, as **root**, edit the **/etc/kdump.conf** configuration file:
    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 8, the directory defined as the **kdump** target using the **path** directive must exist when the **kdump systemd** service starts to avoid failures. This behavior is different from versions earlier than RHEL, where the directory is created automatically if it did 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 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 you proceed 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 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**
>
> When 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 beforehand. To prevent **kdump.service** from mounting the target, use the **dracut_args --mount** directive in **kdump.conf** so that **kdump.service** calls the **dracut** utility with the **--mount** argument to specify the NFS target.

- To store the crash dump to a remote machine 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

Section 15.8, "Files produced by kdump after system crash"

15.4. 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 using various dump levels.
- Excluding unnecessary crash dump pages.
- Filtering the page types to be included in the crash dump.

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 **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. To enable crash dump file compression, execute:

```
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 using **-c**:

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

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

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

Additional resources

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

15.5. 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 in case 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 **root**, 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 desired action.

```
failure_action poweroff
```

Additional resources

- Configuring the kdump target

15.6. 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 may cause **kdump** errors or **kdump** kernel boot failures. These parameters may 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 may 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 may consume a significant portion 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

15.7. 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 and therefore has critical information to help debug 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.

> **IMPORTANT**
>
> Ensure that you schedule significant maintenance time, because **kdump** testing might require several reboots with a long boot time.
>
> 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** performance:
>
> - Package upgrades.
> - Hardware level changes, for example, storage or networking changes.
> - Firmware and BIOS 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** command, you can print the output at the console.

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

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

3. Initiate 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

15.8. 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 post-mortem 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** - contains 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
- What is kdump

15.9. 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 that it is working properly.

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

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

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

- Start the service in the current session:

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

- Stop the **kdump** service:

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

- 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 even if Kernel Address Space Layout (KASLR) is enabled or not 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.

15.10. 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 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 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

15.11. 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.

In case 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 16. ENABLING KDUMP

For your RHEL 8 systems, you can configure to enable or disable the **kdump** functionality on a specific kernel or on all installed kernels. However, you must routinely test the **kdump** functionality and validate that it's working properly.

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. 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 8 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 even if Kernel Address Space Layout (**KASLR**) is enabled or not 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. CONFIGURING KDUMP IN THE WEB CONSOLE

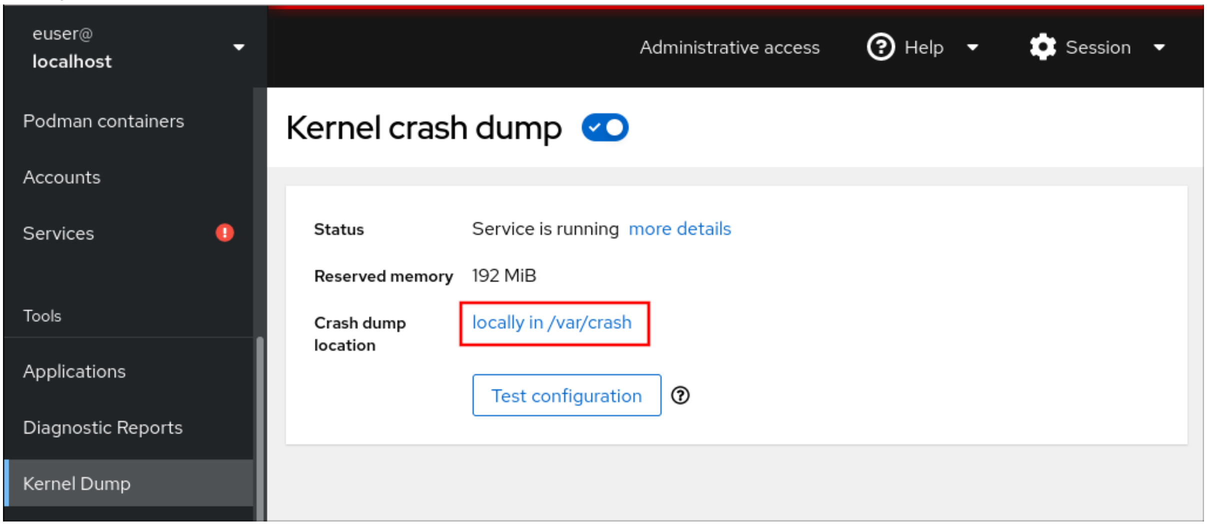
You can setup and test the **kdump** configuration by using the RHEL 8 web console. The web console is part of a default installation of RHEL 8 and enables or disables the **kdump** service at boot time. Further, the web console enables you to configure the reserved memory for **kdump**; or to select the *vmcore* saving location in an uncompressed or compressed format.

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

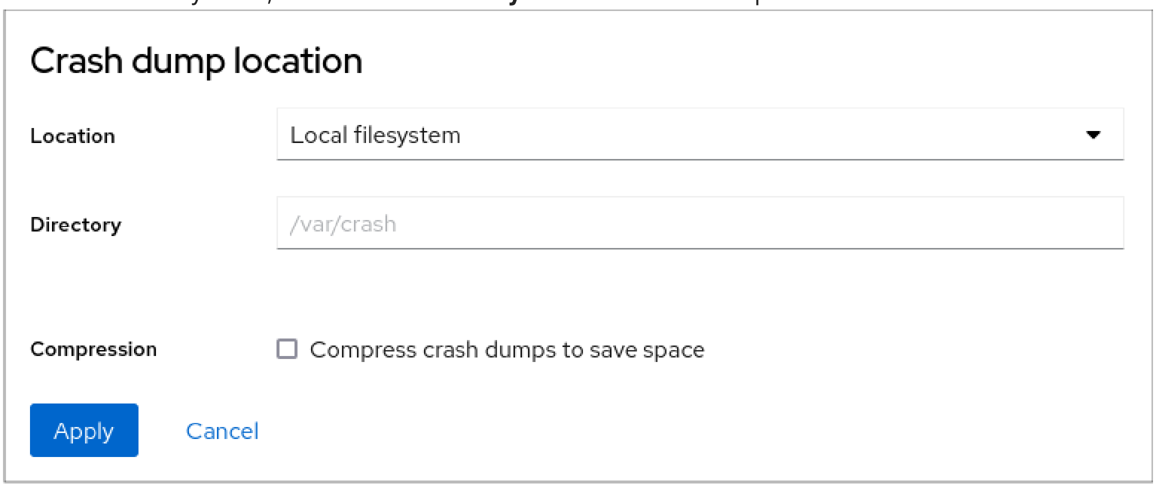
You can configure the memory reserve for the **kdump** kernel and also specify the target location to capture the **vmcore** dump file with the RHEL web console interface.

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 command line.
3. In the **Kernel Dump** tab, go to **Crash dump location** and click the link with the path to the dump location.



4. Specify the target directory for saving the **vmcore** dump file:
   - For a local filesystem, select **Local Filesystem** from the drop-down menu.



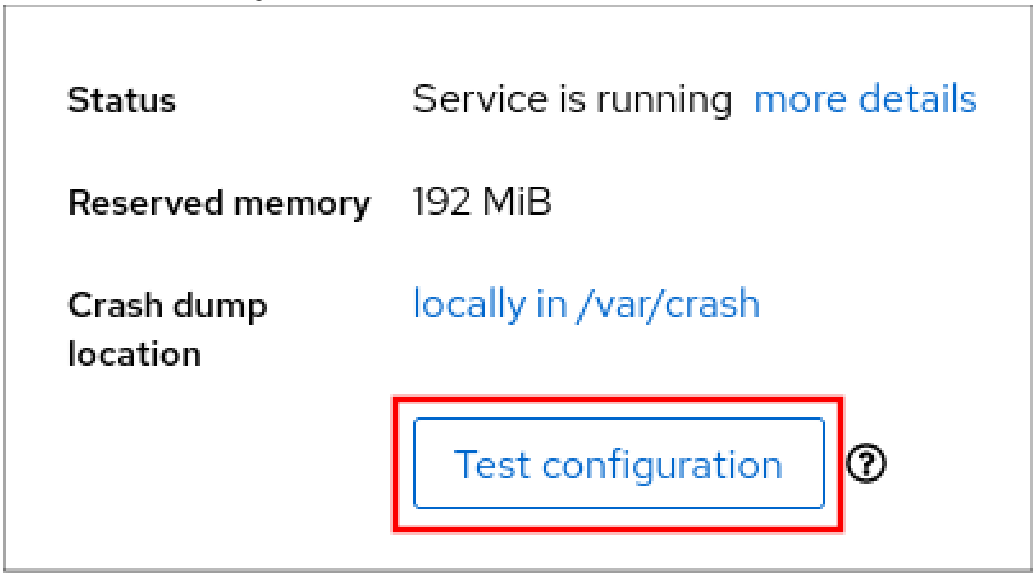
- For a remote system by using the SSH protocol, select **Remote over SSH** from the drop-down menu and specify the following fields:
  - In the **Server** field, enter the remote server address
  - In the **ssh key** field, enter the ssh key location
  - In the **Directory** field, enter the target 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** check box.

Verification

1. Click the **Test configuration**.



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

WARNING

When you initiate the system crash, the kernel's operation stops and results in a system crash with data loss.

Additional resources

- Supported kdump targets
- Using secure communications between two systems with OpenSSH
- Getting started using the RHEL web console

CHAPTER 18. 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.

With the provided information and procedures, you understand the supported configurations and targets on your RHEL 8 systems and properly configure **kdump** and validate it’s working.

18.1. 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 find out 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 18.1. 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 architecture (**arm64**)	2 GB and more	480 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

Architecture	Available Memory	Minimum Reserved Memory
	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 may vary due to other factors such as I/O devices. Using not enough of memory might cause that a debug kernel is not able to boot as a capture kernel in case of a kernel panic. To avoid this problem, sufficiently increase the crash kernel memory.

Additional resources

- How has the crashkernel parameter changed between RHEL8 minor releases?
- Technology capabilities and limits tables
- Minimum threshold for automatic memory reservation

18.2. MINIMUM THRESHOLD FOR AUTOMATIC MEMORY RESERVATION

The **kexec-tools** utility, by default, configures the **crashkernel** command line parameter and reserves a certain amount of memory for **kdump**. On some systems however, it is still possible to allocate 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 18.2. Minimum Amount of Memory Required for Automatic Memory Reservation

Architecture	Required Memory
AMD64 and Intel 64 (**x86_64**)	2 GB
IBM Power Systems (**ppc64le**)	2 GB
IBM Z (**s390x**)	4 GB

NOTE

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

18.3. 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 18.3. kdump targets on RHEL 8

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 **cciss**, **hpsa**, **megaraid_sas**, **mpt2sas**, and **aacraid**. • **SCSI** and **SATA** disks. • **iSCSI** and **HBA** offloads. • Hardware **FCoE** such as **qla2xxx** and **lpfc**.	• BIOS RAID. • Software **iSCSI** with **iBFT**. Currently supported transports are **bnx2i**, **cxgb3i**, and **cxgb4i**. • Software **iSCSI** with a 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).

Target type	Supported Targets	Unsupported Targets
Network	• Hardware using kernel modules: **tg3**, **igb**, **ixgbe**, **sfc**, **e1000e**, **bna**, **cnic**, **netxen_nic**, **qlge**, **bnx2x**, **bnx**, **qlcnic**, **be2net**, **enic**, **virtio-net**, **ixgbevf**, **igbvf**. • IPv4 protocol. • Network bonding on different devices, such as Ethernet devices or VLAN. • VLAN network. • Network Bridge. • Network Teaming. • Tagged VLAN and VLAN over a bond. • Bridge network over bond, team, and VLAN.	• IPv6 protocol. • Wireless connections. • InfiniBand networks. • VLAN network over bridge and team.
Hypervisor	• Kernel-based virtual machines (KVM). • Xen hypervisor in certain configurations only. • VMware ESXi 4.1 and 5.1. • Hyper-V 2012 R2 on RHEL Gen1 UP Guest only.	
File systems	The ext[234], XFS, and NFS file systems.	The **Btrfs** file system.
Firmware	• BIOS-based systems. • UEFI Secure Boot.	

Additional resources

- Configuring the kdump target

18.4. 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 18.4. Filtering levels forkdump

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

Additional resources

- Configuring the core collector

18.5. SUPPORTED DEFAULT FAILURE RESPONSES

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

Table 18.5. Failure responses forkdump

Option	Description
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.

Option	Description
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**.

Additional resources

- Configuring the kdump default failure responses

18.6. 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
```

18.7. 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**, which 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 19. 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, leverage 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.

19.1. 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.

19.2. 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 **GRUB2** boot loader allocates a boot memory region, known as the Real Mode Area (RMA). The RMA has a size of 512 MB, which is divided among the boot components and, if a component exceeds its size allocation, **GRUB2** fails with an out-of-memory (**OOM**) error.

> **WARNING**
>
> Do not enable firmware assisted dump (**fadump**) mechanism in the Secure Boot environment on RHEL 8.7 and 8.6 versions. The **GRUB2** 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.

Procedure

1. Install and configure **kdump**.
2. Enable the **fadump=on** kernel option:

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

3. (Optional) If you want to specify reserved boot memory instead of using the defaults, enable the **crashkernel=*xx*M** option, where ***xx*** is the amount of the memory required in megabytes:

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

   > **IMPORTANT**
   >
   > When specifying boot configuration options, test all boot configuration options before you execute them. If the **kdump** kernel fails to boot, increase the value specified in **crashkernel=** argument gradually to set an appropriate value.

19.3. 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 can provide various benefits:

- The **sadump** mechanism is initiated and controlled from the system console, and is stored 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

- Stand-alone dump program
- Creating dumps on z/VM with VMDUMP
- Using the Dump Tools on Red Hat Enterprise Linux 7.4

19.4. USING SADUMP ON FUJITSU PRIMEQUEST SYSTEMS

The Fujitsu **sadump** mechanism is designed to provide a **fallback** dump capture in an event when **kdump** is unable to complete successfully. The **sadump** mechanism is invoked manually from the system Management Board (MMB) interface. Using MMB, configure **kdump** like for an Intel 64 or AMD 64 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 20. ANALYZING A CORE DUMP

To determine the cause of the system crash, you can use the **crash** utility, which provides an interactive prompt very similar to the GNU Debugger (GDB). This utility allows you to interactively analyze a core dump created by **kdump**, **netdump**, **diskdump** or **xendump** as well as a running Linux system. Alternatively, you have the option to use Kernel Oops Analyzer or the Kdump Helper tool.

20.1. INSTALLING THE CRASH UTILITY

With the provided information, understand the required packages and the procedure to install the **crash** utility. The **crash** utility may not be installed by default on your RHEL 8 systems. **crash** is a tool to interactively analyze a system' 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-8-for-x86_64-baseos-debug-rpms
```

2. Install the **crash** package:

```
# yum install crash
```

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

```
# yum install kernel-debuginfo
```

   The package **kernel-debuginfo** will correspond to the running kernel and provides the data necessary for the dump analysis.

20.2. RUNNING AND EXITING THE CRASH UTILITY

With the provided information, understand the required parameters and the procedure to run and exit the **crash** utility. **crash** is a tool to interactively analyze a system' 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.

Prerequisites

- Identify the currently running kernel (for example **4.18.0-5.el8.x86_64**).

Procedure

1. To start the **crash** utility, pass the following two necessary parameters:

   - The debug-info (a decompressed vmlinuz image), for example **/usr/lib/debug/lib/modules/4.18.0-5.el8.x86_64/vmlinux** provided through a specific **kernel-debuginfo** package.

- The actual vmcore file, for example **/var/crash/127.0.0.1-2018-10-06-14:05:33/vmcore**
  The resulting **crash** command will be as follows:

```
# crash /usr/lib/debug/lib/modules/4.18.0-5.el8.x86_64/vmlinux /var/crash/127.0.0.1-2018-10-06-14:05:33/vmcore
```

  Use the same *<kernel>* version that was captured by **kdump**.

Example 20.1. Running the crash utility

The following example shows analyzing a core dump created on October 6 2018 at 14:05 PM, using the 4.18.0-5.el8.x86_64 kernel.

```
...
WARNING: kernel relocated [202MB]: patching 90160 gdb minimal_symbol values

      KERNEL: /usr/lib/debug/lib/modules/4.18.0-5.el8.x86_64/vmlinux
    DUMPFILE: /var/crash/127.0.0.1-2018-10-06-14:05:33/vmcore  [PARTIAL DUMP]
        CPUS: 2
        DATE: Sat Oct  6 14:05:16 2018
      UPTIME: 01:03:57
LOAD AVERAGE: 0.00, 0.00, 0.00
       TASKS: 586
    NODENAME: localhost.localdomain
     RELEASE: 4.18.0-5.el8.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>
```

2. To exit the interactive prompt and stop **crash**, type **exit** or **q**.

   Example 20.2. Exiting the crash utility

```
crash> exit
~]#
```

> **NOTE**
>
> The **crash** command can also be used as a powerful tool for debugging a live system. However use it with caution so as not to break your system.

Additional resources

- A Guide to Unexpected System Restarts

20.3. 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 and, as such, it is always dumped first in to the **vmcore-dmesg.txt** file. This is useful when an attempt to get the full **vmcore** file failed, for example because of lack of space on the target location. By default, **vmcore-dmesg.txt** is located 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.

20.4. USING KERNEL OOPS ANALYZER

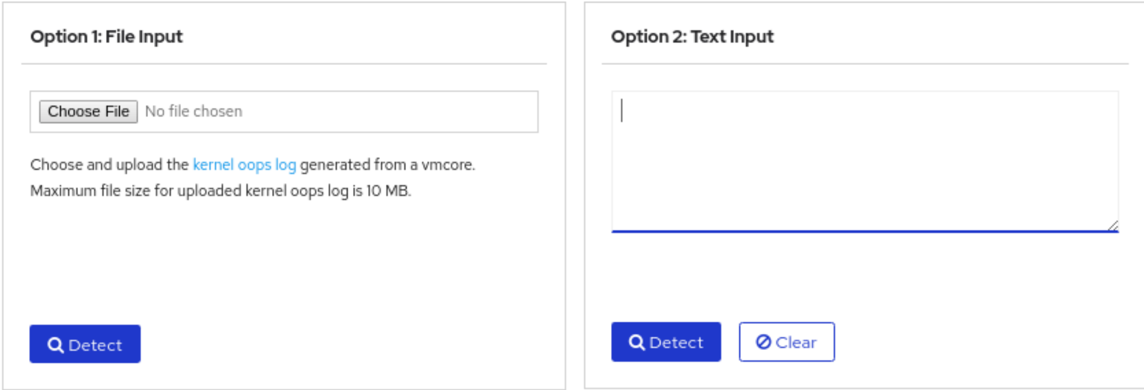
The Kernel Oops Analyzer tool analyzes the crash dump by comparing the oops messages with known issues in the knowledge base.

Prerequisites

- Secure an oops message 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 also 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
- A Guide to Unexpected System Restarts

20.5. 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 21. USING EARLY KDUMP TO CAPTURE BOOT TIME CRASHES

Early kdump is a feature of the **kdump** mechanism to capture 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 crash kernel's **initramfs** in the memory much earlier.

21.1. WHAT IS EARLY KDUMP

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, which is important for troubleshooting, is lost. To address this problem, you can use the **early kdump** feature, which is part of the **kdump** service.

21.2. 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 step

- Verify that **rd.earlykdump** was successfully added and **early kdump** feature was enabled:

```
# cat /proc/cmdline
BOOT_IMAGE=(hd0,msdos1)/vmlinuz-4.18.0-187.el8.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
Mar 20 15:44:41 redhat dracut-cmdline[304]: early-kdump is enabled.
Mar 20 15:44:42 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?
- Enabling kdump

CHAPTER 22. 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.

Note that not every critical or important CVE will be resolved using the kernel live patching solution. Our goal is to reduce the required reboots for security-related patches, not to eliminate them entirely. For more details about the scope of live patching, see the *Customer Portal Solutions article* .

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

22.1. LIMITATIONS OF KPATCH

- The **kpatch** feature is not a general-purpose kernel upgrade mechanism. It is used for applying simple security and bug fix updates when rebooting the system is not immediately possible.
- Do not use the **SystemTap** or **kprobe** tools during or after loading a patch. The patch could fail to take effect until after such probes have been removed.

22.2. 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 will not support any live patches which were not provided by Red Hat itself.

If you require support for an issue that arises with a third-party live patch, Red Hat recommends that you open a case with the live patching vendor at the outset of any investigation in which a root cause determination is necessary. This allows the source code to be supplied if the vendor allows, and for their support organization to provide assistance in root cause determination prior to escalating the investigation to Red Hat Support.

For any system running with third-party live patches, Red Hat reserves the right to ask for reproduction with Red Hat shipped and supported software. In the event that this is not possible, we require a similar system and workload be deployed on your test environment without live patches applied, to confirm if the same behavior is observed.

For more information about third-party software support policies, see How does Red Hat Global Support Services handle third-party software, drivers, and/or uncertified hardware/hypervisors or guest operating systems?

22.3. ACCESS TO KERNEL LIVE PATCHES

Kernel live patching capability is implemented as a kernel module (**kmod**) that is delivered 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 8.2 kernel until the RHEL 8.3 kernel is released.

22.4. COMPONENTS OF KERNEL LIVE PATCHING

The components of kernel live patching are as follows:

Kernel patch module

- The delivery mechanism for kernel live patches.
- A kernel module which is built specifically for the kernel being patched.
- The patch module contains the code of the desired fixes for the kernel.
- The patch modules register with the **livepatch** kernel subsystem and provide information about original functions to be replaced, with corresponding 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.

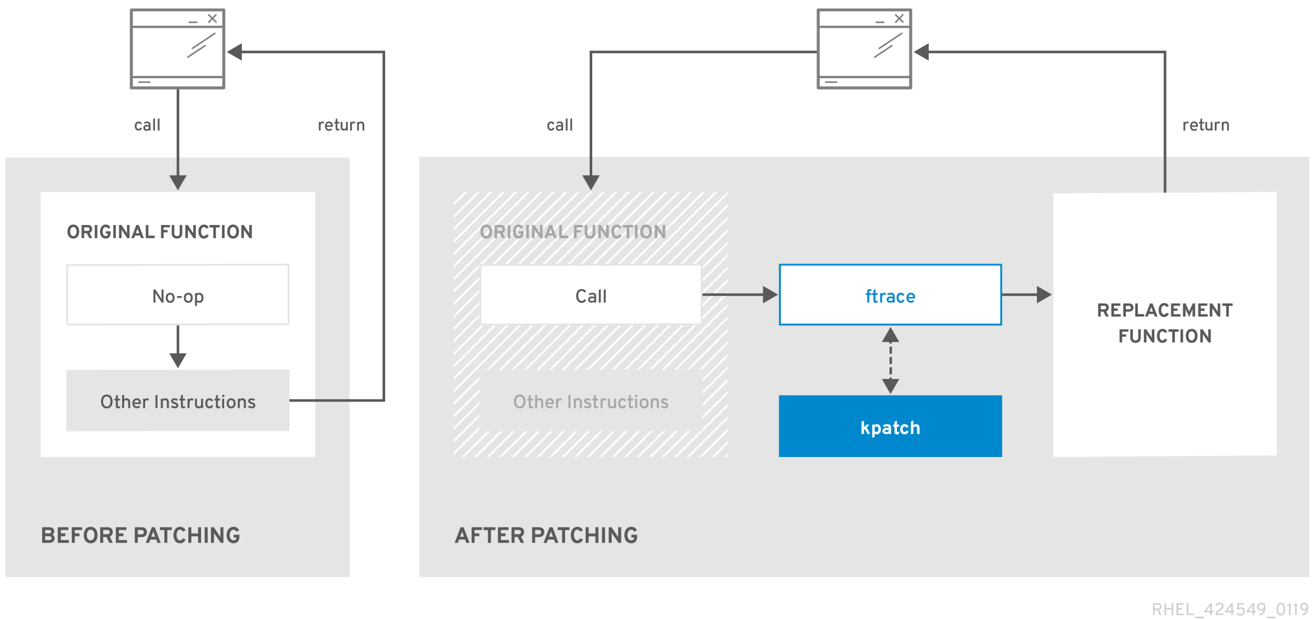
22.5. HOW KERNEL LIVE PATCHING WORKS

The **kpatch** kernel patching solution uses the **livepatch** kernel subsystem to redirect old functions to new ones. When a live kernel patch is applied to a system, the following things happen:

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 is loaded 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.

3. When the kernel accesses the patched function, it is redirected by the **ftrace** mechanism which bypasses the original functions and redirects the kernel to patched version of the function.

Figure 22.1. How kernel live patching works



22.6. 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

- Root permissions

Procedure

1. Optionally, check your kernel version:

```
# uname -r
4.18.0-94.el8.x86_64
```

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

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

3. Install the live patching package:

```
# yum 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-4_18_0-94-0-0.el8.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_4_18_0_94_1_1 [enabled]

Installed patch modules:
kpatch_4_18_0_94_1_1 (4.18.0-94.el8.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-4_18_0-94-1-1.el8.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-patch-4_18_0-477_21_1-0-0.el8_8.x86_64
> kpatch-dnf-0.9.7_0.4-2.el8.noarch
> kpatch-0.9.7-2.el8.noarch
> ```

Additional resources

- **kpatch(1)** manual page
- Installing software packages

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

You can use the **kpatch-dnf** YUM 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. Optionally, check all installed kernels and the kernel you are currently running:

```
# yum list installed | grep kernel
Updating Subscription Management repositories.
Installed Packages
...
kernel-core.x86_64       4.18.0-240.10.1.el8_3        @rhel-8-for-x86_64-baseos-rpms
kernel-core.x86_64       4.18.0-240.15.1.el8_3        @rhel-8-for-x86_64-baseos-rpms
...

# uname -r
4.18.0-240.10.1.el8_3.x86_64
```

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

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

3. Enable automatic subscription to kernel live patches:

```
# yum kpatch auto
Updating Subscription Management repositories.
Last metadata expiration check: 19:10:26 ago on Wed 10 Mar 2021 04:08:06 PM CET.
Dependencies resolved.
==================================================
 Package                        Architecture
==================================================
Installing:
 kpatch-patch-4_18_0-240_10_1       x86_64
 kpatch-patch-4_18_0-240_15_1       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.

In the future, when you update the kernel, live patches will automatically be installed 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-4_18_0-240-0-0.el8.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_4_18_0_240_10_1_0_1 [enabled]

Installed patch modules:
kpatch_4_18_0_240_10_1_0_1 (4.18.0-240.10.1.el8_3.x86_64)
kpatch_4_18_0_240_15_1_0_2 (4.18.0-240.15.1.el8_3.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-4_18_0-240_10_1-0-1.rpm** and **kpatch-patch-4_18_0-240_15_1-0-1.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-patch-4_18_0-477_21_1-0-0.el8_8.x86_64
kpatch-dnf-0.9.7_0.4-2.el8.noarch
kpatch-0.9.7-2.el8.noarch
```

Additional resources

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

22.8. 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, and thus disable automatic installation of **kpatch-patch** packages.

Prerequisites

- You have root permissions.

Procedure

1. Optionally, check all installed kernels and the kernel you are currently running:

```
# yum list installed | grep kernel
Updating Subscription Management repositories.
Installed Packages
...
kernel-core.x86_64      4.18.0-240.10.1.el8_3      @rhel-8-for-x86_64-baseos-rpms
kernel-core.x86_64      4.18.0-240.15.1.el8_3      @rhel-8-for-x86_64-baseos-rpms
...

# uname -r
4.18.0-240.10.1.el8_3.x86_64
```

2. Disable automatic subscription to kernel live patches:

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

Verification step

- 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

22.9. UPDATING KERNEL PATCH MODULES

Since kernel patch modules are delivered and applied through RPM packages, updating a cumulative kernel patch module is like 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:

  ```
  # yum 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:

  ```
  # yum 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

- *Configuring basic system settings* in RHEL

22.10. 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.

   ```
   # yum list installed | grep kpatch-patch
   kpatch-patch-4_18_0-94.x86_64        1-1.el8        @@commandline
   …
   ```

   The example output above lists live patching packages that you installed.

2. Remove the live patching package.

   ```
   # yum remove kpatch-patch-4_18_0-94.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 that the live patching package has been removed.

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

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

5. Optionally, verify that 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
- *Uninstalling software packages* in RHEL

22.11. 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_4_18_0_94_1_1 [enabled]

Installed patch modules:
kpatch_4_18_0_94_1_1 (4.18.0-94.el8.x86_64)
…
```

2. Uninstall the selected kernel patch module.

```
# kpatch uninstall kpatch_4_18_0_94_1_1
uninstalling kpatch_4_18_0_94_1_1 (4.18.0-94.el8.x86_64)
```

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

  ```
  # kpatch list
  Loaded patch modules:
  kpatch_4_18_0_94_1_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.

4. Optionally, verify that the kernel patch module has been uninstalled.

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

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

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

22.12. 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_4_18_0_94_1_1 [enabled]

  Installed patch modules:
  kpatch_4_18_0_94_1_1 (4.18.0-94.el8.x86_64)
  ```

3. Reboot your system.

4. Optionally, 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** has been disabled and is not running. Thereby, the kernel live patching solution is not active.

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

   ```
   # kpatch list
   Loaded patch modules:
   <NO_RESULT>

   Installed patch modules:
   kpatch_4_18_0_94_1_1 (4.18.0-94.el8.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 23. SETTING SYSTEM RESOURCE LIMITS FOR APPLICATIONS BY USING 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.

23.1. 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. This means that 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, proper coordination is limited.
The **cgroups-v1** controllers were developed across a large time span and as a result, the behavior and naming of their control files is not uniform.

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.

> **NOTE**
>
> **cgroups-v2** is fully supported in RHEL 8.2 and later versions. For more information, see Control Group v2 is now fully supported in RHEL 8 .

Additional resources

- Introducing kernel resource controllers
- The **cgroups(7)** manual page
- Role of systemd in control groups

23.2. INTRODUCING KERNEL RESOURCE CONTROLLERS

Kernel resource controllers enable the functionality of control groups. RHEL 8 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 a number of 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
: Can be used to limit 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 a number of 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).

23.3. INTRODUCING NAMESPACES

Namespaces are one of the most important methods for organizing and identifying software objects.

A namespace wraps a global system resource (for example, a mount point, a network device, or a hostname) in an abstraction that makes it appear to processes within the namespace that they have their own isolated instance of the global resource. 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 23.1. 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
- Introducing control groups

23.4. 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 whose CPU consumption you want to restrict.
- You verified that the **cgroups-v1** controllers are mounted:

```
# mount -l | grep cgroup
tmpfs on /sys/fs/cgroup type tmpfs (ro,nosuid,nodev,noexec,seclabel,mode=755)
```

```
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/cpu,cpuacct type cgroup
(rw,nosuid,nodev,noexec,relatime,seclabel,cpu,cpuacct)
cgroup on /sys/fs/cgroup/perf_event type cgroup
(rw,nosuid,nodev,noexec,relatime,seclabel,perf_event)
cgroup on /sys/fs/cgroup/pids type cgroup (rw,nosuid,nodev,noexec,relatime,seclabel,pids)
...
```

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
...
```

This example output of the **top** program reveals that illustrative application **sha1sum** with **PID 6955** consumes a lot 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
```

This example output shows files, such as **cpuacct.usage**, **cpu.cfs._period_us**, that represent specific configurations and/or limits, which can be set for processes in the **Example** control group. Note that the respective file names are prefixed with the name of the control group controller to which they belong.

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 a period of time in microseconds (µs, represented here as "us") for how frequently a control group's access to CPU resources should be reallocated. The upper limit is 1 000 000 microsecond and the lower limit is 1 000 microseconds.
- The **cpu.cfs_quota_us** file represents the total amount of time in microseconds for which all processes collectively in a control group can run during one period (as defined by **cpu.cfs_period_us**). When processes in a control group, during a single period, use up all the time specified by the quota, they are throttled for the remainder of the period and not allowed to run until the next period. The lower limit is 1 000 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 hence does not exceed the CPU limits configured for the **Example** control group. The PID should represent an existing process in the system. The **PID 6955** here was assigned to process **sha1sum /dev/zero &**, 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
```

This example output shows that the process of the desired application runs in the **Example** control group, which applies 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

- Understanding control groups
- What kernel resource controllers are
- **cgroups(7)**, **sysfs(5)** manual pages

CHAPTER 24. USING CGROUPS-V2 TO CONTROL DISTRIBUTION OF CPU TIME FOR APPLICATIONS

Some applications use too much CPU time, which can negatively impact the overall health of your environment. You can put your applications into *control groups version 2* (**cgroups-v2**) and configure CPU limits for those control groups. As a result, you can regulate your applications in CPU consumption.

The user has two methods how to regulate distribution of CPU time allocated to a control group:

- Setting CPU bandwidth (editing the **cpu.max** controller file)
- Setting CPU weight (editing the **cpu.weight** controller file)

24.1. MOUNTING CGROUPS-V2

During the boot process, RHEL 8 mounts the **cgroup-v1** virtual filesystem by default. To utilize **cgroup-v2** functionality in limiting resources for your applications, manually configure the system.

Prerequisites

- You have root permissions.

Procedure

1. Configure the system to mount **cgroups-v2** by default during system boot by the **systemd** system and service manager:

   ```
   # grubby --update-kernel=/boot/vmlinuz-$(uname -r) --args="systemd.unified_cgroup_hierarchy=1"
   ```

   This adds the necessary kernel command-line parameter to the current boot entry.

   To add the **systemd.unified_cgroup_hierarchy=1** parameter to all kernel boot entries:

   ```
   # grubby --update-kernel=ALL --args="systemd.unified_cgroup_hierarchy=1"
   ```

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

Verification steps

1. Optionally, verify that the **cgroups-v2** filesystem was mounted:

   ```
   # mount -l | grep cgroup
   cgroup2 on /sys/fs/cgroup type cgroup2
   (rw,nosuid,nodev,noexec,relatime,seclabel,nsdelegate)
   ```

   The **cgroups-v2** filesystem was successfully mounted on the **/sys/fs/cgroup/** directory.

2. Optionally, inspect the contents of the **/sys/fs/cgroup/** directory:

   ```
   # ll /sys/fs/cgroup/
   -r—r—r--.  1 root root 0 Apr 29 12:03 cgroup.controllers
   -rw-r—r--.  1 root root 0 Apr 29 12:03 cgroup.max.depth
   ```

```
-rw-r—r--.  1 root root 0 Apr 29 12:03 cgroup.max.descendants
-rw-r—r--.  1 root root 0 Apr 29 12:03 cgroup.procs
-r—r—r--.  1 root root 0 Apr 29 12:03 cgroup.stat
-rw-r—r--.  1 root root 0 Apr 29 12:18 cgroup.subtree_control
-rw-r—r--.  1 root root 0 Apr 29 12:03 cgroup.threads
-rw-r—r--.  1 root root 0 Apr 29 12:03 cpu.pressure
-r—r—r--.  1 root root 0 Apr 29 12:03 cpuset.cpus.effective
-r—r—r--.  1 root root 0 Apr 29 12:03 cpuset.mems.effective
-r—r—r--.  1 root root 0 Apr 29 12:03 cpu.stat
drwxr-xr-x.  2 root root 0 Apr 29 12:03 init.scope
-rw-r—r--.  1 root root 0 Apr 29 12:03 io.pressure
-r—r—r--.  1 root root 0 Apr 29 12:03 io.stat
-rw-r—r--.  1 root root 0 Apr 29 12:03 memory.pressure
-r—r—r--.  1 root root 0 Apr 29 12:03 memory.stat
drwxr-xr-x. 69 root root 0 Apr 29 12:03 system.slice
drwxr-xr-x.  3 root root 0 Apr 29 12:18 user.slice
```

The **/sys/fs/cgroup/** directory, also called the *root control group*, by default, contains interface files (starting with **cgroup**) and controller-specific files such as **cpuset.cpus.effective**. In addition, there are some directories related to **systemd**, such as, **/sys/fs/cgroup/init.scope**, **/sys/fs/cgroup/system.slice**, and **/sys/fs/cgroup/user.slice**.

Additional resources

- Understanding control groups
- What kernel resource controllers are
- **cgroups(7)**, **sysfs(5)** manual pages

24.2. PREPARING THE CGROUP FOR DISTRIBUTION OF CPU TIME

To control CPU consumption of your applications, you need to enable specific CPU controllers and create a dedicated control groups. It is recommended to create at least two levels of child control groups inside the **/sys/fs/cgroup/** root control group to maintain better organizational clarity of **cgroup** files.

Prerequisites

- You have root permissions.
- You have identified PIDs of processes that you want to control.
- You have mounted the **cgroups-v2** file system. For more information, see Mounting cgroups-v2.

Procedure

1. Identify the process IDs (PIDs) of applications whose CPU consumption you want to constrict:

```
# top
Tasks: 104 total,   3 running, 101 sleeping,   0 stopped,   0 zombie
%Cpu(s): 17.6 us, 81.6 sy,  0.0 ni,  0.0 id,  0.0 wa,  0.8 hi,  0.0 si,  0.0 st
MiB Mem :   3737.4 total,   3312.7 free,    133.3 used,    291.4 buff/cache
MiB Swap:   4060.0 total,   4060.0 free,      0.0 used.   3376.1 avail Mem
```

```
  PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
34578 root      20   0   18720   1756   1468 R  99.0   0.0   0:31.09 sha1sum
34579 root      20   0   18720   1772   1480 R  99.0   0.0   0:30.54 sha1sum
    1 root      20   0  186192  13940   9500 S   0.0   0.4   0:01.60 systemd
    2 root      20   0       0      0      0 S   0.0   0.0   0:00.01 kthreadd
    3 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 rcu_gp
    4 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 rcu_par_gp
...
```

The example output reveals that **PID 34578** and **34579** (two illustrative applications of **sha1sum**) consume a lot of resources, namely CPU. Both are example applications used to demonstrate managing the **cgroups-v2** functionality.

2. Verify that the **cpu** and **cpuset** controllers are available in the **/sys/fs/cgroup/cgroup.controllers** file:

```
# cat /sys/fs/cgroup/cgroup.controllers
cpuset cpu io memory hugetlb pids rdma
```

3. Enable CPU-related 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 children groups of the **/sys/fs/cgroup/** root 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.

4. Create the **/sys/fs/cgroup/Example/** directory:

```
# mkdir /sys/fs/cgroup/Example/
```

The **/sys/fs/cgroup/Example/** directory defines a child group. Also, the previous step enabled the **cpu** and **cpuset** controllers for this child group.

When you create the **/sys/fs/cgroup/Example/** directory, some **cgroups-v2** interface files and **cpu** and **cpuset** controller-specific files are automatically created in the directory. The **/sys/fs/cgroup/Example/** directory contains also controller-specific files for the **memory** and **pids** controllers.

5. Optionally, 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.max.depth
-rw-r—r--. 1 root root 0 Jun  1 10:33 cgroup.max.descendants
-rw-r—r--. 1 root root 0 Jun  1 10:33 cgroup.procs
-r—r—r--. 1 root root 0 Jun  1 10:33 cgroup.stat
-rw-r—r--. 1 root root 0 Jun  1 10:33 cgroup.subtree_control
…
-rw-r—r--. 1 root root 0 Jun  1 10:33 cpuset.cpus
-r—r—r--. 1 root root 0 Jun  1 10:33 cpuset.cpus.effective
-rw-r—r--. 1 root root 0 Jun  1 10:33 cpuset.cpus.partition
-rw-r—r--. 1 root root 0 Jun  1 10:33 cpuset.mems
-r—r—r--. 1 root root 0 Jun  1 10:33 cpuset.mems.effective
-r—r—r--. 1 root root 0 Jun  1 10:33 cpu.stat
-rw-r—r--. 1 root root 0 Jun  1 10:33 cpu.weight
-rw-r—r--. 1 root root 0 Jun  1 10:33 cpu.weight.nice
…
-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 files such as **cpuset.cpus** and **cpu.max**. These files are specific to the **cpuset** and **cpu** controllers. The **cpuset** and **cpu** controllers are manually enabled for the root's (**/sys/fs/cgroup/**) *direct child control groups* using the **/sys/fs/cgroup/cgroup.subtree_control** file.

The directory also includes general **cgroup** control interface files such as **cgroup.procs** or **cgroup.controllers**, which 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 always enabled by default.

By default, the newly created child group inherits access to all of the system's CPU and memory resources, without any limits.

6. Enable the CPU-related controllers in **/sys/fs/cgroup/Example/** to obtain controllers that are relevant only to CPU:

```
# echo "+cpu" >> /sys/fs/cgroup/Example/cgroup.subtree_control
# echo "+cpuset" >> /sys/fs/cgroup/Example/cgroup.subtree_control
```

These commands ensure that the immediate child control group will *only* have controllers relevant to regulate the CPU time distribution - not to **memory** or **pids** controllers.

7. 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.

8. Optionally, inspect another 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
```

9. Ensure the processes that you want to control for CPU time compete on the same CPU:

```
# echo "1" > /sys/fs/cgroup/Example/tasks/cpuset.cpus
```

The previous command ensures that the processes you will place in the **Example/tasks** child control group, compete on the same CPU. This setting is important for the **cpu** controller to activate.

> **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 steps

1. Optional: ensure that the CPU-related controllers are enabled for the immediate children cgroups:

```
# cat /sys/fs/cgroup/cgroup.subtree_control
/sys/fs/cgroup/Example/cgroup.subtree_control
cpuset cpu memory pids
cpuset cpu
```

2. Optional: ensure the processes that you want to control for CPU time compete on the same CPU:

```
# cat /sys/fs/cgroup/Example/tasks/cpuset.cpus
1
```

Additional resources

- What are control groups
- What are kernel resource controllers
- Mounting cgroups-v2
- **cgroups(7)**, **sysfs(5)** manual pages

24.3. CONTROLLING DISTRIBUTION OF CPU TIME FOR APPLICATIONS BY ADJUSTING CPU BANDWIDTH

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 at least two applications for which you want to control distribution of CPU time.
- You ensured the relevant applications compete for CPU time on the same CPU as described in Preparing the cgroup for distribution of CPU time .
- You mounted **cgroups-v2** filesystem as described in Mounting cgroups-v2.
- You enabled **cpu** and **cpuset** controllers both in the parent control group and in child control group similarly as described in Preparing the cgroup for distribution of CPU time .
- You created two levels of *child control groups* inside the **/sys/fs/cgroup/** *root control group* as in the example below:

```
…
  ├── Example
  │   ├── tasks
…
```

Procedure

1. Configure CPU bandwidth to achieve resource restrictions within the control group:

   ```
   # echo "200000 1000000" > /sys/fs/cgroup/Example/tasks/cpu.max
   ```

   The first value is the allowed time quota in microseconds for which all processes collectively in a child group can run during one period. The second value specifies the length of the period.

   During a single period, when processes in a control group collectively exhaust the time specified by this quota, they are throttled for the remainder of the period and not allowed to run until the next period.

   This command sets CPU time distribution controls so that all processes collectively in the **/sys/fs/cgroup/Example/tasks** child group can run on the CPU for only 0.2 seconds of every 1 second. That is, one fifth of each second.

2. Optionally, verify the time quotas:

```
# cat /sys/fs/cgroup/Example/tasks/cpu.max
200000 1000000
```

3. Add the applications' PIDs to the **Example/tasks** child group:

```
# echo "34578" > /sys/fs/cgroup/Example/tasks/cgroup.procs
# echo "34579" > /sys/fs/cgroup/Example/tasks/cgroup.procs
```

The example commands ensure that desired applications become members of the **Example/tasks** child group and do not exceed the CPU time distribution configured for this child group.

Verification steps

1. Verify that the applications run in the specified control group:

```
# cat /proc/34578/cgroup /proc/34579/cgroup
0::/Example/tasks
0::/Example/tasks
```

The output above shows the processes of the specified applications that run in the **Example/tasks** child group.

2. Inspect the current CPU consumption of the throttled applications:

```
# top
top - 11:13:53 up 23:10,  1 user,  load average: 0.26, 1.33, 1.66
Tasks: 104 total,   3 running, 101 sleeping,   0 stopped,   0 zombie
%Cpu(s):  3.0 us,  7.0 sy,  0.0 ni, 89.5 id,  0.0 wa,  0.2 hi,  0.2 si,  0.2 st
MiB Mem :   3737.4 total,   3312.6 free,    133.4 used,    291.4 buff/cache
MiB Swap:   4060.0 total,   4060.0 free,      0.0 used.   3376.0 avail Mem

    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
  34578 root      20   0   18720   1756   1468 R  10.0   0.0  37:36.13 sha1sum
  34579 root      20   0   18720   1772   1480 R  10.0   0.0  37:41.22 sha1sum
      1 root      20   0  186192  13940   9500 S   0.0   0.4   0:01.60 systemd
      2 root      20   0       0      0      0 S   0.0   0.0   0:00.01 kthreadd
      3 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 rcu_gp
      4 root       0 -20       0      0      0 I   0.0   0.0   0:00.00 rcu_par_gp
...
```

Notice that the CPU consumption for the **PID 34578** and **PID 34579** has decreased to 10%. The **Example/tasks** child group regulates its processes to 20% of the CPU time collectively. Since there are 2 processes in the control group, each can utilize 10% of the CPU time.

Additional resources

- Understanding control groups
- What kernel resource controllers are
- Mounting cgroups-v2
- Preparing the cgroup for distribution of CPU time

- **cgroups(7)**, **sysfs(5)** manual pages

24.4. 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 ensured the relevant applications compete for CPU time on the same CPU as described in Preparing the cgroup for distribution of CPU time .
- You mounted **cgroups-v2** filesystem as described in Mounting cgroups-v2.
- 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 **cpu** and **cpuset** controllers in the parent control group and in child control groups similarly as described in Preparing the cgroup for distribution of CPU time .

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 had multiple running processes, the CPU time allocated to the respective cgroup would be distributed equally to the member processes of that cgroup.

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**
>
> We forced all the example processes to run on a single CPU for clearer illustration. The CPU weight applies the same principles also when used on multiple CPUs.

Notice that the CPU resource for the **PID 33373**, **PID 33374**, and **PID 33377** was allocated based on the weights, 150, 100, 50, you assigned to the respective child cgroups. The weights correspond to around 50%, 33%, and 16% allocation of CPU time for each application.

Additional resources

- Understanding control groups
- What are kernel resource controllers
- Mounting cgroups-v2
- Preparing the cgroup for distribution of CPU time
- Resource Distribution Models
- **cgroups(7)**, **sysfs(5)** manual pages

CHAPTER 25. USING CONTROL GROUPS VERSION 1 WITH SYSTEMD

You can manage **cgroups** with the **systemd** system and service manager and the utilities they provide. This is also the preferred way of the **cgroups** management.

25.1. ROLE OF SYSTEMD IN CONTROL GROUPS VERSION 1

RHEL 8 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.

By default, the **systemd** system and service manager makes use of the **slice**, the **scope** and the **service** units to organize and structure processes in the control groups. The **systemctl** command enables you to further modify this structure by creating custom **slices**. Also, **systemd** automatically mounts hierarchies for important kernel resource controllers in the **/sys/fs/cgroup/** directory.

Three **systemd** unit types are used for resource control:

- **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

- What are kernel resource controllers
- **systemd.resource-control(5)**, **cgroups(7)**, **fork()**, **fork(2)** manual pages

25.2. CREATING TRANSIENT CONTROL GROUPS

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 run-time 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

- What are control groups
- Role of systemd in control groups
- *Managing systemd* in RHEL
- The **systemd-run(1)** manual page

25.3. CREATING PERSISTENT CONTROL GROUPS

To assign a persistent control group to a service, it is necessary to edit its unit configuration file. The configuration is preserved after the system reboot, so it can be used to manage services that are started automatically.

Procedure

- To create a persistent control group, enter:

```
# systemctl enable <name>.service
```

The command above automatically creates a unit configuration file into the **/usr/lib/systemd/system/** directory and by default, it assigns **<*name*>.service** to the **system.slice** unit.

Additional resources

- Understanding control groups
- Role of systemd in control groups

- *Managing system services with systemctl* in RHEL
- **systemd-run(1)** manual page

25.4. CONFIGURING MEMORY RESOURCE CONTROL SETTINGS ON THE COMMAND-LINE

Executing commands in the command-line interface is one of the ways how to set limits, prioritize, or control access to hardware resources for groups of processes.

Procedure

- To limit the memory usage of a service, run the following:

  ```
  # systemctl set-property example.service MemoryMax=1500K
  ```

  The command instantly assigns the memory limit of 1,500 KB to processes executed in a control group the **example.service** service belongs to. The **MemoryMax** parameter, in this configuration variant, is defined in the **/etc/systemd/system.control/example.service.d/50-MemoryMax.conf** file and controls the value of the **/sys/fs/cgroup/memory/system.slice/example.service/memory.limit_in_bytes** file.

- Optionally, to temporarily limit the memory usage of a service, run:

  ```
  # systemctl set-property --runtime example.service MemoryMax=1500K
  ```

  The command instantly assigns the memory limit to the **example.service** service. The **MemoryMax** parameter is defined until the next reboot in the **/run/systemd/system.control/example.service.d/50-MemoryMax.conf** file. With a reboot, the whole **/run/systemd/system.control/** directory and **MemoryMax** are removed.

> **NOTE**
>
> The **50-MemoryMax.conf** file stores the memory limit as a multiple of 4096 bytes - one kernel page size specific for AMD64 and Intel 64. The actual number of bytes depends on a CPU architecture.

Additional resources

- What are control groups
- What are kernel resource controllers
- **systemd.resource-control(5)** and **cgroups(7)** manual pages
- Role of systemd in control groups

25.5. CONFIGURING MEMORY RESOURCE CONTROL SETTINGS WITH UNIT FILES

Each persistent unit is supervised by the **systemd** system and service manager, and has a unit configuration file in the **/usr/lib/systemd/system/** directory. To change the resource control settings of the persistent units, modify its unit configuration file either manually in a text editor or from the command-line interface.

Manually modifying unit files is one of the ways how to set limits, prioritize, or control access to hardware resources for groups of processes.

Procedure

1. To limit the memory usage of a service, modify the **/usr/lib/systemd/system/example.service** file as follows:

   ```
   …
   [Service]
   MemoryMax=1500K
   …
   ```

   The configuration above places a limit on maximum memory consumption of processes executed in a control group, which **example.service** is part of.

   > **NOTE**
   >
   > 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
   ```

4. Reboot the system.

5. Optionally, check that the changes took effect:

   ```
   # cat /sys/fs/cgroup/memory/system.slice/example.service/memory.limit_in_bytes
   1536000
   ```

   The example output shows that the memory consumption was limited at around 1,500 KB.

   > **NOTE**
   >
   > The **memory.limit_in_bytes** file stores the memory limit as a multiple of 4096 bytes - one kernel page size specific for AMD64 and Intel 64. The actual number of bytes depends on a CPU architecture.

Additional resources

- Understanding control groups
- What kernel resource controllers are
- **systemd.resource-control(5)**, **cgroups(7)** manual pages

- *Managing system services with systemctl* in RHEL
- Role of systemd in control groups version 1

25.6. 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 once 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
- The **systemd.resource-control(5)** and **cgroups(7)** man pages
- Role of systemd in control groups version 1
- *Managing systemd* in RHEL

25.7. REMOVING PERSISTENT CONTROL GROUPS

You can use the **systemd** system and service manager to remove persistent control groups (**cgroups**) if you no longer need to limit, prioritize, or control access to hardware resources for groups of processes.

Persistent **cgroups** are released when a service or a scope unit is stopped or disabled and its configuration file is deleted.

Procedure

1. Stop the service unit:

```
# systemctl stop <name>.service
```

2. Disable the service unit:

```
# systemctl disable <name>.service
```

3. Remove the relevant unit configuration file:

```
# rm /usr/lib/systemd/system/<name>.service
```

4. Reload all unit configuration files so that changes take effect:

```
# systemctl daemon-reload
```

Additional resources

- What are control groups
- What are kernel resource controllers
- **systemd.resource-control(5)**, **cgroups(7)**, and **systemd.kill(5)** manual pages
- Role of systemd in control groups
- *Managing system services with systemctl* in RHEL

25.8. 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 contains 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

25.9. 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

- What are kernel resource controllers
- The **systemd.resource-control(5)** and **cgroups(7)** man pages

25.10. VIEWING RESOURCE CONTROLLERS

Find out which processes use which resource controllers.

Procedure

1. View which resource controllers a process interacts with, enter the **cat proc/<*PID*>/cgroup** command.

```
# cat /proc/11269/cgroup
12:freezer:/
11:cpuset:/
10:devices:/system.slice
9:memory:/system.slice/example.service
8:pids:/system.slice/example.service
7:hugetlb:/
6:rdma:/
5:perf_event:/
4:cpu,cpuacct:/
3:net_cls,net_prio:/
2:blkio:/
1:name=systemd:/system.slice/example.service
```

The example output relates to a process of interest. In this case, it is a process identified by **PID 11269**, 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.

> **NOTE**
>
> By default, the items and their ordering in the list of resource controllers is the same for all units started by **systemd**, since it automatically mounts all the default resource controllers.

Additional resources

- The **cgroups(7)** manual page
- Documentation in the **/usr/share/doc/kernel-doc-<kernel_version>/Documentation/cgroups-v1/** directory

25.11. 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

CHAPTER 26. CONFIGURING RESOURCE MANAGEMENT BY USING CGROUPS-V2 AND SYSTEMD

The primary function of the **systemd** suite is service management and supervision. As such **systemd** ensures that the appropriate services start at the appropriate time and in the correct order during the boot process. When the services are running, they have to run smoothly to use the underlying hardware platform optimally. Therefore, **systemd** also provides capabilities to define resource management policies and to tune various options, which can improve the performance of the service.

26.1. PREREQUISITES

- Basic knowledge of the Linux cgroup subsystem.

26.2. INTRODUCTION TO RESOURCE DISTRIBUTION MODELS

For resource management, **systemd** uses the control groups version 2 (**cgroups-v2**) interface.

> **NOTE**
>
> By default, RHEL 8 uses **cgroups-v1**. Therefore, you must enable **cgroups-v2** so that **systemd** can use the cgroups-v2 interface for resource management. For more information about how to enable **cgroups-v2**, see Mounting cgroups-v2.

To modify the distribution of system resources, you can apply one or more of the following resource distribution models:

Weights

A resource is distributed by adding up the weights of all sub-groups and giving each sub-group a fraction of the resource based on its weight as compared to the overall sum of all weights.
For example, if you have 10 **cgroups**, each with Weight of value 100, the sum is 1000 and each **cgroup** receives one tenth of the resource.

Weight is usually used to distribute stateless resources. To adjust the weight of a control group, use the *CPUWeight=* option.

Limits

A **cgroup** can consume up to the configured amount of a resource, but you can also overcommit resources. Therefore, the sum of sub-group limits can exceed the limit of the parent **cgroup**.
To adjust the limits of a control group, use the *MemoryMax=* option.

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.
To adjust the protected resource amounts for a control group, use the *MemoryLow=* option.

Allocations

Exclusive allocations of a specific amount of a finite resource, such as the real-time budget. An overcommit is possible.

Additional resources

- Managing CPU with systemd
- Allocating memory resources using systemd
- Configuring I/O bandwidth using systemd

26.3. ALLOCATING CPU RESOURCES BY USING SYSTEMD

On a system managed by **systemd**, each system service is started in its **cgroup**. By enabling the support for the CPU **cgroup** controller, the system uses the service-aware distribution of CPU resources instead of the per-process distribution. In the service-aware distribution, each service receives approximately the same amount of CPU time relative to all other services running on the system, regardless of the number of processes that comprise the service.

If a specific service requires more CPU resources, you can grant them by changing the CPU time allocation policy for the service.

Procedure

To set a CPU time allocation policy option when using **systemd**:

1. Check the assigned values of the CPU time allocation policy option in the service of your choice:

   ```
   $ systemctl show --property <CPU time allocation policy option> <service name>
   ```

2. Set the required value of the CPU time allocation policy option as a root:

   ```
   # systemctl set-property <service name> <CPU time allocation policy option>=<value>
   ```

The cgroup properties are applied immediately after they are set. Therefore, the service does not need to be restarted.

Verification

- To verify whether you successfully changed the required value of the CPU time allocation policy option for your service, enter:

  ```
  $ systemctl show --property <CPU time allocation policy option> <service name>
  ```

Additional resources

- CPU time allocation policy options for systemd
- Introduction to resource distribution models

26.4. CPU TIME ALLOCATION POLICY OPTIONS FOR SYSTEMD

The most frequently used CPU time allocation policy options include:

CPUWeight=

Assigns **higher priority** to a particular service over all other services. You can select a value from the interval 1 – 10,000. The default value is 100.

For example, to give **httpd.service** twice as much CPU as to all other services, set the value to **CPUWeight=200**.

Note that **CPUWeight=** is applied only in cases when available CPU resources are depleted.

CPUQuota=

Assigns the **absolute CPU time quota** to a service. The value of this option specifies the maximum percentage of CPU time that a service will receive relative to the total CPU time available, for example **CPUQuota=30%**.
Note that **CPUQuota=** represents the limit value for particular resource distribution models, such as Weights and Limits.

For more information about **CPUQuota=**, see the **systemd.resource-control(5)** man page.

Additional resources

- Introduction to resource distribution models
- Allocating CPU resources using systemd
- Introduction to resource distribution models

26.5. ALLOCATING MEMORY RESOURCES BY USING SYSTEMD

To allocate memory resources by using **systemd**, use any of the memory configuration options:

- **MemoryMin**
- **MemoryLow**
- **MemoryHigh**
- **MemoryMax**
- **MemorySwapMax**

Procedure

To set a memory allocation configuration option when using **systemd**:

1. Check the assigned values of the memory allocation configuration option in the service of your choice.

```
$ systemctl show --property <memory allocation configuration option> <service name>
```

2. Set the required value of the memory allocation configuration option as a **root**.

```
# systemctl set-property <service name> <memory allocation configuration option>=<value>
```

NOTE

The **cgroup** properties are applied immediately after they are set. Therefore, the service does not need to be restarted.

Verification

- To verify whether you have successfully changed the required value of the memory allocation configuration option for your service, enter:

```
$ systemctl show --property <memory allocation configuration option> <service name>
```

Additional resources

- Memory allocation configuration options for systemd
- Introduction to resource distribution models

26.6. MEMORY ALLOCATION CONFIGURATION OPTIONS FOR SYSTEMD

You can use the following options when using **systemd** to configure system memory allocation:

MemoryMin

Hard memory protection. If the memory usage is below the specified limit, the cgroup memory will not be reclaimed.

MemoryLow

Soft memory protection. If the memory usage is below the specified limit, the cgroup memory can be reclaimed only if no memory is reclaimed from unprotected cgroups.

MemoryHigh

Memory throttle limit. If the memory usage goes above the specified limit, the processes in the cgroup are throttled and put under a heavy reclaim pressure.

MemoryMax

Absolute limit for the memory usage. You can use the kilo (K), mega (M), giga (G), tera (T) suffixes, for example **MemoryMax=1G**.

MemorySwapMax

Hard limit on the swap usage.

NOTE

When you exhaust your memory limit, the Out-of-memory (OOM) killer will stop the running service. To prevent this, lower the **OOMScoreAdjust=** value to increase the memory tolerance.

Additional resources

- Allocating memory resources using systemd
- Introduction to resource distribution models

26.7. CONFIGURING I/O BANDWIDTH BY USING SYSTEMD

To improve the performance of a specific service in RHEL 8, you can allocate I/O bandwidth resources to that service by using **systemd**.

To do so, you can use the following I/O configuration options:

- IOWeight
- IODeviceWeight
- IOReadBandwidthMax
- IOWriteBandwidthMax
- IOReadIOPSMax
- IOWriteIOPSMax

Procedure

To set a **I/O bandwidth configuration** option using **systemd**:

1. Check the assigned values of the I/O bandwidth configuration option in the service of your choice:

   ```
   $ systemctl show --property <I/O bandwidth configuration option> <service name>
   ```

2. Set the required value of the I/O bandwidth configuration option as a **root**:

   ```
   # systemctl set-property <service name> <I/O bandwidth configuration option>=
   <value>
   ```

The **cgroup** properties are applied immediately after they are set. Therefore, the service does not need to be restarted.

Verification

- To verify whether you successfully changed the required value of the I/O bandwidth configuration option for your service, enter:

  ```
  $ systemctl show --property <I/O bandwidth configuration option> <service name>
  ```

Additional resources

- I/O bandwidth configuration options for systemd
- Introduction to resource distribution models

26.8. I/O BANDWIDTH CONFIGURATION OPTIONS FOR SYSTEMD

To manage the block layer I/O policies by using **systemd**, the following configuration options are available:

IOWeight

Sets the default I/O weight. The weight value is used as a basis for the calculation of how much of the real I/O bandwidth the service receives in relation to the other services.

IODeviceWeight

Sets the I/O weight for a specific block device.
For example, **IODeviceWeight=/dev/disk/by-id/dm-name-rhel-root 200**.

IOReadBandwidthMax, IOWriteBandwidthMax

Sets the absolute bandwidth per device or a mount point.
For example, **IOWriteBandwith=/var/log 5M**.

NOTE

systemd handles the file-system-to-device translation automatically.

IOReadIOPSMax, IOWriteIOPSMax

Sets the absolute bandwidth in Input/Output Operations Per Second (IOPS).

NOTE

Weight-based options are supported only if the block device is using the CFQ I/O scheduler. No option is supported if the device uses the Multi-Queue Block I/O queuing mechanism.

Additional resources

- Configuring I/O bandwidth using systemd
- Introduction to resource distribution models

26.9. CONFIGURING CPUSET CONTROLLER BY USING SYSTEMD

With the **systemd** resource management API, you can configure limits on a set of CPUs and NUMA nodes that a service can use. This limit restricts access to system resources used by the processes. The requested configuration is written in the **cpuset.cpus** and **cpuset.mems** files.

However, the requested configuration may not be used, as the parent **cgroup** limits either **cpus** or **mems**. To access the current configuration, the **cpuset.cpus.effective** and **cpuset.mems.effective** files are exported to the users.

Procedure

- To set **AllowedCPUs**:

  ```
  # systemctl set-property <service name>.service AllowedCPUs=<value>
  ```

  For example:

  ```
  # systemctl set-property <service name>.service AllowedCPUs=0-5
  ```

- To set **AllowedMemoryNodes**:

```
# systemctl set-property <service name>.service AllowedMemoryNodes=<value>
```

For example:

```
# systemctl set-property <service name>.service AllowedMemoryNodes=0
```

CHAPTER 27. CONFIGURING CPU AFFINITY AND NUMA POLICIES USING SYSTEMD

The CPU management, memory management, and I/O bandwidth options deal with partitioning available resources.

27.1. CONFIGURING CPU AFFINITY USING SYSTEMD

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 and a manager configuration option in 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. 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.

> **NOTE**
>
> After configuring CPU affinity mask for a particular systemd service, you must restart the system to apply the changes.

Procedure

To set CPU affinity mask for a particualr 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 a root, 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>
```

To set CPU affinity mask for a particular systemd service using the **manager configuration** option:

1. Edit the **/etc/systemd/system.conf** file:

```
# vi /etc/systemd/system.conf
```

2. Search for the **CPUAffinity=** option and set the CPU numbers

3. Save the edited file and restart the server to apply the changes.

27.2. 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

- NUMA policy configuration options for systemd
- The **systemd.resource-control(5)**, **systemd.exec(5)**, and **set_mempolicy(2)** man pages.

27.3. 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 which 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

- The **systemd.resource-control(5)**, **systemd.exec(5)**, and **set_mempolicy(2)** man pages
- Configuring NUMA using systemd

CHAPTER 28. ANALYZING SYSTEM PERFORMANCE WITH BPF COMPILER COLLECTION

As a system administrator, you can use the BPF Compiler Collection (BCC) library to create tools for analyzing the performance of your Linux operating system and gathering information, which could be difficult to obtain through other interfaces.

28.1. INSTALLING THE BCC-TOOLS PACKAGE

Install the **bcc-tools** package, which also installs the BPF Compiler Collection (BCC) library as a dependency.

Procedure

1. Install **bcc-tools**.

```
# yum install bcc-tools
```

   The BCC tools are installed in the **/usr/share/bcc/tools/** directory.

2. Optionally, inspect the tools:

```
# ll /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 above contains documentation for each tool.

28.2. 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

Using execsnoop to examine the system processes

1. Run the **execsnoop** program in one terminal:

```
# /usr/share/bcc/tools/execsnoop
```

2. In another terminal run, for example:

```
$ ls /usr/share/bcc/tools/doc/
```

The above creates a short-lived process of the **ls** command.

3. 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, which consumes 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**, refer to the **/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. Run the **opensnoop** program in one terminal:

```
# /usr/share/bcc/tools/opensnoop -n uname
```

The above prints output for files, which are opened only by the process of the **uname** command.

2. In another terminal, enter:

```
$ uname
```

The command above opens certain files, which are captured in the next step.

3. 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**, refer to the **/usr/share/bcc/tools/doc/opensnoop_example.txt** file.

For more information about **open()**, see **open(2)** manual pages.

Using biotop to examine the I/O operations on the disk

1. Run the **biotop** program in one terminal:

```
# /usr/share/bcc/tools/biotop 30
```

The command enables you to monitor the top processes, which perform I/O operations on the disk. The argument ensures that the command will produce a 30 second summary.

NOTE

When no argument provided, the output screen by default refreshes every 1 second.

2. In another terminal enter, for example :

```
# dd if=/dev/vda of=/dev/zero
```

The command above reads the content from the local hard disk device and writes the output to the /**dev**/**zero** file. This step generates certain I/O traffic to illustrate **biotop**.

3. 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)

To see more details, examples, and options for **biotop**, refer to 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

1. Run the **xfsslower** program in one terminal:

```
# /usr/share/bcc/tools/xfsslower 1
```

The command above measures the time the XFS file system spends 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.

> **NOTE**
>
> When no arguments provided, **xfsslower** by default displays operations slower than 10 ms.

2. In another terminal enter, for example, the following:

```
$ vim text
```

The command above creates a text file in the **vim** editor to initiate certain interaction with the XFS file system.

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 above represents an operation in the file system, which took more time than a certain threshold. **xfsslower** is good at exposing 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 being read, written, or synced.

To see more details, examples, and options for **xfsslower**, refer to the **/usr/share/bcc/tools/doc/xfsslower_example.txt** file.

For more information about **fsync**, see **fsync(2)** manual pages.

CHAPTER 29. 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.

29.1. THE KERNEL INTEGRITY SUBSYSTEM

The integrity subsystem is the part of the kernel that maintains overall integrity of system data. This subsystem helps to keep the state of a system the same from the time it was built. By using this subsystem, you can prevent undesired modification of specific system files.

The kernel integrity subsystem consists of two major components:

Integrity Measurement Architecture (IMA)

- IMA measures file content whenever it is executed or opened 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*) that are 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, which is built according to the TPM specification by the Trusted Computing Group (TCG) for important cryptographic functions. TPMs are usually built as dedicated hardware attached to the platform's motherboard. 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)

29.2. 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. The integrity of the keys can be verified, which means that they can be used, for example, by 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**
>
> Red Hat Enterprise Linux 8 supports both TPM 1.2 and TPM 2.0. For more information, see the Is Trusted Platform Module (TPM) supported by Red Hat? solution.

You can verify that a TPM 2.0 chip has been enabled by entering the following command:

```
$ 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. This means that PCR-sealed keys can only be decrypted by the TPM on the same system on which they were encrypted. However, when a PCR-sealed trusted key is loaded (added to a keyring), and thus its associated PCR values are verified, it can be updated with new (or future) PCR values, so that a new kernel, for example, can be booted. You can save a single key also 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 encrypted key is only as secure as the user key used to encrypt it.

29.3. WORKING WITH TRUSTED KEYS

You can improve system security by using the **keyctl** utility to create, export, load and update trusted keys.

Prerequisites

- For the 64-bit ARM architecture and IBM Z, the **trusted** kernel module is loaded.

  ```
  # modprobe trusted
  ```

  For more information about how to load kernel modules, see Loading kernel modules at system runtime.

- Trusted Platform Module (TPM) is enabled and active. See The kernel integrity subsystem and Trusted and encrypted keys.

> **NOTE**
>
> Red Hat Enterprise Linux 8 supports both TPM 1.2 and TPM 2.0. If you use TPM 1.2, skip step 1.

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:

   a. 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).

b. By using a TPM 1.2 with the syntax of **keyctl add trusted *<NAME>* "new <KEY_LENGTH>" <KEYRING>**:

```
# keyctl add trusted kmk "new 32" @u
```

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
- Trusted and encrypted keys
- Kernel Key Retention Service
- The kernel integrity subsystem

29.4. WORKING WITH ENCRYPTED KEYS

You can improve system security on systems where a Trusted Platform Module (TPM) is not available by managing encrypted keys.

Prerequisites

- For the 64-bit ARM architecture and IBM Z, the **encrypted-keys** kernel module is loaded:

```
# modprobe encrypted-keys
```

For more information about how to load kernel modules, see Loading kernel modules at system runtime.

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
```

3. Optionally, 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
```

IMPORTANT

Encrypted keys that are not sealed by a trusted primary key are only as secure as the user primary key (random-number key) that was used to encrypt them. Therefore, load the primary user key as securely as possible and preferably early during the boot process.

Additional resources

- The **keyctl(1)** manual page
- Kernel Key Retention Service

29.5. 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.

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
[ 0.598533] ima: No TPM chip found, activating TPM-bypass!
[ 0.599435] ima: Allocated hash algorithm: sha256
[ 0.600266] ima: No architecture policies found
[ 0.600813] evm: Initialising EVM extended attributes:
[ 0.601581] evm: security.selinux
[ 0.601963] evm: security.ima
[ 0.602353] evm: security.capability
[ 0.602713] evm: HMAC attrs: 0x1
[ 1.455657] systemd[1]: systemd 239 (239-74.el8_8) running in system mode. (+PAM
+AUDIT +SELINUX +IMA -APPARMOR +SMACK +SYSVINIT +UTMP +LIBCRYPTSETUP
+GCRYPT +GNUTLS +ACL +XZ +LZ4 +SECCOMP +BLKID +ELFUTILS +KMOD +IDN2 -
IDN +PCRE2 default-hierarchy=legacy)
[ 2.532639] systemd[1]: systemd 239 (239-74.el8_8) running in system mode. (+PAM
+AUDIT +SELINUX +IMA -APPARMOR +SMACK +SYSVINIT +UTMP +LIBCRYPTSETUP
+GCRYPT +GNUTLS +ACL +XZ +LZ4 +SECCOMP +BLKID +ELFUTILS +KMOD +IDN2 -
IDN +PCRE2 default-hierarchy=legacy)
```

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 and allows users 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 that the parameters have been added to the kernel command line:

   ```
   # cat /proc/cmdline
   BOOT_IMAGE=(hd0,msdos1)/vmlinuz-4.18.0-167.el8.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 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 have been 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
```

Additional resources

- grep(1) manpage
- The kernel integrity subsystem
- Trusted and encrypted keys

29.6. 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 thus 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

CHAPTER 30. CONFIGURING KERNEL PARAMETERS PERMANENTLY BY USING THE KERNEL_SETTINGS RHEL SYSTEM ROLE

You can use the **kernel_settings** RHEL system role to configure kernel parameters on multiple clients at once. This solution:

- 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.

30.1. INTRODUCTION TO THE KERNEL_SETTINGS ROLE

RHEL system roles is a set of roles that provide a consistent configuration interface to remotely manage multiple systems.

RHEL system roles were introduced for automated configurations of the kernel using the **kernel_settings** RHEL system role. The **rhel-system-roles** package contains this system role, and also the reference documentation.

To apply the kernel parameters on one or more systems in an automated fashion, use the **kernel_settings** role with one or more of its role variables of your choice in a playbook. A playbook is a list of one or more plays that are human-readable, and are written in the YAML format.

You can use an inventory file to define a set of systems that you want Ansible to configure according to the playbook.

With the **kernel_settings** role you can configure:

- The kernel parameters using the **kernel_settings_sysctl** role variable
- Various kernel subsystems, hardware devices, and device drivers using the **kernel_settings_sysfs** role variable
- The CPU affinity for the **systemd** service manager and processes it forks using the **kernel_settings_systemd_cpu_affinity** role variable
- The kernel memory subsystem transparent hugepages using the **kernel_settings_transparent_hugepages** and **kernel_settings_transparent_hugepages_defrag** role variables

Additional resources

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

- **/usr/share/doc/rhel-system-roles/kernel_settings/** directory
- Working with playbooks
- How to build your inventory

30.2. APPLYING SELECTED KERNEL PARAMETERS BY USING THE KERNEL_SETTINGS ROLE

Follow these steps to prepare and apply an Ansible playbook to remotely configure kernel parameters with persisting effect on multiple managed operating systems.

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: Configure kernel settings
  hosts: managed-node-01.example.com
  roles:
    - 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
```

   - **name**: optional key which associates an arbitrary string with the play as a label and identifies what the play is for.
   - **hosts**: key in the play which specifies the hosts against which the play is run. The value or values for this key can be provided as individual names of managed hosts or as groups of hosts as defined in the **inventory** file.
   - **vars**: section of the playbook which represents a list of variables containing selected kernel parameter names and values to which they have to be set.
   - **role**: key which specifies what RHEL system role is going to configure the parameters and values mentioned in the **vars** section.

NOTE

You can modify the kernel parameters and their values in the playbook to fit your needs.

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
   ```

4. Restart your managed hosts and check the affected kernel parameters to verify that the changes have been applied and persist across reboots.

Additional resources

- **/usr/share/ansible/roles/rhel-system-roles.kernel_settings/README.md** file
- **/usr/share/doc/rhel-system-roles/kernel_settings/** directory
- Working With Playbooks
- Using Variables
- Roles

CHAPTER 31. USING ADVANCED ERROR REPORTING

When you use the **Advanced Error Reporting** (**AER**), you receive notifications of error events for **Peripheral Component Interconnect Express** (**PCIe**) devices. RHEL enables this kernel feature by default and collects the reported errors in the kernel logs. Moreover, if you use the **rasdaemon** program, these errors are parsed and stored in its database.

31.1. OVERVIEW OF AER

Advanced Error Reporting (**AER**) is a kernel feature that provides enhanced error reporting for **Peripheral Component Interconnect Express** (**PCIe**) devices. The **AER** kernel driver attaches root ports which support **PCIe AER** capability in order to:

- Gather the comprehensive error information
- Report errors to the users
- Perform error recovery actions

When **AER** captures an error, it sends an *error* message to the console. For a repairable error, the console output is a *warning*.

Example 31.1. Example AER output

```
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0: AER: Corrected error received:
id=ae00
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0: AER: Multiple Corrected error received:
id=ae00
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0: PCIe Bus Error: severity=Corrected,
type=Data Link Layer, id=0000(Receiver ID)
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0:   device [8086:2030] error
status/mask=000000c0/00002000
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0:    [ 6] Bad TLP
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0:    [ 7] Bad DLLP
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0: AER: Multiple Corrected error received:
id=ae00
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0: PCIe Bus Error: severity=Corrected,
type=Data Link Layer, id=0000(Receiver ID)
Feb  5 15:41:33 hostname kernel: pcieport 10003:00:00.0:   device [8086:2030] error
status/mask=00000040/00002000
```

31.2. COLLECTING AND DISPLAYING AER MESSAGES

In order to collect and display AER messages, use the **rasdaemon** program.

Procedure

1. Install the **rasdaemon** package.

```
# yum install rasdaemon
```

2. Enable and start the **rasdaemon** service.

```
# systemctl enable --now rasdaemon
Created symlink /etc/systemd/system/multi-user.target.wants/rasdaemon.service →
/usr/lib/systemd/system/rasdaemon.service.
```

3. Issue the **ras-mc-ctl** command.

```
# ras-mc-ctl --summary
# ras-mc-ctl --errors
```

The command displays a summary of the logged errors (the **--summary** option) or displays the errors stored in the error database (the **--errors** option).

Additional resources

- The **rasdaemon(8)** manual page
- The **ras-mc-ctl(8)** manual page