Hands-on Booting

Learn the Boot Process of Linux, Windows, and Unix

Yogesh Babar

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Printed on acid-free paper

*This book is dedicated to Red Hat. Its amazing work culture
has proved that sharing is caring.*

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About the Author

Yogesh Babar has been with Red Hat for the past ten years. Currently he is a principal technical support engineer in the Linux kernel domain. He specializes in the troubleshooting and performance tuning of Linux enterprise servers. The Linux boot process is his forte, and he regularly speaks at open source conferences and forums. He also conducts workshops on operating systems for engineering students.

About the Technical Reviewer

Marc Sandusky is an embedded software engineer with 28 years' experience in low-level programming. He has worked in industries such as PC BIOS, medical devices, and defense. He is experienced in embedded OSs (Linux, Windows Embedded Compact), RTOS (uCOS/II, FreeRTOS), and bare-metal systems. He currently lives in southern California with his wife and three children. You can reach him at `marc_sandusky@outlook.com` or `www.linkedin.com/in/marc-sandusky-67852b2/`.

Acknowledgments

I would like to thank Harald Hoyer for writing dracut and Lennart Poettering for writing systemd. Harald, you had tremendous patience when answering my back-to-back questions.

Thanks also to: Sheetal, Rama and Shoumik, who encouraged me to document the booting procedure; Parth Goswami, who helped me write a brief article about it; Rangan and Raghvendra Pai for asking for regular updates on it; and Gokhale Sir for igniting a spark in me and also for showing me what I am really good at.

To the entire Apress team, especially acquisitions editor Celestine John, project coordinator Aditee Mirashi, and development editor Matthew Moodie who put tremendous efforts into developing this book. Special thanks to Marc Sandusky for technically reviewing the book. With it being my first book, I made a lot of mistakes, but the entire Apress team stood behind me throughout the process.

Last but not the least, thanks to my beautiful, strong, and amazing wife. Darshana, what patience you have shown! Sometimes I wonder how you managed to stay with someone like me who is always chasing some project.

Introduction

I was in the first week at a new job, and I saw one of our customers asking for assistance on a “can’t boot” issue. I was new and inexperienced. I wanted to assist, but I could not. The customer was panicked since it brought production down. Every minute was counting for them, because thousands of users were not able to access that system since it was unbootable. Everyone was panicking. Eventually some of our most senior engineers resolved the issue. It took them almost five hours to put the system back in production. Everything turned out well in the end, but that tense situation created something in me, which was a desire to learn. I decided to learn the entire booting sequence.

When I started looking for books and articles on the Internet, I was disappointed. There are thousands of books and countless articles available on operating systems, but I could not find a single book that thoroughly explained the entire booting sequence.

There is a saying in the open source world: if there is something you are looking for and it is not available, then build it. So, I decided to learn the booting sequence on my own. It took me years to understand the entire booting sequence. The best thing I did on my journey was to keep notes and also start teaching what I learned to others. After all, sharing is caring. My booting sessions became popular among engineering students and system administrators. Some of them really pushed me hard to write a proper book on the topic. I contacted Apress, and they liked the idea, so today you have the first book of booting in your hands.

This book has a unique approach. First I discuss why someone should learn about booting. In other words, why is it important? Next I explain how different bootloaders work by installing almost 100+ operating systems on one machine. There is a dedicated chapter on the Linux bootloader. In fact, there are dedicated chapters for every component involved in the booting sequence. Next, I explain the kernel’s role in the booting sequence. The kernel plays a vital role along with systemd. Since systemd is the first process started by kernel, eventually it takes care of the entire booting sequence. There are several chapters that cover systemd, so this book is a good resource for those who want to read about systemd. I have also covered the most common “can’t boot” scenarios of Linux. This makes the book a great resource for system admins as well. It does not mean this book is for Linux experts only. If you know basics of Linux, then this book is for you. The book is a great bridge between the beginners and experts of Linux. I hope you will like the effort.

There is an old saying: no book is perfect. If you find some bugs in this book or you simply want to get in touch with me, please feel free to write to me at `yogeshbabar420@gmail.com`.

Thank you,

Yogesh Babar

CHAPTER 1

Introduction

Not everyone knows Fedora. One day, someone asked me a question:

> **Student**: What is Fedora?
>
> **Me**: Fedora is Linux.
>
> **Student**: What is Linux?
>
> **Me**: Linux is an operating system.
>
> **Student**: What is an operating system?
>
> **Me**: It runs computers.
>
> **Student**: What is a computer?
>
> **Me**: Computers help users.
>
> **Student**: What is a user?
>
> **Me**: A user is just like me.
>
> **Student**: Who the hell are you?
>
> **Me**: Well, my name is Yogesh Babar. I have worked at Red Hat for the last ten years, and I love talking about how operating systems boot.

Why?

Everyone knows that an operating system takes approximately 20 to 30 seconds to boot. So, why did I write a 486-page book about a 30-second booting sequence? The answer is simple.

- There is no proper document/article/book available that explains the complete booting sequence. You will find hundreds of good books on operating systems but none on how a system boots.

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- You can resolve boot issues only if you know how the system boots.
- If you are a sysadmin and attending an interview, the interviewers will ask about how Linux boots.
- "Can't boot" issues are always the highest severity as the entire production system goes down because of them. If the system is slow, the production is still up and running; though it is affected, at least it is still running. A server that has 10,000 users but can't boot means the entire production system is down. That's the importance of booting, and as I said, you cannot solve boot issues if you don't know how a system boots.
- It's fun to understand the booting procedure.
- While learning all of this, you will gain immense happiness.

What?

So, what exactly is booting? In technical terms, the process of copying the kernel from the hard disk to memory and then executing it is called *booting*. But that definition does not really inspire us to learn about booting.

I will put it in my own words: A mother is a superset, and her newborn baby is a subset of her. In the same way, an operating system is a superset, and booting is a subset of it. A subset belongs to its superset.

Now consider this statement: "A child gives birth to a mother."

Technically it is wrong, but imagine that until a woman has a baby, she is a woman; the moment she has a baby, a woman becomes a mother. So, a child gives birth to a mother.

The same happens in computers. Technically booting is part of an operating system, and the operating system should give birth to booting, but it's the other way around. It's booting that gives birth to the operating system. Hence, we can say that *booting* is the procedure that gives birth to an operating system.

The Focus of This Book

The book explains the booting procedure of an x86 architecture–based desktop or server system, and it covers the booting procedure of various operating systems. The primary focus is on the in-depth analysis of the Linux booting procedure, with a secondary focus on other popular operating systems such as Windows and UNIX. As you know, there are a huge number of Linux distributions. Some are for desktop users, some are for enterprise customers, some are solely for gaming purposes, and some are available for users who prefer to follow a do-it-yourself approach. It is almost impossible to cover each and every distribution's booting sequence. Hence, I have decided to choose the Linux distribution that is the first choice for enterprise customers, and that is Red Hat Enterprise Linux (RHEL).

RHEL is based on Fedora Linux. Fedora is fast moving (a six-month release cycle), whereas RHEL is a slow-moving distribution (a two- to three-year release cycle). This means Fedora adopts the latest developments as soon as the QE (Quality Engineering) team gives them the green light. Since Fedora is a testing bed of popular enterprise Linux distributions, whatever is available in Fedora eventually becomes part of RHEL. systemd is the best example of this. That's why I have chosen Fedora Linux to explain the Linux booting sequence.

Power Supply

It all starts when you hit the power button. When you press the power button, the power supply goes to the motherboard. The motherboard sends a signal to your power supply (SMPS/PSU), which returns a good power supply, and as a result, the motherboard tries to start the CPU.

CPU

When the x86 architecture–based CPU starts, it clears the old data from all the registers and starts with this:

```
IP              0xfff0
CS selector     0xf000
CS base         0xffff0000
```

`0xffff0000` + `0xfff0` = `0xfffffff0`. This is the memory location at which the CPU expects to find the first instruction to execute. At this location, it contains a jump instruction that points to a BIOS entry point. In other words, this is how the BIOS starts or the CPU lands at the BIOS/firmware.

After this, the firmware and bootloader are the next stage of a booting procedure. It's the job of the firmware to launch the bootloader of an operating system. In the next chapter, I will discuss what happens in the firmware and how it executes the bootloader.

CHAPTER 2

Multiboot

Understanding the bootloader and firmware is complex. It is not necessarily difficult, but the topic can be complicated. To make it easy to digest for the readers of this book, I will use three test systems.

System Number	System Name	Purpose
1	BIOS	To demonstrate the BIOS
2	UEFI	To demonstrate UEFI
3	Jarvis	For a 100+ OS multiboot project

Since the bootloaders and firmware work closely together, I will start by installing a specific list of operating systems on each system and while doing that explain the relationship between the bootloader and the firmware. This approach will make complex topics easier to understand, more interesting, and a lot of fun. In short, I will explain the bootloader and firmware (BIOS/UEFI) together though they are different concepts.

Note The BIOS-based multiboot part of this chapter was inspired by Mr Vijay Gokhale Sir's workshop on the subject. I thank him for the inspiration.

List of Operating Systems

We will be installing the following operating systems on our first BIOS system, which means on a system that has the BIOS firmware installed:

- Sun OpenSolaris 2009
- Fedora Linux 15
- PC-BSD 9.0

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- Windows 7
- Red Hat Enterprise Linux 6.0
- Windows Server 2003 (2k3)
- Windows XP

I know these operating systems are quite old, but I have chosen them for a reason.

See, the BIOS itself is an outdated firmware, so if you want to understand the BIOS, you have to use old operating systems only. Remember, you can understand UEFI (the current firmware) only if you understand the BIOS. It's like you will understand Java better if you know C well. Also, using these old operating systems will give me a chance to touch upon the Windows and Unix bootloaders as well. In addition, it will provide me with the opportunity to explain the GRUB legacy bootloader of Linux.

The idea is to multiboot our BIOS system with all the operating systems mentioned earlier. To do that, we need to follow every operating system's rules and regulations.

OS	Rules
Unix	Unix operating systems (OpenSolaris and BSD) have to be installed on a primary partition only.
Linux	Linux does not have any installation rules. It can be installed on any primary or logical partition.
Windows	The Windows operating system can be installed on any partition (primary or logical), but the predecessor of the Windows family has to be present on the first primary. That means you can install Windows 7 on a logical partition, but its predecessor, which is XP or win2k3, has to be present on the first primary partition. Also, you cannot break the Windows operating system sequence of installation. For example, one cannot install Windows 7 first and then the older win2k3 or XP. It has to be in this sequence: 98, then 2000, and then XP.

Take some time and try to prepare your OS installation sequence. Verify your booting sequence now.

The final sequence of the operating system is as shown here:

1) Windows XP
2) Sun OpenSolaris 2008

3) PC-BSD 9.0
4) Windows Server 2003
5) Windows 7
6) Red Hat Enterprise Linux 6
7) Fedora 15

Installing the Operating Systems

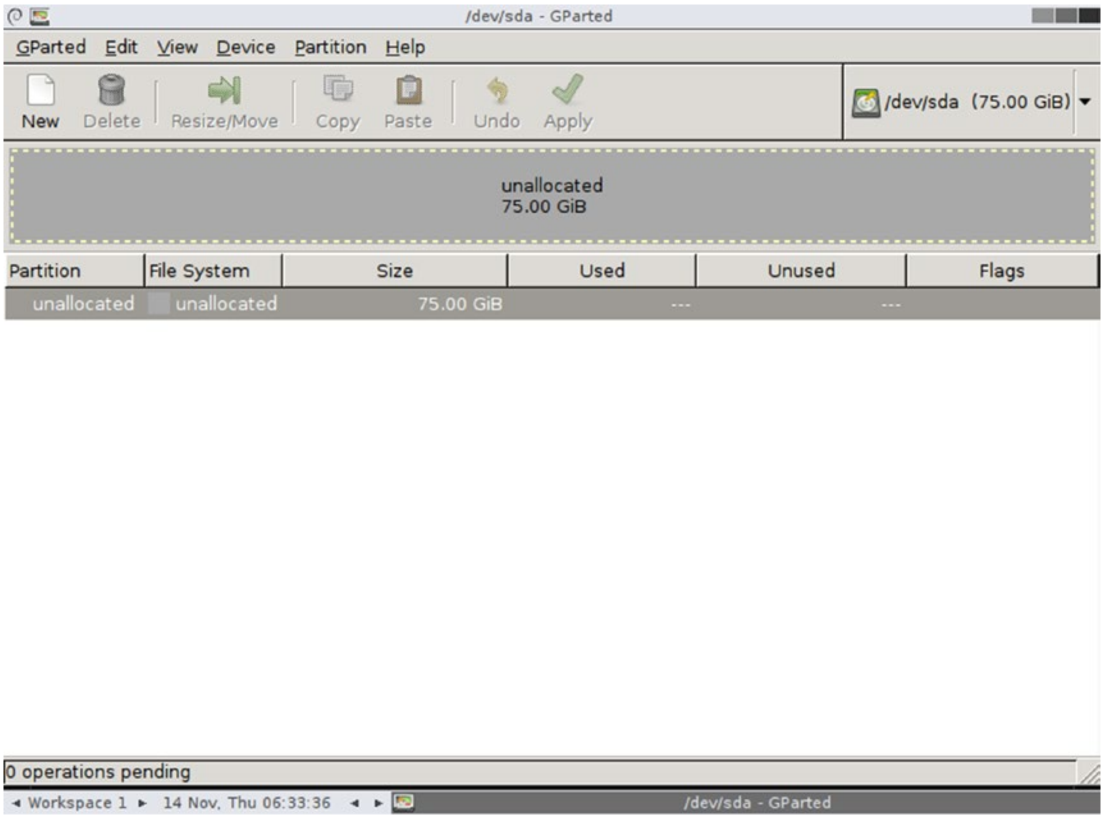
Now we'll talk about installing the operating systems.

Primary/Logical Partitions

With the BIOS, we can create only four partitions. But of course you probably have seen more partitions used than that. So, let me change my statement a bit. On a BIOS-based system, you can create only four *primary* partitions on your disk. If you want more than that, then you need to make the fourth primary partition a *secondary* (also called an *extended*) partition. The extended partition will work as a container, and inside this container you can create as many *logical* partitions as you want. Why are these partitions called logical partitions, because they are not visible to BIOS? Also, why can the BIOS make only four primary partitions? These questions will be answered when we discuss the master boot record.

Partitioning

Let's partition the BIOS system's hard disk first. We will use the GParted live CD for this. GParted is a tool from the GNU community. It's a free, open source, Debian Linux–based live ISO image. Figure 2-1 shows our BIOS system's partition layout.

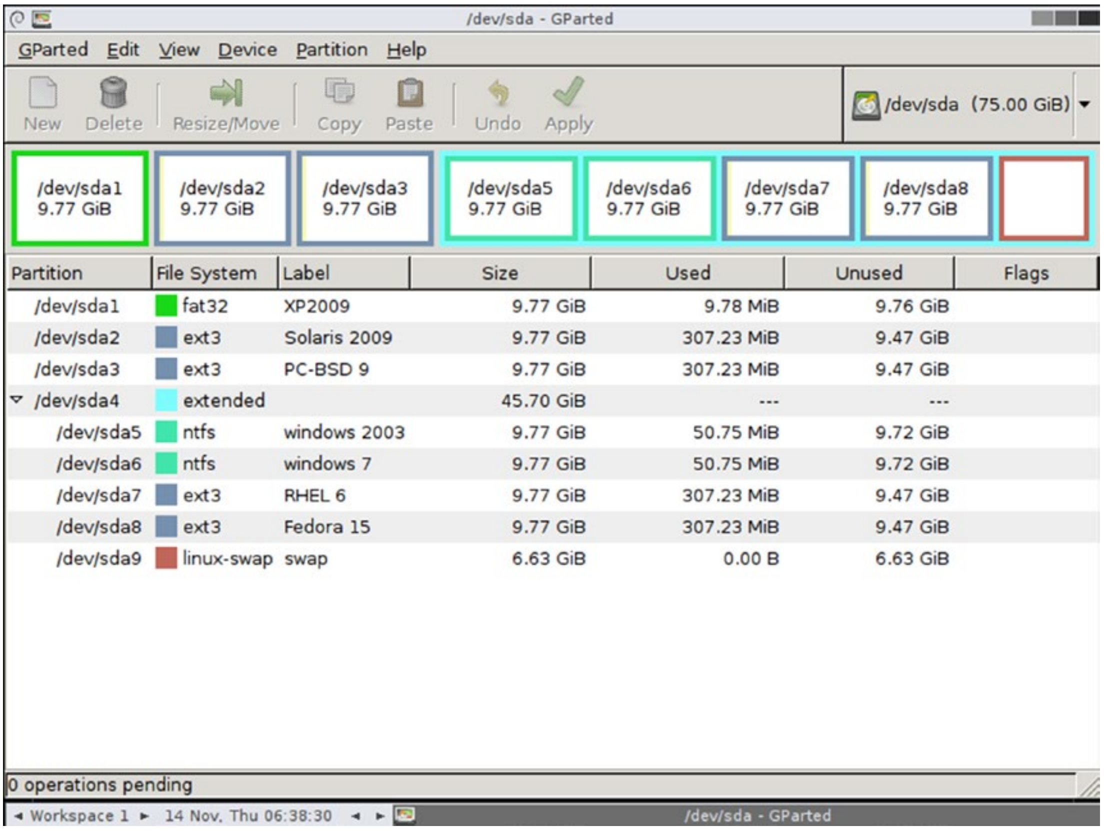

/dev/sda - GParted
GParted Edit View Device Partition Help
New Delete Resize/Move Copy Paste Undo Apply
/dev/sda (75.00 GiB)
unallocated
75.00 GiB

Partition	File System	Size	Used	Unused	Flags
unallocated	unallocated	75.00 GiB	---	---	

0 operations pending

Figure 2-1. *The partition layout of the BIOS in GParted*

The GParted operation to partition a hard disk is straightforward. We will create the partition layout shown in Figure 2-2 on the 75 GB of disk space.



Partition	File System	Label	Size	Used	Unused	Flags
/dev/sda1	fat32	XP2009	9.77 GiB	9.78 MiB	9.76 GiB	
/dev/sda2	ext3	Solaris 2009	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda3	ext3	PC-BSD 9	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda4	extended		45.70 GiB	---	---	
/dev/sda5	ntfs	windows 2003	9.77 GiB	50.75 MiB	9.72 GiB	
/dev/sda6	ntfs	windows 7	9.77 GiB	50.75 MiB	9.72 GiB	
/dev/sda7	ext3	RHEL 6	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda8	ext3	Fedora 15	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda9	linux-swap	swap	6.63 GiB	0.00 B	6.63 GiB	

0 operations pending

Figure 2-2. *GParted-made partition layout*

For more information on how to use GParted to partition your hard drive, please refer to the GParted documentation at `https://gparted.org/articles.php`.

In Figure 2-3, you can see the disk name, partition size, used filesystem, and associated flags (if any).

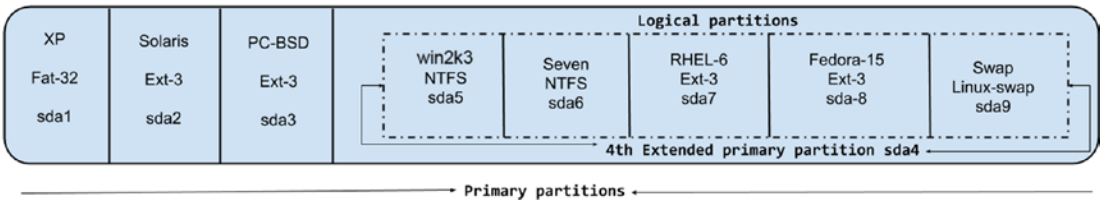
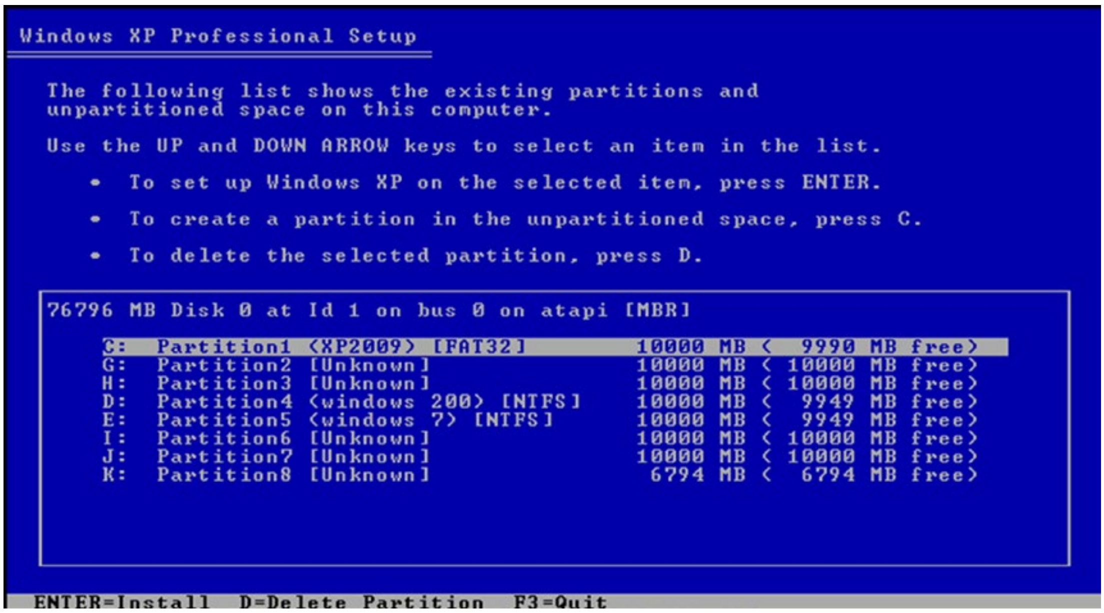


Figure 2-3. *GParted-made filesystem layout*

Let's install our first operating system on our first primary partition.

First OS Installation: XP

In Figure 2-4, you can see a partition layout shown by the Windows XP installer.



```
Windows XP Professional Setup

   The following list shows the existing partitions and
   unpartitioned space on this computer.

   Use the UP and DOWN ARROW keys to select an item in the list.

      •  To set up Windows XP on the selected item, press ENTER.

      •  To create a partition in the unpartitioned space, press C.

      •  To delete the selected partition, press D.

   76796 MB Disk 0 at Id 1 on bus 0 on atapi [MBR]

        C:  Partition1 (XP2009) [FAT32]          10000 MB (  9990 MB free)
        G:  Partition2 [Unknown]                 10000 MB ( 10000 MB free)
        H:  Partition3 [Unknown]                 10000 MB ( 10000 MB free)
        D:  Partition4 (windows 200) [NTFS]      10000 MB (  9949 MB free)
        E:  Partition5 (windows 7) [NTFS]        10000 MB (  9949 MB free)
        I:  Partition6 [Unknown]                 10000 MB ( 10000 MB free)
        J:  Partition7 [Unknown]                 10000 MB ( 10000 MB free)
        K:  Partition8 [Unknown]                  6794 MB (  6794 MB free)

  ENTER=Install   D=Delete Partition   F3=Quit
```

Figure 2-4. *Partition layout shown by XP's installer*

We are installing XP on the first primary partition. In terms of Windows, it is a C: drive, as shown in Figure 2-4. After finishing the installation and rebooting the system, we get Windows XP on our screen (Figure 2-5).

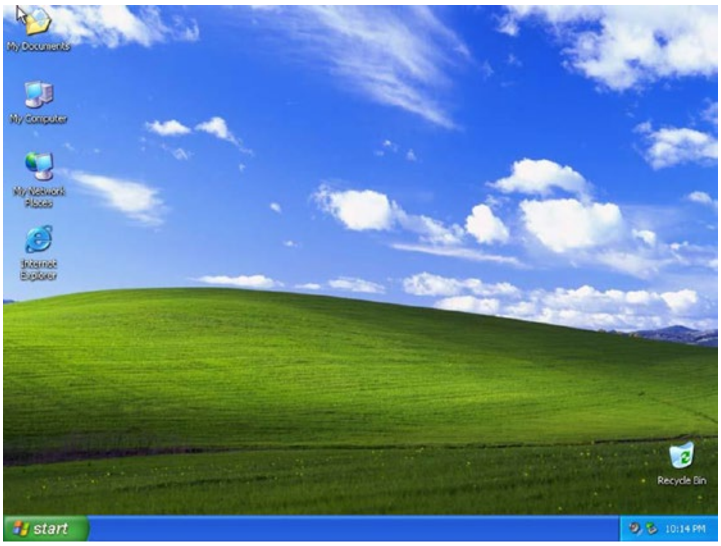


***Figure 2-5.** XP after successful installation*

It's time to understand how Windows XP has been booted, but before that, we need to understand the boot sector. The *boot sector* is every HDD's first sector (512 bytes) plus 31 KB of space; in other words, it's the first 63 sectors on the boot medium (0 to 62). Or, you can consider under the boot sector that some space (512 bytes + 31 KB) of every partition will be reserved to store the bootloader-related information. This space (again, 512 bytes + 31 KB) will not be shown by the OS to users. The actual data storage in a partition starts after this reserved space. Refer to Figure 2-6 for a better understanding of this.

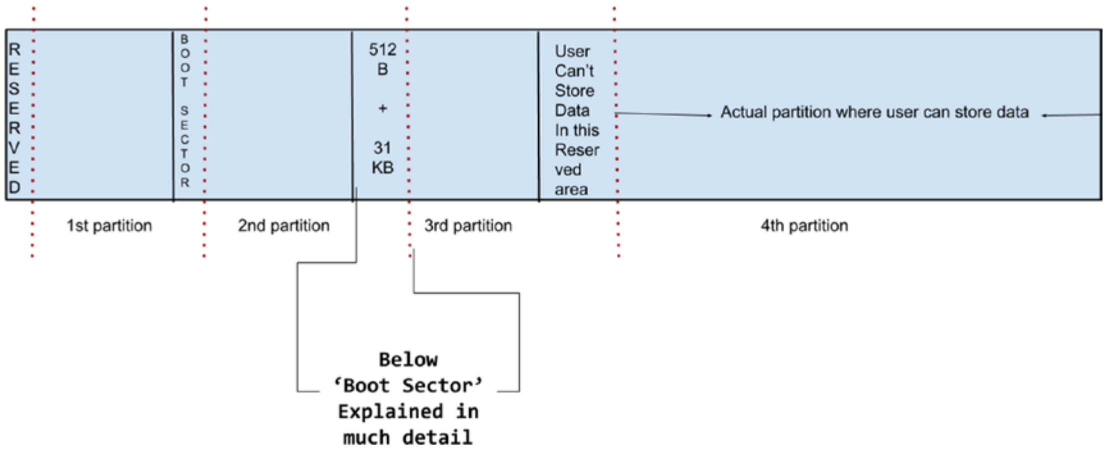

RESERVED
BOOT SECTOR
512 B + 31 KB
User Can't Store Data In this Reserved area
Actual partition where user can store data
1st partition
2nd partition
3rd partition
4th partition
Below 'Boot Sector' Explained in much detail

***Figure 2-6.** The disk layout on a BIOS-based system*

Boot Sector

There is one amazing saying in Sanskrit that goes like this: "एकम सत विप्रा: बहुधा: वदन्ति सत्य". This means there is only one truth but various ways to reach it. As shown in Figure 2-7, the boot sector is called by different names, but ultimately the concept remains the same. People refer this structure with the following names:

- Master boot record (MBR)
- Boot record
- Boot sector
- Bootloader

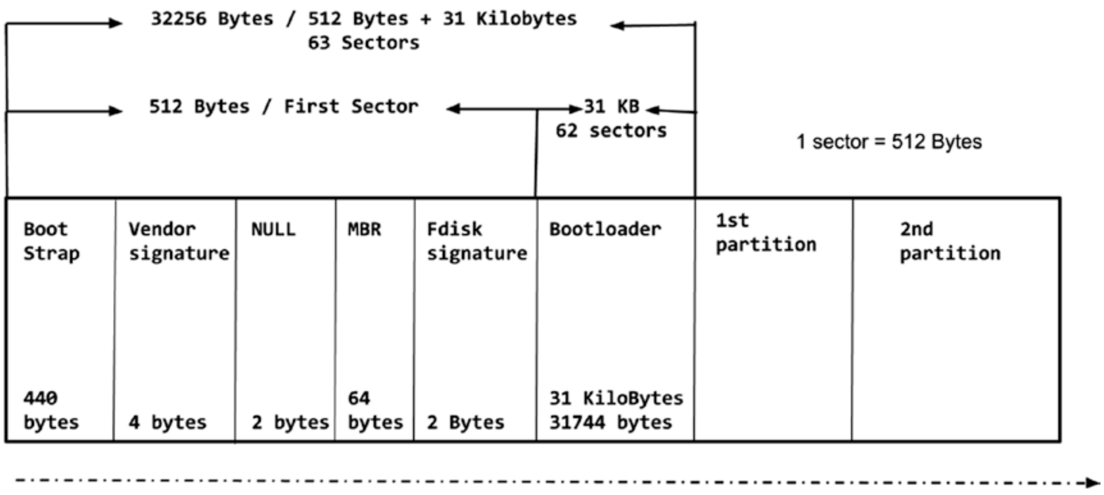


Figure 2-7. *The boot sector*

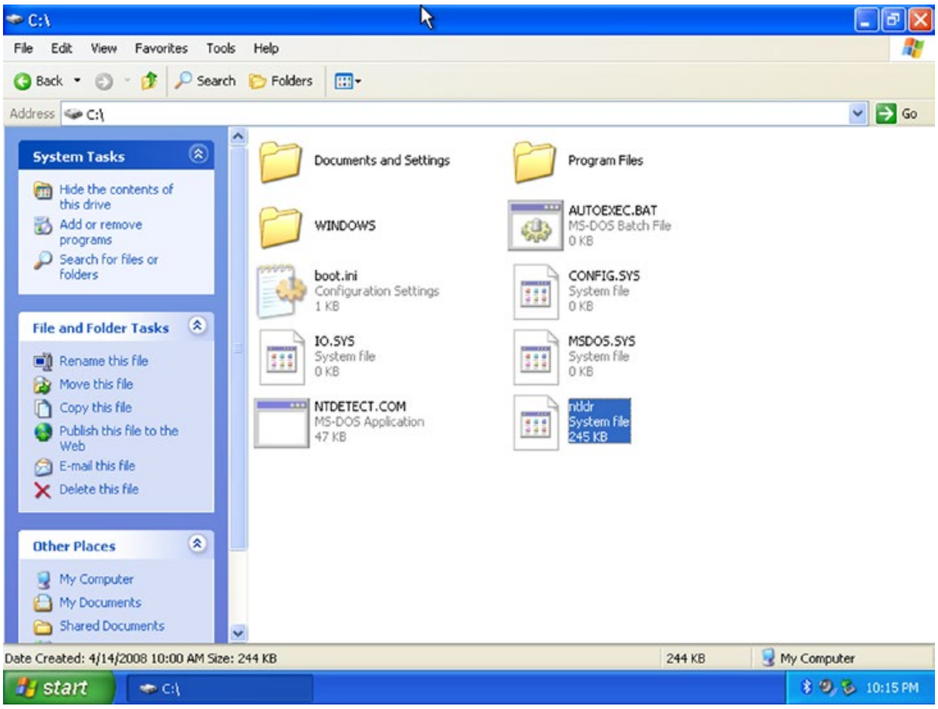
In this book, we'll call it the *boot sector* because the hard disk drive (HDD) is always divided into sectors, and every sector is of either 512 bytes or 4 KB in size. Most HDDs follow a 512-byte sector size.

On a BIOS-based system, every OS vendor (it does not matter if it is Windows, Unix, or Linux) has to divide the bootloader into three parts. Part-1 of the bootloader will be kept at the bootstrap, which is 440 bytes. Part-2 will be kept in the bootloader section, which is 31 KB in size, and the final part-3 will be kept inside the actual partition where a particular OS has been installed. So, in simple terms, whenever an OS gets installed (in our case it's Windows XP), it divides its New Technology Loader (NTLDR) bootloader into three parts.

Location	Size	Part	Information
Bootstrap	440 bytes	NTLDR part-1	The tiniest part
Bootloader	31 KB	NTLDR part-2	Bigger compared to part-1
Inside an actual OS partition	No size limitation	NTLDR part-3	The biggest part

But why is the bootloader divided into three parts?

It is because of historical reasons. The BIOS has technical limitations in that it cannot access more than 512 bytes or cannot read beyond the first sector. So, it is obvious that when BIOS finishes its task, it jumps on the entire HDD's first 512 bytes and whoever is there simply runs that program. Fortunately, that program will be our bootstrap (440 bytes). Since the bootstrap is tiny in size, it does only one thing, which is to jump on a bigger space, which is the part-2 bootloader. It is 31 KB in size. This 31 KB is again very tiny, and it has to find an even bigger size. This bootloader will jump to part-3, which is inside a partition. This part-3 file will be at the C: drive with the file name NTLDR. The part-3 file of XP's bootloader is visible in Figure 2-8.



Documents and Settings
Program Files
WINDOWS
AUTOEXEC.BAT MS-DOS Batch File 0 KB
boot.ini Configuration Settings 1 KB
CONFIG.SYS System file 0 KB
IO.SYS System file 0 KB
MSDOS.SYS System file 0 KB
NTDETECT.COM MS-DOS Application 47 KB
ntldr System file 245 KB

Date Created: 4/14/2008 10:00 AM Size: 244 KB 244 KB My Computer

Figure 2-8. *The part-3 file of XP's bootloader*

As you can see, the file is much bigger in size (245 KB). This file will do the heavy lifting of the bootloader's actual job, which is copying the kernel of Windows XP called `winload.exe` (this file knows where XP's kernel is) from `C:\windows` in memory. Once the kernel is copied into memory, the bootloader's job is done, and it goes away. Remember, `OS==kernel==OS`. Once the kernel is in memory, it will take care of the rest of the booting sequence. You can see XP's boot sequence in Figure 2-9.

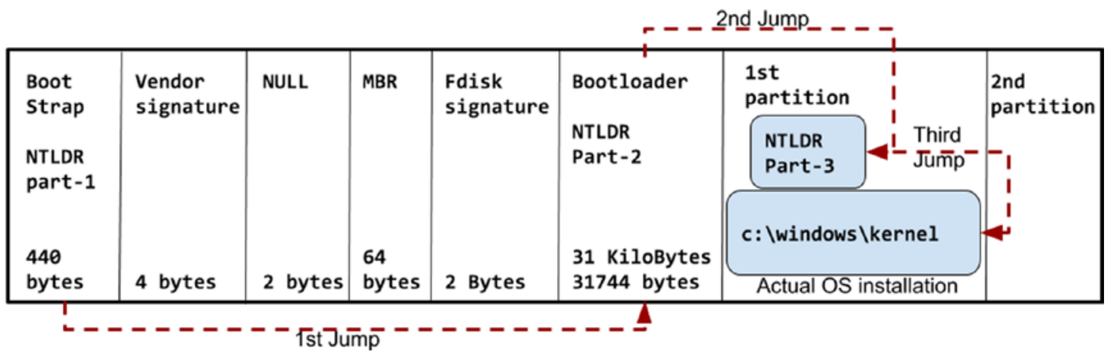


***Figure 2-9.** The boot sequence of Windows XP*

I know there are probably a lot of questions in your mind. But keep reading, and all of your questions will be answered. Let's go ahead and discuss the fields of the boot sector that I have not explained yet. You can refer to Figure 2-10 for this.

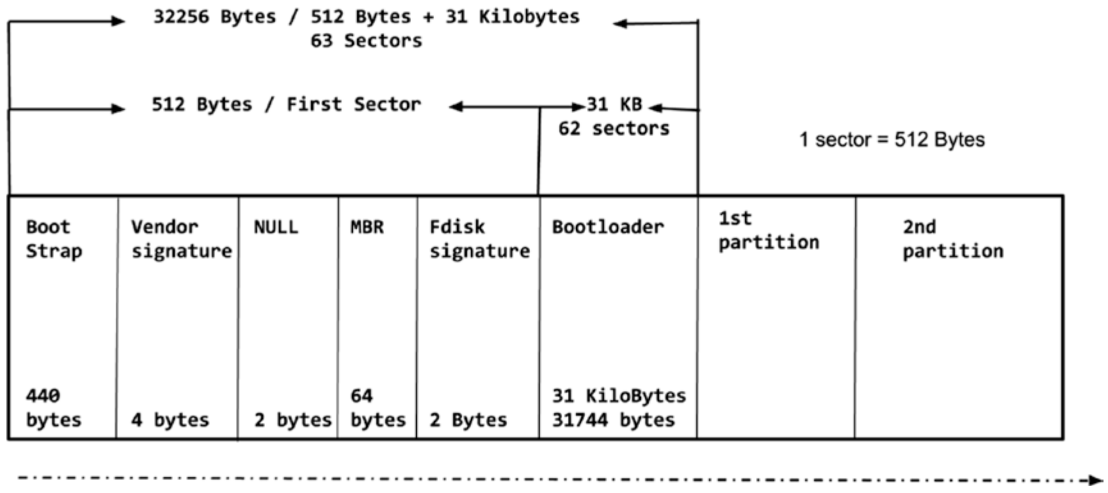


***Figure 2-10.** The boot sector*

The vendor signature field is for HDD vendors. The data that is mentioned here tells us which vendor has manufactured this HDD, such as Seagate, Western Digital, Samsung, etc. So, basically it holds the HDD manufacturer information.

NULL has only 2 bytes of space. The NULL means NULL. If this is not NULL, then the BIOS will consider this HDD as faulty/corrupted at the time of the POST routine, and booting will be halted. So, it has to be NULL. Whenever the OS abruptly reboots or when the OS or HDD itself detects the bad sector or some sort of serious corruption, this field will be marked as non-NULL.

The MBR field could be the most popular section of all of these fields. MBR stands for "master boot record," and it is 64 bytes in size. The MBR is further divided into four parts. Each part is 16 bytes in size, and every part holds one partition's information.

Size	Parts	Stores
16 bytes	Part-1	First partition's information
16 bytes	Part-2	Second partition's information
16 bytes	Part-3	Third partition's information
16 bytes	Part-4	Fourth partition's information

This means 64 bytes of the MBR can hold only four entries of the partition, and this is the reason why you can make only four primary partitions on a BIOS-based system.

The fdisk signature is also called the *boot flag*; some people simply call it *, or in Windows style, it is also called an *active/inactive flag*. The fdisk is important in the case of multibooting different operating systems, which we will not talk about now. For now, I want you to remember these two rules:

- The logical partition cannot be active.
- The OS cannot boot from the logical partition.

As of now, these two rules will not make any sense to you, but we will discuss them at the right time. Figure 2-11 shows the complete booting sequence of Windows XP.

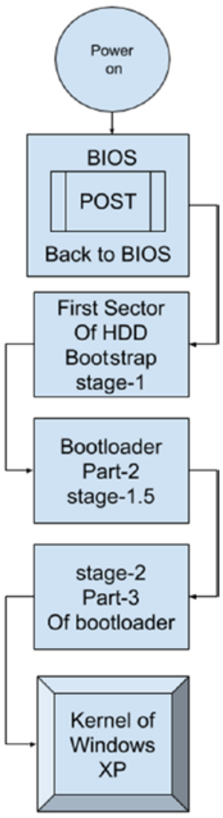
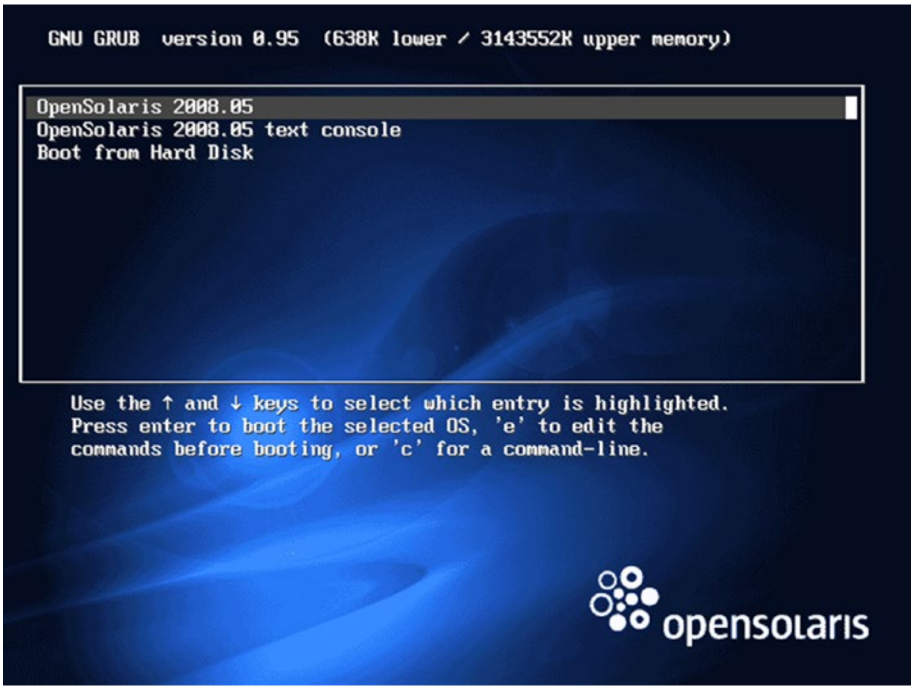

Power on
BIOS
POST
Back to BIOS
First Sector Of HDD Bootstrap stage-1
Bootloader Part-2 stage-1.5
stage-2 Part-3 Of bootloader
Kernel of Windows XP

Figure 2-11. *The boot sequence of Windows XP*

We will install and boot a new OS now, namely, OpenSolaris 2008.

OpenSolaris 2008

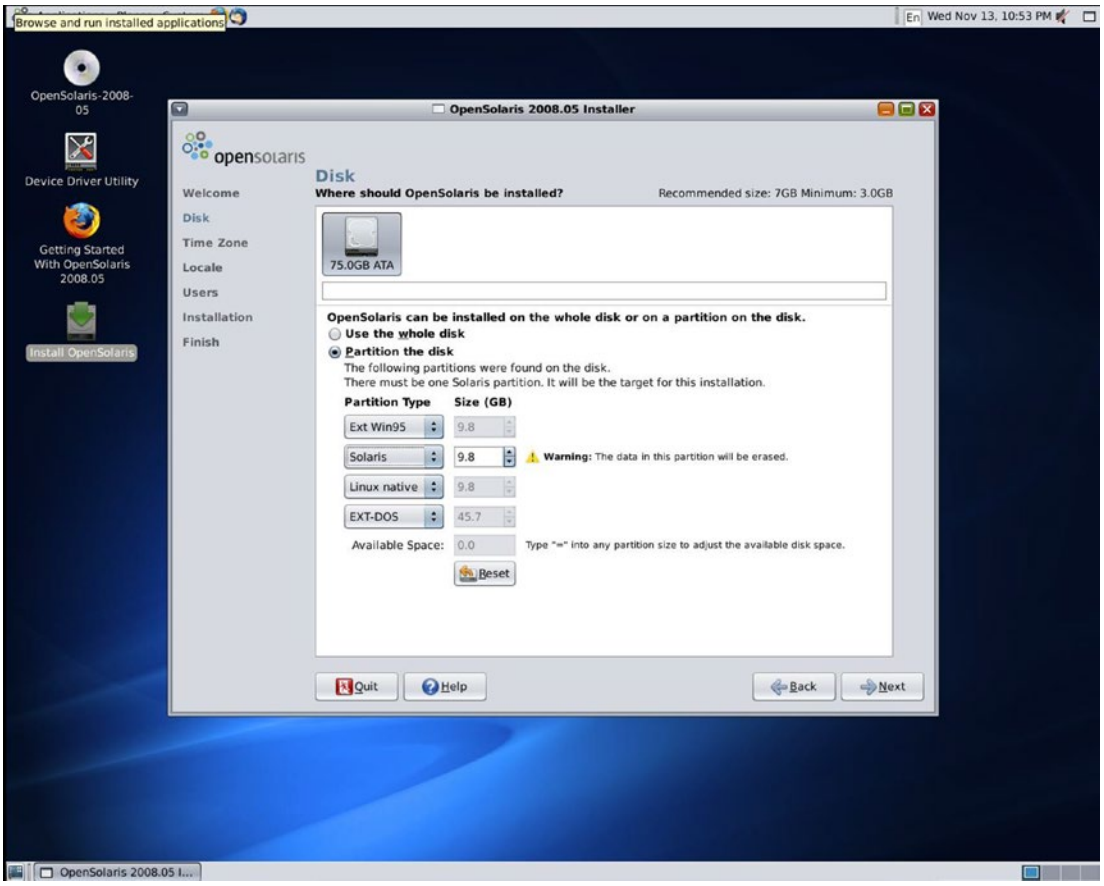
Figure 2-12 shows the screen when booting with an OpenSolaris 2008 installation medium.



```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05
OpenSolaris 2008.05 text console
Boot from Hard Disk

Use the ↑ and ↓ keys to select which entry is highlighted.
Press enter to boot the selected OS, 'e' to edit the
commands before booting, or 'c' for a command-line.
```

Figure 2-12. *The welcome screen of the OpenSolaris 2008 installation medium*

We need to install OpenSolaris on the second partition. You can see in Figure 2-13 that we have chosen the second primary partition for the installation.



Disk

Where should OpenSolaris be installed? Recommended size: 7GB Minimum: 3.0GB

OpenSolaris can be installed on the whole disk or on a partition on the disk.

○ **Use the whole disk**

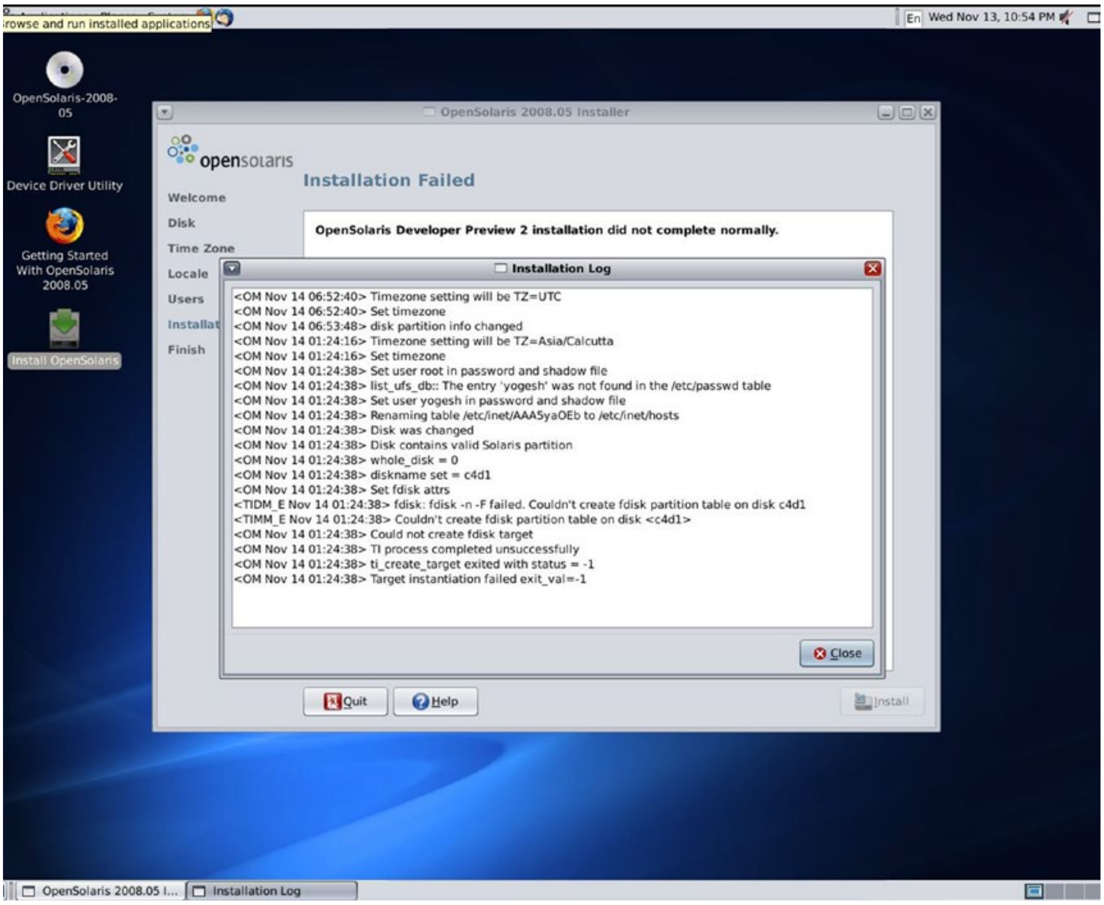
● **Partition the disk**

The following partitions were found on the disk.
There must be one Solaris partition. It will be the target for this installation.

Partition Type	Size (GB)	
Ext Win95	9.8	
Solaris	9.8	**Warning:** The data in this partition will be erased.
Linux native	9.8	
EXT-DOS	45.7	
Available Space:	0.0	Type "=" into any partition size to adjust the available disk space.

Figure 2-13. Disk layout shown by the OpenSolaris 2008 installer

But as you can see in Figure 2-14, the installation fails with some error messages.

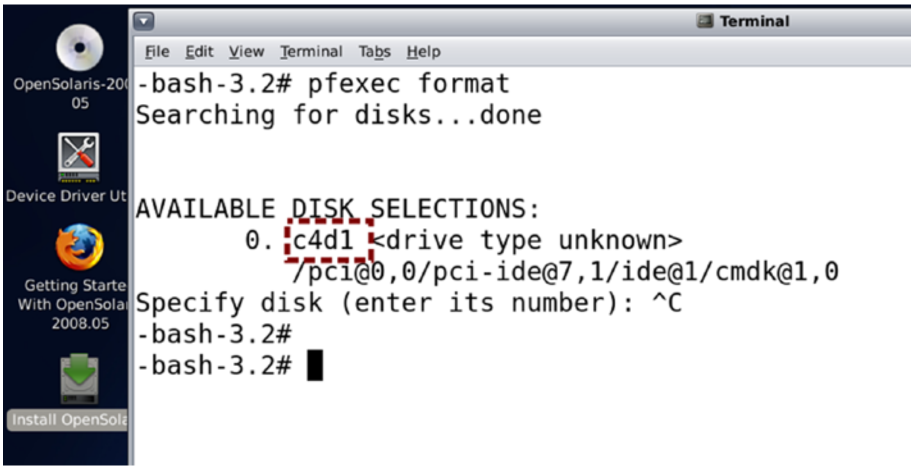


OpenSolaris Developer Preview 2 installation did not complete normally.

```
<OM Nov 14 06:52:40> Timezone setting will be TZ=UTC
<OM Nov 14 06:52:40> Set timezone
<OM Nov 14 06:53:48> disk partition info changed
<OM Nov 14 01:24:16> Timezone setting will be TZ=Asia/Calcutta
<OM Nov 14 01:24:16> Set timezone
<OM Nov 14 01:24:38> Set user root in password and shadow file
<OM Nov 14 01:24:38> list_ufs_db:: The entry 'yogesh' was not found in the /etc/passwd table
<OM Nov 14 01:24:38> Set user yogesh in password and shadow file
<OM Nov 14 01:24:38> Renaming table /etc/inet/AAA5yaOEb to /etc/inet/hosts
<OM Nov 14 01:24:38> Disk was changed
<OM Nov 14 01:24:38> Disk contains valid Solaris partition
<OM Nov 14 01:24:38> whole_disk = 0
<OM Nov 14 01:24:38> diskname set = c4d1
<OM Nov 14 01:24:38> Set fdisk attrs
<TIDM_E Nov 14 01:24:38> fdisk: fdisk -n -F failed. Couldn't create fdisk partition table on disk c4d1
<TIMM_E Nov 14 01:24:38> Couldn't create fdisk partition table on disk <c4d1>
<OM Nov 14 01:24:38> Could not create fdisk target
<OM Nov 14 01:24:38> TI process completed unsuccessfully
<OM Nov 14 01:24:38> ti_create_target exited with status = -1
<OM Nov 14 01:24:38> Target instantiation failed exit_val=-1
```

Figure 2-14. *The installation fails with some error messages.*

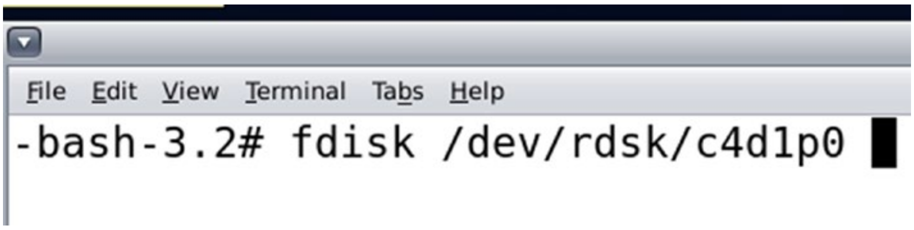
The error messages are related to the filesystem. So, we will prepare the filesystem manually by using the fdisk utility; however, before that, you should know what hard disk name has been assigned by OpenSolaris. The `pfexec format` command output (shown in Figure 2-15) will provide us with the HDD name.



```
-bash-3.2# pfexec format
Searching for disks...done


AVAILABLE DISK SELECTIONS:
       0. c4d1 <drive type unknown>
          /pci@0,0/pci-ide@7,1/ide@1/cmdk@1,0
Specify disk (enter its number): ^C
-bash-3.2#
-bash-3.2#
```

Figure 2-15. *The HDD name assigned by OpenSolaris*

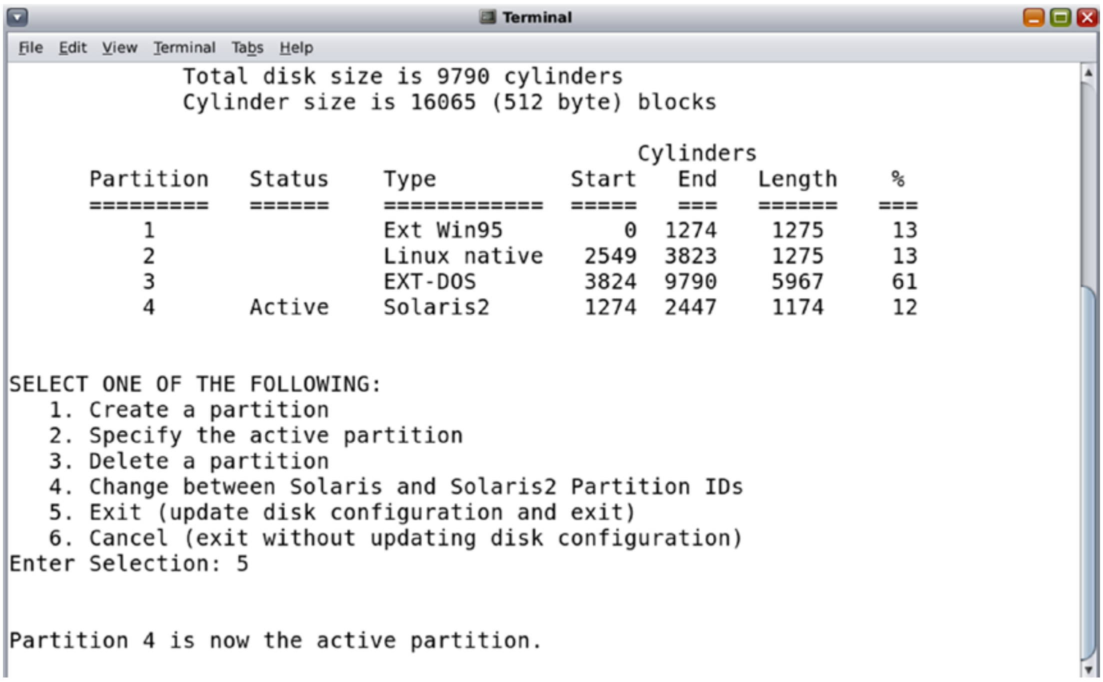
So, the assigned hard disk's name is c4d1. We need to pass this device name to the fdisk utility. See the complete command in Figure 2-16.



```
-bash-3.2# fdisk /dev/rdsk/c4d1p0
```

Figure 2-16. *The fdisk command*

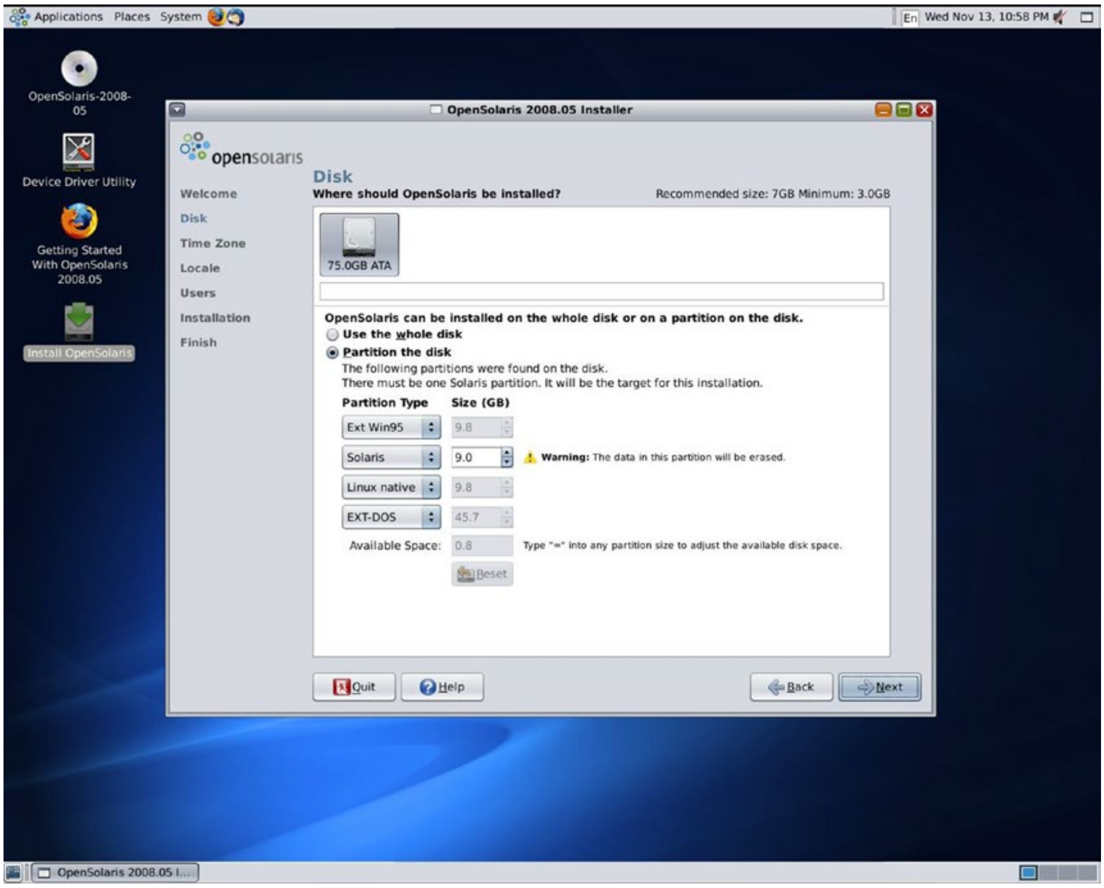
The disk name indicates controller number 4, disk number 1, and partition number 0. Through the fdisk utility, we first deleted the second partition (which was ext3/Linux native) and created a new partition with a Solaris2 filesystem. The new partition becomes partition number 4. Also, it automatically becomes the active partition (refer to Figure 2-17). We have not yet talked about the "active or fdisk signature" part, but we will talk about it soon.



```
             Total disk size is 9790 cylinders
             Cylinder size is 16065 (512 byte) blocks

                                                Cylinders
      Partition   Status    Type          Start   End   Length    %
      =========   ======    ============  =====   ===   ======   ===
          1                 Ext Win95         0  1274    1275     13
          2                 Linux native   2549  3823    1275     13
          3                 EXT-DOS        3824  9790    5967     61
          4       Active    Solaris2       1274  2447    1174     12


SELECT ONE OF THE FOLLOWING:
   1. Create a partition
   2. Specify the active partition
   3. Delete a partition
   4. Change between Solaris and Solaris2 Partition IDs
   5. Exit (update disk configuration and exit)
   6. Cancel (exit without updating disk configuration)
Enter Selection: 5


Partition 4 is now the active partition.
```

Figure 2-17. *The changes made through the fdisk command*

Returning to our installation, let's restart the installation, and as you can see in Figure 2-18, this time we have chosen the OpenSolaris filesystem–formatted partition to install our OpenSolaris 2008.



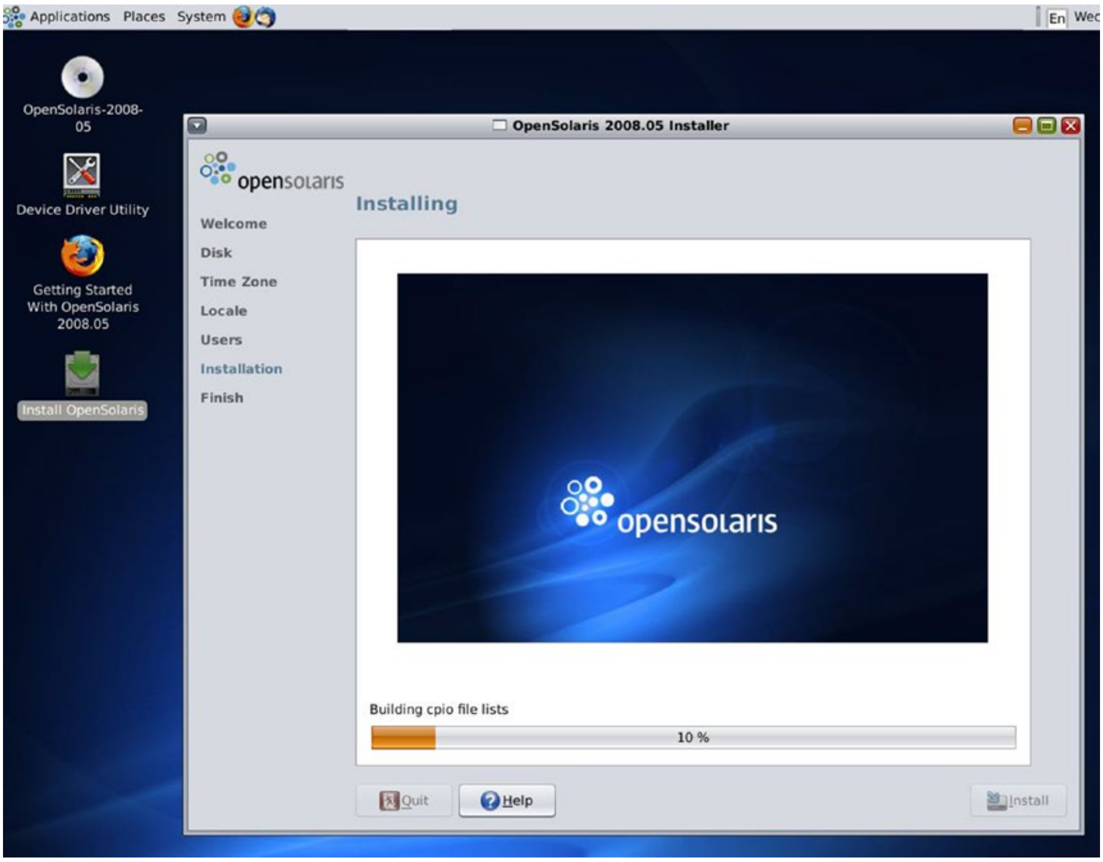
Disk
Where should OpenSolaris be installed?
Recommended size: 7GB Minimum: 3.0GB

OpenSolaris can be installed on the whole disk or on a partition on the disk.
( ) Use the whole disk
(•) Partition the disk
The following partitions were found on the disk.
There must be one Solaris partition. It will be the target for this installation.

Partition Type	Size (GB)	
Ext Win95	9.8	
Solaris	9.0	Warning: The data in this partition will be erased.
Linux native	9.8	
EXT-DOS	45.7	
Available Space:	0.8	Type "=" into any partition size to adjust the available disk space.

***Figure 2-18.** Installing OpenSolaris on the OpenSolaris filesystem partition*

This time, the installation will not fail (refer to Figure 2-19), and OpenSolaris 2008 will be installed.



Building cpio file lists

10 %

Figure 2-19. *The installer will not fail*

After the installation, we will reboot our BIOS system. What OS do you think will boot?

- Windows XP?
- OpenSolaris?
- XP and OpenSolaris together?
- None?

Take a while and think before continuing....

Figure 2-20 shows what we get on-screen after rebooting.

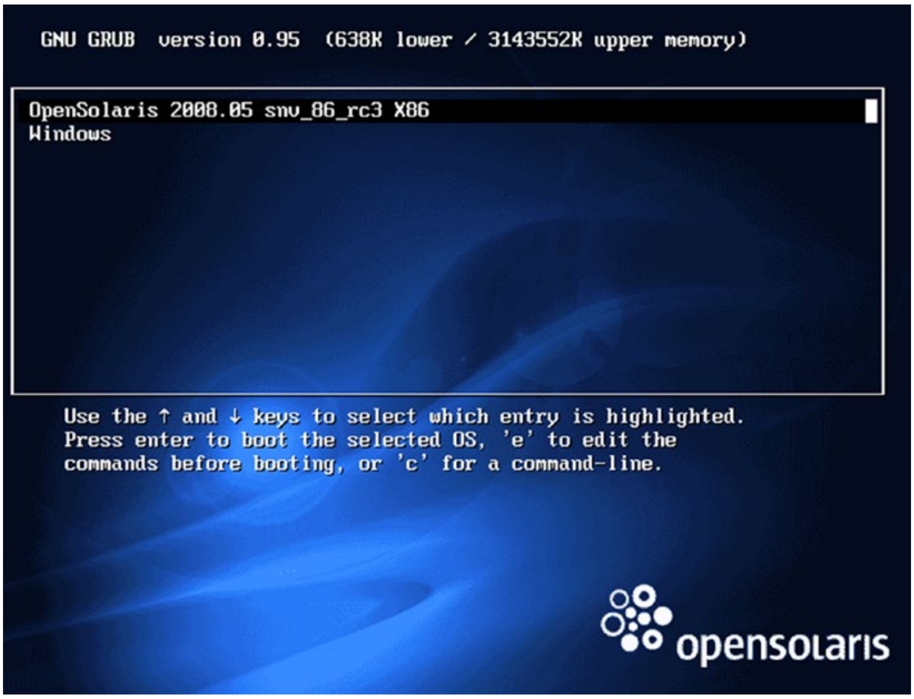

```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

Use the ↑ and ↓ keys to select which entry is highlighted.
Press enter to boot the selected OS, 'e' to edit the
commands before booting, or 'c' for a command-line.
```

Figure 2-20. *The welcome screen after reboot*

So, the OS that is booting here is OpenSolaris, and it is giving us an option to boot XP as well. Let's shed some light on what happened in the background. OpenSolaris saw that it was getting installed in its own partition (the second partition), but there is another OS available in the first partition, which is Windows (or at least a "non-Unix OS").

But how did OpenSolaris come to know there is another OS installed on the first primary partition?

When OpenSolaris was installed in its own partition, it saw that the fdisk signature was set on the first primary partition. (Again, the fdisk signature is also called the *active flag* or simply the * flag.) As we saw earlier in our boot sector specification diagram (Figure 2-21), every partition has 512 bytes + 31 KB of space reserved for booting purposes, and this space is hidden from the user.

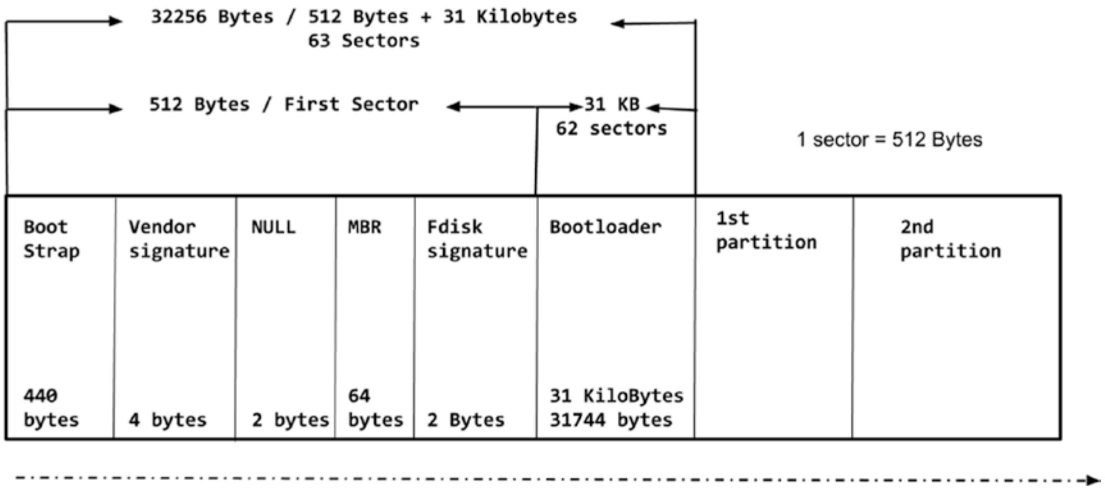


Figure 2-21. *The boot sector*

In other words, when we created a partition layout through GParted, the tool made the following compartments for every partition:

1) Bootstrap
2) Vendor signature
3) NULL
4) MBR
5) Fdisk signature
6) Bootloader

But it filled data only in the vendor signature and MBR fields. The vendor signature field will have data as per the vendor of the HDD, whereas in the case of the MBR field, the data will be as follows:

- The start and end of the first primary partition
- The start and end of the second primary partition
- The start and end of the third primary partition
- The start and end of the fourth primary partition

Basically, there will be four entries, and each entry will consume 16 bytes. Apart from the vendor signature and MBR, the other fields will be empty. Also, please note that GParted will prepare all the compartments (512 bytes + 31 KB) but will fill only the vendor signature and MBR fields for the first primary partition.

Coming back to the fdisk signature field, when Windows XP was installed, it established the following:

- Part-1 of NTLDR in the bootstrap
- Part-2 of NTLDR in the bootloader
- Part-3 of NTLDR inside the first primary partition

Then it set the fdisk signature in its own partition (2 bytes).

So, the disk layout will be something like shown in Figure 2-22.

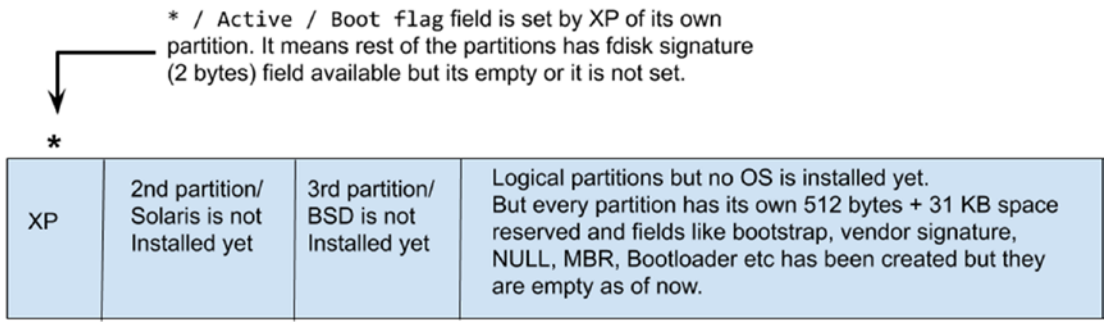
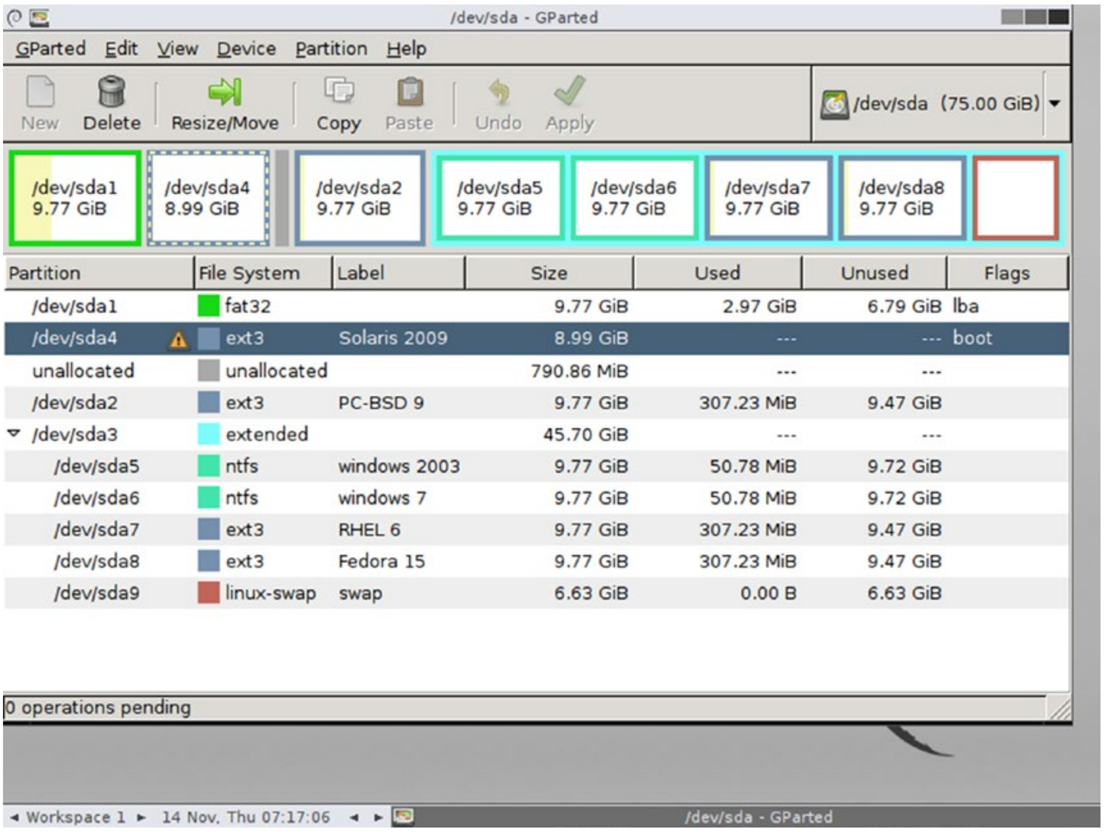

* / Active / Boot flag field is set by XP of its own partition. It means rest of the partitions has fdisk signature (2 bytes) field available but its empty or it is not set.
*
XP
2nd partition/ Solaris is not Installed yet
3rd partition/ BSD is not Installed yet
Logical partitions but no OS is installed yet. But every partition has its own 512 bytes + 31 KB space reserved and fields like bootstrap, vendor signature, NULL, MBR, Bootloader etc has been created but they are empty as of now.

Figure 2-22. *The disk layout after XP's installation*

OpenSolaris found this disk layout. When the OpenSolaris installation was complete and it wanted to install its bootloader (GRUB), it saw an asterisk (*) on the first primary partition, and that is when it realized there is a Windows OS already installed. Now GRUB (the OpenSolaris bootloader) has two options.

- Install part-1 (bootstrap) and part-2 (bootloader) of Grand Unified Bootloader (GRUB) in the first primary partition, and install part-3 of GRUB in its own partition (the second partition where OpenSolaris has been installed).
- Or install part-1 (bootloader) in its own partition's first 512 bytes, part-2 in its own partition's 31 KB, and part-3 also in its own partition; then put * on its own second partition (refer to Figure 2-23).



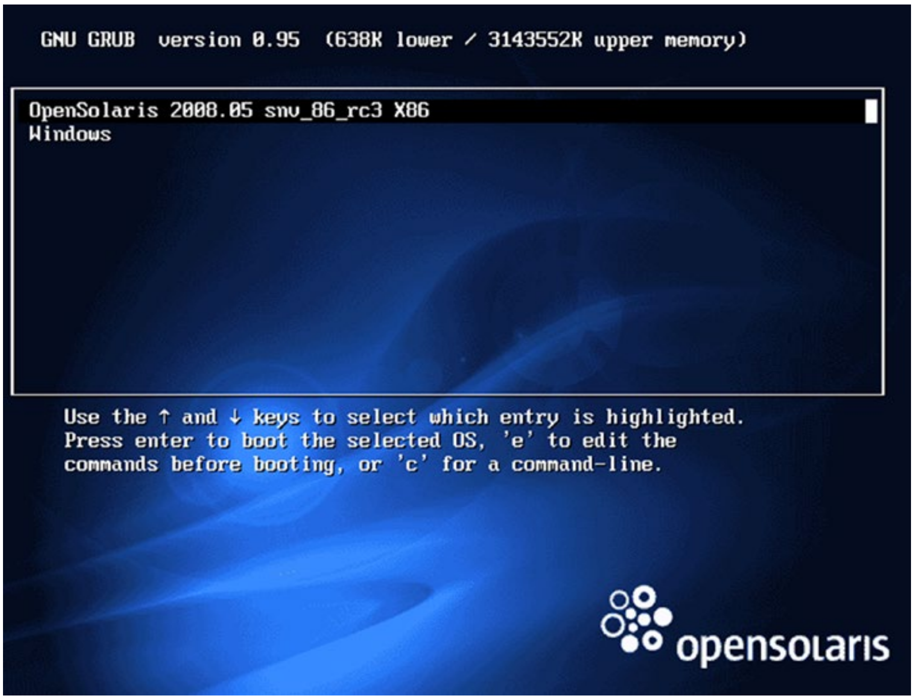
Partition	File System	Label	Size	Used	Unused	Flags
/dev/sda1	fat32		9.77 GiB	2.97 GiB	6.79 GiB	lba
/dev/sda4	ext3	Solaris 2009	8.99 GiB	---	---	boot
unallocated	unallocated		790.86 MiB	---	---	
/dev/sda2	ext3	PC-BSD 9	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda3	extended		45.70 GiB	---	---	
/dev/sda5	ntfs	windows 2003	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda6	ntfs	windows 7	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda7	ext3	RHEL 6	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda8	ext3	Fedora 15	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda9	linux-swap	swap	6.63 GiB	0.00 B	6.63 GiB	

0 operations pending

Figure 2-23. *The disk layout in GParted after OpenSolaris installation*

Please note that the boot flag is back to the OpenSolaris partition. Also, GParted does not understand the Solaris2 partition; hence, it shows ext3 as a filesystem name.

If OpenSolaris chooses option 1, then OpenSolaris has to clear Windows XP's part-1 and part-2 of the bootloader. It also means only OpenSolaris will boot, and XP will never be able to boot. Hence, OpenSolaris chooses option-2, giving equal opportunity to boot Windows XP. OpenSolaris also makes a Windows XP entry in one of its own files (we will talk about this file later in the chapter). Whenever OpenSolaris starts booting up, GRUB will refer to that file, and it will find the Windows entry in it, which will be shown on-screen. Figure 2-24 shows the OpenSolaris welcome screen.



```
 GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

 OpenSolaris 2008.05 snv_86_rc3 X86
 Windows

    Use the ↑ and ↓ keys to select which entry is highlighted.
    Press enter to boot the selected OS, 'e' to edit the
    commands before booting, or 'c' for a command-line.
```

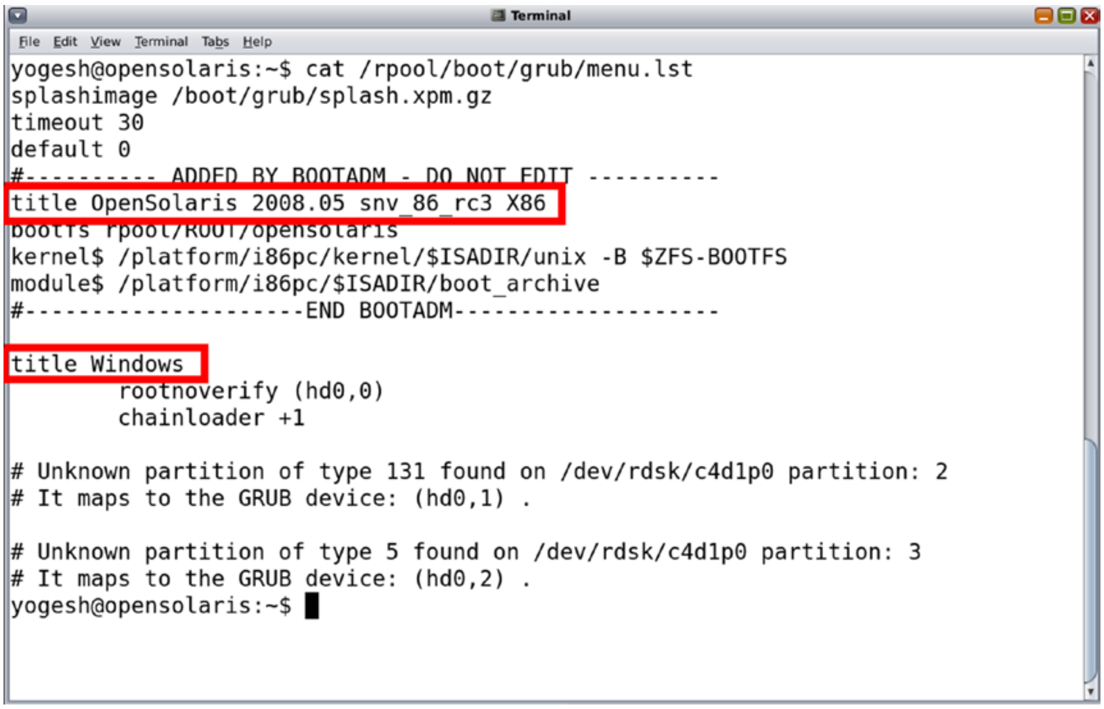
Figure 2-24. *The OpenSolaris welcome screen*

So, the complete booting sequence of OpenSolaris is as follows:

1. Power on the system.
2. The CPU jumps to the BIOS.
3. The BIOS runs the POST routine.
4. We go back to the BIOS.
5. The BIOS is kind of dumb; it will check the boot priority set by the user.
    - When I say *boot priority*, I means the device through which system will boot.
    - It could be CDROM, USB, HDD, PXE, etc.
6. The BIOS will jump to the entire HDD's first 512 bytes or on the first sector of the boot device.
    - The boot device could be anything, but as of now we are considering an HDD.

7. The BIOS will hand over control to whichever binary is present in the bootstrap.
   - Who do you think is there? The Windows bootloader (NTLDR) or OpenSolaris (GRUB)? Think for a while and then continue.
   - The boot sector stored in the first 512 bytes is NTLDR of Windows XP.
   - You must have noticed the 440 bytes of the bootstrap space is very tiny, and no code can boot an OS from it. Hence, part-1 of NTLDR (bootstrap) just jumps to the bigger space, which is part-2 (bootloader/31 KB/virtual boot record). Part-2 checks the MBR (64 bytes) and finds four entries in it. This means the disk has four primary partitions. But there is an issue here: out of four primary partitions, which partition has the OS? You might say, of course, it's the first and second partitions, but how will the bootloader know where the OS is? And which one should it boot? This is a genuine question, and to solve this problem, the fdisk signature field has been created. Whichever partition has these 2 bytes filled or set, that partition has an OS. So, when Windows XP or OpenSolaris was getting installed, it's a duty of that OS to fill the 2 bytes of the fdisk signature field or set the * on its own partition so that the bootloader will know which partition has the OS. In our case, the * is on its second partition (OpenSolaris kept it while it was getting installed). This is how part-2 of NTLDR will know that it has to jump to the second partition.
8. Part-2 of NTLDR jumps to the second partition, which means it simply jumps to part-1 of the GRUB bootloader in the second partition (bootstrap).
9. Part-1 of GRUB (bootstrap/440 bytes) is again tiny, so it will again jump to a bigger space, which is part-2 of GRUB (bootloader).

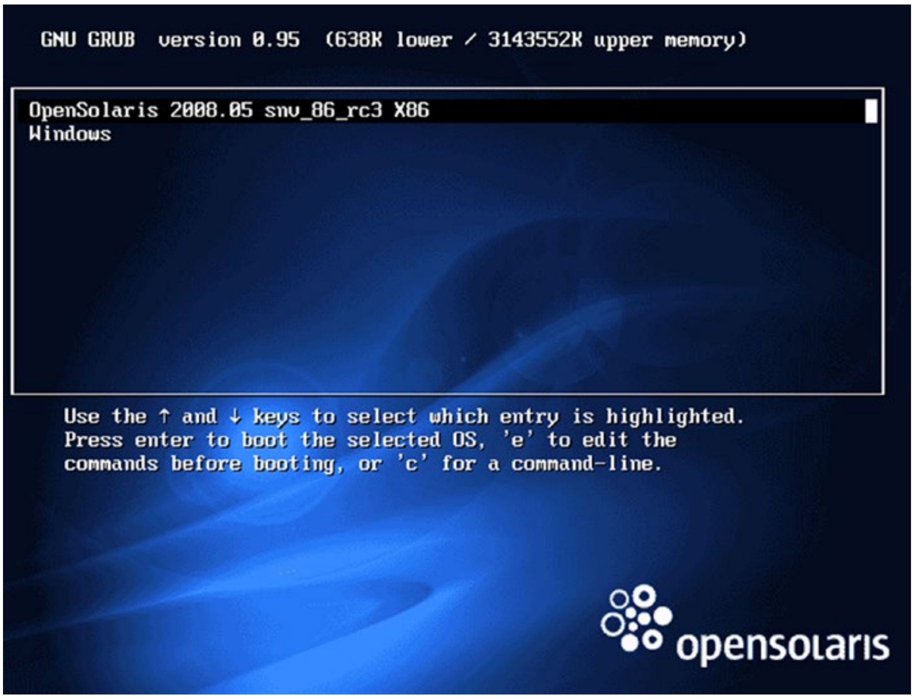
10. Part-2 knows where part-3 is. The location of part-3 will be hard-coded in part-2, so it will simply jump to part-3. Part-3 will read the text file `/rpool/boot/grub/menu.lst` (see Figure 2-25); this is the same file that was created by OpenSolaris when it detected XP on the first primary.



```
yogesh@opensolaris:~$ cat /rpool/boot/grub/menu.lst
splashimage /boot/grub/splash.xpm.gz
timeout 30
default 0
#---------- ADDED BY BOOTADM - DO NOT EDIT ----------
title OpenSolaris 2008.05 snv_86_rc3 X86
bootfs rpool/ROOT/opensolaris
kernel$ /platform/i86pc/kernel/$ISADIR/unix -B $ZFS-BOOTFS
module$ /platform/i86pc/$ISADIR/boot_archive
#---------------------END BOOTADM--------------------

title Windows
        rootnoverify (hd0,0)
        chainloader +1

# Unknown partition of type 131 found on /dev/rdsk/c4d1p0 partition: 2
# It maps to the GRUB device: (hd0,1) .

# Unknown partition of type 5 found on /dev/rdsk/c4d1p0 partition: 3
# It maps to the GRUB device: (hd0,2) .
yogesh@opensolaris:~$ 
```

Figure 2-25. *The OpenSolaris menu.lst file*

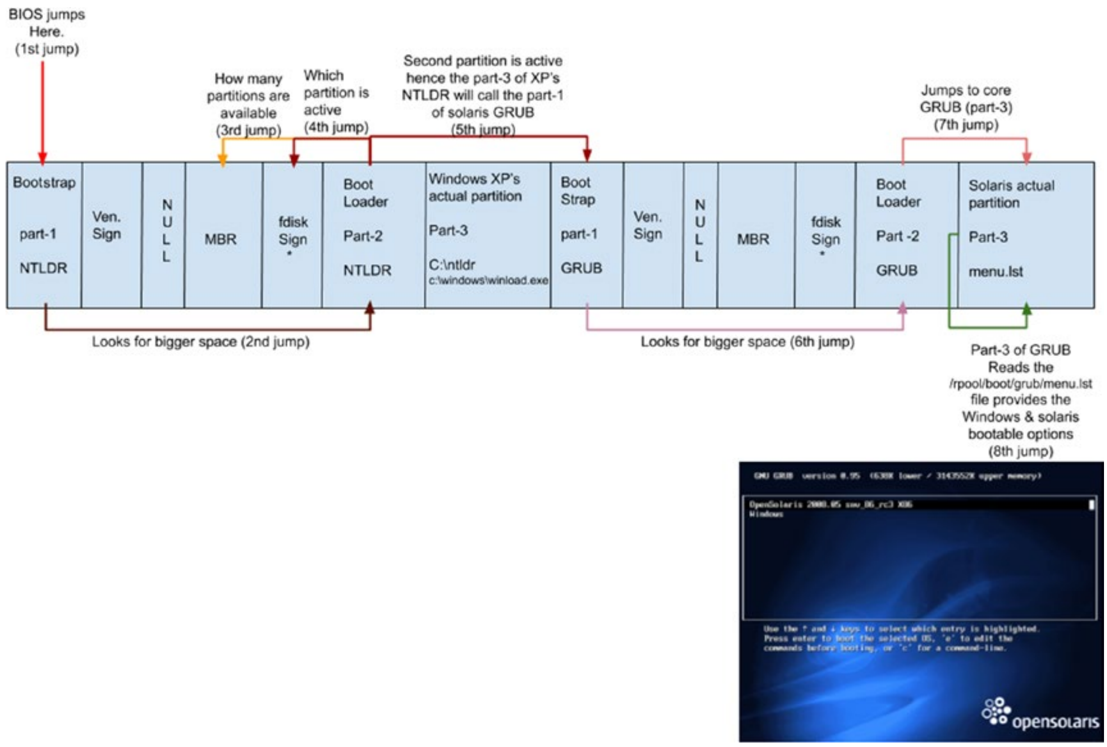
11. Part-3 of GRUB will read this text file and print whatever is written after the `'title` variable, and that is how we reach the screen shown in Figure 2-26.



```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

Use the ↑ and ↓ keys to select which entry is highlighted.
Press enter to boot the selected OS, 'e' to edit the
commands before booting, or 'c' for a command-line.
```

Figure 2-26. *The OpenSolaris welcome screen*

Figure 2-27 shows the complete booting sequence of OpenSolaris.


BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active (4th jump)
Second partition is active hence the part-3 of XP's NTLDR will call the part-1 of solaris GRUB (5th jump)
Jumps to core GRUB (part-3) (7th jump)
Bootstrap part-1 NTLDR
Ven. Sign
N U L L
MBR
fdisk Sign
Boot Loader Part-2 NTLDR
Windows XP's actual partition Part-3 C:\ntldr c:\windows\winload.exe
Boot Strap part-1 GRUB
Ven. Sign
N U L L
MBR
fdisk Sign
Boot Loader Part -2 GRUB
Solaris actual partition Part-3 menu.lst
Looks for bigger space (2nd jump)
Looks for bigger space (6th jump)
Part-3 of GRUB Reads the /rpool/boot/grub/menu.lst file provides the Windows & solaris bootable options (8th jump)
opensolaris

```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

    Use the ↑ and ↓ keys to select which entry is highlighted.
    Press enter to boot the selected OS, 'e' to edit the
    commands before booting, or 'c' for a command-line.
```

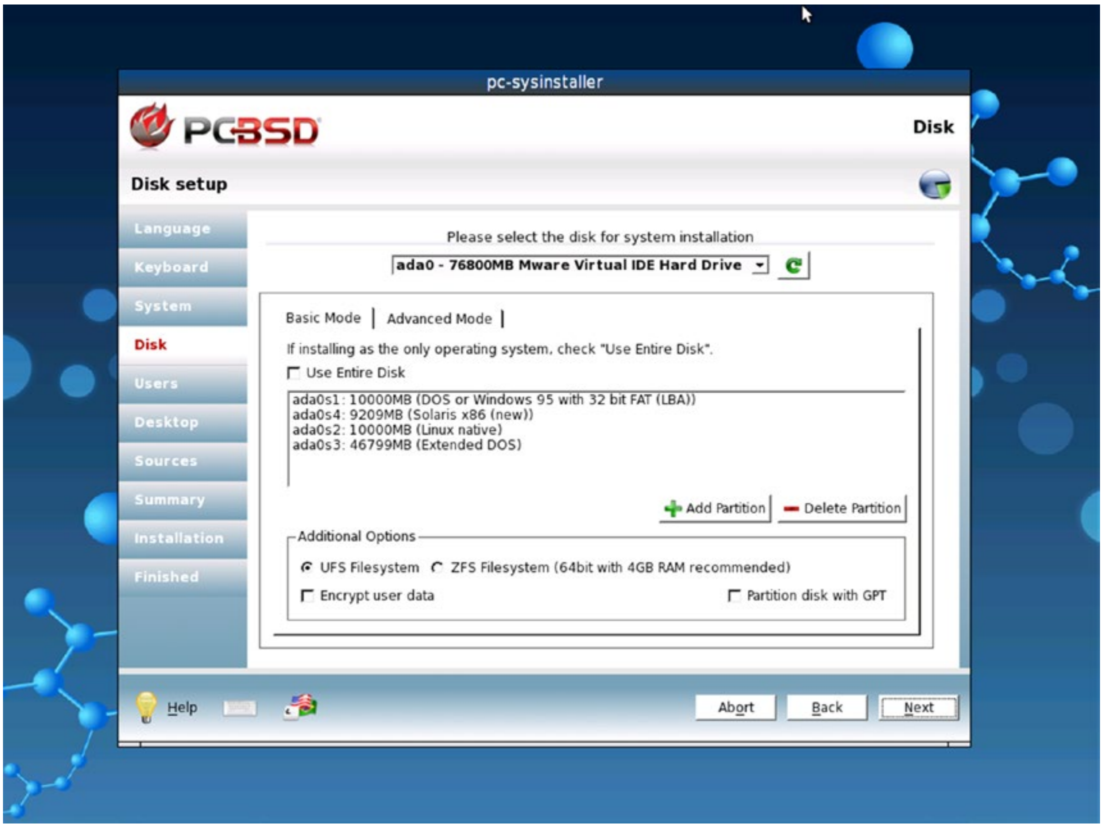
Figure 2-27. *The OpenSolaris booting sequence*

If a user chooses the OpenSolaris option to boot, then part-3 of the OpenSolaris GRUB knows where the kernel of OpenSolaris is, which is in the `/boot` directory. GRUB will copy the kernel from `/boot` to memory and give control to the kernel. This is where the GRUB bootloader's task ends, and it goes away. Now the kernel of OpenSolaris will take care of the rest of the booting sequence. We will talk about the kernel in Chapter 4.

If a user chooses the Windows XP option to boot, then part-3 of the OpenSolaris GRUB will jump back to part-1 of NTLDR (bootstrap). Part-1 of NTLDR will jump to part-2 of NTLDR. Part-2 will jump to part-3. Part-3 of NTLDR will load `winload.exe` in memory. The `winload.exe` file knows where the kernel of XP is. It will eventually be copied or loaded into memory by NTLDR. Once the kernel is in memory, NTLDR's job is done (remember, kernel=OS=kernel). Since XP's kernel is in memory, it will take care of the rest of the booting sequence.

PC-BSD 9.0

The * or the boot flag is on the OpenSolaris partition, so now we will install PC-BSD 9.0. In Figure 2-28, the installer of PC-BSD shows the number of partitions on which PC-BSD 9.0 can be installed.



Please select the disk for system installation

ada0 - 76800MB Mware Virtual IDE Hard Drive

If installing as the only operating system, check "Use Entire Disk".

☐ Use Entire Disk

```
ada0s1: 10000MB (DOS or Windows 95 with 32 bit FAT (LBA))
ada0s4: 9209MB (Solaris x86 (new))
ada0s2: 10000MB (Linux native)
ada0s3: 46799MB (Extended DOS)
```

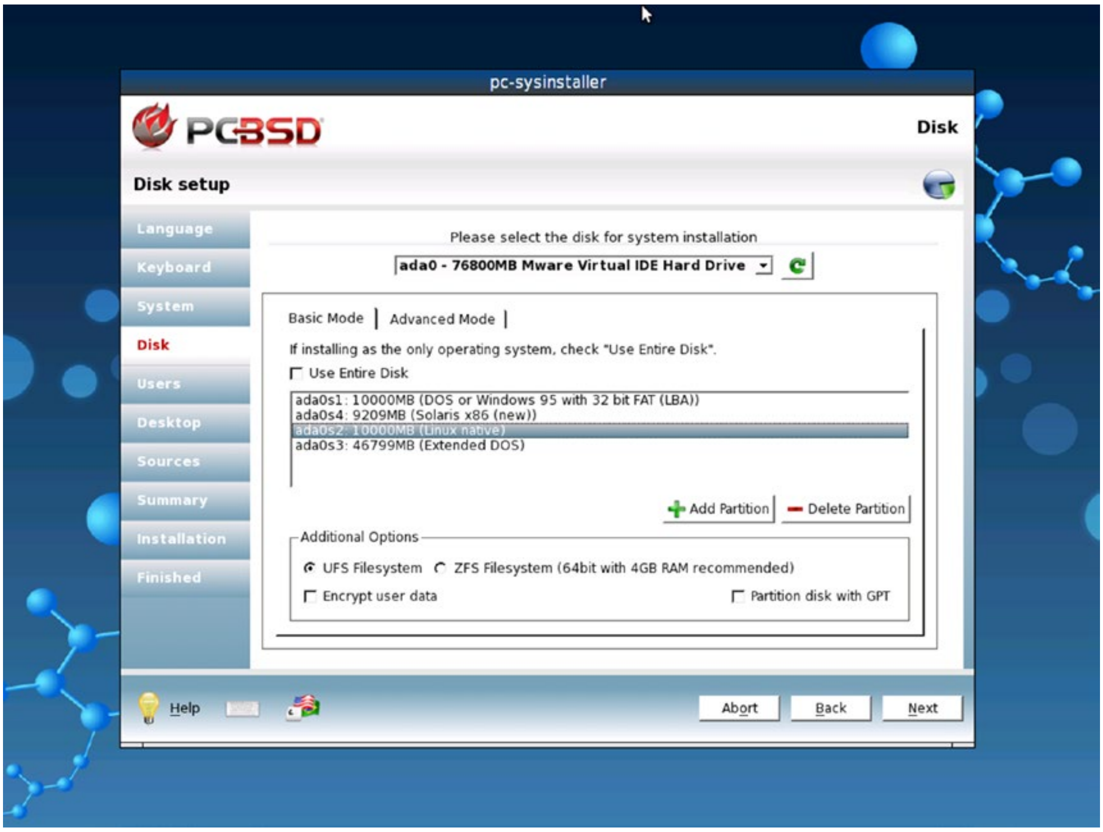
Additional Options

[✓ UFS Filesystem] ZFS Filesystem (64bit with 4GB RAM recommended)

☐ Encrypt user data ☐ Partition disk with GPT

Figure 2-28. *The number of partitions*

As you can see, the hard disk naming convention is different in BSD compared to earlier OSs. We need to install BSD on the third partition, which is ada0s2. It stands for "Adapter number zero and slice number 2." The slice can be considered as a partition. Figure 2-29 shows the disk layout and disk naming conventions.



Please select the disk for system installation

ada0 - 76800MB Mware Virtual IDE Hard Drive

Basic Mode | Advanced Mode |

If installing as the only operating system, check "Use Entire Disk".

- [ ] Use Entire Disk

```
ada0s1: 10000MB (DOS or Windows 95 with 32 bit FAT (LBA))
ada0s4: 9209MB (Solaris x86 (new))
ada0s2: 10000MB (Linux native)
ada0s3: 46799MB (Extended DOS)
```

Add Partition | Delete Partition

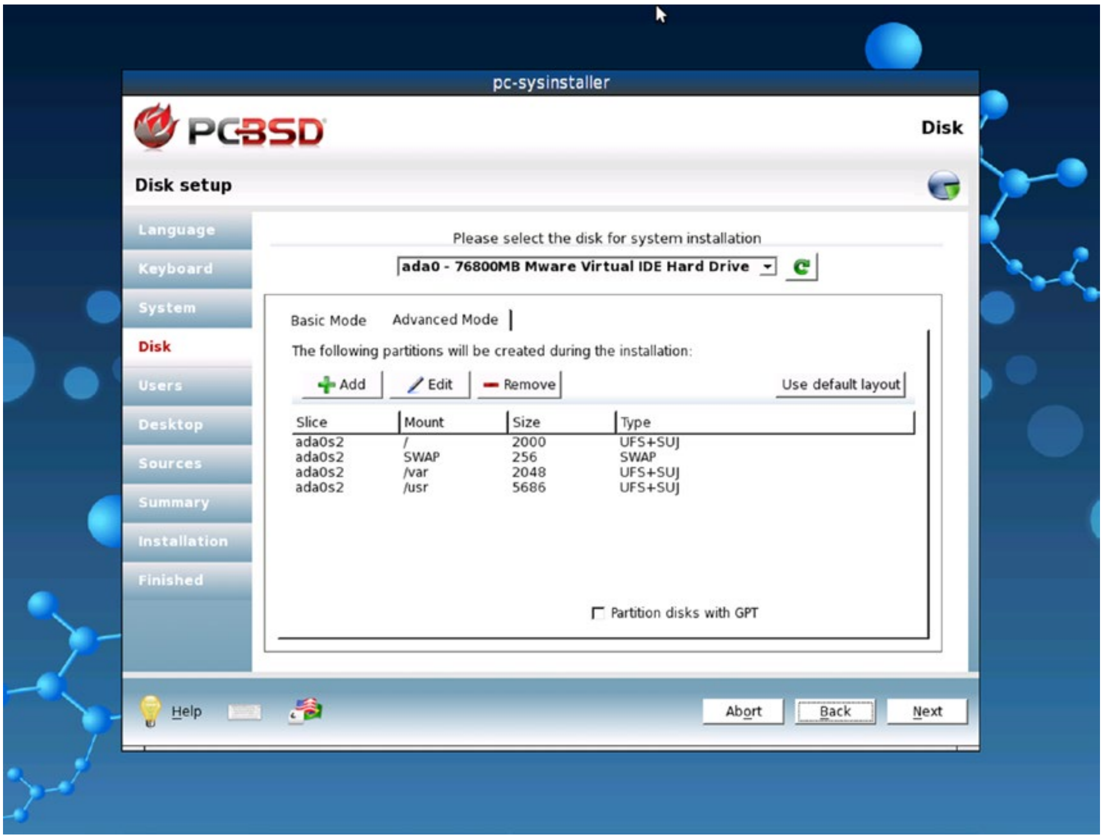
Additional Options

[✓ UFS Filesystem] ZFS Filesystem (64bit with 4GB RAM recommended)

- [ ] Encrypt user data
- [ ] Partition disk with GPT

Figure 2-29. *The disk layout and disk naming conventions*

Assign the `ada0s2` space to `/` (the root filesystem). Figure 2-30 shows the partition layout of PC-BSD 9.0. You will also notice that the filesystem of BSD is `UFS`, which is the Unix File System.



Please select the disk for system installation

ada0 - 76800MB Mware Virtual IDE Hard Drive

The following partitions will be created during the installation:

Slice	Mount	Size	Type
ada0s2	/	2000	UFS+SUJ
ada0s2	SWAP	256	SWAP
ada0s2	/var	2048	UFS+SUJ
ada0s2	/usr	5686	UFS+SUJ

☐ Partition disks with GPT

Figure 2-30. *The partition layout of PC-BSD 9.0*

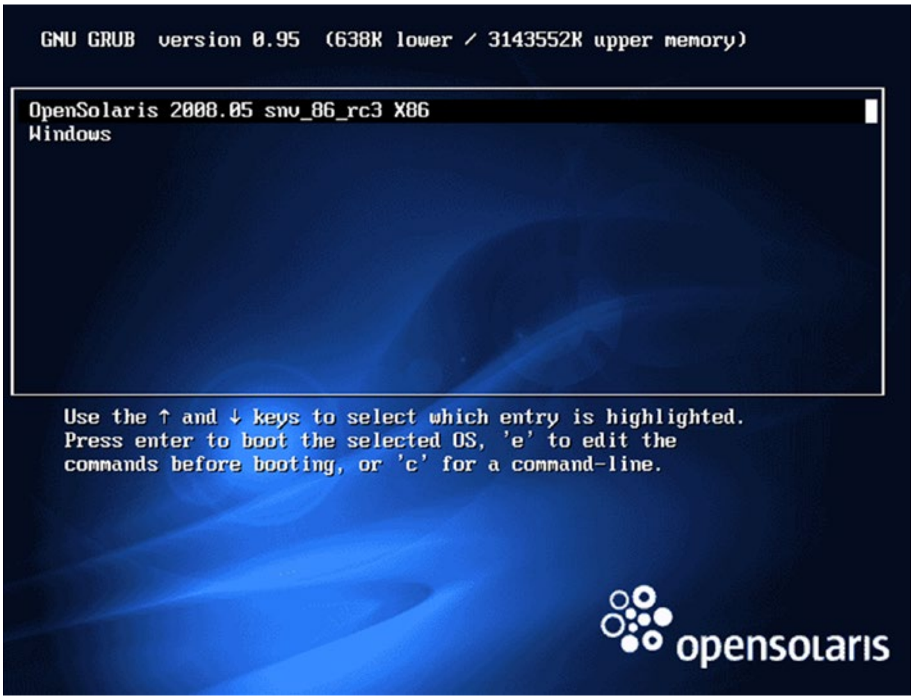
After the installation, the system will restart. Now take some time and think about which OS will boot.

Which of the following will it be?

- OpenSolaris, which would give it a chance to boot Windows and BSD
- Will it be PC-BSD, which would give it chance to boot the other two OSs?
- Will it be PC-BSD alone?
- Will it be Windows XP alone?
- Will it be OpenSolaris alone?
- Or will none of the OSs boot?

Please visit the booting flowcharts of earlier operating systems and try to come up with your own booting sequence.

As you can see in Figure 2-31, the OS that will boot is OpenSolaris, which will create a chance to boot Windows only.

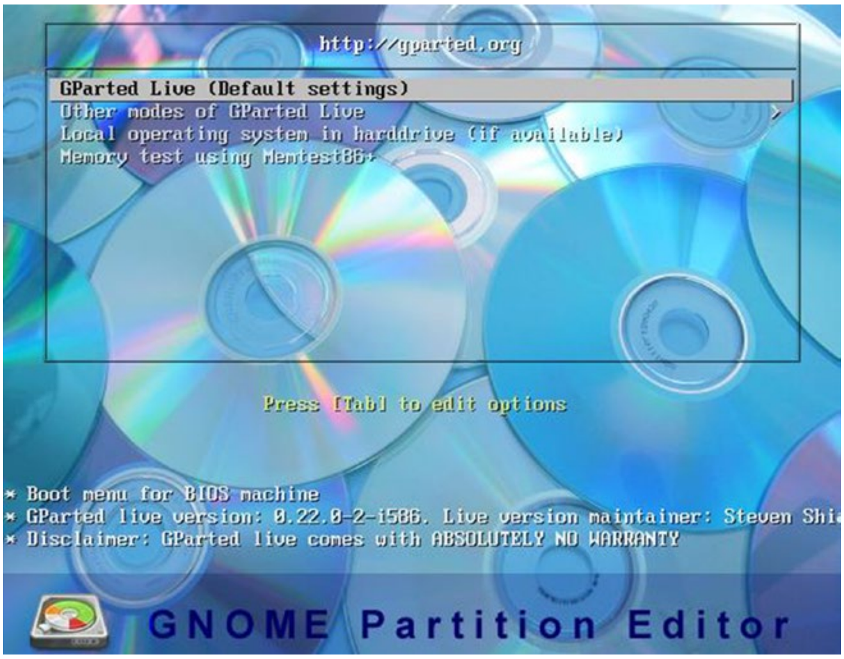


```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

     Use the ↑ and ↓ keys to select which entry is highlighted.
     Press enter to boot the selected OS, 'e' to edit the
     commands before booting, or 'c' for a command-line.
```

Figure 2-31. *PC-BSD is not booting.*

PC-BSD is not booting. Before going to the next page, again take some time and think about what happened

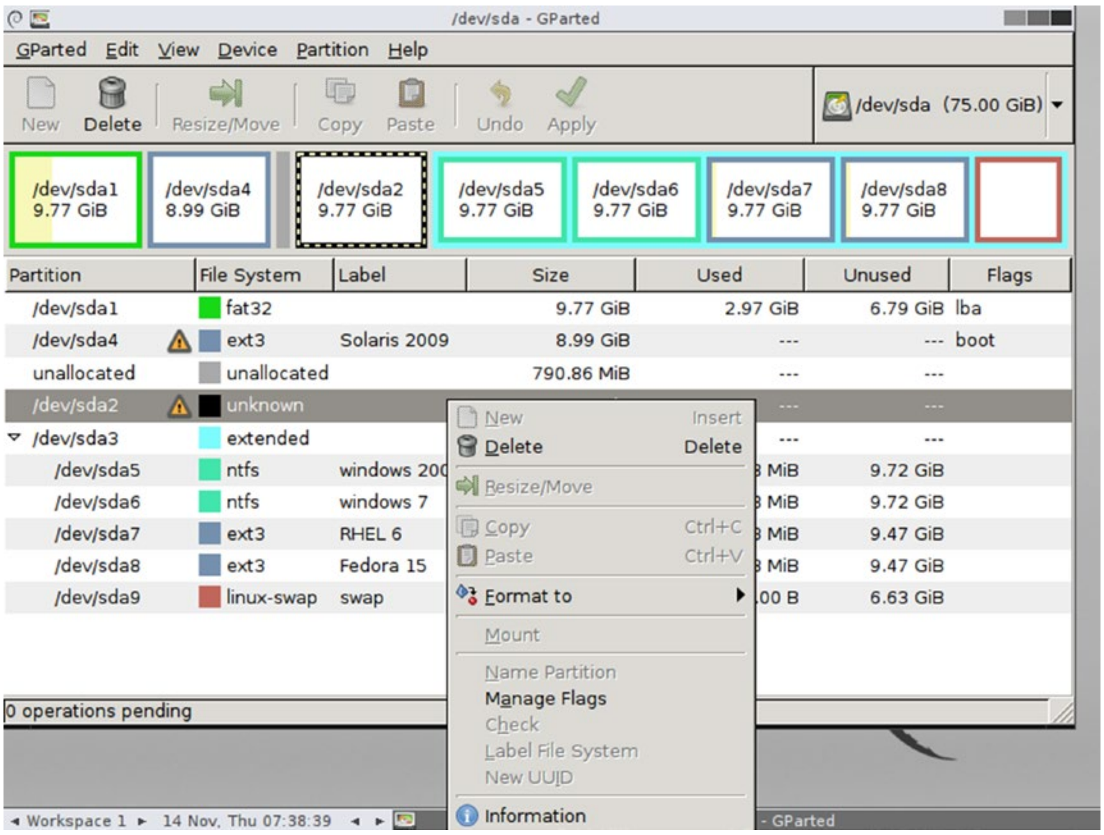
You are right—there is a chance that PC-BSD might have not kept the */boot flag/fdisk signature on its own partition. Let's see if that is the case. We will boot with GParted (Figure 2-32) and verify our theory.



```
http://gparted.org
GParted Live (Default settings)
Other modes of GParted Live                                >
Local operating system in harddrive (if available)
Memory test using Memtest86+

Press [Tab] to edit options

* Boot menu for BIOS machine
* GParted live version: 0.22.0-2-i586. Live version maintainer: Steven Shi
* Disclaimer: GParted live comes with ABSOLUTELY NO WARRANTY
```

Figure 2-32. *The GParted welcome screen*

As you can see in Figure 2-33, PC-BSD does not have * set on its own partition.

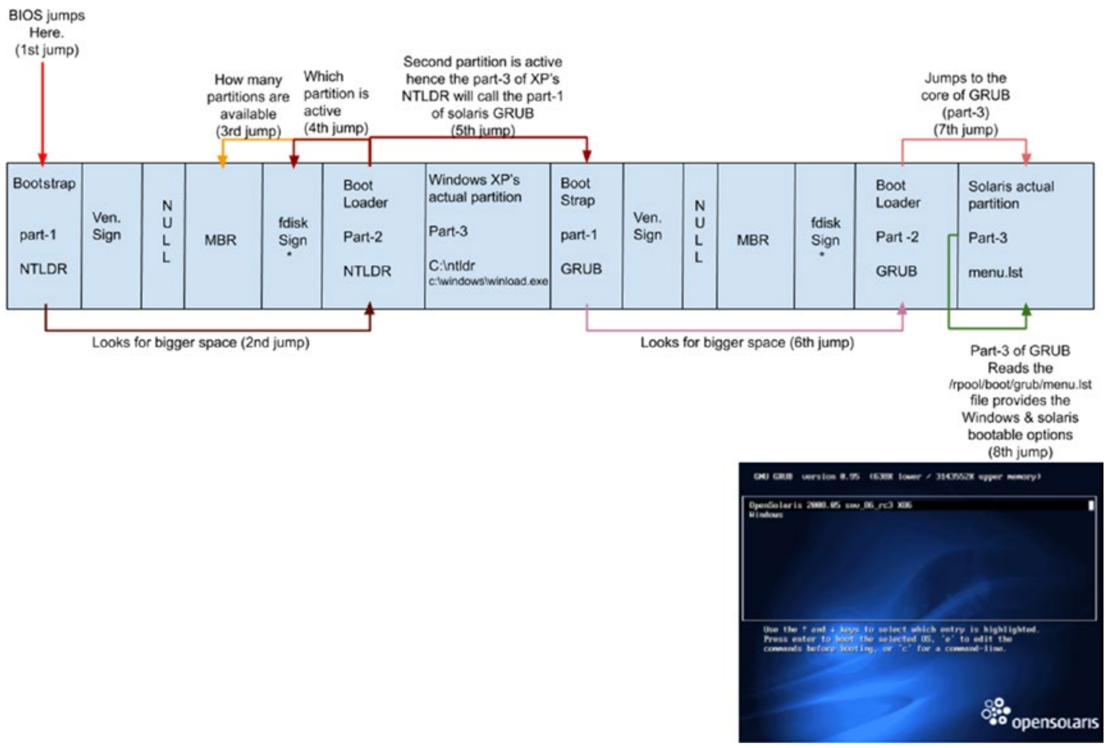


Partition	File System	Label	Size	Used	Unused	Flags
/dev/sda1	fat32		9.77 GiB	2.97 GiB	6.79 GiB	lba
/dev/sda4 ⚠	ext3	Solaris 2009	8.99 GiB	---	---	boot
unallocated	unallocated		790.86 MiB	---	---	
/dev/sda2 ⚠	unknown			---	---	
/dev/sda3	extended			---	---	
/dev/sda5	ntfs	windows 200		MiB	9.72 GiB	
/dev/sda6	ntfs	windows 7		MiB	9.72 GiB	
/dev/sda7	ext3	RHEL 6		MiB	9.47 GiB	
/dev/sda8	ext3	Fedora 15		MiB	9.47 GiB	
/dev/sda9	linux-swap	swap		00 B	6.63 GiB	

0 operations pending

Figure 2-33. *The disk layout on GParted*

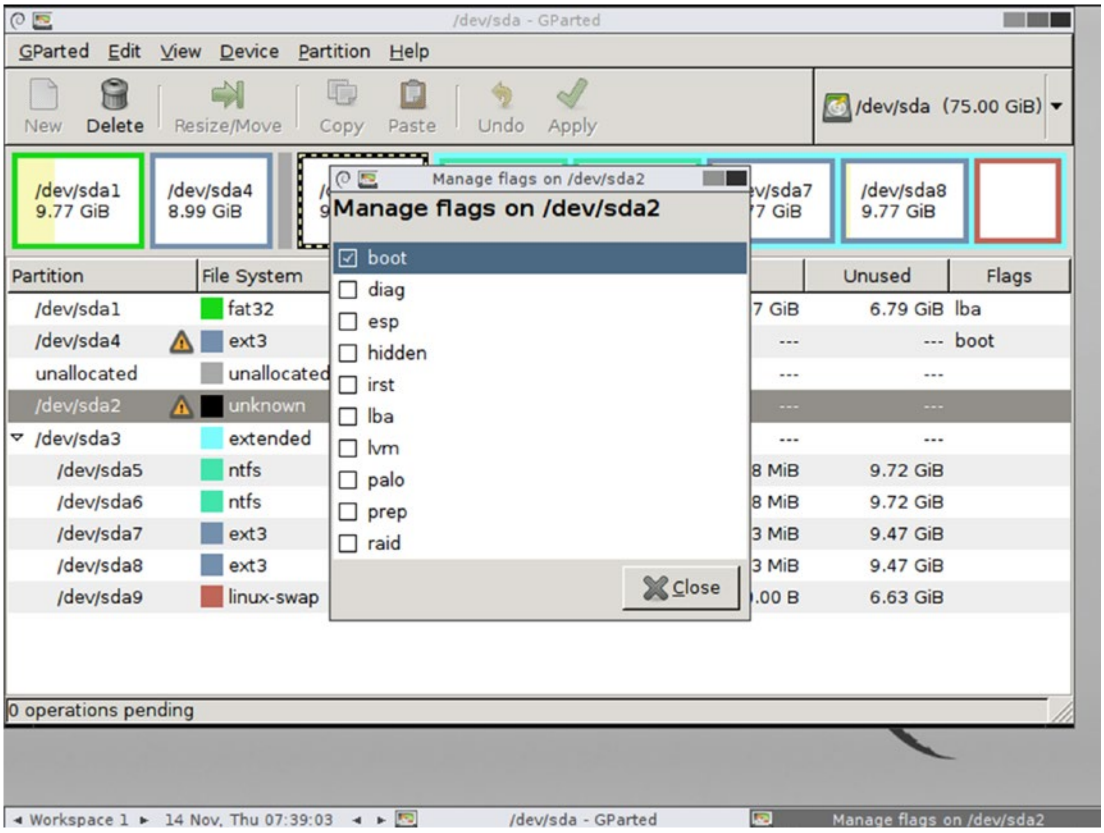
So, the booting sequence looks like Figure 2-34.


BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active (4th jump)
Second partition is active hence the part-3 of XP's NTLDR will call the part-1 of solaris GRUB (5th jump)
Jumps to the core of GRUB (part-3) (7th jump)
Bootstrap part-1 NTLDR
Ven. Sign
NULL
MBR
fdisk Sign
Boot Loader Part-2 NTLDR
Windows XP's actual partition Part-3 C:\ntldr c:\windows\winload.exe
Boot Strap part-1 GRUB
Ven. Sign
NULL
MBR
fdisk Sign
Boot Loader Part -2 GRUB
Solaris actual partition Part-3 menu.lst
Looks for bigger space (2nd jump)
Looks for bigger space (6th jump)
Part-3 of GRUB Reads the /rpool/boot/grub/menu.lst file provides the Windows & solaris bootable options (8th jump)
opensolaris

```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

  Use the ↑ and ↓ keys to select which entry is highlighted.
  Press enter to boot the selected OS, 'e' to edit the
  commands before booting, or 'c' for a command-line.
```

***Figure 2-34.** The boot sequence and why PC-BSD is not able to boot*

This means OpenSolaris does not know BSD is installed on the third partition. Hence, the PC-BSD entry is not with OpenSolaris. What if we keep the boot flag on BSD's partition? Will it boot? But how do we keep the boot flag on the third partition? It's simple—GParted gives us that option. Right-click the third partition and select the boot flag, as shown in Figure 2-35.



Manage flags on /dev/sda2

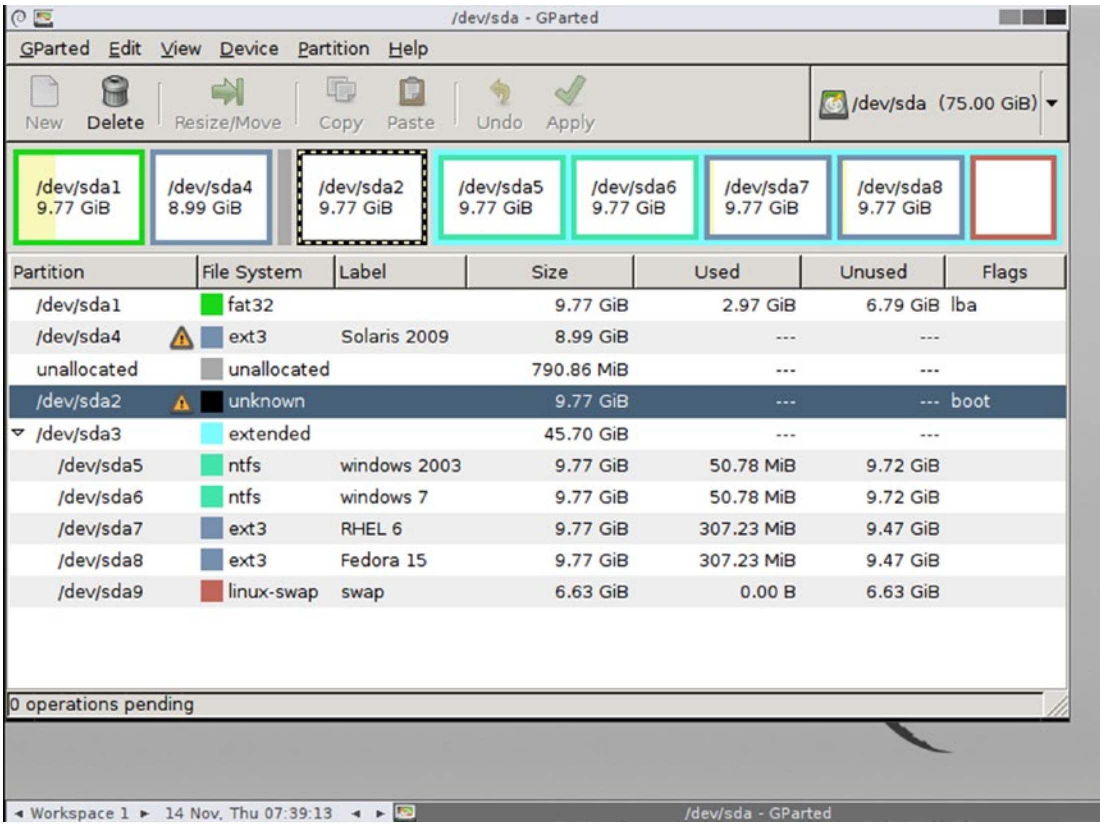
- [✓] boot
- diag
- esp
- hidden
- irst
- lba
- lvm
- palo
- prep
- raid

Partition	File System		Unused	Flags
/dev/sda1	fat32	7 GiB	6.79 GiB	lba
/dev/sda4	ext3	---	---	boot
unallocated	unallocated	---	---	
/dev/sda2	unknown	---	---	
/dev/sda3	extended	---	---	
/dev/sda5	ntfs	8 MiB	9.72 GiB	
/dev/sda6	ntfs	8 MiB	9.72 GiB	
/dev/sda7	ext3	3 MiB	9.47 GiB	
/dev/sda8	ext3	3 MiB	9.47 GiB	
/dev/sda9	linux-swap	.00 B	6.63 GiB	

0 operations pending

Figure 2-35. *Setting the boot flag on PC-BSD*

Figure 2-36 shows how the disk layout looks after setting the boot flag on BSD's third partition.



Partition	File System	Label	Size	Used	Unused	Flags
/dev/sda1	fat32		9.77 GiB	2.97 GiB	6.79 GiB	lba
/dev/sda4	ext3	Solaris 2009	8.99 GiB	---	---	
unallocated	unallocated		790.86 MiB	---	---	
/dev/sda2	unknown		9.77 GiB	---	---	boot
/dev/sda3	extended		45.70 GiB	---	---	
/dev/sda5	ntfs	windows 2003	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda6	ntfs	windows 7	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda7	ext3	RHEL 6	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda8	ext3	Fedora 15	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda9	linux-swap	swap	6.63 GiB	0.00 B	6.63 GiB	

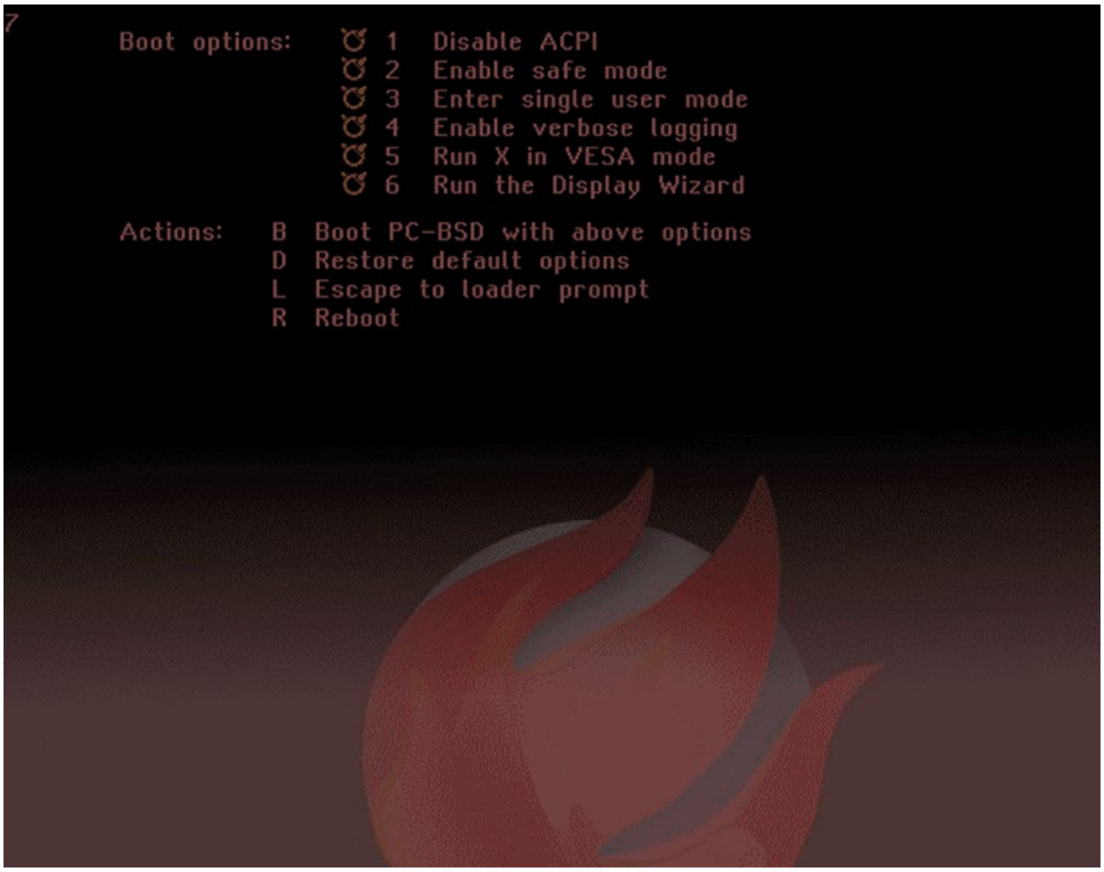
0 operations pending

Figure 2-36. *The disk layout*

Now which OS do you think will boot?

- PC-BSD alone?
- PC-BSD, which would give the chance to boot every other OS?
- Again OpenSolaris, which would create an option to boot Windows?
- OpenSolaris alone?
- Windows XP alone?

Figure 2-37 shows the answer; after reboot, it's only PC-BSD that is booting, and it is not giving an option to boot any other OS.



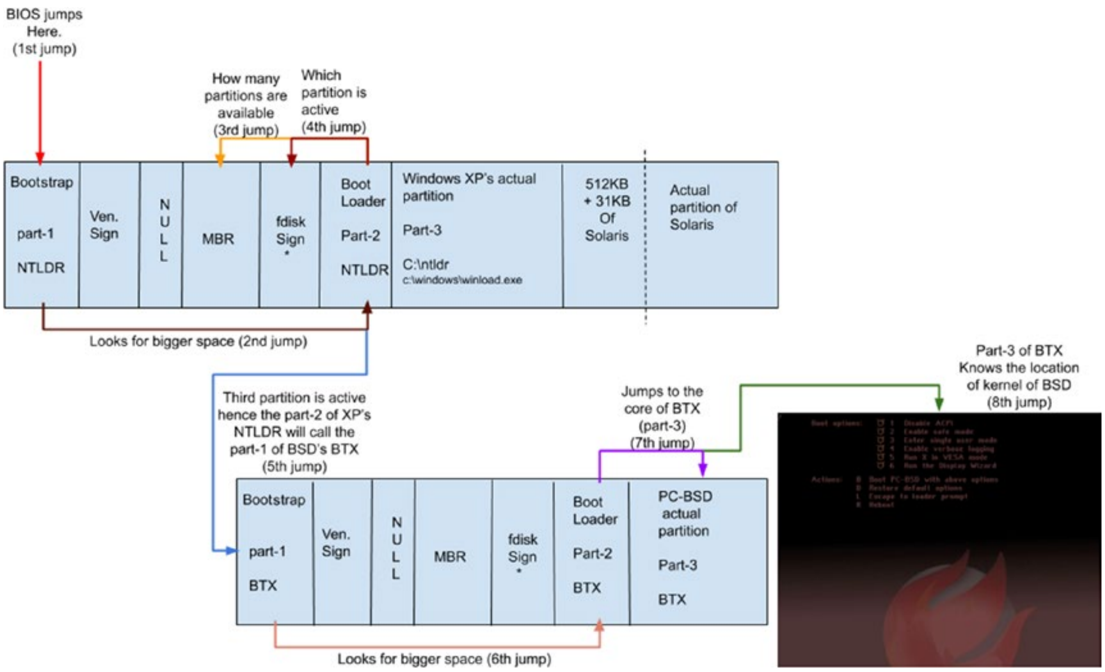
```
7
      Boot options:    Ö 1  Disable ACPI
                       Ö 2  Enable safe mode
                       Ö 3  Enter single user mode
                       Ö 4  Enable verbose logging
                       Ö 5  Run X in VESA mode
                       Ö 6  Run the Display Wizard

      Actions:     B  Boot PC-BSD with above options
                   D  Restore default options
                   L  Escape to loader prompt
                   R  Reboot
```

Figure 2-37. *The welcome screen of PC-BSD*

Let's try to understand how PC-BSD managed to boot.

1. Power on the system.
2. The BIOS executes the POST routine. The POST checks the hardware health and gives a healthy beep if everything is good and goes back to the BIOS.
3. The BIOS is dumb, and it simply jumps to the first sector of the entire HDD, which is a bootstrap of Windows XP.
4. XP's part-1 (NTLDR) jumps to a bigger space, which is part-2 of NTLDR (the bootloader). The bootloader checks the MBR and finds there are four primary partitions, but which one is active? To check that, the bootloader checks the first primary partition's fdisk signature, which is not set, so it checks the second partition's boot

flag, which is also not set. Hence, it jumps to the third partition where it finds the boot flag set. The bootloader (part-2) of NTLDR jumps to BSD's partition and runs the bootstrap of BSD's bootloader. The bootloader of BSD is BTX, which stands for Boot Extended. BTX jumps to its second part and eventually to the third part. The third part of BTX knows where the kernel of BSD is. Part-3 of BTX copies the kernel image of BSD in memory, and this is where BTX stops and PC-BSD starts booting and shows us a welcome screen. Figure 2-38 shows the flowchart of the booting sequence of PC-BSD.


BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active (4th jump)
Bootstrap
part-1
NTLDR
Ven. Sign
NULL
MBR
fdisk Sign
Boot Loader
Part-2
NTLDR
Windows XP's actual partition
Part-3
C:\ntldr
c:\windows\winload.exe
512KB + 31KB Of Solaris
Actual partition of Solaris
Looks for bigger space (2nd jump)
Third partition is active hence the part-2 of XP's NTLDR will call the part-1 of BSD's BTX (5th jump)
Jumps to the core of BTX (part-3) (7th jump)
Part-3 of BTX Knows the location of kernel of BSD (8th jump)
Bootstrap
part-1
BTX
Ven. Sign
NULL
MBR
fdisk Sign
Boot Loader
Part-2
BTX
PC-BSD actual partition
Part-3
BTX
Looks for bigger space (6th jump)

```
Boot options:   ☐ 1   Disable ACPI
                ☐ 2   Enable safe mode
                ☐ 3   Enter single user mode
                ☐ 4   Enable verbose logging
                ☐ 5   Run X in VESA mode
                ☐ 6   Run the Display Wizard

Actions:     B  Boot PC-BSD with above options
             D  Restore default options
             L  Escape to loader prompt
             R  Reboot
```

Figure 2-38. *The boot sequence of PC-BSD*

The interesting part of BSD booting is that when PC-BSD was getting installed, it found the boot flag on the second partition, which is the OpenSolaris partition. Now BSD has three options.

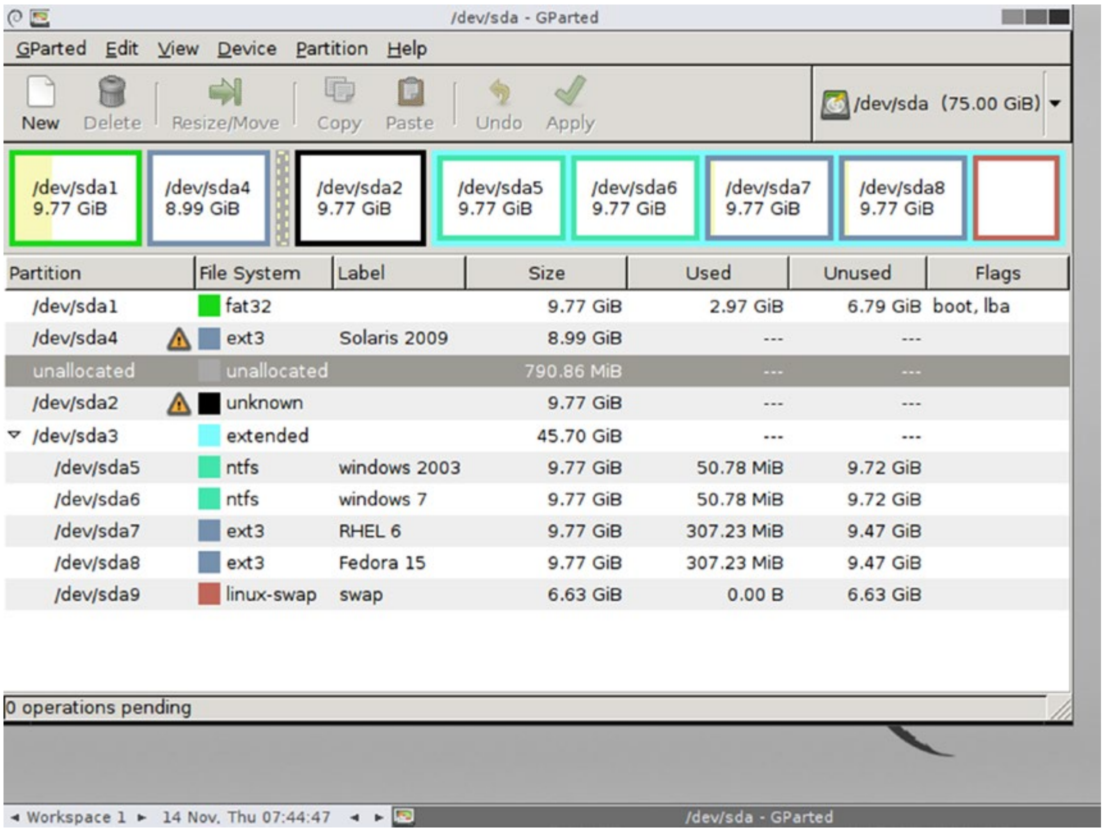
a. Keep the boot flag on its own third partition.

b. Keep the boot flag on its own third partition and make a OpenSolaris entry in some of its files.

c. Keep the boot flag as it is on the second partition.

If BSD chooses the first option (a), then only BSD would be able to boot, and that would be an injustice to the other installed operating systems. We want BSD to choose the second option (b) since it gives justice to boot every other OS, but BTX is an old bootloader, and it does not have the ability to multiboot other operating systems. Hence, BSD chooses the third option (c). Therefore, it's only OpenSolaris that is booting, and it provides the option to boot XP. Remember, XP is not booting. It's only OpenSolaris that is booting, and by reading the `menu.lst` file, it is giving the option to boot XP. It also means BSD itself chose not to boot.

What if we go back and keep the boot flag on the first partition of Windows XP? Then which OS will boot? In Figure 2-39, we have achieved this.



Partition	File System	Label	Size	Used	Unused	Flags
/dev/sda1	fat32		9.77 GiB	2.97 GiB	6.79 GiB	boot, lba
/dev/sda4 ⚠	ext3	Solaris 2009	8.99 GiB	---	---	
unallocated	unallocated		790.86 MiB	---	---	
/dev/sda2 ⚠	unknown		9.77 GiB	---	---	
/dev/sda3	extended		45.70 GiB	---	---	
/dev/sda5	ntfs	windows 2003	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda6	ntfs	windows 7	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda7	ext3	RHEL 6	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda8	ext3	Fedora 15	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda9	linux-swap	swap	6.63 GiB	0.00 B	6.63 GiB	

0 operations pending

Figure 2-39. *The boot sequence of PC-BSD*

It's Windows XP alone that will boot, and the booting sequence is simple. Figure 2-40 explains how Windows XP is able to boot.

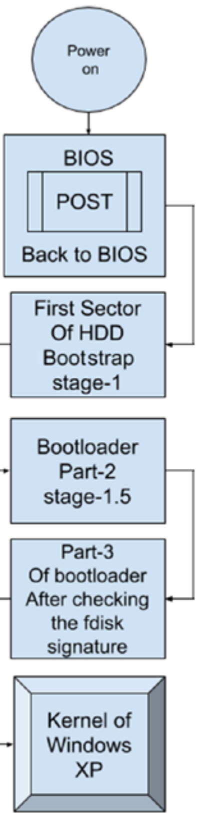
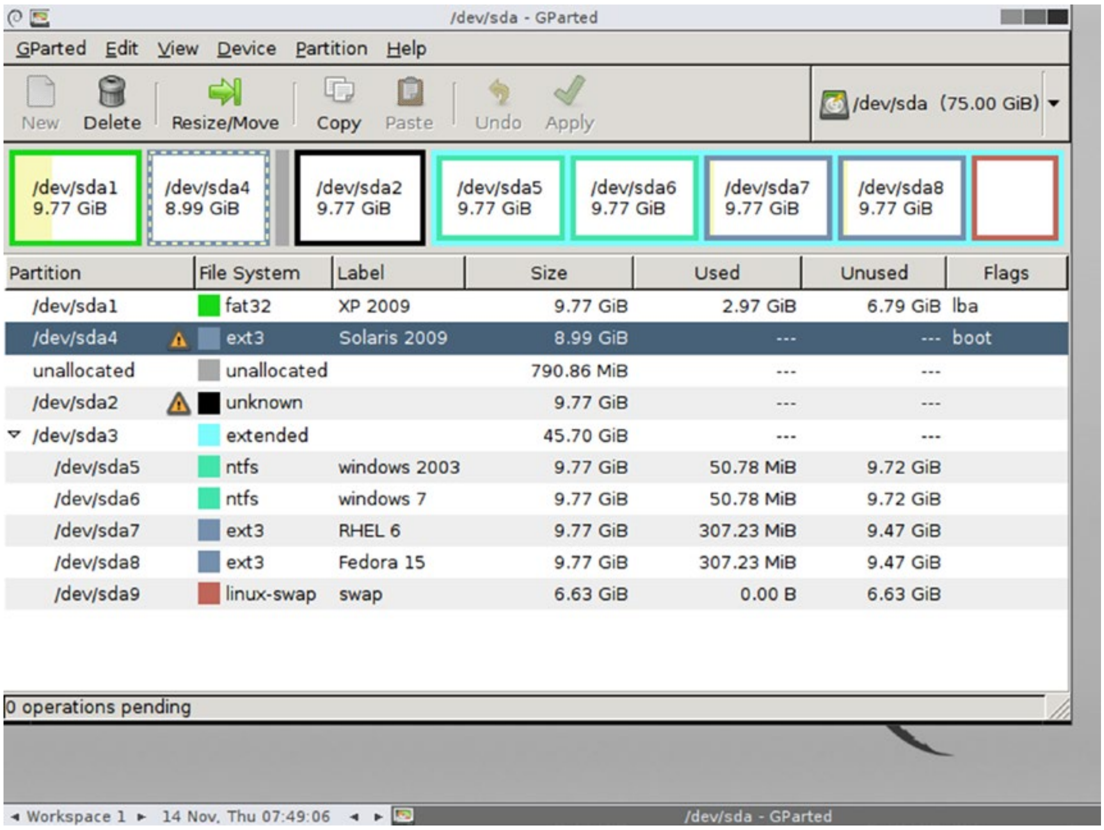

Power on
BIOS
POST
Back to BIOS
First Sector Of HDD Bootstrap stage-1
Bootloader Part-2 stage-1.5
Part-3 Of bootloader After checking the fdisk signature
Kernel of Windows XP

Figure 2-40. *The boot sequence of Windows XP*

Before installing the new OS, we need to move the boot flag from BSD's third partition to OpenSolaris' second partition. Figure 2-41 shows the changed boot flag from XP's partition to the OpenSolaris partition.



Partition	File System	Label	Size	Used	Unused	Flags
/dev/sda1	fat32	XP 2009	9.77 GiB	2.97 GiB	6.79 GiB	lba
/dev/sda4	ext3	Solaris 2009	8.99 GiB	---	---	boot
unallocated	unallocated		790.86 MiB	---	---	
/dev/sda2	unknown		9.77 GiB	---	---	
/dev/sda3	extended		45.70 GiB	---	---	
/dev/sda5	ntfs	windows 2003	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda6	ntfs	windows 7	9.77 GiB	50.78 MiB	9.72 GiB	
/dev/sda7	ext3	RHEL 6	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda8	ext3	Fedora 15	9.77 GiB	307.23 MiB	9.47 GiB	
/dev/sda9	linux-swap	swap	6.63 GiB	0.00 B	6.63 GiB	

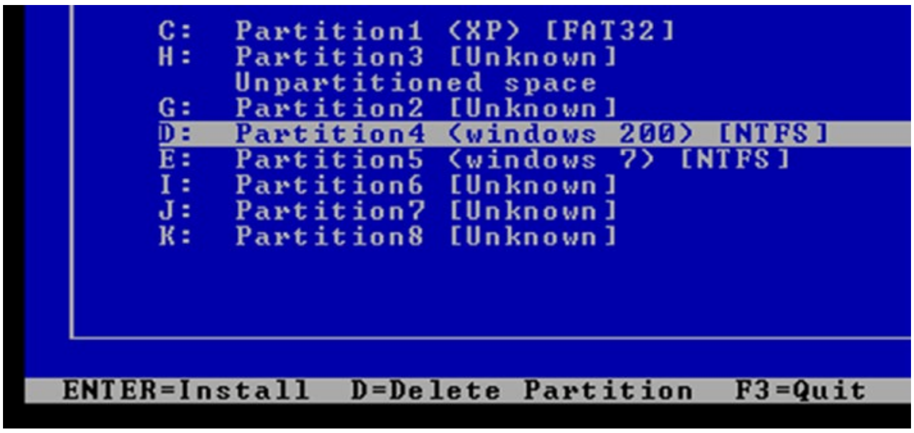
0 operations pending

Figure 2-41. *The disk layout from GParted*

With this change, OpenSolaris will start booting, and along with that, Windows XP will also boot, but BSD will not be able to boot. So, does this mean that every time we boot BSD we have to put the boot flag back to BSD's partition? As of now, yes, but we will automate all of this with the help of bootloaders.

Windows Server 2003

As you can see in Figure 2-42, we will install Windows Server 2003 (win2k3) on the first logical partition. For win2k3, it is a D: drive.



```
C:   Partition1 (XP) [FAT32]
H:   Partition3 [Unknown]
     Unpartitioned space
G:   Partition2 [Unknown]
D:   Partition4 (windows 200) [NTFS]
E:   Partition5 (windows 7) [NTFS]
I:   Partition6 [Unknown]
J:   Partition7 [Unknown]
K:   Partition8 [Unknown]

ENTER=Install  D=Delete Partition   F3=Quit
```

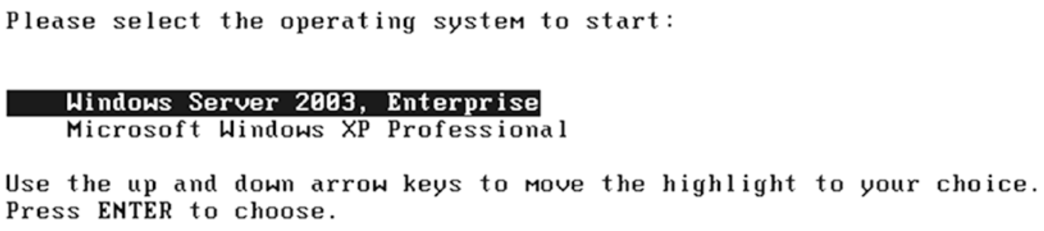
Figure 2-42. *The disk layout shown by the win2k3 installer*

After the installation, which OS do you think will boot?

- win2k3 alone?
- Will win2k3 provide an option to boot every other OS?
- win2k3 and OpenSolaris together?
- PC-BSD?
- XP alone?
- win2k3 and XP?

Before continuing, think for a while and come up with your own answer.

As you can see in Figure 2-43, the OS that will boot is win2k3.



```
Please select the operating system to start:


    Windows Server 2003, Enterprise
    Microsoft Windows XP Professional

Use the up and down arrow keys to move the highlight to your choice.
Press ENTER to choose.
```

Figure 2-43. *win2k3's welcome screen after reboot*

And win2k3 is giving the option to boot Windows XP. This means only the Windows family of operating systems is booting. Also, here are some questions that we should consider:

- Where is the boot flag now?
- Which OS will boot if we keep the boot flag on the second partition?
- Which OS will boot if we keep the boot flag on the third partition?
- Which OS will boot if we keep the boot flag on the logical partition (win2k3's partition)?
- Is there any way to boot only Windows XP?

You will receive all the answers to these questions in the following discussion.

One thing is clear here: win2k3 is the only OS that is booting. Before discussing how it is able to boot, we need to check what scenario it has created on the disk to boot successfully.

When win2k3 was getting installed, it saw that it was getting installed on a logical partition and that the boot flag is on the OpenSolaris partition (refer to Figure 2-44).

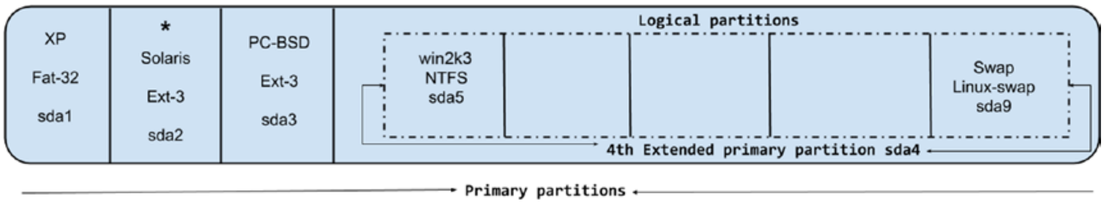


Figure 2-44. *The disk layout when win2k3 was getting installed*

To boot, win2k3 has to put the boot flag on its own partition by installing its bootloader's (again, NTLDR's) part-1 and part-2 in its own 512 bytes + 31 KB. But there is a problem here. Do you remember the rules we saw at the time of Windows XP's installation?

- The logical partition cannot be active.
- The OS cannot boot from the logical partition.

Because of these two rules, win2k3 cannot keep the boot flag on its own partition, and ultimately it cannot boot from the logical partition. Figure 2-45 shows the boot sequence of why win2k3 cannot boot from the logical partition. But what is the reason for such rules?

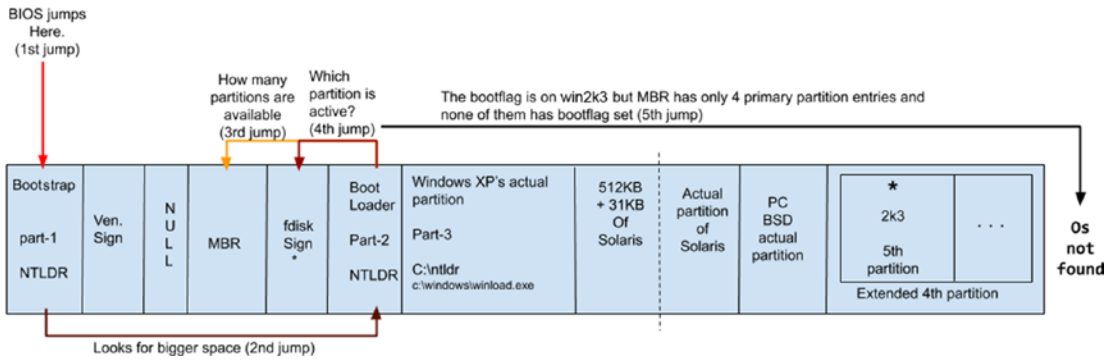

BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active? (4th jump)
The bootflag is on win2k3 but MBR has only 4 primary partition entries and none of them has bootflag set (5th jump)
Bootstrap part-1 NTLDR
Ven. Sign
NULL
MBR
fdisk Sign *
Boot Loader Part-2 NTLDR
Windows XP's actual partition Part-3 C:\ntldr c:\windows\winload.exe
512KB + 31KB Of Solaris
Actual partition of Solaris
PC BSD actual partition
* 2k3 5th partition
. . .
Extended 4th partition
Os not found
Looks for bigger space (2nd jump)

Figure 2-45. *win2k3's boot sequence if it tries to boot from the logical partition*

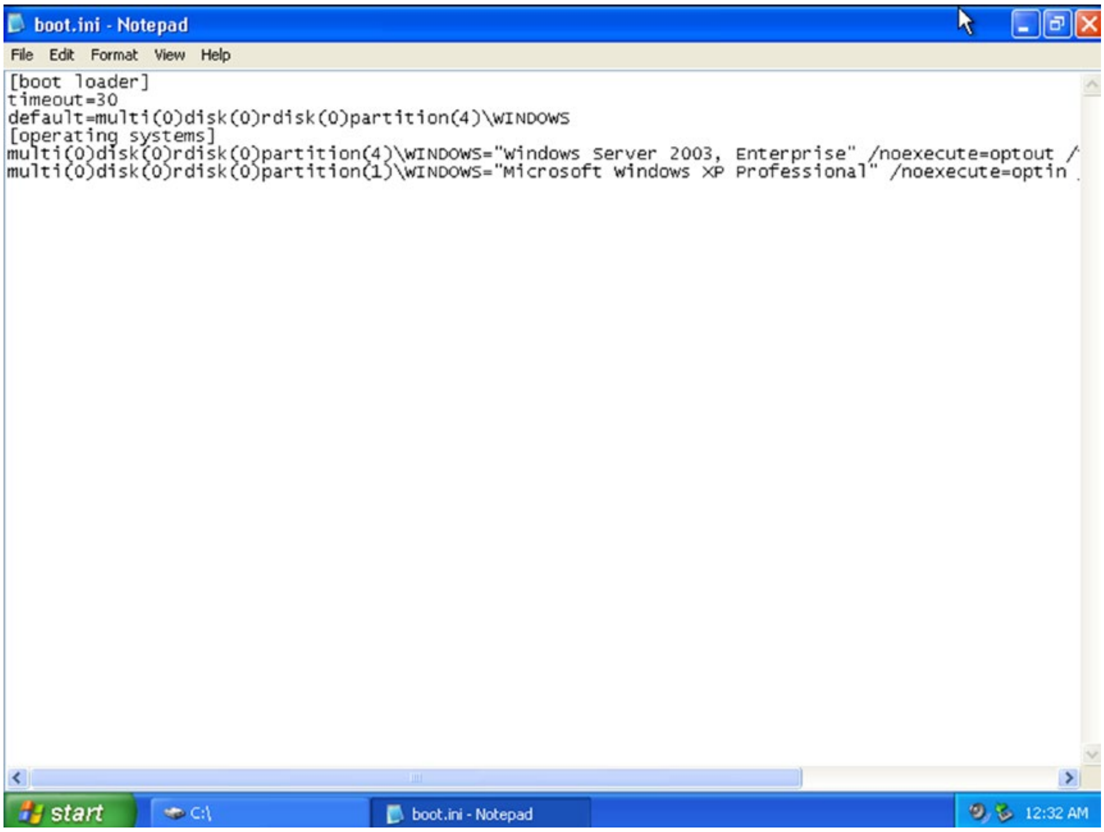
It's simple: MBR has only four entries, which are as follows:

- First primary = sda1
- Second primary = sda2
- Third primary = sda3
- Fourth primary = extended partition (not logical partition) = sda4

The win2k3 partition is sda5. In other words, it is SATA disk a (first) and partition number 5. Since the MBR does not have an entry for a logical partition, part-2 of XP's NTLDR does not know that there is a fifth partition available. So, even if win2k3 keeps the boot flag on its own partition, XP's NTLDR cannot see it. Hence, win2k3 will never boot. Now, why can the MBR not have more than five entries? It's because 64 bytes can store only four entries. Why not increase the size of the MBR? Actually, even if the developers want to increase the size of the MBR, they simply can't. You will understand the reason when we talk about the UEFI firmware later in this chapter.

Now this has become a chicken-and-egg problem for win2k3. It wants to boot, but for that it has to keep the boot flag on its own partition, but if it does that, then the BIOS cannot see that partition. How do we resolve this problem?

Some amazing developers have resolved this problem, and whoever came up with this idea is simply a legend. win2k3 transfers its NTLDR bootloader on the first primary, which means part-1, part-2, and part-3. It also means win2k3 will delete all the XP NTLDR's parts since the space (512 bytes + 31 KB) is tiny and both the bootloaders can't fit there. (There is one sweet spot here, which is called VBR, which is beyond the scope of this book.) However, while deleting, XP's bootloader win2k3 makes XP's entry in one of its text files and keeps it at the first primary partition. The file is called `boot.ini`, as shown in Figure 2-46.



```
[boot loader]
timeout=30
default=multi(0)disk(0)rdisk(0)partition(4)\WINDOWS
[operating systems]
multi(0)disk(0)rdisk(0)partition(4)\WINDOWS="Windows Server 2003, Enterprise" /noexecute=optout /
multi(0)disk(0)rdisk(0)partition(1)\WINDOWS="Microsoft Windows XP Professional" /noexecute=optin
```

Figure 2-46. *The boot.ini file*

While doing this, win2k3 keeps the boot flag on the first primary partition only. So, this is how win2k3 is booting:

1. Power on the system.
2. The CPU goes to the BIOS. The BIOS runs the POST.
3. POST checks, and the hardware gives the healthy beep and goes back to the BIOS.
4. The BIOS jumps to the first primary partition's first 512 bytes.

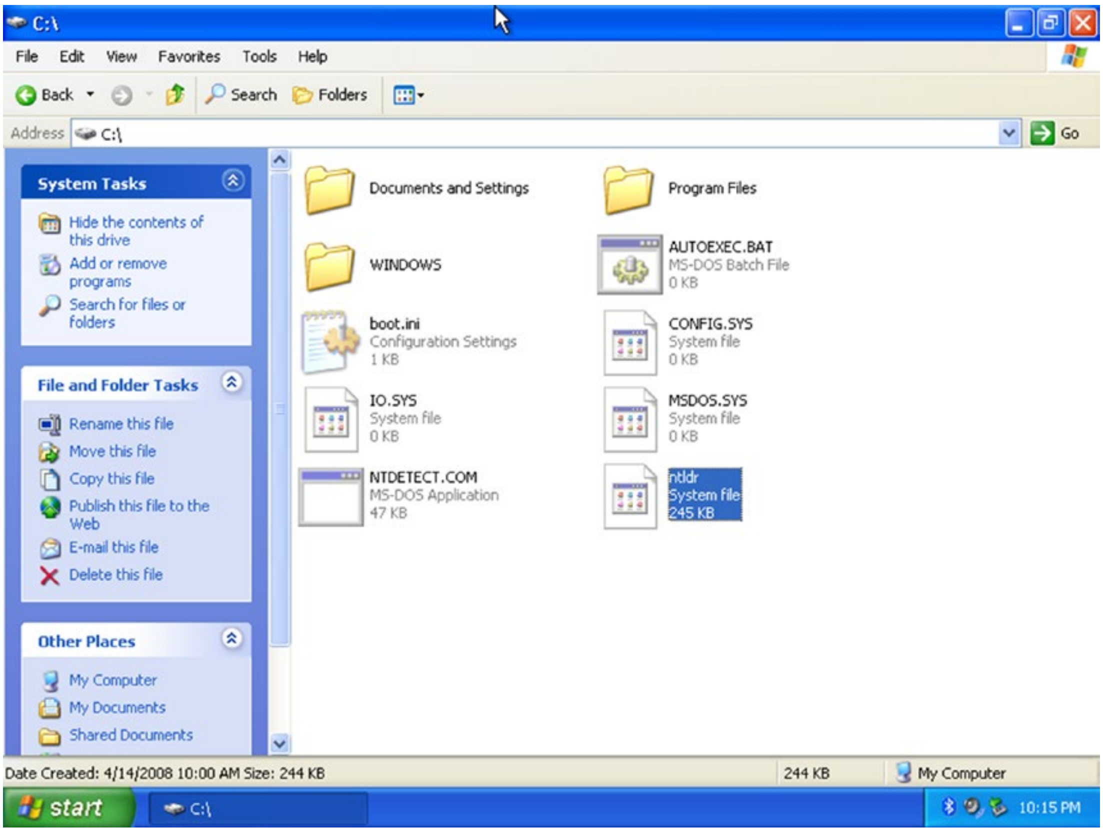
5. The bootstrap will start, which is win2k3's part-1 of NTLDR.

6. Part-1 will look for part-2 of NTLDR.

7. Part-2 will check the MBR and check the fdisk signature.

8. The fdisk signature is set on the first primary, which means part-2 will jump inside XP's first primary partition and will run part-3 of win2k3's NTLDR. To just give you an idea, part-3 is new and not XP's old NTLDR. Here I provide two images.

   - Note the size of NTLDR (part-3) in Figure 2-47. This is when we installed Windows XP.



Documents and Settings
Program Files
WINDOWS
AUTOEXEC.BAT MS-DOS Batch File 0 KB
boot.ini Configuration Settings 1 KB
CONFIG.SYS System file 0 KB
IO.SYS System file 0 KB
MSDOS.SYS System file 0 KB
NTDETECT.COM MS-DOS Application 47 KB
ntldr System file 245 KB

Date Created: 4/14/2008 10:00 AM Size: 244 KB | 244 KB | My Computer

Figure 2-47. *The size of NTLDR's part-3 file of Windows XP*

   - In Figure 2-48, note the size of NTLDR (part-3) after the installation of win2k3.

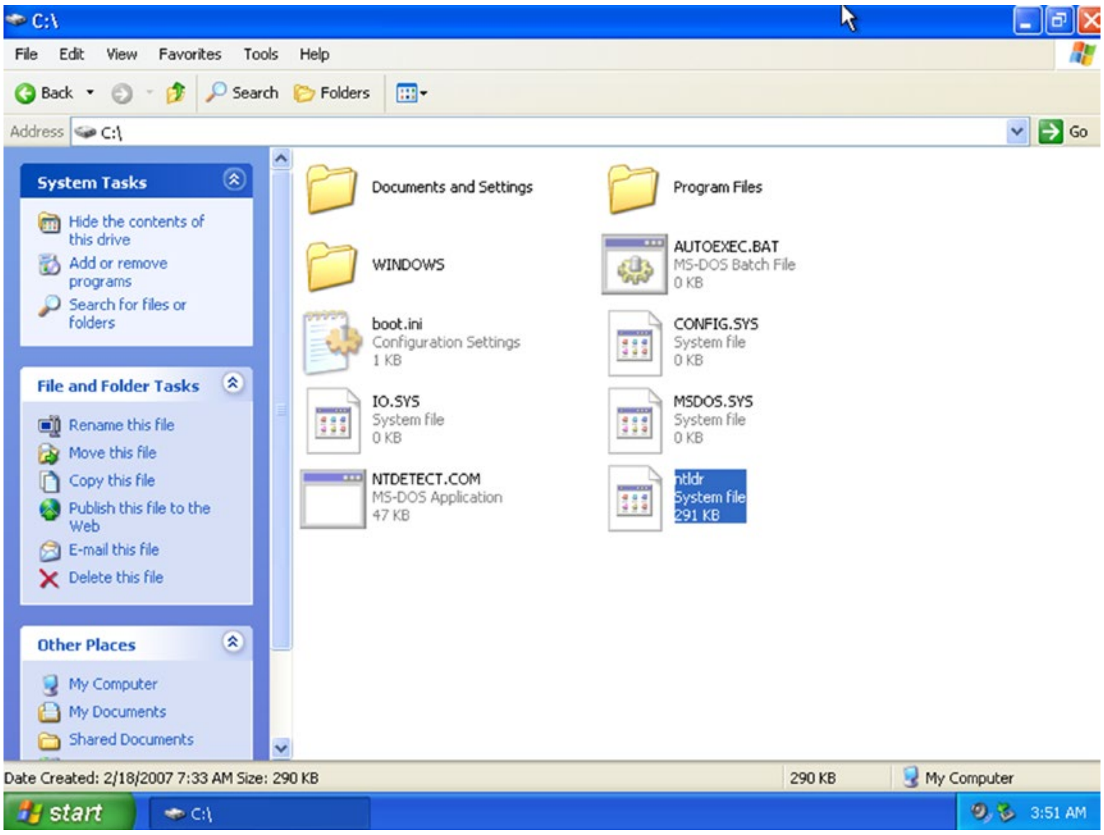
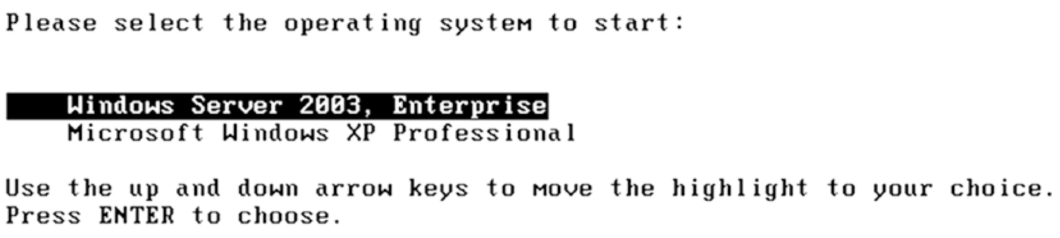


Figure 2-48. *The size of NTLDR's part-3 file of win2k3*

As you can see, part-3 of NTLDR of Windows XP was 245 KB, but now with win2k3 it's 291 KB.

9. Part-3 of NTLDR (win2k3) will read the `boot.ini` file from the same partition (the first primary) and will print whatever is written in quotes. Figure 2-49 shows what will be printed on the screen.



```
Please select the operating system to start:


     Windows Server 2003, Enterprise
     Microsoft Windows XP Professional

Use the up and down arrow keys to move the highlight to your choice.
Press ENTER to choose.
```

Figure 2-49. *The welcome screen shown by win2k3*

10. If a user chooses the Windows Server 2003, Enterprise option, then part-3 of win2k3's NTLDR knows where the kernel of win2k3 is. This is in the fifth partition where win2k3 has been installed. It copies the kernel in memory, and NTLDR of win2k3 goes away.

11. If a user chooses the Microsoft Windows XP Professional option, then part-3 of NTLDR also knows where the kernel of Windows XP is. This is in the first primary partition. First it starts `winload.exe`; eventually `winload.exe` copies XP's kernel in memory, and NTLDR goes away. Figure 2-50 shows the complete boot sequence of Windows XP.

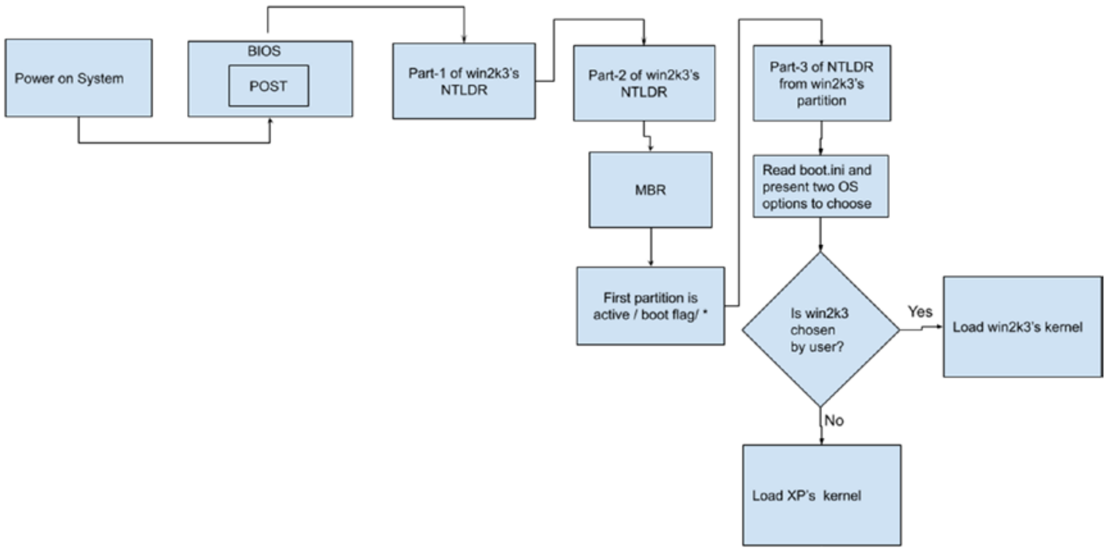

Power on System
BIOS
POST
Part-1 of win2k3's NTLDR
Part-2 of win2k3's NTLDR
MBR
First partition is active / boot flag/ *
Part-3 of NTLDR from win2k3's partition
Read boot.ini and present two OS options to choose
Is win2k3 chosen by user?
Yes
Load win2k3's kernel
No
Load XP's kernel

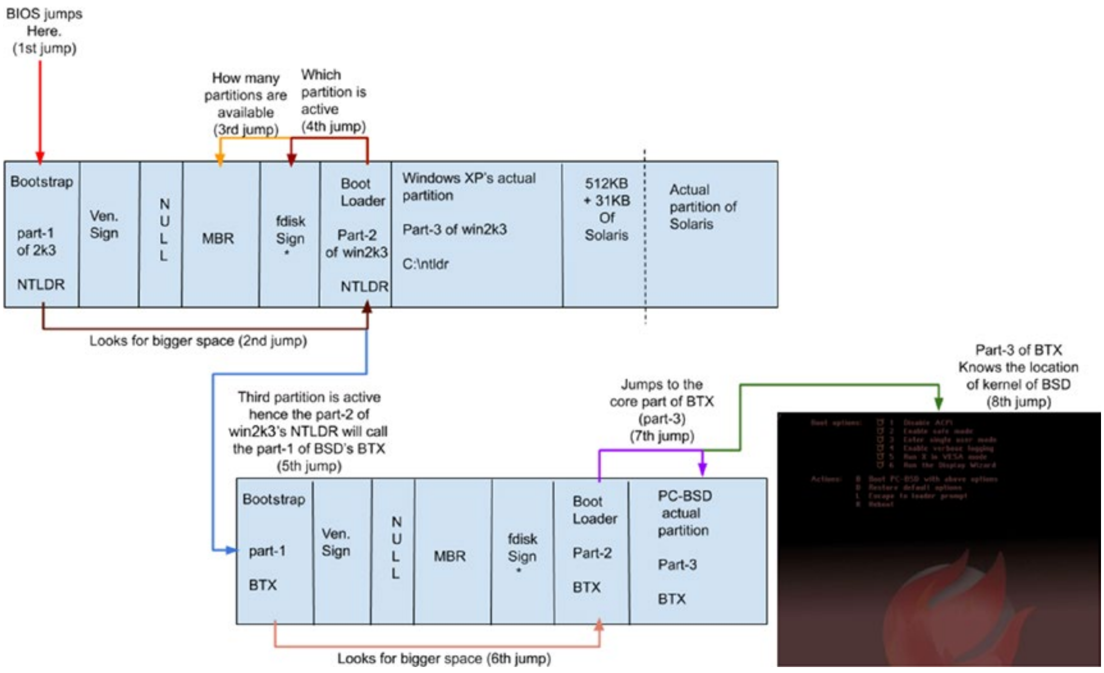
Figure 2-50. *The boot sequence of Windows XP*

So, this is how Windows XP and win2k3 are able to boot. Let's return to our fdisk signatures discussion; since only win2k3 is booting and the other OSs are not able to boot, I have some questions to ask:

- Can we boot only Windows XP?
- What if we keep the boot flag on OpenSolaris?
- What if we keep the boot flag on PC-BSD?
- What if we don't keep the boot flag anywhere?

Take your time, think, revisit the flowcharts, and come up with your answer.

Ready? We cannot boot only Windows XP. It's just not possible since in the Windows XP bootloaders all the parts have been replaced by win2k's NTLDR. Also, only win2k3 knows now where XP is, and only win2k3 can boot Windows XP. This also means if win2k3's bootloader's part-1 is corrupted or deleted, we will lose XP forever. But if we keep the boot flag on PC-BSD, then it will boot as usual. Figure 2-51 shows the boot sequence of PC-BSD.


BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active (4th jump)
Bootstrap part-1 of 2k3 NTLDR
Ven. Sign
N U L L
MBR
fdisk Sign
Boot Loader Part-2 of win2k3 NTLDR
Windows XP's actual partition Part-3 of win2k3 C:\ntldr
512KB + 31KB Of Solaris
Actual partition of Solaris
Looks for bigger space (2nd jump)
Third partition is active hence the part-2 of win2k3's NTLDR will call the part-1 of BSD's BTX (5th jump)
Jumps to the core part of BTX (part-3) (7th jump)
Part-3 of BTX Knows the location of kernel of BSD (8th jump)
Bootstrap part-1 BTX
Ven. Sign
N U L L
MBR
fdisk Sign
Boot Loader Part-2 BTX
PC-BSD actual partition Part-3 BTX
Looks for bigger space (6th jump)

```
Boot options:   1  Disable ACPI
                2  Enable safe mode
                3  Enter single user mode
                4  Enable verbose logging
                5  Run X in VESA mode
                6  Run the Display Wizard

Actions:    B  Boot PC-BSD with above options
            D  Restore default options
            L  Escape to loader prompt
            R  Reboot
```

Figure 2-51. *The boot sequence of PC-BSD*

If we don't keep the boot flag on any of the partitions, then it simply won't boot. This is similar to the situation that we discussed when talking about what would happen if the boot flag was set on the logical partition. Figure 2-52 shows the boot sequence to explain why none of the OSs is able to boot.

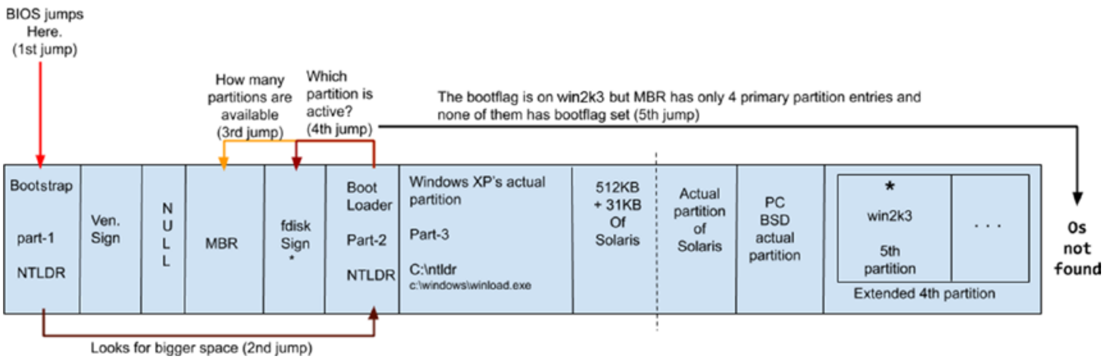

BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active? (4th jump)
The bootflag is on win2k3 but MBR has only 4 primary partition entries and none of them has bootflag set (5th jump)
Bootstrap
part-1
NTLDR
Ven. Sign
NULL
MBR
fdisk Sign *
Boot Loader
Part-2
NTLDR
Windows XP's actual partition
Part-3
C:\ntldr
c:\windows\winload.exe
512KB + 31KB Of Solaris
Actual partition of Solaris
PC BSD actual partition
*
win2k3
5th partition
. . .
Extended 4th partition
Os not found
Looks for bigger space (2nd jump)

Figure 2-52. *The boot sequence to show why none of the OSs is able to boot*

Setting up a boot flag on the logical partition is as good as not setting up a boot flag anywhere.

Now, the main question is, what if we keep the boot flag on the OpenSolaris partition? OpenSolaris will fail to boot. The OpenSolaris bootloader, which is GRUB, will throw the error message shown in Figure 2-53.

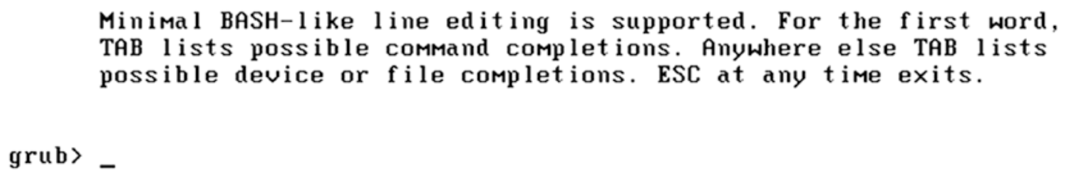

```
    Minimal BASH-like line editing is supported. For the first word,
    TAB lists possible command completions. Anywhere else TAB lists
    possible device or file completions. ESC at any time exits.


 grub> _
```

Figure 2-53. *GRUB dropped on prompt*

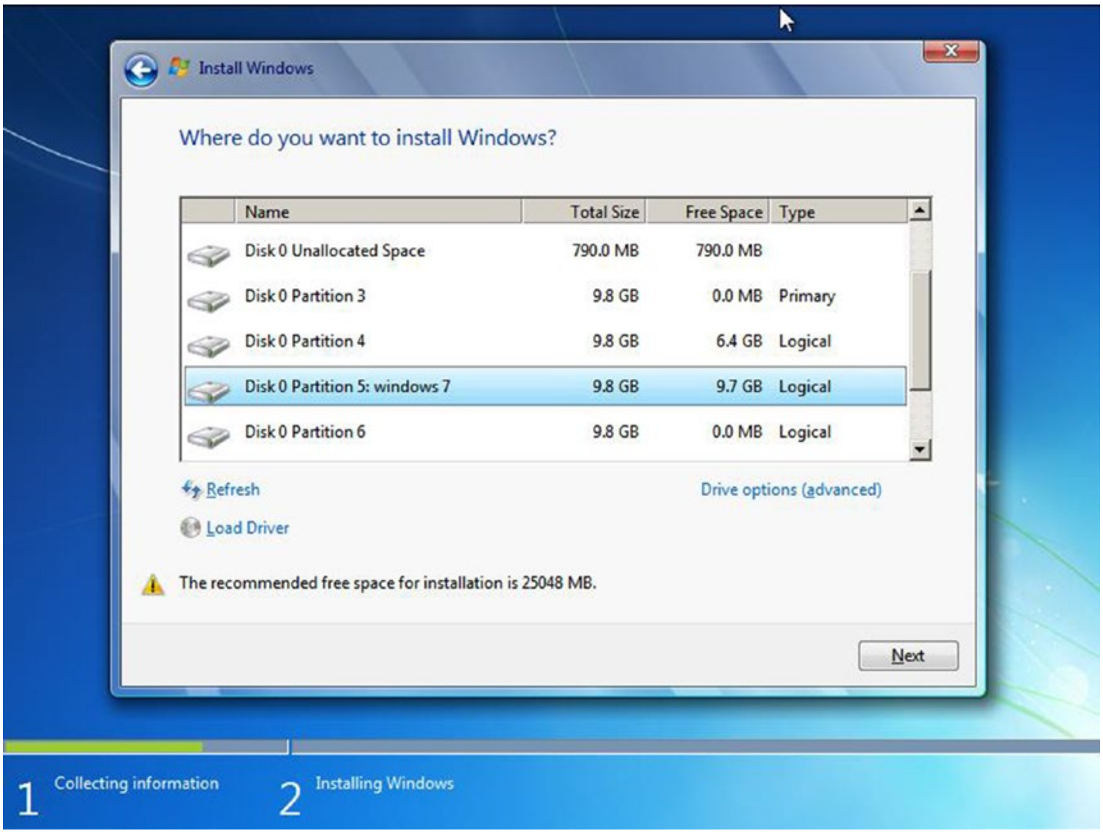
But why? It should boot, right? Nothing has been changed in OpenSolaris (512 bytes + 31 KB). It's just that win2k3 has moved the boot flag from the OpenSolaris partition to the first primary. So, ideally, it should boot, but it won't, and the reason is win2k3's behavior. When win2k3 was getting installed, it faced a similar situation that OpenSolaris and PC-BSD faced. In other words, the boot flag is on a different partition, and that partition has another OS. What OpenSolaris did in that situation was move the boot flag from XP's partition to its own second partition, but since this will make XP unbootable, it generously made an entry for XP in its own file (`menu.lst`). OpenSolaris reads this file every time and gives an equal chance to XP to boot.

In the case of PC-BSD, it detects that the boot flag is on OpenSolaris, and if it is moved to its own partition, it would make OpenSolaris unbootable. Hence, BSD generously chose not to put the boot flag on its own partition so that another OS would not become unbootable. But win2k3 does not have that generosity. When win2k3 was getting installed, it saw that the boot flag is on a non-Windows-based OS. So, it moved the boot flag of OpenSolaris, but since that is a non-Windows-based OS, it did not create an entry in `boot.ini`. Going further, win2k3 even corrupted/removed part-1 of the OpenSolaris GRUB. Hence, OpenSolaris is not able to boot now.

Later, win2k3 went ahead and cleared XP's bootloader, but it made the entry for XP in `boot.ini` since it is a Windows operating system. That's why I said win2k3 does not have the same generosity that is shown by OpenSolaris and PC-BSD. But we will fix OpenSolaris in the "Tweaking GRUB" section of this chapter.

Windows 7

As you can see in Figure 2-54, we are installing Windows 7 in the fifth partition.



Where do you want to install Windows?

Name	Total Size	Free Space	Type
Disk 0 Unallocated Space	790.0 MB	790.0 MB	
Disk 0 Partition 3	9.8 GB	0.0 MB	Primary
Disk 0 Partition 4	9.8 GB	6.4 GB	Logical
Disk 0 Partition 5: windows 7	9.8 GB	9.7 GB	Logical
Disk 0 Partition 6	9.8 GB	0.0 MB	Logical

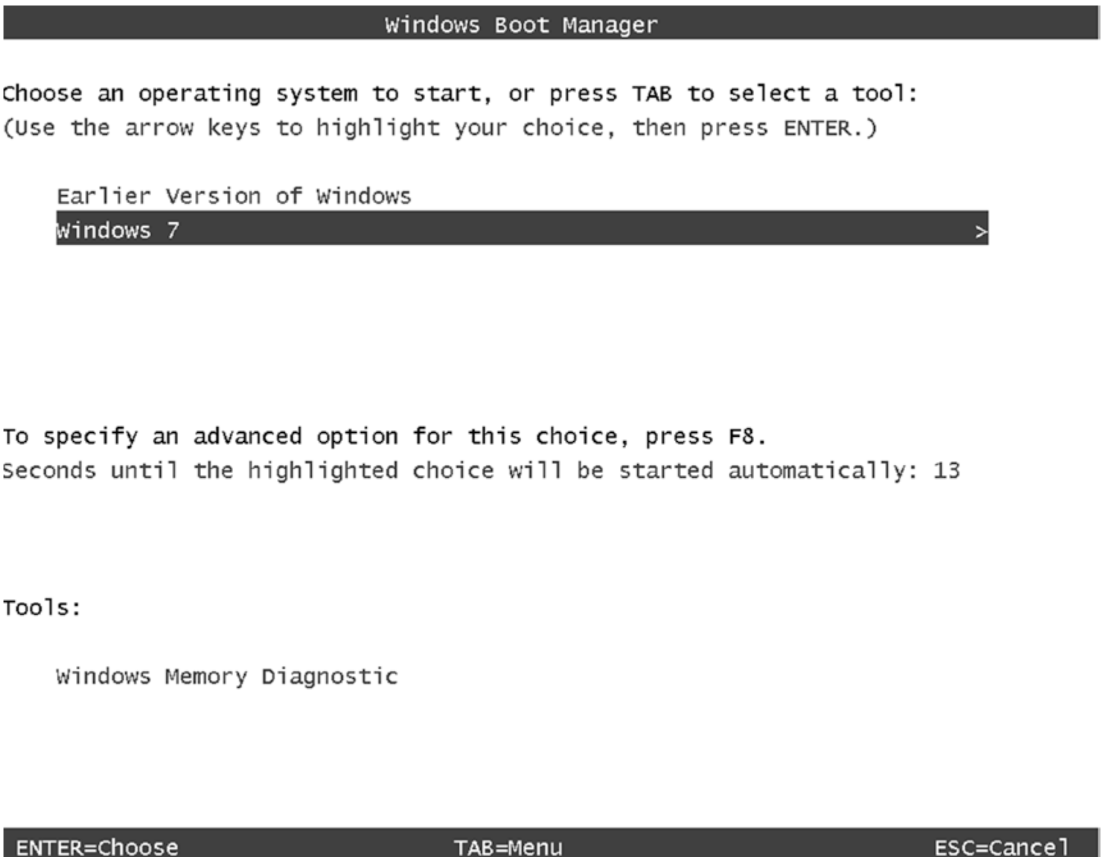
The recommended free space for installation is 25048 MB.

Figure 2-54. *The disk layout shown by the Windows 7 installer*

Windows does not show an extended partition to avoid confusion for simple desktop users.

1st = XP **2nd** = Solaris **3rd** = PC-BSD **4th** = win2k3 **5th** = 7

After the installation, which OS do you think will boot? As usual, take your time and come up with your answer before continuing to Figure 2-55.



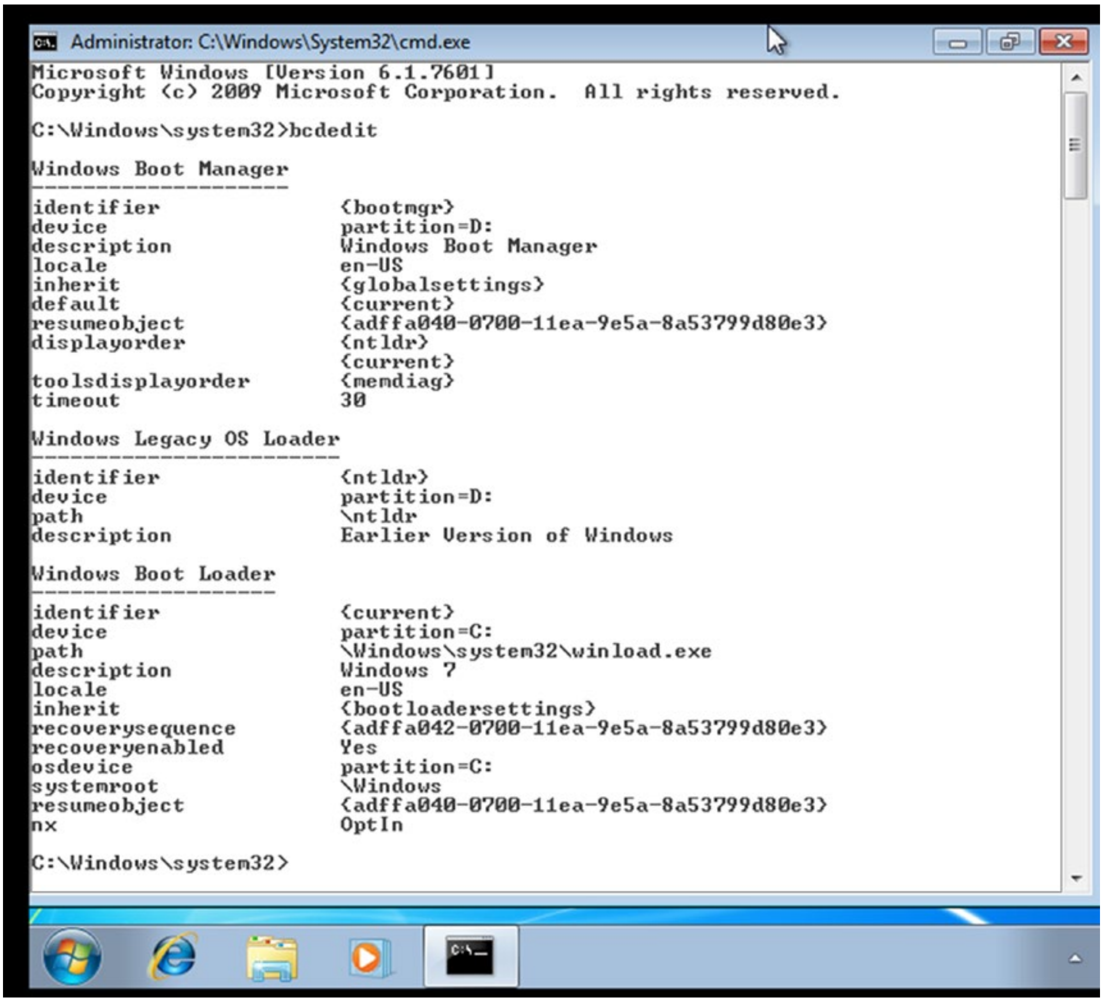
```
                          Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

    Earlier Version of Windows
    Windows 7                                                          >



To specify an advanced option for this choice, press F8.
Seconds until the highlighted choice will be started automatically: 13


Tools:

    Windows Memory Diagnostic



ENTER=Choose                     TAB=Menu                        ESC=Cancel
```

Figure 2-55. *The welcome screen shown by Windows 7*

You guessed right: Windows 7 will boot. The following is the complete booting sequence of Windows 7:

1. Power on the system.
2. The CPU will jump to the BIOS.
3. After the POST routine, the BIOS will jump to the entire HDD's first sector.
4. When Windows 7 was getting installed, the * was on the first primary, and Windows 7 was getting installed in a logical partition. So, Windows 7 is facing the same problems that win2k3 faced.
5. To make itself bootable, Windows 7 will follow the same path, which is followed by win2k3. Windows 7 will install its part-1, part-2, and part-3 on the first primary partition. Part-3 is not necessary to install on the first primary since part-2 has a hard-coded location for part-3, but this is how the Windows family works.
6. When part-1 and part-2 of Windows 7 were getting installed on the first primary, obviously Windows 7 has to delete the win2k3 NTLDR (part-1 and part-2), but while deleting the files, Windows 7 recognizes that win2k3 is a Windows family OS; hence, Windows 7's bootloader called Boot Configuration Data (BCD) makes an entry for win2k3 in its own file, which can be seen in `bcdedit.exe`. Check Figure 2-56 to see the output of `bcdedit.exe`.

"Windows Legacy OS Loader" in Figure 2-56 means win2k3.



```
Microsoft Windows [Version 6.1.7601]
Copyright (c) 2009 Microsoft Corporation.  All rights reserved.

C:\Windows\system32>bcdedit

Windows Boot Manager
--------------------
identifier              {bootmgr}
device                  partition=D:
description             Windows Boot Manager
locale                  en-US
inherit                 {globalsettings}
default                 {current}
resumeobject            {adffa040-0700-11ea-9e5a-8a53799d80e3}
displayorder            {ntldr}
                        {current}
toolsdisplayorder       {memdiag}
timeout                 30

Windows Legacy OS Loader
------------------------
identifier              {ntldr}
device                  partition=D:
path                    \ntldr
description             Earlier Version of Windows

Windows Boot Loader
-------------------
identifier              {current}
device                  partition=C:
path                    \Windows\system32\winload.exe
description             Windows 7
locale                  en-US
inherit                 {bootloadersettings}
recoverysequence        {adffa042-0700-11ea-9e5a-8a53799d80e3}
recoveryenabled         Yes
osdevice                partition=C:
systemroot              \Windows
resumeobject            {adffa040-0700-11ea-9e5a-8a53799d80e3}
nx                      OptIn

C:\Windows\system32>
```

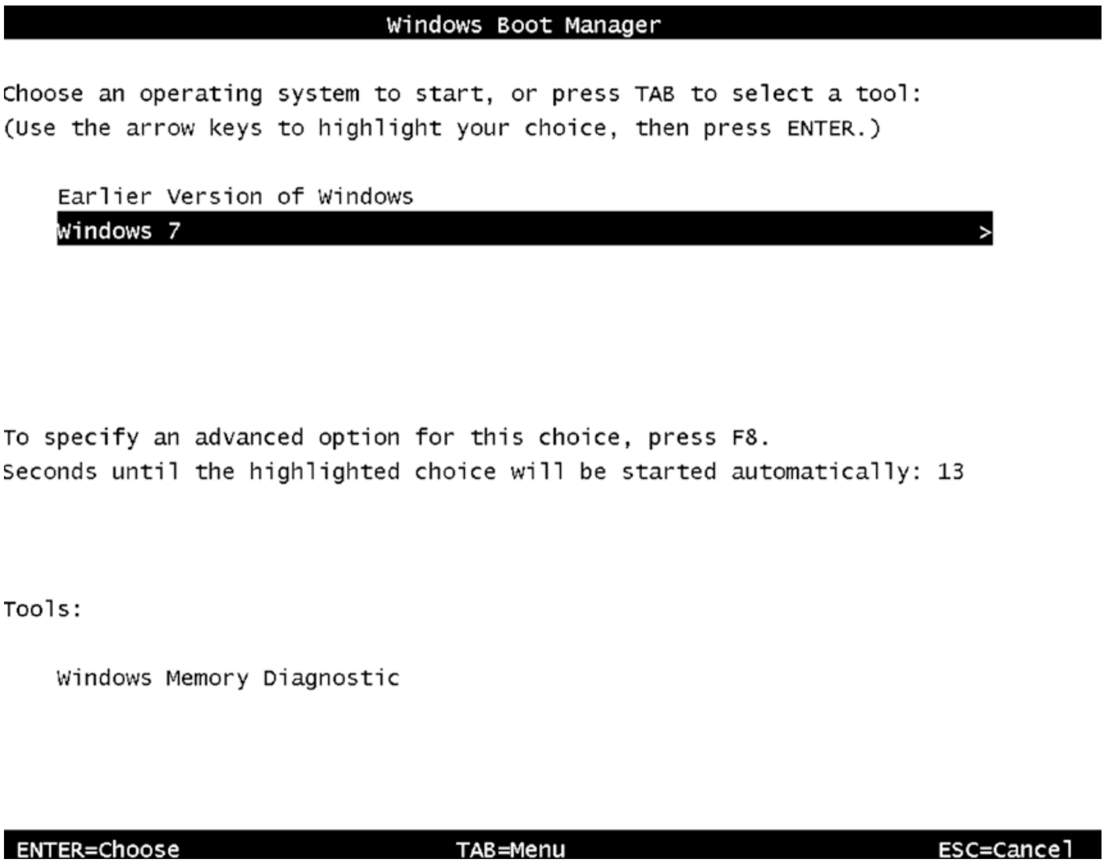
Figure 2-56. *The output of bcdedit.exe*

7. So, coming back to booting sequence, it looks like this: BIOS ➤ POST ➤ BIOS ➤ first sector of HDD.

8. The first 440 bytes of the bootstrap is part-1 of Window 7's BCD bootloader. It will look for a bigger space, which is part-2 of BCD.

9. Part-2 of BCD will read the MBR and will come to know that on this HDD there are four primary partitions, but to check which one is active, it will start checking the fdisk signature of every partition, but it will find the first primary itself is active.

10. Part-2 will jump inside the first primary where part-3 of Window 7's BCD bootloader is stored. Part-3 will read its bootloader configuration file through `bcdedit.exe` and will list the entries that are mentioned in front of the `description` variable. Figure 2-57 shows what will appear on-screen.



```
                              Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

    Earlier Version of Windows
    Windows 7                                                          >




To specify an advanced option for this choice, press F8.
Seconds until the highlighted choice will be started automatically: 13



Tools:

    Windows Memory Diagnostic




ENTER=Choose                    TAB=Menu                          ESC=Cancel
```

Figure 2-57. *Welcome screen shown by Windows 7*

11. If a user chooses Windows 7, then as you can see in `bcdedit.exe`, part-3 of BCD will call `winload.exe` from `C:\windows\systemd32`. Remember, here C: means Windows 7's partition, which is the sixth logical partition.

12. The `winload.exe` file knows the location of Windows 7's kernel. It will start loading the kernel in memory, and once it is done, Windows 7's kernel will take care of the rest of the booting sequence. You can see the animation shown by Windows 7 once it starts its booting sequence in Figure 2-58.

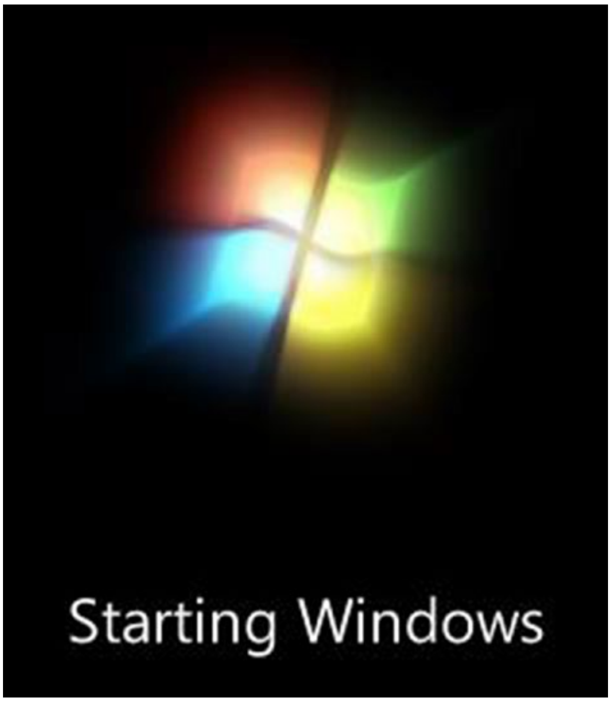
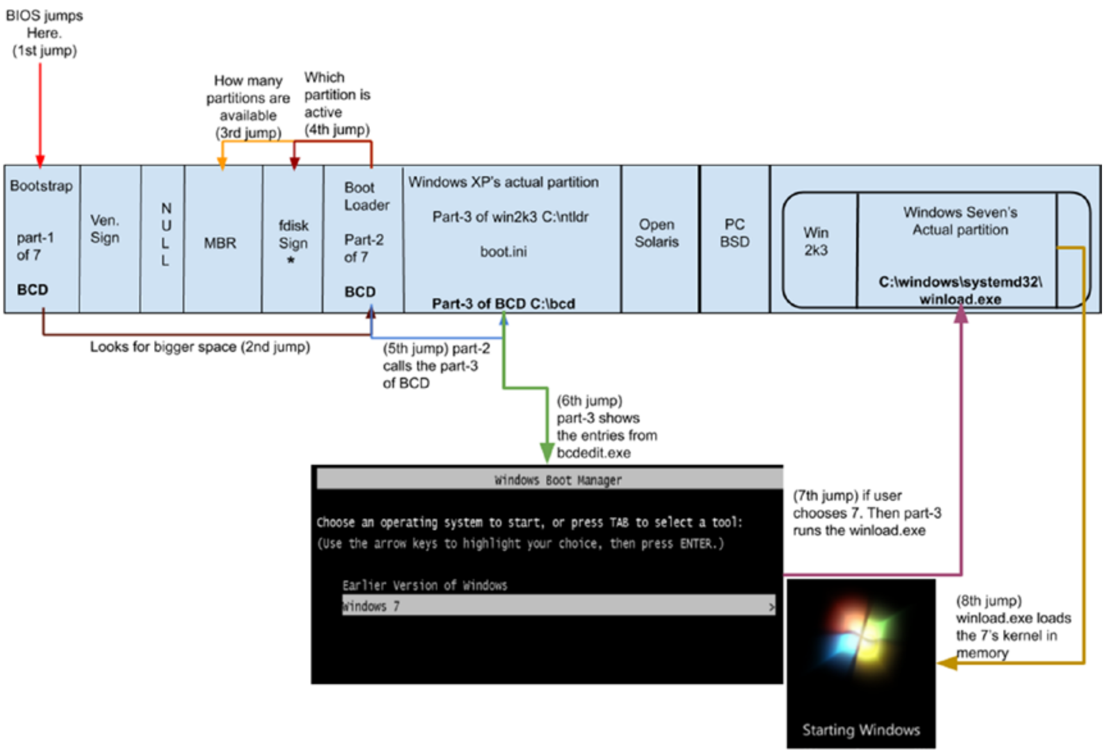


Figure 2-58. *The animation shown by Windows 7 during the booting sequence*

Figure 2-59 shows the complete flowchart of Windows 7's booting sequence.


BIOS jumps Here. (1st jump)
How many partitions are available (3rd jump)
Which partition is active (4th jump)
Bootstrap
part-1 of 7
BCD
Ven. Sign
N U L L
MBR
fdisk Sign *
Boot Loader
Part-2 of 7
BCD
Windows XP's actual partition
Part-3 of win2k3 C:\ntldr
boot.ini
Part-3 of BCD C:\bcd
Open Solaris
PC BSD
Win 2k3
Windows Seven's Actual partition
C:\windows\systemd32\ winload.exe
Looks for bigger space (2nd jump)
(5th jump) part-2 calls the part-3 of BCD
(6th jump) part-3 shows the entries from bcdedit.exe
(7th jump) if user chooses 7. Then part-3 runs the winload.exe
(8th jump) winload.exe loads the 7's kernel in memory
Starting Windows

```
Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

    Earlier Version of Windows
    Windows 7                                                    >
```

Figure 2-59. *The booting sequence of Windows 7*

13. If the user chooses Earlier Version of Windows, then BCD's part-3 will call part-3 of NTLDR, which is on the first primary partition only, and the booting sequence will continue, which we saw with win2k3. Figure 2-60 explains the boot sequence of win2k3 and XP.

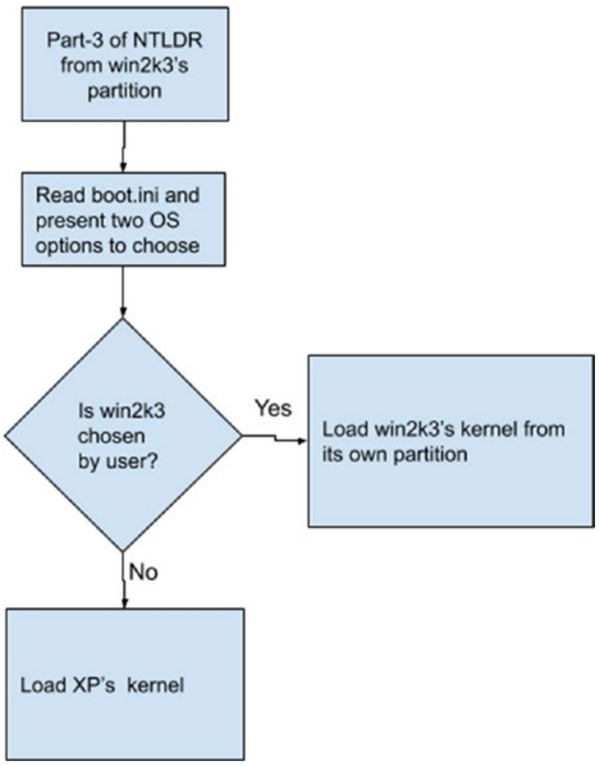
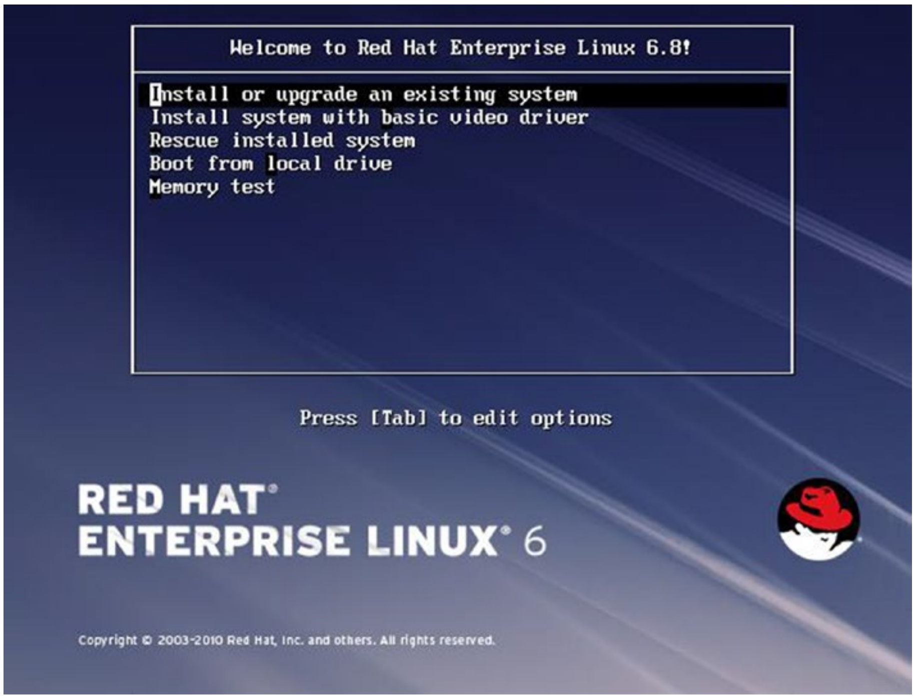

Part-3 of NTLDR from win2k3's partition
Read boot.ini and present two OS options to choose
Is win2k3 chosen by user?
Yes
Load win2k3's kernel from its own partition
No
Load XP's kernel

Figure 2-60. *The boot sequence of win2k3 and XP*

Red Hat Enterprise Linux 6 (RHEL 6)

The RHEL installer's name is Anaconda. The Anaconda installer is used by all the Fedora-based distributions. In Figure 2-61, we have started installing RHEL 6.

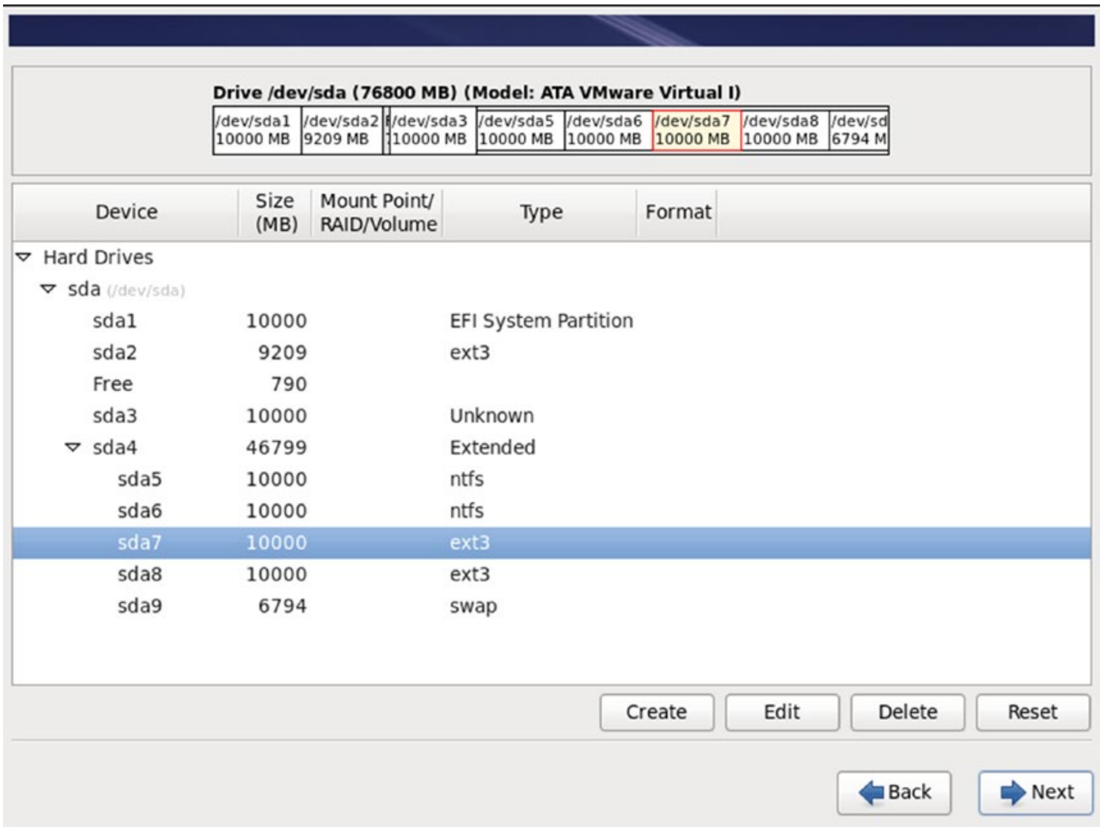


```
Welcome to Red Hat Enterprise Linux 6.8!

Install or upgrade an existing system
Install system with basic video driver
Rescue installed system
Boot from local drive
Memory test

Press [Tab] to edit options
```

RED HAT®
ENTERPRISE LINUX® 6
Copyright © 2003-2010 Red Hat, Inc. and others. All rights reserved.

Figure 2-61. *The welcome screen of RHEL 6's boot medium*

Figure 2-62 shows our current partition layout.



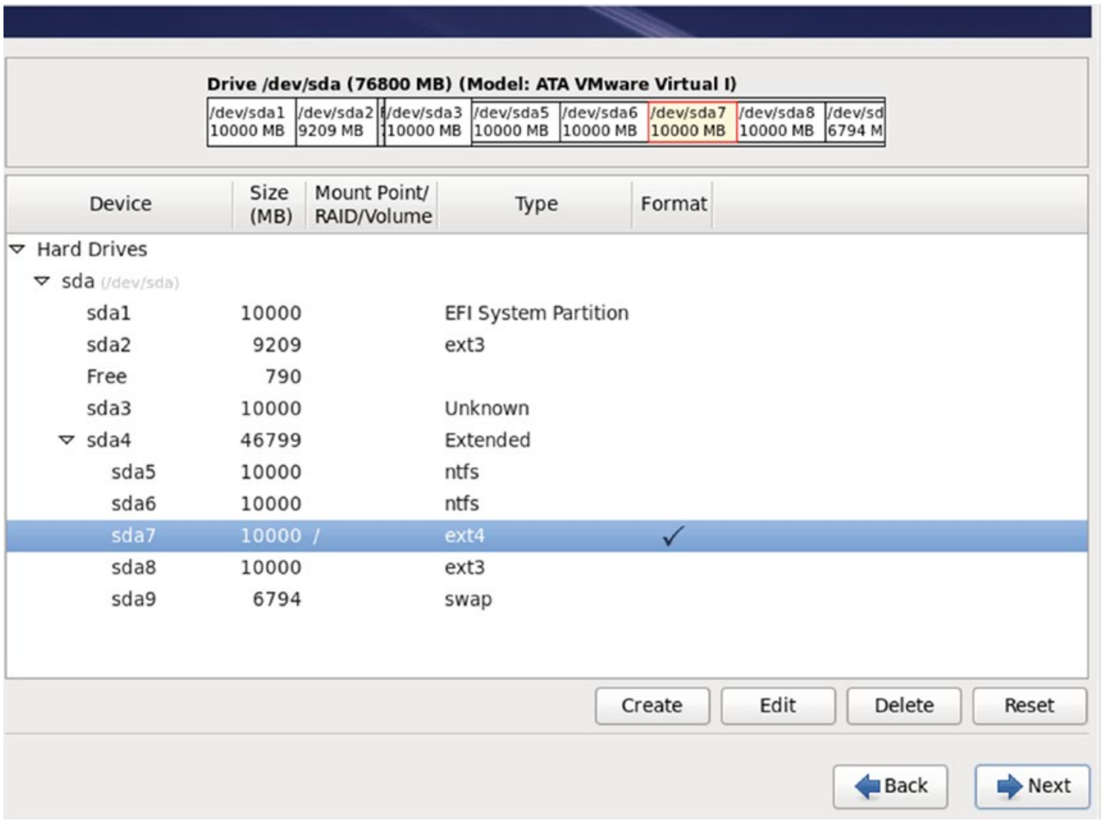
Drive /dev/sda (76800 MB) (Model: ATA VMware Virtual I)

/dev/sda1	/dev/sda2	/dev/sda3	/dev/sda5	/dev/sda6	/dev/sda7	/dev/sda8	/dev/sd
10000 MB	9209 MB	10000 MB	10000 MB	10000 MB	10000 MB	10000 MB	6794 M

Device	Size (MB)	Mount Point/ RAID/Volume	Type	Format
Hard Drives				
sda (/dev/sda)				
sda1	10000		EFI System Partition	
sda2	9209		ext3	
Free	790			
sda3	10000		Unknown	
sda4	46799		Extended	
sda5	10000		ntfs	
sda6	10000		ntfs	
sda7	10000		ext3	
sda8	10000		ext3	
sda9	6794		swap	

Figure 2-62. *Partition layout shown by the Anaconda installer*

As shown in Figure 2-63, we need to assign root (/) to the sda7 partition and reformat it with ext4, which is the default filesystem choice of RHEL 6.



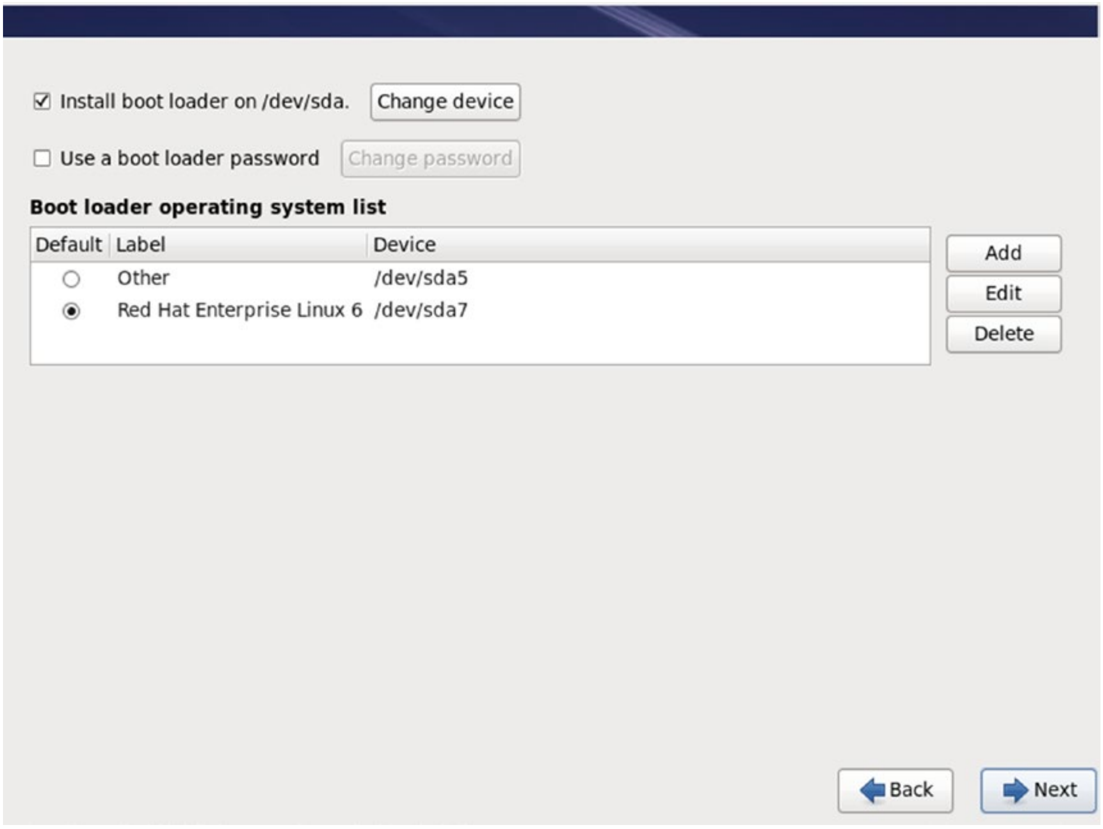
Drive /dev/sda (76800 MB) (Model: ATA VMware Virtual I)

/dev/sda1	/dev/sda2	/dev/sda3	/dev/sda5	/dev/sda6	/dev/sda7	/dev/sda8	/dev/sd
10000 MB	9209 MB	10000 MB	10000 MB	10000 MB	10000 MB	10000 MB	6794 M

Device	Size (MB)	Mount Point/ RAID/Volume	Type	Format
Hard Drives				
sda (/dev/sda)				
sda1	10000		EFI System Partition	
sda2	9209		ext3	
Free	790			
sda3	10000		Unknown	
sda4	46799		Extended	
sda5	10000		ntfs	
sda6	10000		ntfs	
sda7	10000	/	ext4	✓
sda8	10000		ext3	
sda9	6794		swap	

Figure 2-63. *The partition scheme that Anaconda will implement*

As visible in Figure 2-64, RHEL 6 (or Anaconda) has detected some OS, and it is trying to give equal opportunity to the other OS to boot (specified as Other). There are two OS entries, which RHEL 6's bootloader (GRUB) will show at the time of the boot.



☑ Install boot loader on /dev/sda.

☐ Use a boot loader password

Boot loader operating system list

Default	Label	Device
○	Other	/dev/sda5
●	Red Hat Enterprise Linux 6	/dev/sda7

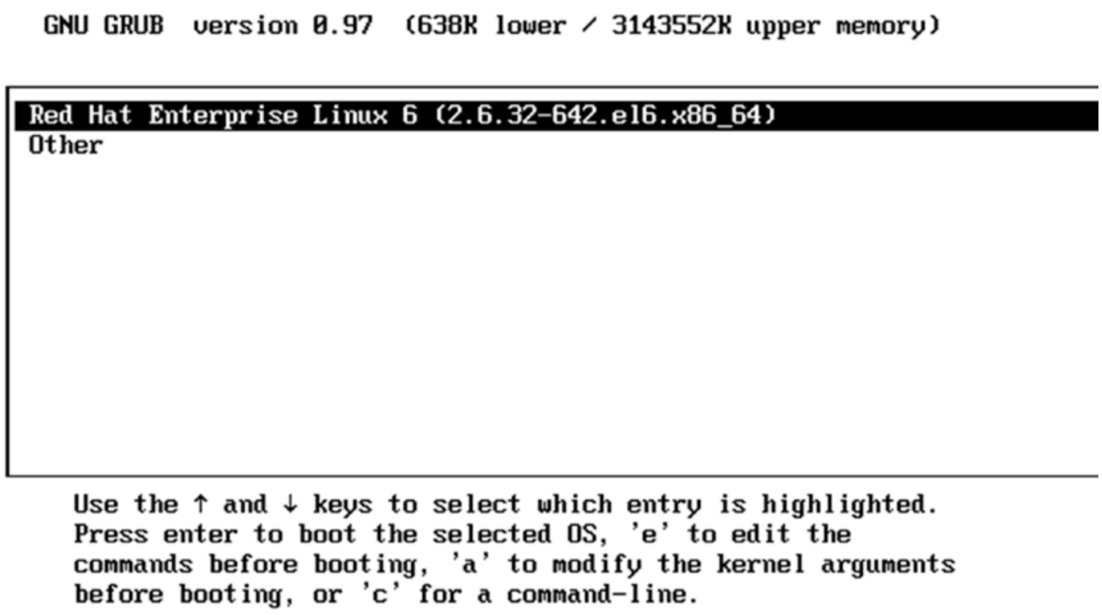
Figure 2-64. *Anaconda detecting another OS*

As per RHEL 6, the other OS will boot from sda5. This means the following:

```
sda1 = XP
sda2 = Solaris
sda3 = PC BSD
sda4 = Extended partition
sda5 = Win win2k3    <<<-----------
```

At the time of the boot, if a user chooses the Other option, win2k3 is supposed to boot. Which OS will boot after choosing the Other option? Take your time and come up with your own booting sequence.

Let's reboot the system and see which OS is booting. As you can see in Figure 2-65, it's RHEL 6 that is booting and giving you a chance to boot the other OS.



```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

 Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
 Other

    Use the ↑ and ↓ keys to select which entry is highlighted.
    Press enter to boot the selected OS, 'e' to edit the
    commands before booting, 'a' to modify the kernel arguments
    before booting, or 'c' for a command-line.
```

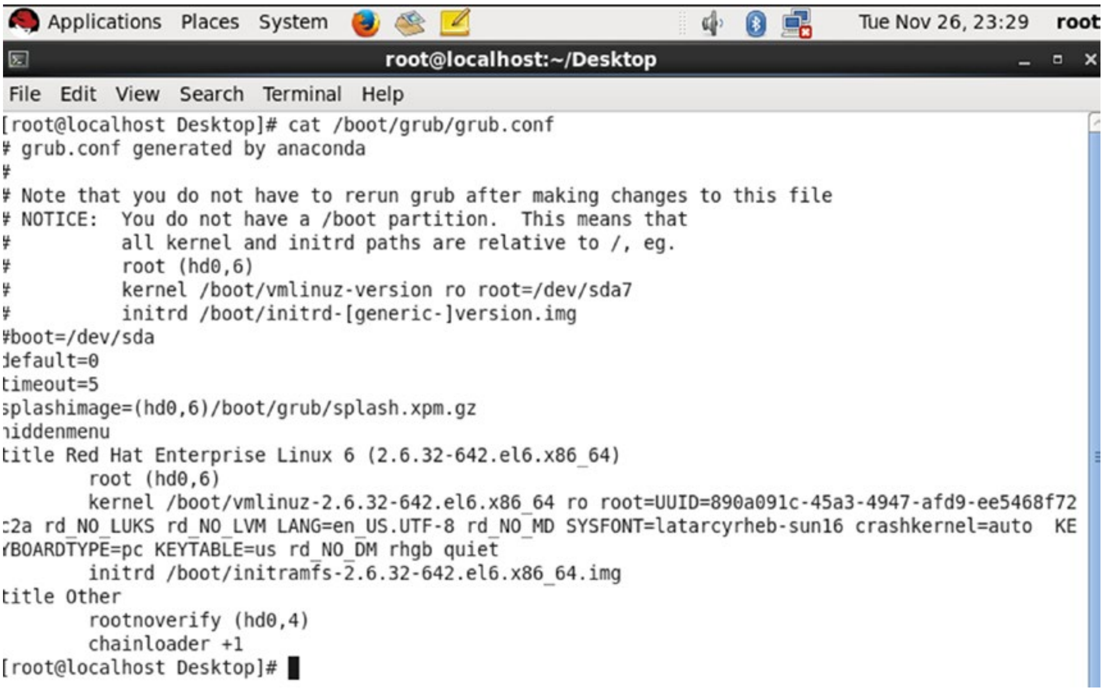
Figure 2-65. *The RHEL 6 welcome screen*

This is how RHEL 6 boots:

1. When the system is powered on, it goes to the BIOS, then from the BIOS to POST, and from POST back to the BIOS.
2. The BIOS ultimately lands in the entire HDD's first sector and runs the bootstrap.
3. When RHEL 6 was getting installed, the * was on the first primary partition.
4. The problem that was faced by win2k3 and Windows 7 is faced by RHEL 6 also. RHEL 6 is getting installed in a logical partition that the BIOS cannot reach or see. So, to tackle this issue, RHEL 6 has to shift its part-1 and part-2 of the bootloader (GRUB) to the first

primary partition. Remember, Windows shifted part-3 as well to the first primary, but RHEL (and in general any Linux OS) will shift only the first two parts to the first primary partition, and part-3 of GRUB will be kept in its own partition; in our case, this is sda-7.

5. While replacing the first primary partition's part-1 and part-2, RHEL noticed that there is already some other OS installed, and to give it an equal chance to boot, it made an entry for it in its own partition's `/boot/grub/grub.conf` named configuration file. Figure 2-66 shows the `grub.conf` file.


Applications Places System
Tue Nov 26, 23:29 root
root@localhost:~/Desktop
File Edit View Search Terminal Help

```
[root@localhost Desktop]# cat /boot/grub/grub.conf
# grub.conf generated by anaconda
#
# Note that you do not have to rerun grub after making changes to this file
# NOTICE:  You do not have a /boot partition.  This means that
#          all kernel and initrd paths are relative to /, eg.
#          root (hd0,6)
#          kernel /boot/vmlinuz-version ro root=/dev/sda7
#          initrd /boot/initrd-[generic-]version.img
#boot=/dev/sda
default=0
timeout=5
splashimage=(hd0,6)/boot/grub/splash.xpm.gz
hiddenmenu
title Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
        root (hd0,6)
        kernel /boot/vmlinuz-2.6.32-642.el6.x86_64 ro root=UUID=890a091c-45a3-4947-afd9-ee5468f72
c2a rd_NO_LUKS rd_NO_LVM LANG=en_US.UTF-8 rd_NO_MD SYSFONT=latarcyrheb-sun16 crashkernel=auto  KE
YBOARDTYPE=pc KEYTABLE=us rd_NO_DM rhgb quiet
        initrd /boot/initramfs-2.6.32-642.el6.x86_64.img
title Other
        rootnoverify (hd0,4)
        chainloader +1
[root@localhost Desktop]# 
```

Figure 2-66. *The grub.conf file*

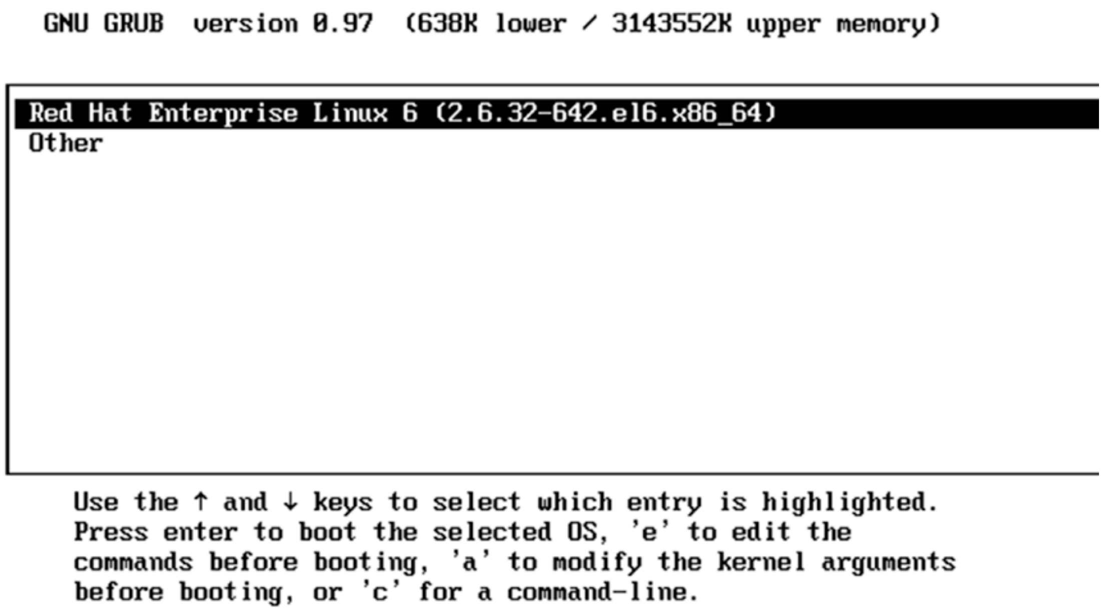
As you can see, whatever is written after the `title` variable will be printed on the screen.

6. Returning to the boot sequence, the bootstrap that is in the first primary partition is from RHEL.

7. Part-1 of RHEL's GRUB will jump to part-2.

8. Part-2 of GRUB has a hard-coded location for part-3 of GRUB. Part-3 of GRUB is on RHEL's partition, which is sda7.

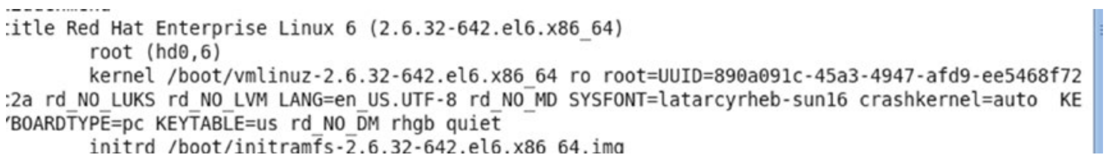
9. Part-3 of GRUB will read the `grub.conf` file from the `/boot/grub` directory, and whatever is written after `title` will be printed on the screen. Figure 2-67 shows this.



```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

 Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
 Other

      Use the ↑ and ↓ keys to select which entry is highlighted.
      Press enter to boot the selected OS, 'e' to edit the
      commands before booting, 'a' to modify the kernel arguments
      before booting, or 'c' for a command-line.
```

Figure 2-67. *The welcome screen shown by RHEL 6's GRUB*

10. If a user chooses the first entry, which is Red Hat Enterprise Linux 6, then part-3 of GRUB knows where the kernel of RHEL is. Figure 2-68 shows the `grub.conf` file.



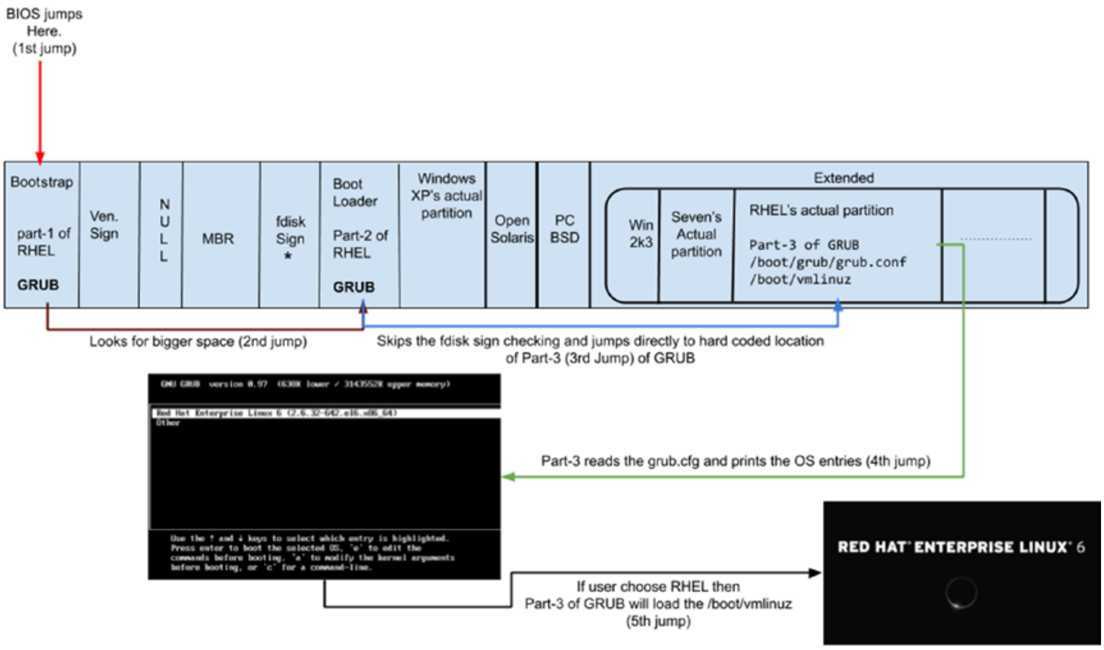
```
:itle Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
        root (hd0,6)
        kernel /boot/vmlinuz-2.6.32-642.el6.x86_64 ro root=UUID=890a091c-45a3-4947-afd9-ee5468f72
:2a rd_NO_LUKS rd_NO_LVM LANG=en_US.UTF-8 rd_NO_MD SYSFONT=latarcyrheb-sun16 crashkernel=auto  KE
'BOARDTYPE=pc KEYTABLE=us rd_NO_DM rhgb quiet
        initrd /boot/initramfs-2.6.32-642.el6.x86_64.img
```

Figure 2-68. *The grub.conf file of RHEL 6*

11. The kernel binary file will be at `/boot/vmlinuz`. (Notice the `kernel` variable from Figure 2-68.) Basically, the same `grub.conf` file will tell the location of the kernel to part-3 of GRUB. It will copy the kernel (`vmlinuz`) in memory, and the GRUB bootloader's job is done. RHEL's kernel will take care of the rest of the booting sequence. Meanwhile, when the system is booting, a nice animation, as shown in Figure 2-69, will appear on the screen.

Figure 2-69. *The animation to hide the complicated log messages*

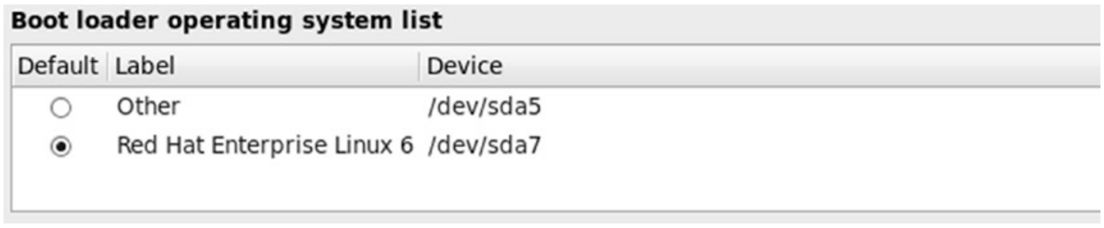
Figure 2-70 shows the flowchart of the complete booting sequence of RHEL 6.


BIOS jumps Here. (1st jump)
Bootstrap
part-1 of RHEL
GRUB
Ven. Sign
N U L L
MBR
fdisk Sign *
Boot Loader
Part-2 of RHEL
GRUB
Windows XP's actual partition
Open Solaris
PC BSD
Extended
Win 2k3
Seven's Actual partition
RHEL's actual partition
Part-3 of GRUB
/boot/grub/grub.conf
/boot/vmlinuz
Looks for bigger space (2nd jump)
Skips the fdisk sign checking and jumps directly to hard coded location of Part-3 (3rd Jump) of GRUB
Part-3 reads the grub.cfg and prints the OS entries (4th jump)
If user choose RHEL then Part-3 of GRUB will load the /boot/vmlinuz (5th jump)
RED HAT ENTERPRISE LINUX 6

```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
Other

Use the ↑ and ↓ keys to select which entry is highlighted.
Press enter to boot the selected OS, 'e' to edit the
commands before booting, 'a' to modify the kernel arguments
before booting, or 'c' for a command-line.
```

Figure 2-70. *The boot sequence of RHEL 6*

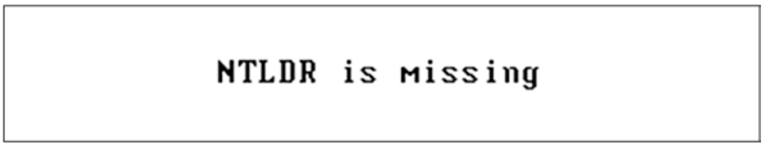
12. If a user chooses Other instead, then it will call whatever is present on the sda5 partition. As you can see in Figure 2-71, sda5 is on win2k3's partition.


Boot loader operating system list

Default	Label	Device
○	Other	/dev/sda5
●	Red Hat Enterprise Linux 6	/dev/sda7

Figure 2-71. *The other OS is on partition 5*

13. When win2k3 was installed, it shifted all of its bootloader's parts to the first primary. This means win2k3's partition does not have a bootloader present, so of course no OS will boot. Figure 2-72 shows the error message thrown on-screen if you try to boot the other OS.



```
NTLDR is missing
```

Figure 2-72. *The error message*

Now, I have a couple of questions to ask:

- Where is the * now?
- If I keep the * on the second partition, which OS will boot?
- If I keep the * on the third partition, which OS will boot?
- If I keep the * on the fifth (logical) partition, which OS will boot?
- If I do not keep the * on any of the partition, which OS will boot?

In all of these scenarios, only one OS will boot, and that will be RHEL 6 (Figure 2-73).

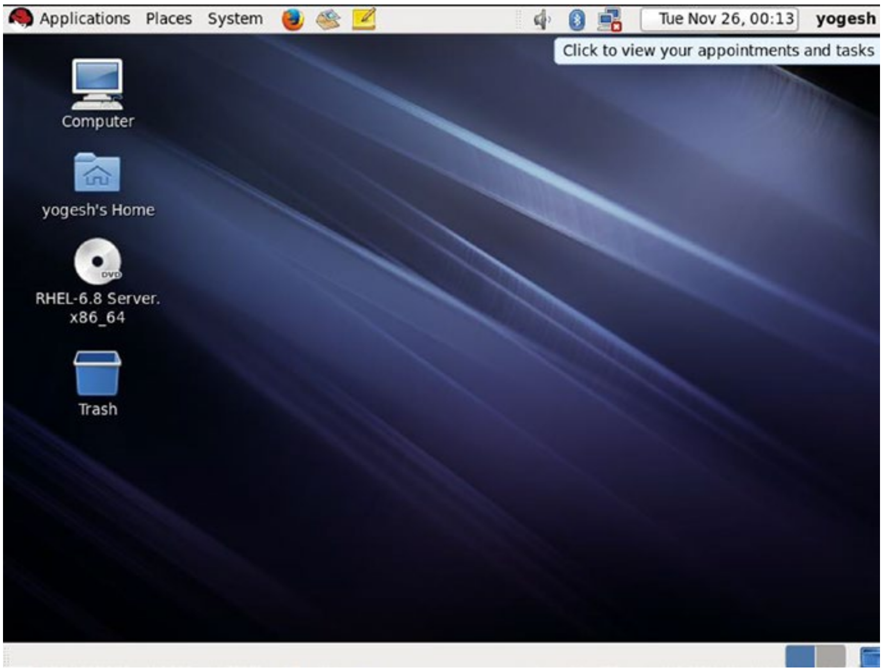


Figure 2-73. *The RHEL 6 desktop screen*

No matter where you keep the * or even if you don't keep the * on any partition, it's only the RHEL that will be booting all the time. The reason is simple, but it changes the booting sequence altogether. The Red Hat Enterprise Linux bootloader, which is GRUB, does not follow the *, and it does not check which partition is active before calling part-3 of its bootloader. In fact, none of the Linux OSs bothers to check the active partition. They simply skip that step. So, the booting sequence becomes the following:

1. First the system goes to the BIOS, then POST, then back to the BIOS, and finally to the first primary partition's bootstrap.
2. RHEL's part-1 of GRUB jumps to part-2 of GRUB, which (after skipping the fdisk signature part) jumps to part-3 of GRUB.
3. Part-3 of GRUB goes to `/boot/grub.conf`, which prints the OS entries.
4. If a user chooses RHEL, then the kernel loads from `/boot/vmlinuz` in memory.
5. The kernel will take care of the rest of the OS booting, which has been extensively explained in the rest of the book.

This also means there is only one OS currently booting, and that is RHEL 6. That's bad! Hence, we need to tweak GRUB to boot the rest of the operating systems.

Tweaking GRUB

The best feature of GRUB is that it can boot any other OS, regardless of whether it is Linux based or not. The trick to boot another OS used by GRUB is simple but amazing. For any bootloader to boot OS, you need to do nothing more than load the respective OS's kernel in memory. GRUB knows where the kernel of a Linux OS is (`/boot/vmlinuz`). But GRUB does not know where the kernel of Windows or PC-BSD is. The trick is that these operating systems' respective bootloaders know the location of their respective kernels. So, GRUB just calls their respective bootloaders; for example, if GRUB wants to boot BSD, it is at the third primary partition. Refer to Figure 2-74, which shows the partition layout, for a better understanding of this.

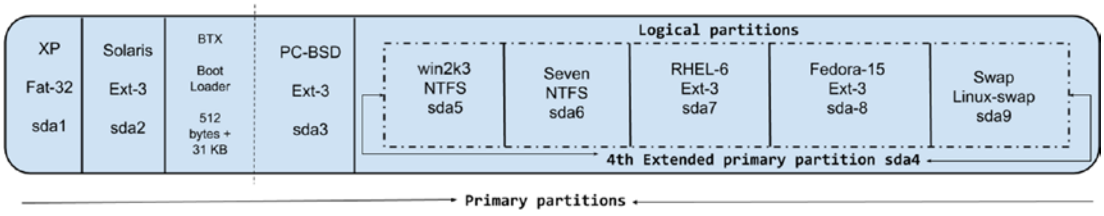
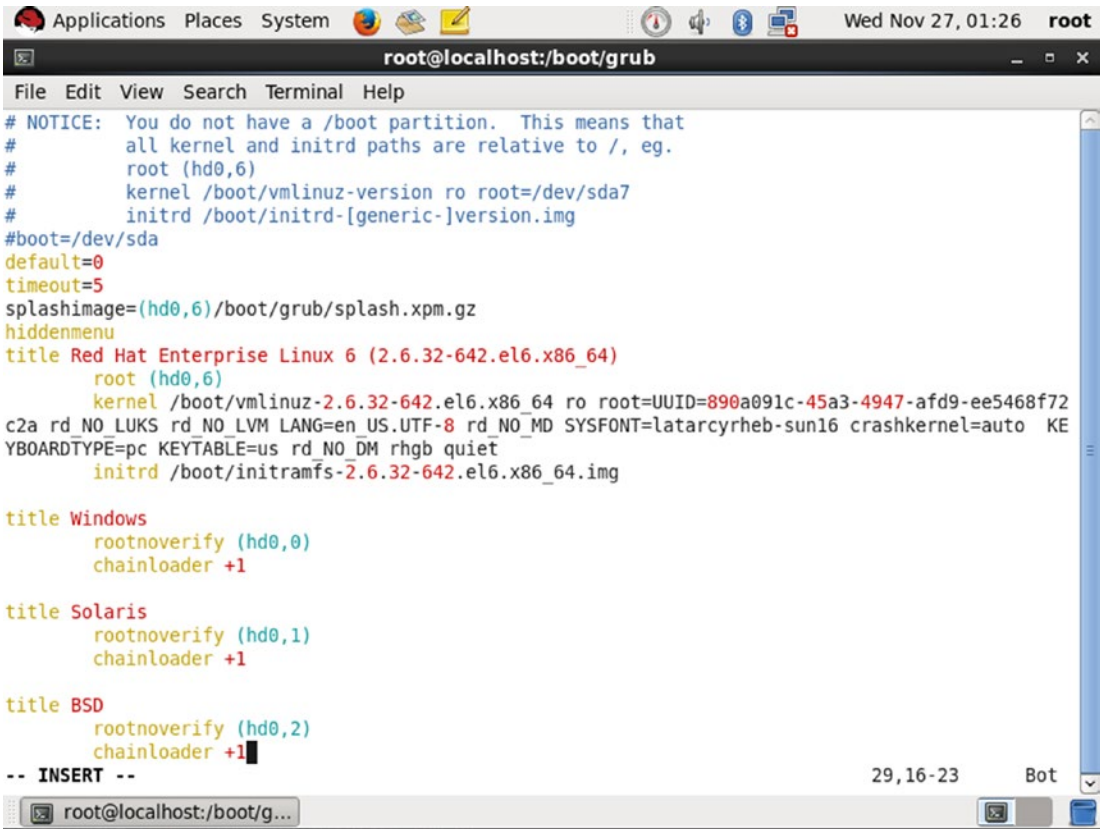


Figure 2-74. *The partition layout of the BIOS*

BSD installed its bootloader on its own partition's reserved 512 bytes + 31 KB. So, GRUB will call part-1 of BTX. This is called *chainloading*. The GRUB bootloader's part-3 will chainload part-1 of BTX. BTX's part-1 knows what to do next, which is to look for part-2. Part-2 will jump to part-3, and it will load BSD's kernel in memory so BSD will start booting up. To achieve this chainloading, we need to tell GRUB the location of part-1 of BTX through the `grub.conf` file. The location will be hard disk number 1 and partition number 3, but GRUB starts its count from 0 so the location will be hard disk number 0 and partition number 2. The entry in `/boot/grub.conf` is as follows:

```
title pc-bsd              <<<---- the os entry title
rootnoverify (hd0,2)      <<<---- location of BTX
chainloader +1            <<<---- grub will chainload the BTX
```

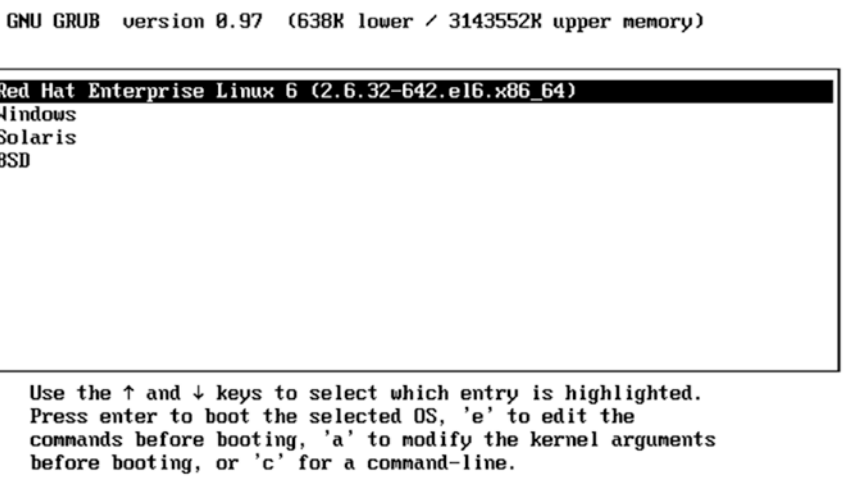
As you can see in Figure 2-75, the other operating system entries are similar to BSD; only the partition number will change.


Applications Places System
Wed Nov 27, 01:26 root
root@localhost:/boot/grub
File Edit View Search Terminal Help
root@localhost:/boot/g...

```
# NOTICE:  You do not have a /boot partition.  This means that
#          all kernel and initrd paths are relative to /, eg.
#          root (hd0,6)
#          kernel /boot/vmlinuz-version ro root=/dev/sda7
#          initrd /boot/initrd-[generic-]version.img
#boot=/dev/sda
default=0
timeout=5
splashimage=(hd0,6)/boot/grub/splash.xpm.gz
hiddenmenu
title Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
        root (hd0,6)
        kernel /boot/vmlinuz-2.6.32-642.el6.x86_64 ro root=UUID=890a091c-45a3-4947-afd9-ee5468f72
c2a rd_NO_LUKS rd_NO_LVM LANG=en_US.UTF-8 rd_NO_MD SYSFONT=latarcyrheb-sun16 crashkernel=auto  KE
YBOARDTYPE=pc KEYTABLE=us rd_NO_DM rhgb quiet
        initrd /boot/initramfs-2.6.32-642.el6.x86_64.img

title Windows
        rootnoverify (hd0,0)
        chainloader +1

title Solaris
        rootnoverify (hd0,1)
        chainloader +1

title BSD
        rootnoverify (hd0,2)
        chainloader +1
-- INSERT --                                                                  29,16-23      Bot
```

***Figure 2-75.** The tweaked grub.conf file of RHEL 6*

After rebooting, GRUB will show the mentioned `title` entries. See Figure 2-76.

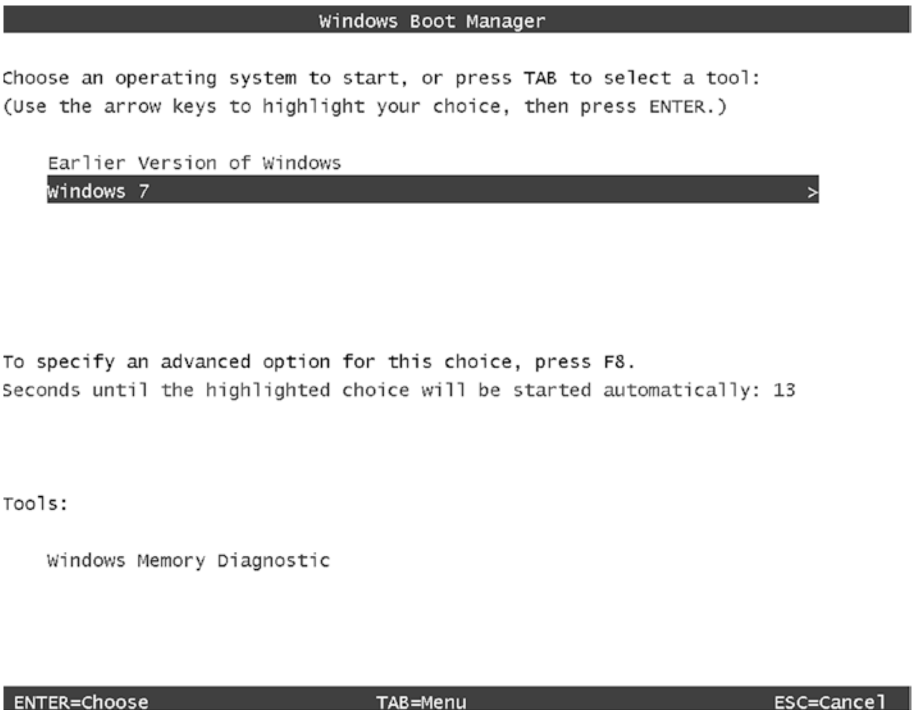


```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

 Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
 Windows
 Solaris
 BSD

   Use the ↑ and ↓ keys to select which entry is highlighted.
   Press enter to boot the selected OS, 'e' to edit the
   commands before booting, 'a' to modify the kernel arguments
   before booting, or 'c' for a command-line.
```

Figure 2-76. *The GRUB welcome screen shown by RHEL 6*

If a user chooses Windows, it will call part-2 of BCD, which is in the 31 KB space of the first primary. This 31 KB space is also called the *volume boot record* (VBR). I deliberately skipped the VBR explanation since it will unnecessarily create confusion. So, in the case of Windows chainloading, just keep in mind that instead of part-1, part-2 will be called. For those who want a bit more information about VBR, MBR is the master boot record for the hard drive, located at the first sector of the hard drive. Each volume (think partition) has its own boot record called the VBR as the first sector of the partition. Two names for two similar things.

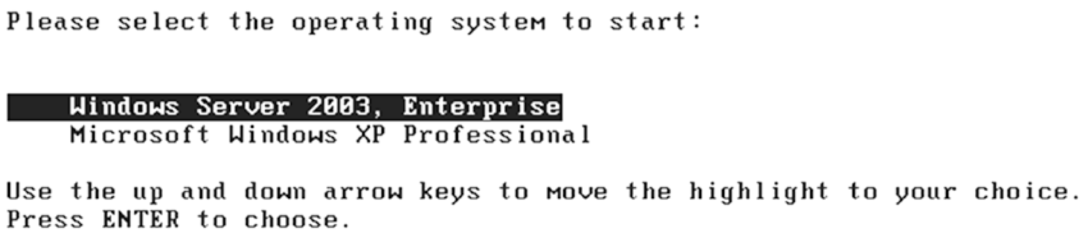
So, BCD's part-2 will call part-3 of BCD, which is in the first primary partition. It will read the BCD OS entries (`bcdedit.exe`), as shown in Figure 2-77, and will print them on-screen.



```
                          Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

    Earlier Version of Windows
    Windows 7                                                         >



To specify an advanced option for this choice, press F8.
Seconds until the highlighted choice will be started automatically: 13


Tools:

    Windows Memory Diagnostic



ENTER=Choose                    TAB=Menu                     ESC=Cancel
```

Figure 2-77. *The OS entries shown by the BCD bootloader*

If a user chooses the Earlier Version of Windows, as we saw earlier (during Windows 7's booting sequence), it will run part-3 of NTLDR, which is again on the first primary partition. As shown in Figure 2-78, NTLDR will read the `boot.ini` file from the C drive and will print the OS entries.

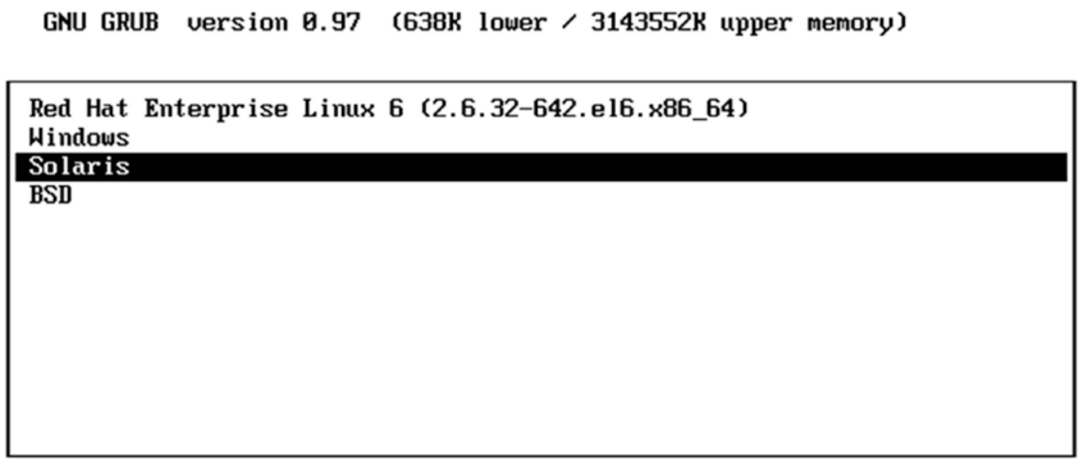


```
Please select the operating system to start:


    Windows Server 2003, Enterprise
    Microsoft Windows XP Professional

Use the up and down arrow keys to move the highlight to your choice.
Press ENTER to choose.
```

Figure 2-78. *The OS entries shown by win2k3's NTLDR*

If a user chooses XP, part-3 of NTLDR knows where the kernel of XP is. Instead, the user chooses win2k3, and then the same NTLDR will load the kernel of win2k3 in memory.

Refer to Figure 2-79, which is the main boot screen provided by RHEL, if the user chooses OpenSolaris.



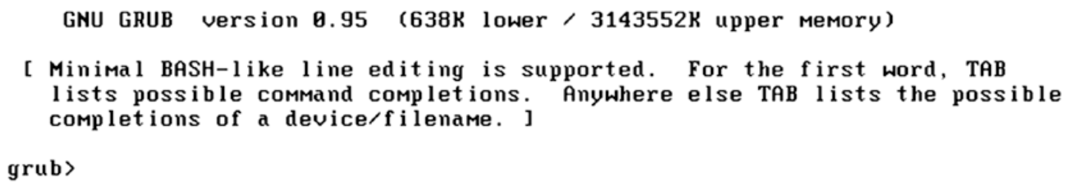
```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
Windows
Solaris
BSD
```

Figure 2-79. *The OS entries shown by RHEL*

The following are the instructions that will be followed by GRUB:

```
title Solaris
      rootnoverify (hd0,1)
      chainloader  +1
```

So, RHEL GRUB's part-3 will hand over control to the bootstrap of the second primary partition, but remember that win2k3 has cleared part-1 of OpenSolaris GRUB. Hence, as visible in Figure 2-80, it will fail to boot.

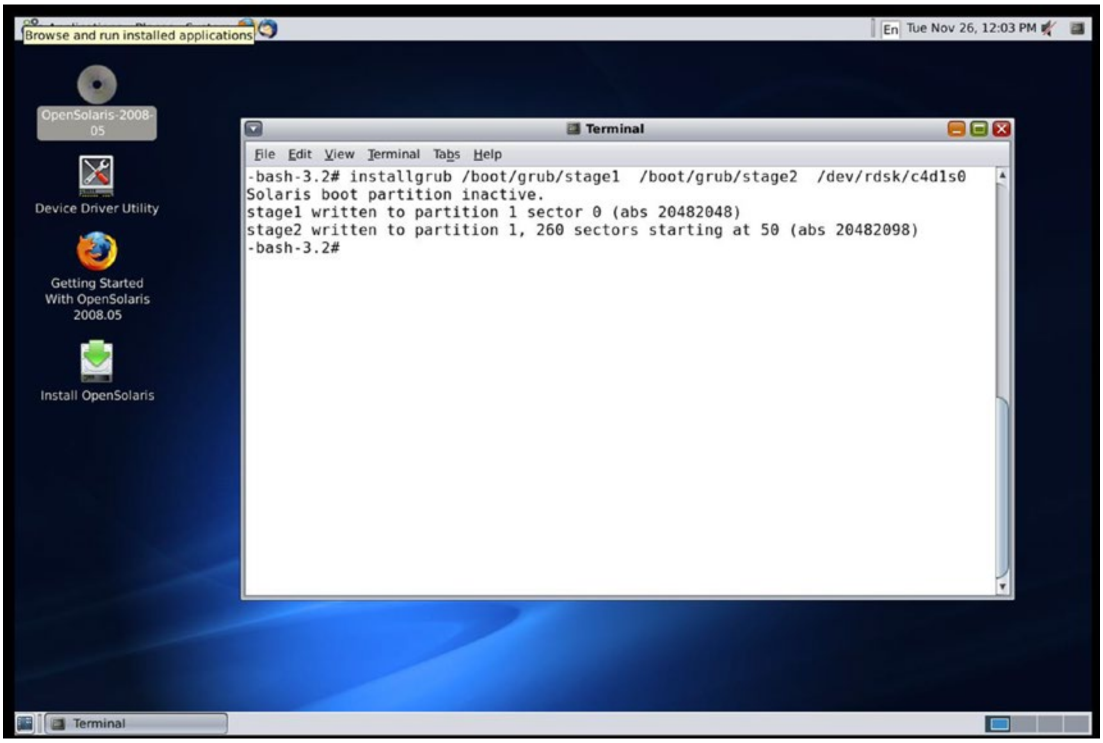


```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

[ Minimal BASH-like line editing is supported.  For the first word, TAB
  lists possible command completions.  Anywhere else TAB lists the possible
  completions of a device/filename. ]

grub>
```

Figure 2-80. *OpenSolaris failed to boot*

This means we need to fix the OpenSolaris bootloader first. To fix it, we need to boot from the OpenSolaris live CD image, which we used to install OpenSolaris and, once it was booted, installed part-1 and part-2 (part-2 is not necessary but good to reinstall) of GRUB from the live CD to the OpenSolaris partition's reserved 512 bytes + 31 KB. The command that we will use is `installgrub`. As the name suggests, the command will copy part-1 (`stage1`) and part-2 (`stage2`) of GRUB from the live image and place them in the OpenSolaris partition's 512 bytes + 31 KB space. Figure 2-81 shows the command in action.

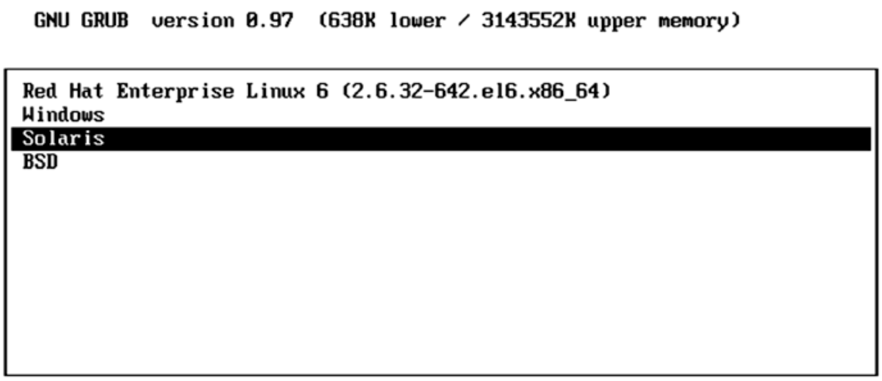
```
#installgrub  /boot/grub/stage1  /boot/grub/stage2  /dev/rdsk/c4d1s0
```


Browse and run installed applications
En Tue Nov 26, 12:03 PM
OpenSolaris-2008-05
Device Driver Utility
Getting Started With OpenSolaris 2008.05
Install OpenSolaris
Terminal
File Edit View Terminal Tabs Help
Terminal

```
-bash-3.2# installgrub /boot/grub/stage1  /boot/grub/stage2  /dev/rdsk/c4d1s0
Solaris boot partition inactive.
stage1 written to partition 1 sector 0 (abs 20482048)
stage2 written to partition 1, 260 sectors starting at 50 (abs 20482098)
-bash-3.2#
```

Figure 2-81. *The installgrub command*

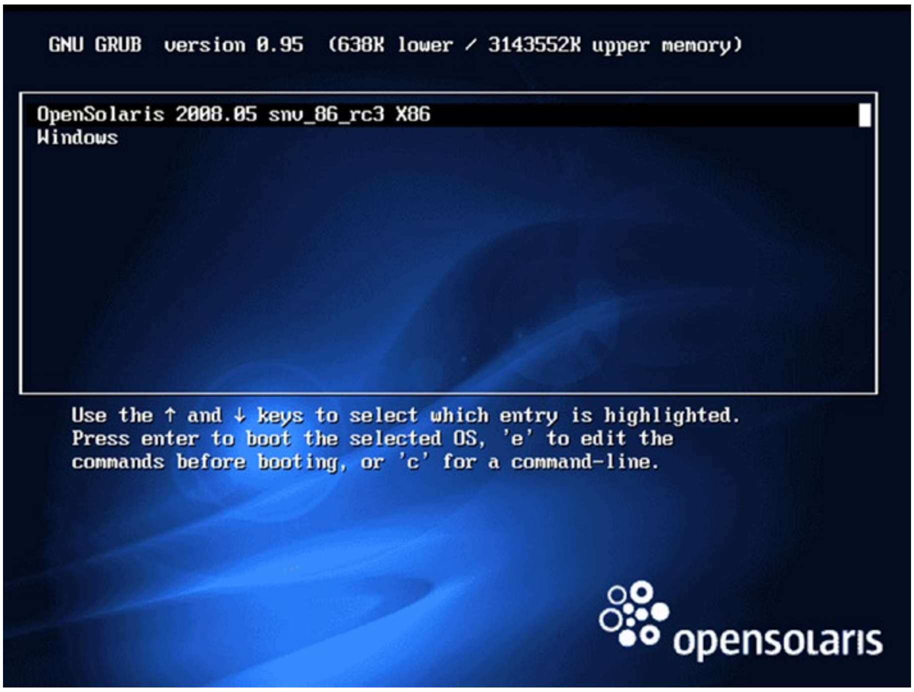
After rebooting, RHEL will again show the same OS entries (Figure 2-82) since for RHEL nothing has changed.



```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
Windows
Solaris
BSD
```

Figure 2-82. *The OS entries shown by RHEL*

If this time we choose OpenSolaris, then RHEL GRUB's part-3 will chainload part-1 of OpenSolaris GRUB from the second partition. Part-1 will call part-2, and eventually it will call part-3 from the actual OpenSolaris partition. Part-3 of OpenSolaris GRUB will read `/rpool/boot/grub/menu.lst`, and as shown in Figure 2-83, it will print the titles on the screen.



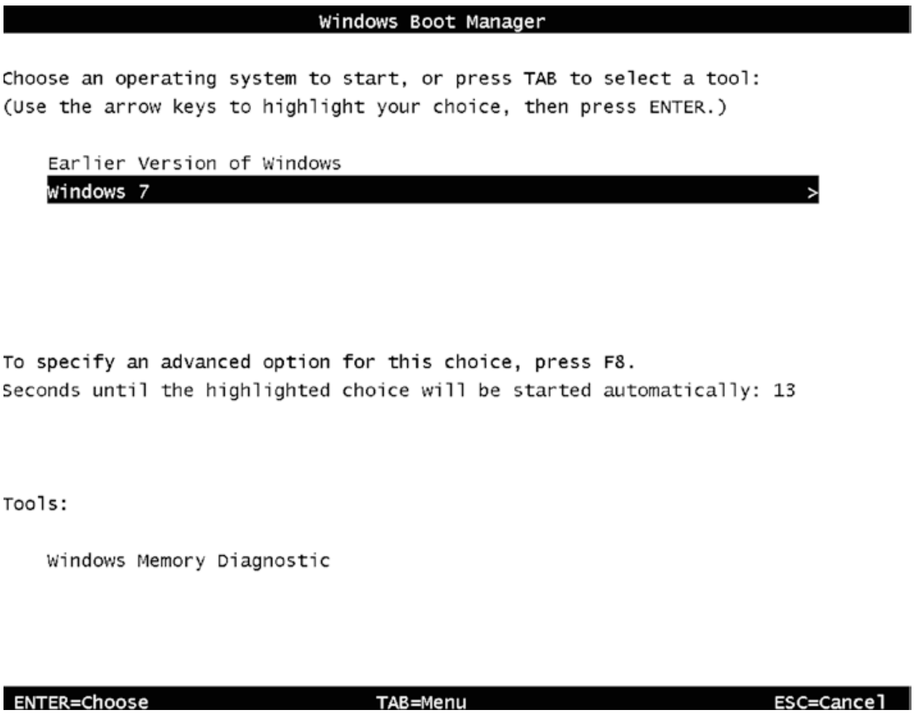
```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

Use the ↑ and ↓ keys to select which entry is highlighted.
Press enter to boot the selected OS, 'e' to edit the
commands before booting, or 'c' for a command-line.
```

Figure 2-83. *The OS entries shown by OpenSolaris*

If a user chooses OpenSolaris, then part-3 of OpenSolaris GRUB will load the kernel from `/boot`. If the user chooses Windows, then part-3 of OpenSolaris GRUB will follow these instructions from `/rpool/boot/grub/menu.lst`:

```
title Solaris
      rootnoverify (hd0,1)
      chainloader  +1
```

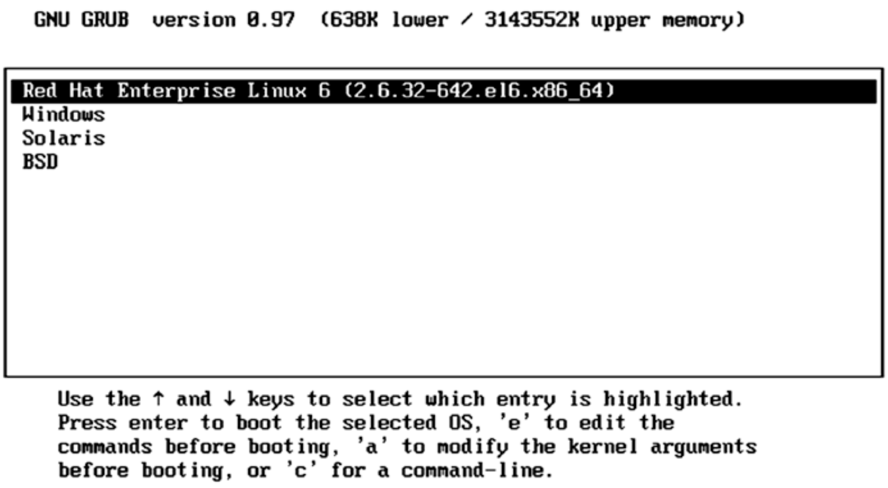
We know now what is going to appear on-screen (refer to Figure 2-84).



```
                         Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

    Earlier Version of Windows
    Windows 7                                                  >



To specify an advanced option for this choice, press F8.
Seconds until the highlighted choice will be started automatically: 13


Tools:

    Windows Memory Diagnostic



ENTER=Choose                    TAB=Menu                      ESC=Cancel
```

Figure 2-84. *The OS entries shown by BCD*

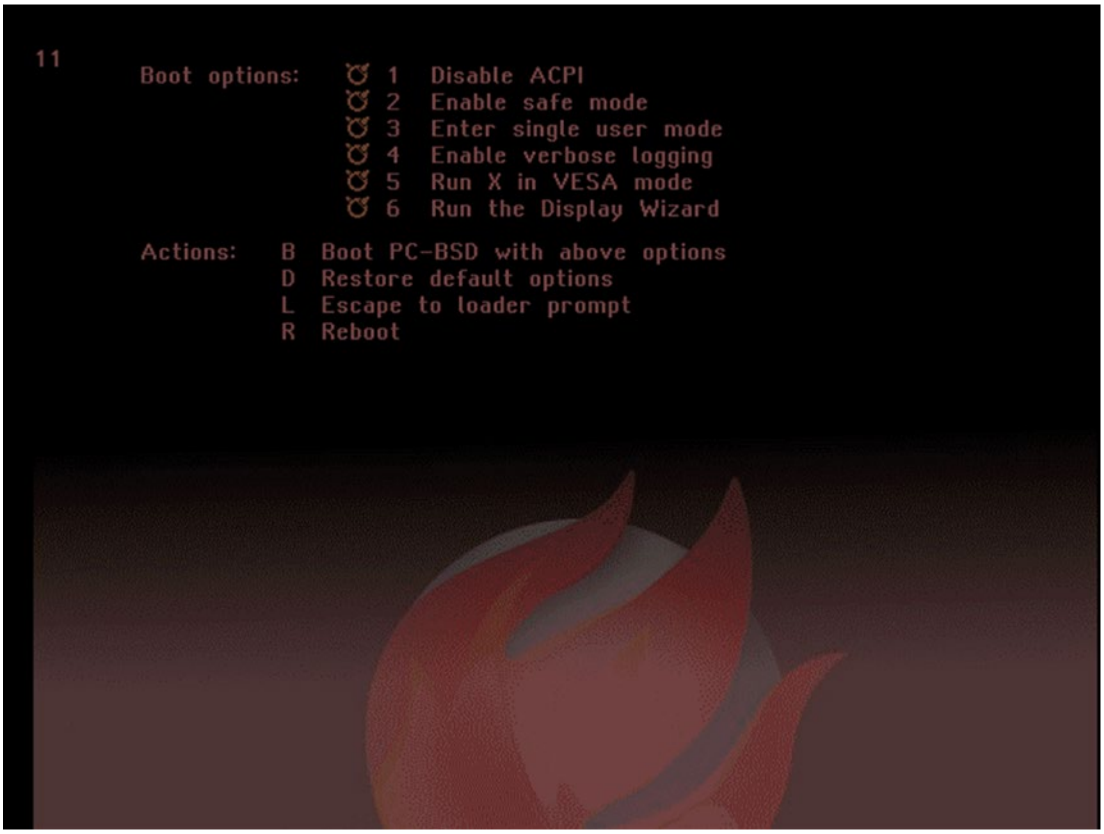
The story will continue if the user chooses Earlier Version of Windows, which we have already discussed. Going back to the original OS list, Figure 2-85 shows what is presented by RHEL's GRUB.



```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

 Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
 Windows
 Solaris
 BSD

    Use the ↑ and ↓ keys to select which entry is highlighted.
    Press enter to boot the selected OS, 'e' to edit the
    commands before booting, 'a' to modify the kernel arguments
    before booting, or 'c' for a command-line.
```

Figure 2-85. *The OS entries shown by RHEL*

If the user chooses to boot BSD, you know exactly what is going to happen. Part-3 of RHEL's GRUB will chainload part-1 of BTX from the third primary partition. Part-1 of BTX will call part-2, and part-2 will call part-3 of BTX. Part-3 of BTX will show the welcome screen, as shown in Figure 2-86.



```
11
     Boot options:   ✪ 1  Disable ACPI
                     ✪ 2  Enable safe mode
                     ✪ 3  Enter single user mode
                     ✪ 4  Enable verbose logging
                     ✪ 5  Run X in VESA mode
                     ✪ 6  Run the Display Wizard

     Actions:    B  Boot PC-BSD with above options
                 D  Restore default options
                 L  Escape to loader prompt
                 R  Reboot
```

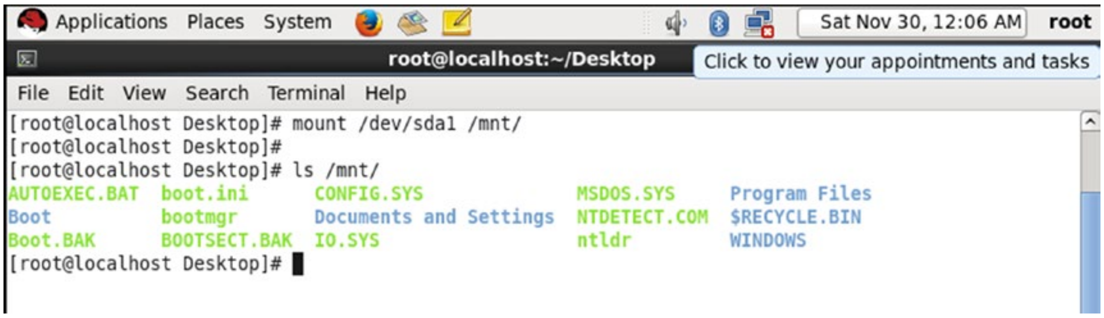
Figure 2-86. *PC-BSD's welcome screen*

Once chosen to boot, part-3 of BTX will load the kernel of BSD Unix in memory. So, all the operating systems, whichever we installed so far, are able to boot now, and it does not matter which partition is active. But can we hack the Windows bootloaders and force them to boot the Linux and Unix operating systems from our list? We can, and that's what we will do now.

Hacking the Windows Bootloaders

It's actually pretty easy to trick the Windows bootloaders. As we saw earlier, bootloaders do chainloading; for example, part-1 calls part-2 of its bootloader and so on. To understand the trick, let's take BSD as an example. Part-1 of BCD is calling its part-2 of BCD, but if we tell BCD's part-1 to chainload part-1 of RHEL, then part-1 of RHEL will run, and it will eventually follow its own booting sequence. Part-1 of GRUB (RHEL) will call part-2 of GRUB, and it will eventually chainload part-3 of GRUB since part-3's block address is hard-coded in part-2. This means once part-1 of any bootloader runs, it will start following its own boot sequence, and we will take advantage of this behavior.

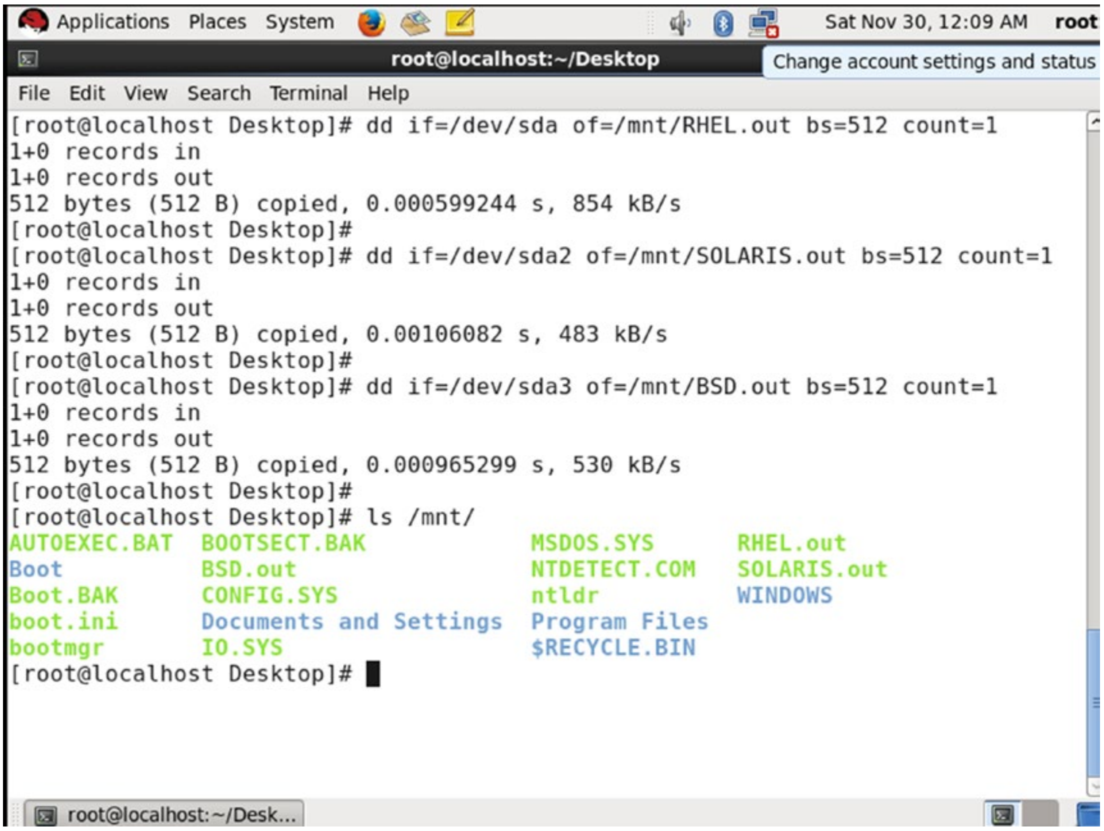
To achieve this, we need to get part-1 of every non-Windows-based bootloader and place it into the Windows filesystem. So, the filesystem could be FAT32 or NTFS. Obviously, placing part-1 of every non-Windows-based bootloader on the first primary has the most advantages since every Windows operating system has installed their respective bootloaders on the first primary partition. So, through the `dd` command, we will copy the first 512 bytes (even the first 440 bytes is enough) of every non-Windows-based OS and place them in XP's partition. Let's mount the first primary partition, as shown in Figure 2-87.


Applications Places System
Sat Nov 30, 12:06 AM
root
root@localhost:~/Desktop
Click to view your appointments and tasks
File Edit View Search Terminal Help

```
[root@localhost Desktop]# mount /dev/sda1 /mnt/
[root@localhost Desktop]#
[root@localhost Desktop]# ls /mnt/
AUTOEXEC.BAT  boot.ini     CONFIG.SYS              MSDOS.SYS    Program Files
Boot          bootmgr      Documents and Settings  NTDETECT.COM $RECYCLE.BIN
Boot.BAK      BOOTSECT.BAK IO.SYS                  ntldr        WINDOWS
[root@localhost Desktop]#
```

Figure 2-87. *The mount command*

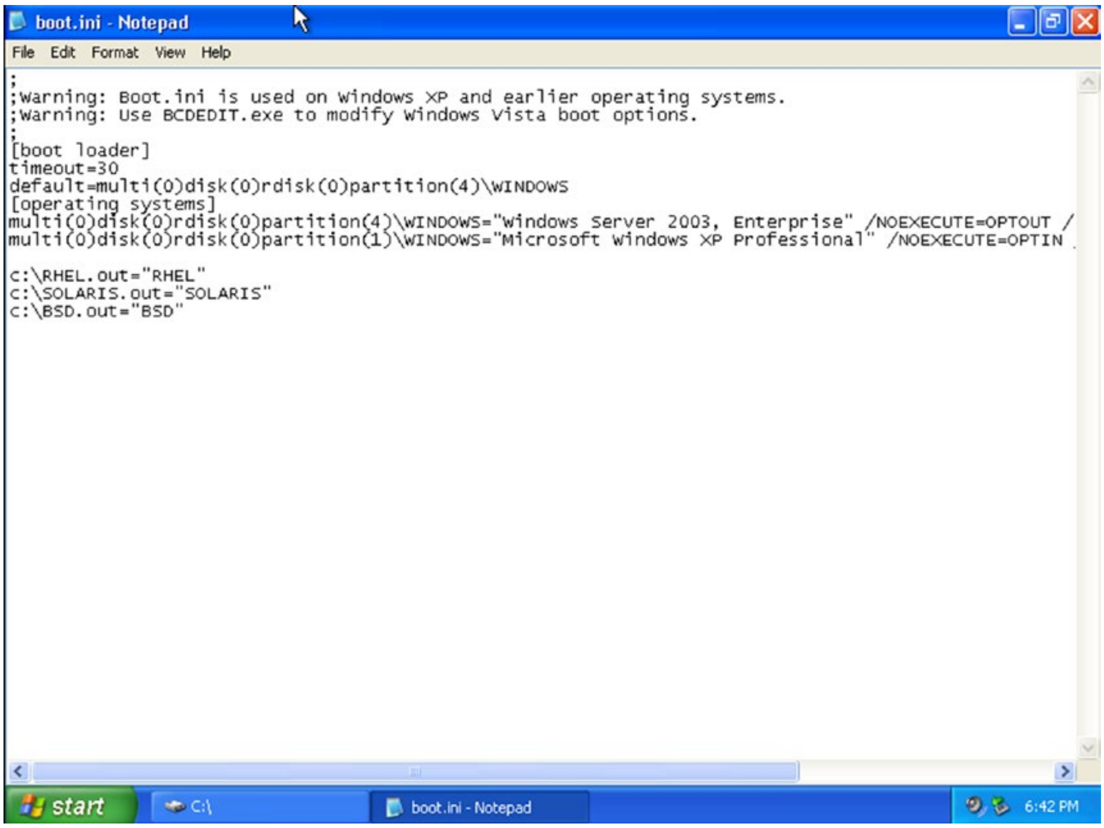
Let's copy the first 512 bytes and place them on the sda1 partition. Refer to Figure 2-88 for this.


Applications Places System
Sat Nov 30, 12:09 AM root
root@localhost:~/Desktop
Change account settings and status
File Edit View Search Terminal Help
root@localhost:~/Desk...

```
[root@localhost Desktop]# dd if=/dev/sda of=/mnt/RHEL.out bs=512 count=1
1+0 records in
1+0 records out
512 bytes (512 B) copied, 0.000599244 s, 854 kB/s
[root@localhost Desktop]#
[root@localhost Desktop]# dd if=/dev/sda2 of=/mnt/SOLARIS.out bs=512 count=1
1+0 records in
1+0 records out
512 bytes (512 B) copied, 0.00106082 s, 483 kB/s
[root@localhost Desktop]#
[root@localhost Desktop]# dd if=/dev/sda3 of=/mnt/BSD.out bs=512 count=1
1+0 records in
1+0 records out
512 bytes (512 B) copied, 0.000965299 s, 530 kB/s
[root@localhost Desktop]#
[root@localhost Desktop]# ls /mnt/
AUTOEXEC.BAT  BOOTSECT.BAK            MSDOS.SYS      RHEL.out
Boot          BSD.out                 NTDETECT.COM   SOLARIS.out
Boot.BAK      CONFIG.SYS              ntldr          WINDOWS
boot.ini      Documents and Settings  Program Files
bootmgr       IO.SYS                  $RECYCLE.BIN
[root@localhost Desktop]# 
```

Figure 2-88. *Transferring the first 512 bytes to the first primary*

Now we will boot back in XP, and as shown in Figure 2-89, we will add the part-1 files entries in the `boot.ini` file. The `boot.ini` file is read by both Windows bootloaders, which are BCD and win2k3's NTLDR.



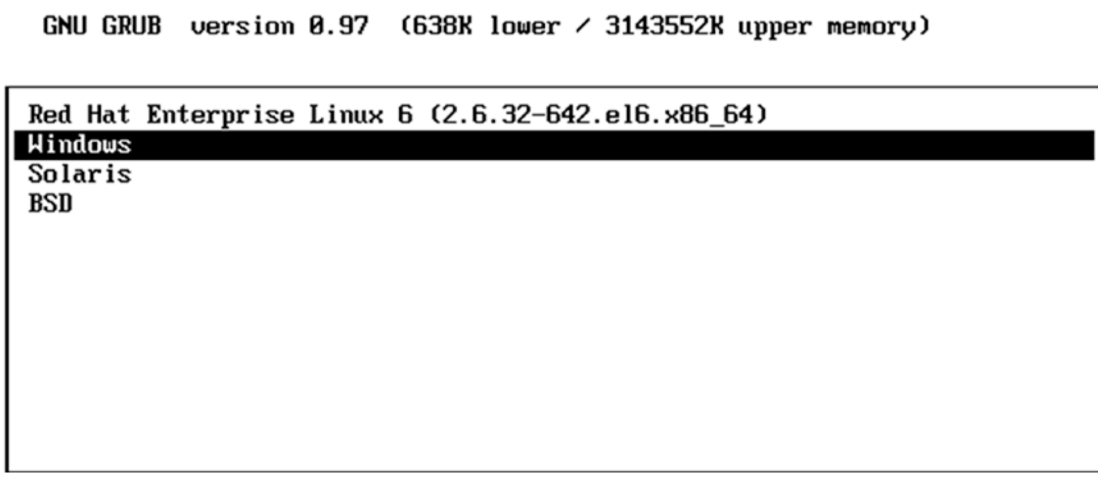
```
;
;Warning: Boot.ini is used on Windows XP and earlier operating systems.
;Warning: Use BCDEDIT.exe to modify Windows Vista boot options.
;
[boot loader]
timeout=30
default=multi(0)disk(0)rdisk(0)partition(4)\WINDOWS
[operating systems]
multi(0)disk(0)rdisk(0)partition(4)\WINDOWS="Windows Server 2003, Enterprise" /NOEXECUTE=OPTOUT /
multi(0)disk(0)rdisk(0)partition(1)\WINDOWS="Microsoft Windows XP Professional" /NOEXECUTE=OPTIN

c:\RHEL.out="RHEL"
c:\SOLARIS.out="SOLARIS"
c:\BSD.out="BSD"
```

Figure 2-89. *Adding the entries in the boot.ini file*

The following are the entries that we have added:

```
c:\RHEL.out="RHEL"
c:\SOLARIS.out = "SOLARIS"
c:\BSD.out="BSD"
```

Just like the `grub.conf` file, whatever is written in double quotes in `boot.ini` will be considered the title of the OS entry. Now let's reboot the system and choose the Windows OS entry from the RHEL OS list (refer to Figure 2-90).



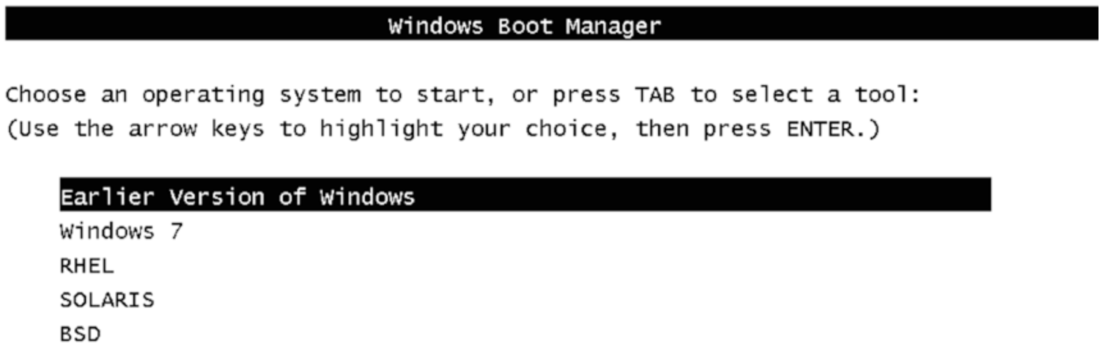
```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
Windows
Solaris
BSD
```

Figure 2-90. *The OS list shown by RHEL*

How we reached this screen is easy to understand.

1. The system goes first to the BIOS, then to POST, then to the BIOS, then to the first 512 bytes, and then to the bootstrap (part-1) of RHEL (GRUB).
2. Then comes part-1 of GRUB, which jumps to part-2 of GRUB, which jumps to part-3 of GRUB, which goes to `/boot/grub.conf`, which prints the OS titles.
3. The user has chosen Windows, so next comes part-1 of BCD from the first primary partition and then part-2 of BCD.
4. Finally, it goes to part-3, then `bcd.exe`, and it will read the `boot.ini` file and whatever is written into the double quotes will be printed on screen.

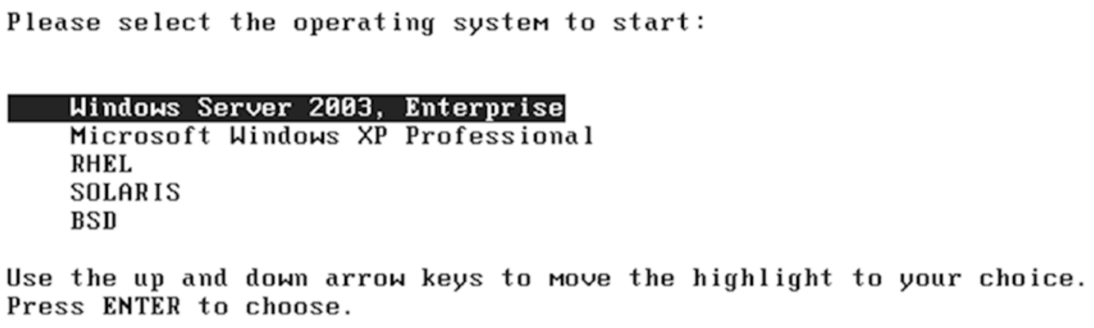
The OS list is visible in Figure 2-91.



```
                          Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

    Earlier Version of Windows
    Windows 7
    RHEL
    SOLARIS
    BSD
```

Figure 2-91. *The OS entries shown by Windows 7 (BCD)*

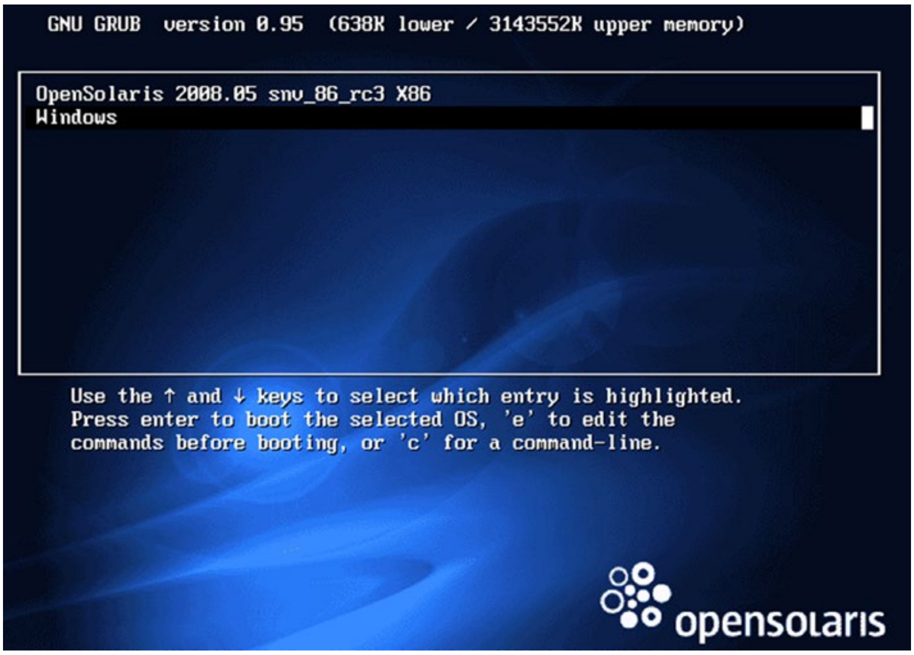
If the user chooses Earlier Version of Windows, then BCD's part-3 will call part-3 of win2k3's NTLDR. NTLDR will again read the `boot.ini` file and print the OS list, as shown in Figure 2-92.



```
Please select the operating system to start:


    Windows Server 2003, Enterprise
    Microsoft Windows XP Professional
    RHEL
    SOLARIS
    BSD

Use the up and down arrow keys to move the highlight to your choice.
Press ENTER to choose.
```

Figure 2-92. *The OS entries shown by win2k3's NTLDR*

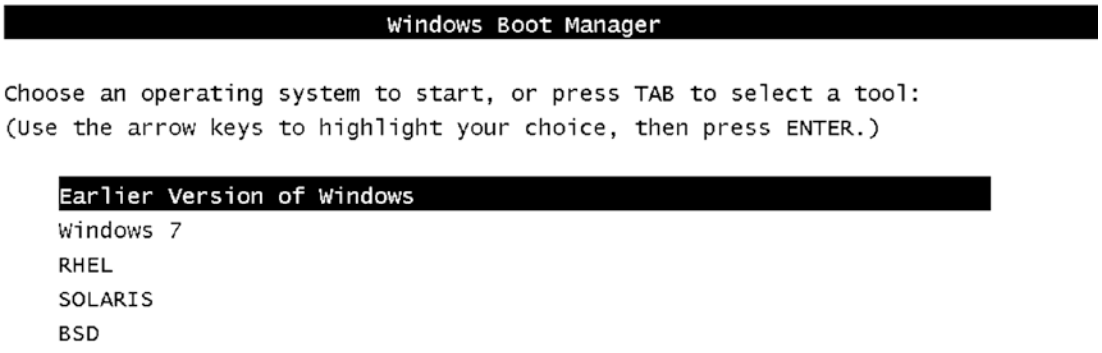
If a user chooses OpenSolaris, then part-3 of NTLDR will run the `Solaris.out` file from C: (the first primary partition). The `Solaris.out` file is nothing but part-1 of the OpenSolaris bootloader from the second partition. Part-1 of the OpenSolaris bootloader will call part-2 and eventually part-3 of GRUB. It will read the `menu.lst` file and will print the OS list (Figure 2-93).



```
GNU GRUB  version 0.95  (638K lower / 3143552K upper memory)

OpenSolaris 2008.05 snv_86_rc3 X86
Windows

Use the ↑ and ↓ keys to select which entry is highlighted.
Press enter to boot the selected OS, 'e' to edit the
commands before booting, or 'c' for a command-line.
```

Figure 2-93. *The OS entries shown by OpenSolaris GRUB*

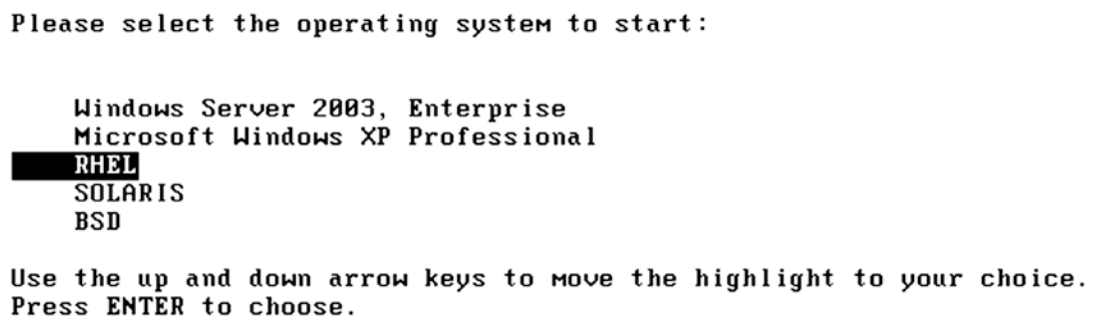
If the user again chooses Windows, then part-3 of OpenSolaris will call part-2 of BCD from the first primary partition (`rootnoverify (hd0,0)`). (Part-2 of BCD will be in the VBR section of the first primary partition. We will not cover the VBR in this book.) BCD's part-2 will call part-3 of BCD. It will read the OS entries through `bcdedit.exe` and from `boot.ini` and print the OS entries. The OS entries printed on the screen are visible in Figure 2-94.



```
                          Windows Boot Manager

Choose an operating system to start, or press TAB to select a tool:
(Use the arrow keys to highlight your choice, then press ENTER.)

   Earlier Version of Windows
   Windows 7
   RHEL
   SOLARIS
   BSD
```

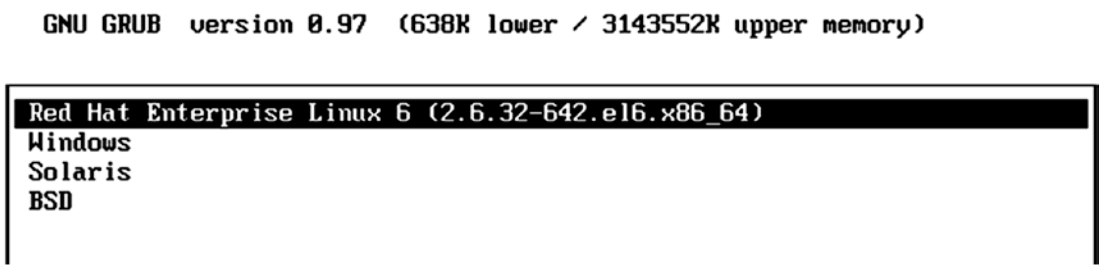
Figure 2-94. *The OS entries shown by Windows 7 (BCD)*

This is how we have created a bootloader's loop (refer to Figure 2-95 and Figure 2-96).



```
Please select the operating system to start:


    Windows Server 2003, Enterprise
    Microsoft Windows XP Professional
    RHEL
    SOLARIS
    BSD

Use the up and down arrow keys to move the highlight to your choice.
Press ENTER to choose.
```

Figure 2-95. *The RHEL entry has been chosen to boot*



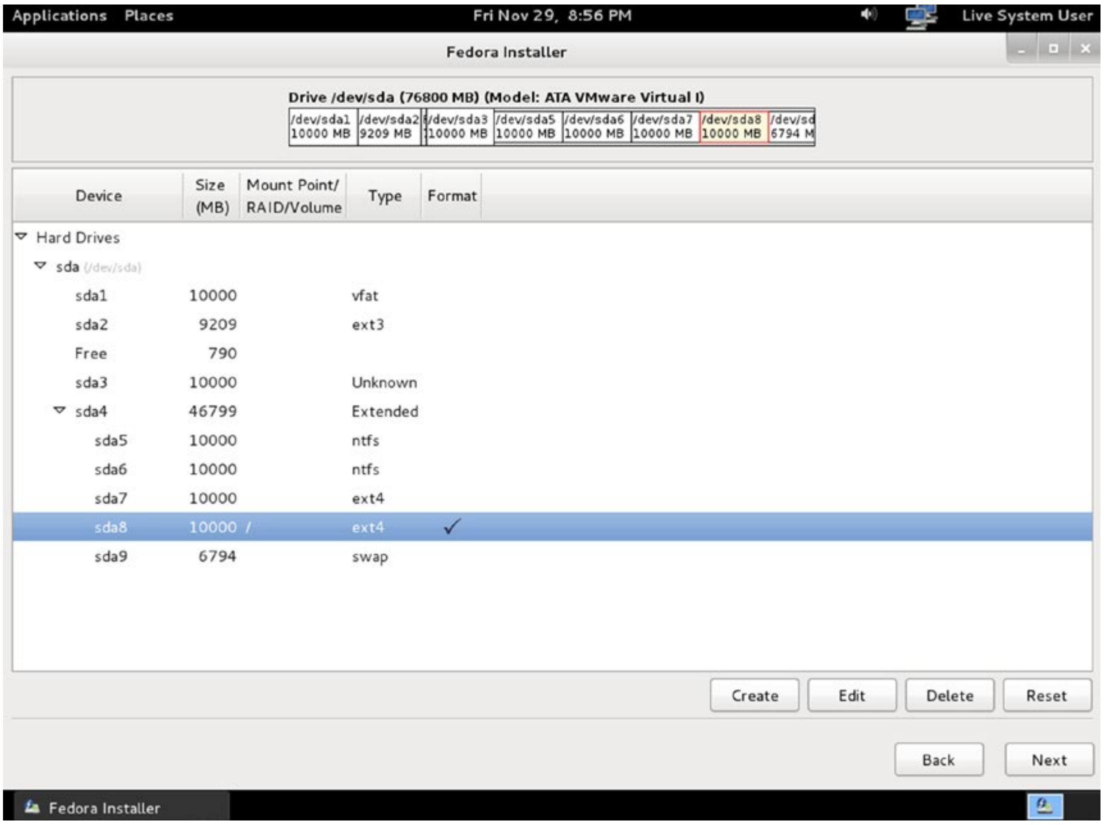
```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

 Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
 Windows
 Solaris
 BSD
```

Figure 2-96. *The OS entries shown by RHEL's GRUB*

As you can see, Linux is booting Windows, Linux is booting Unix, Unix is booting Windows, Windows is booting Windows, and Windows is booting Linux, but one thing is still missing, and that is Linux is booting Linux. For that, we will install the final OS from our list, and that is Fedora 15.

Fedora 15

As shown in Figure 2-97, we are installing Fedora 15 on sda8.



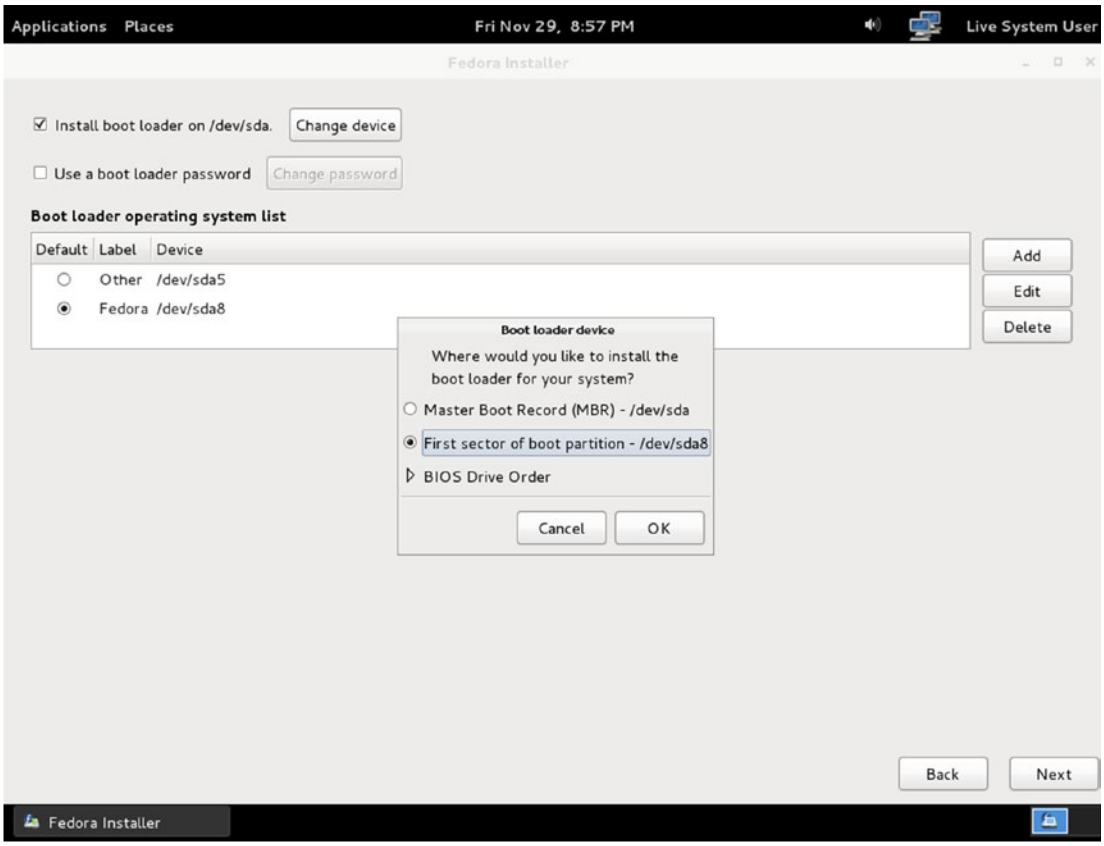
Drive /dev/sda (76800 MB) (Model: ATA VMware Virtual I)

/dev/sda1	/dev/sda2	/dev/sda3	/dev/sda5	/dev/sda6	/dev/sda7	/dev/sda8	/dev/sd
10000 MB	9209 MB	10000 MB	10000 MB	10000 MB	10000 MB	10000 MB	6794 M

Device	Size (MB)	Mount Point/ RAID/Volume	Type	Format
Hard Drives				
sda (/dev/sda)				
sda1	10000		vfat	
sda2	9209		ext3	
Free	790			
sda3	10000		Unknown	
sda4	46799		Extended	
sda5	10000		ntfs	
sda6	10000		ntfs	
sda7	10000		ext4	
sda8	10000	/	ext4	✓
sda9	6794		swap	

Figure 2-97. *The Fedora installer*

By default Fedora will try to install its bootloader on the first primary, but if we allow that, then again we need to add the entry of every other OS in its `grub.conf`. Instead, we will follow a different approach. We will install the bootloader of Fedora (GRUB) on its own partition (sda8) instead of sda1. See Figure 2-98.



[✓] Install boot loader on /dev/sda.

[ ] Use a boot loader password

Boot loader operating system list

Default	Label	Device
○	Other	/dev/sda5
●	Fedora	/dev/sda8

Where would you like to install the boot loader for your system?

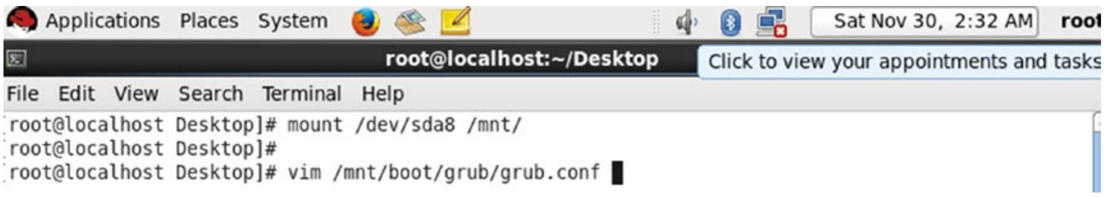
○ Master Boot Record (MBR) - /dev/sda

[✓ First sector of boot partition - /dev/sda8]

BIOS Drive Order

Figure 2-98. *The bootloader device selection*

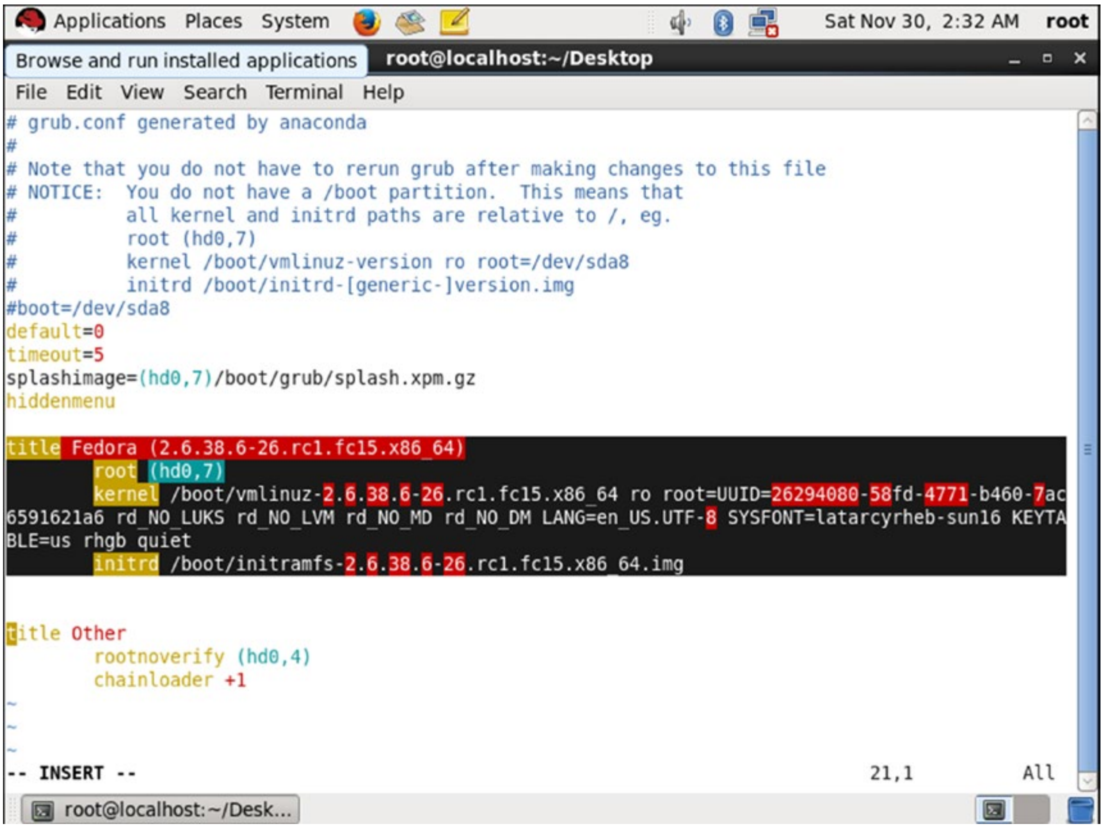
This means after rebooting Fedora will never be able to boot since RHEL's GRUB does not know about this new OS, so we need to add Fedora's entry into `grub.conf` of RHEL. To do that, let's mount sda8, as shown in Figure 2-99.


Applications Places System
Sat Nov 30, 2:32 AM
root
root@localhost:~/Desktop
Click to view your appointments and tasks
File Edit View Search Terminal Help

```
root@localhost Desktop]# mount /dev/sda8 /mnt/
root@localhost Desktop]#
root@localhost Desktop]# vim /mnt/boot/grub/grub.conf
```

Figure 2-99. *The mounting of Fedora's partition*

Copy Fedora's entries (see Figure 2-100) from Fedora GRUB's `grub.conf` file: `/mnt/boot/grub.conf`.

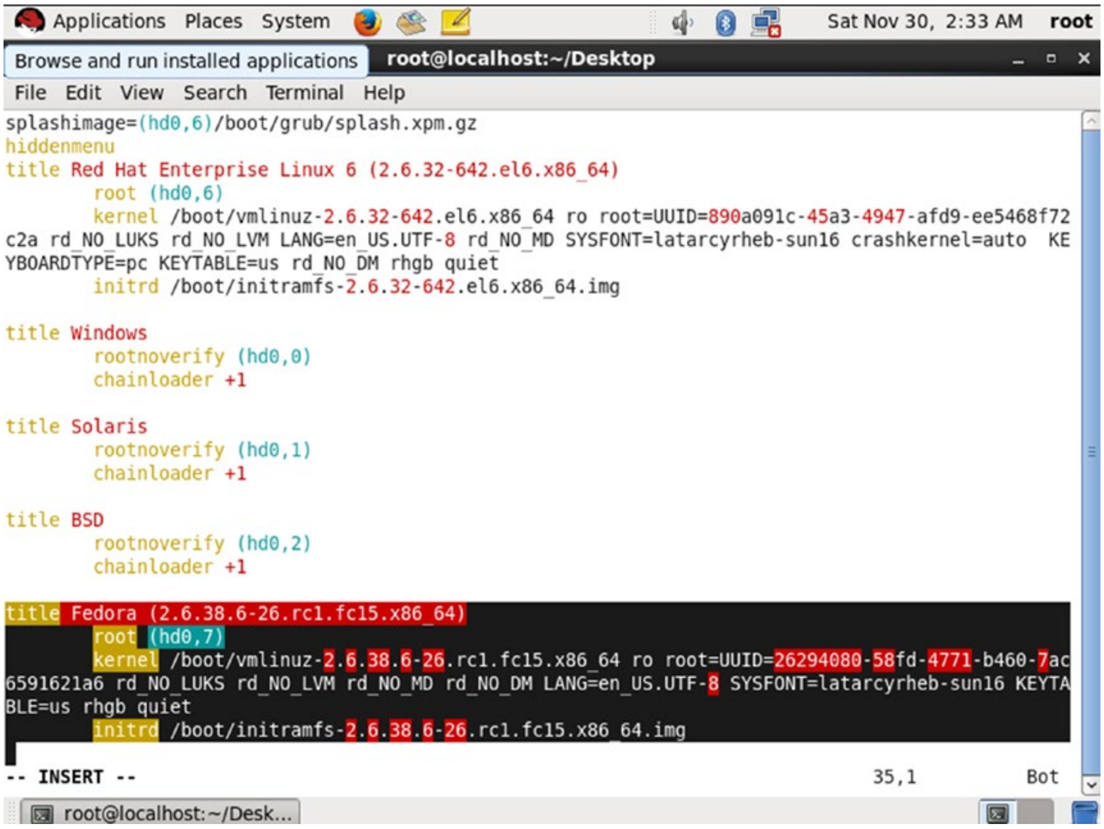

Applications Places System
Sat Nov 30, 2:32 AM root
Browse and run installed applications
root@localhost:~/Desktop
File Edit View Search Terminal Help
root@localhost:~/Desk...

```
# grub.conf generated by anaconda
#
# Note that you do not have to rerun grub after making changes to this file
# NOTICE:  You do not have a /boot partition.  This means that
#          all kernel and initrd paths are relative to /, eg.
#          root (hd0,7)
#          kernel /boot/vmlinuz-version ro root=/dev/sda8
#          initrd /boot/initrd-[generic-]version.img
#boot=/dev/sda8
default=0
timeout=5
splashimage=(hd0,7)/boot/grub/splash.xpm.gz
hiddenmenu

title Fedora (2.6.38.6-26.rc1.fc15.x86_64)
        root (hd0,7)
        kernel /boot/vmlinuz-2.6.38.6-26.rc1.fc15.x86_64 ro root=UUID=26294080-58fd-4771-b460-7ac
6591621a6 rd_NO_LUKS rd_NO_LVM rd_NO_MD rd_NO_DM LANG=en_US.UTF-8 SYSFONT=latarcyrheb-sun16 KEYTA
BLE=us rhgb quiet
        initrd /boot/initramfs-2.6.38.6-26.rc1.fc15.x86_64.img


title Other
        rootnoverify (hd0,4)
        chainloader +1
~
~
~
-- INSERT --                                                                    21,1          All
```

Figure 2-100. *The grub.conf file of Fedora 15*

The entries are simple. Whenever part-3 of Fedora is called, it will load the kernel of Fedora from `/boot/vmlinuz-2.6.38.6-26.rc1.fc15.x86_64` into the memory. After that, it will load initramfs from `/boot/initramfs-2.6.38.6-26.rc1.fc15.x86_64.img` into the memory.

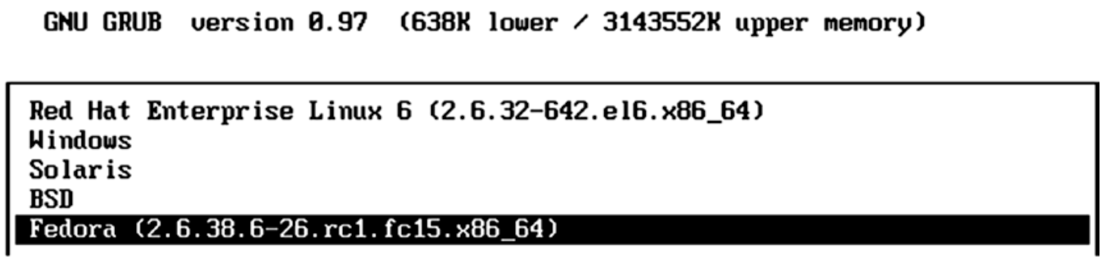
Figure 2-101 shows RHEL's `/etc/grub.conf` file after copying the entry of Fedora from `/mnt/etc/grub.conf`.


Applications Places System
Sat Nov 30, 2:33 AM root
Browse and run installed applications
root@localhost:~/Desktop
File Edit View Search Terminal Help
root@localhost:~/Desk...

```
splashimage=(hd0,6)/boot/grub/splash.xpm.gz
hiddenmenu
title Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
        root (hd0,6)
        kernel /boot/vmlinuz-2.6.32-642.el6.x86_64 ro root=UUID=890a091c-45a3-4947-afd9-ee5468f72
c2a rd_NO_LUKS rd_NO_LVM LANG=en_US.UTF-8 rd_NO_MD SYSFONT=latarcyrheb-sun16 crashkernel=auto  KE
YBOARDTYPE=pc KEYTABLE=us rd_NO_DM rhgb quiet
        initrd /boot/initramfs-2.6.32-642.el6.x86_64.img

title Windows
        rootnoverify (hd0,0)
        chainloader +1

title Solaris
        rootnoverify (hd0,1)
        chainloader +1

title BSD
        rootnoverify (hd0,2)
        chainloader +1

title Fedora (2.6.38.6-26.rc1.fc15.x86_64)
        root (hd0,7)
        kernel /boot/vmlinuz-2.6.38.6-26.rc1.fc15.x86_64 ro root=UUID=26294080-58fd-4771-b460-7ac
6591621a6 rd_NO_LUKS rd_NO_LVM rd_NO_MD rd_NO_DM LANG=en_US.UTF-8 SYSFONT=latarcyrheb-sun16 KEYTA
BLE=us rhgb quiet
        initrd /boot/initramfs-2.6.38.6-26.rc1.fc15.x86_64.img

-- INSERT --                                                         35,1          Bot
```

Figure 2-101. *The grub.conf file of RHEL*

After reboot, we will get the Fedora entry (Figure 2-102).



```
GNU GRUB  version 0.97  (638K lower / 3143552K upper memory)

 Red Hat Enterprise Linux 6 (2.6.32-642.el6.x86_64)
 Windows
 Solaris
 BSD
 Fedora (2.6.38.6-26.rc1.fc15.x86_64)
```

Figure 2-102. *The OS entries shown by RHEL*

When the user chooses Fedora to boot, as per the entry in RHEL's `grub.conf` file, part-3 of RHEL's GRUB will load the kernel from the eighth partition (sda8 of Fedora) and will also load initramfs from the same location (we will talk about initramfs in Chapter 5), and the bootloader will go away.

Complete Flowchart

Figure 2-103 shows the complete flowchart of every OS that we have installed so far.

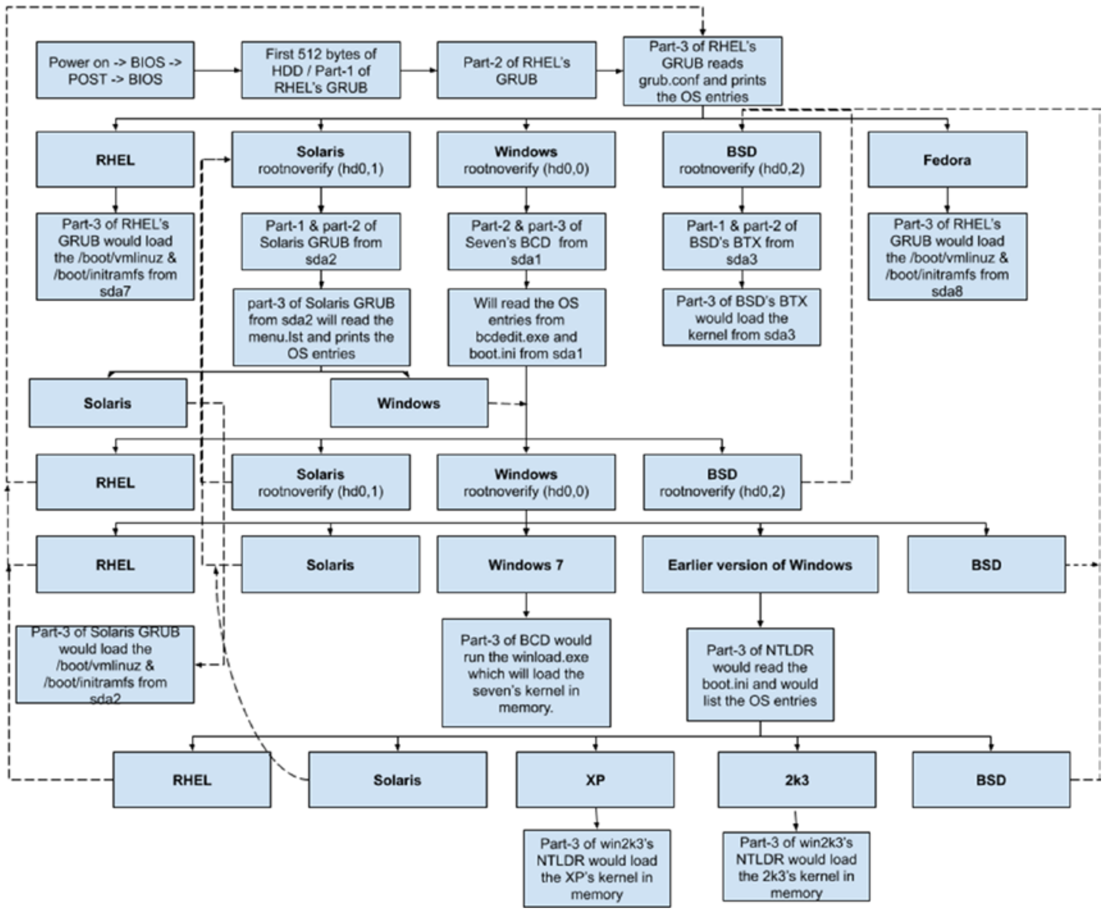

Power on -> BIOS -> POST -> BIOS
First 512 bytes of HDD / Part-1 of RHEL's GRUB
Part-2 of RHEL's GRUB
Part-3 of RHEL's GRUB reads grub.conf and prints the OS entries
RHEL
Solaris rootnoverify (hd0,1)
Windows rootnoverify (hd0,0)
BSD rootnoverify (hd0,2)
Fedora
Part-3 of RHEL's GRUB would load the /boot/vmlinuz & /boot/initramfs from sda7
Part-1 & part-2 of Solaris GRUB from sda2
Part-2 & part-3 of Seven's BCD from sda1
Part-1 & part-2 of BSD's BTX from sda3
Part-3 of RHEL's GRUB would load the /boot/vmlinuz & /boot/initramfs from sda8
part-3 of Solaris GRUB from sda2 will read the menu.lst and prints the OS entries
Will read the OS entries from bcdedit.exe and boot.ini from sda1
Part-3 of BSD's BTX would load the kernel from sda3
Solaris
Windows
RHEL
Solaris rootnoverify (hd0,1)
Windows rootnoverify (hd0,0)
BSD rootnoverify (hd0,2)
RHEL
Solaris
Windows 7
Earlier version of Windows
BSD
Part-3 of Solaris GRUB would load the /boot/vmlinuz & /boot/initramfs from sda2
Part-3 of BCD would run the winload.exe which will load the seven's kernel in memory.
Part-3 of NTLDR would read the boot.ini and would list the OS entries
RHEL
Solaris
XP
2k3
BSD
Part-3 of win2k3's NTLDR would load the XP's kernel in memory
Part-3 of win2k3's NTLDR would load the 2k3's kernel in memory

Figure 2-103. *The complete flowchart of all the operating systems*

I hope you now understand the way bootloaders boot the operating systems on a BIOS-based system. Now it's time to understand the new firmware, which is Unified Extensible Firmware Interface (UEFI).

Unified Extensible Firmware Interface (UEFI)

Here are the BIOS limitations you have observed so far:

- You can have only four primary partitions.
- The BIOS cannot read the logical partitions.
- The BIOS is kind of dumb; it just jumps to the first sector of your HDD.
- The maximum partition size with a BIOS-based system is 2.2 TB.

Why does it have such limitations? The BIOS firmware was designed in 1982 for IBM PC-5150 (Figure 2-104), which used to have this configuration:

```
CPU       = 8088 - 16bit x86 processor
Memory    = upto 256KB max
OS        = MS-DOS
```

Figure 2-104. *IBM PC-5150*

As you can see, the BIOS was designed for this PC 38 years ago. In these three decades, operating systems grew from floppy disks to NVME disks and from text mode to shiny GUIs. The hardware devices went from drivers to plug and play, but the BIOS remained the same, which initially had a 16-bit instruction set, and in later stages it started using a 32-bit instruction set. Nowadays we have 64-bit CPUs, but the BIOS is still made from 32-bit instructions. The reason we did not upgrade the BIOS to 64-bit is because of historical reasons. When everything is working, why rewrite something? That's the philosophy the computer industry has adopted anyway. When the CPU went from 16-bit (8088) to 64-bit (i9), the BIOS remained either on 16-bit or on 32-bit, because at the time of the early stages of booting, it was not necessary to have a 64-bit CPU, and this is the reason we have CPU modes (real, protected, and long).

In real mode, the CPU will be restricted to 16 bits. In this mode, programs like the old BIOS that have 16-bit instructions will run. These programs cannot run in any other mode. Later, the CPU will switch from real mode to protected mode. The protected mode is 32 bits, and programs these days, like the BIOS, that have 32-bit instructions sets will run under this mode, and later the CPU will be placed in long mode, which is 64 bits. Remember, these modes are not implemented by the CPU; rather, they are implemented by firmware like the BIOS. This means if we remove the same CPU from a real mode-enabled system and place it on a system that does not have real mode, then the same CPU will directly start in protected mode. We will talk about these modes again in Chapter 4.

Since the BIOS runs in protected mode, the address space that is available for the BIOS is only 4 GB. If the system has 20 GB of memory, the BIOS will only be able to address up to 4 GB. Though the system has a 64-bit I9 processor, the BIOS will still be able to use only 32 bits of it. Because of these hardware challenges, the BIOS has limitations.

BIOS Limitations

These are some limitations of the BIOS:

- BIOS will only be able to jump to the first sector, which is 512 bytes.
    - The MBR, which is 64 bytes in size, is part of the first boot sector. If we increase the size of the MBR, it will go beyond the 512 bytes; hence, we cannot increase the size of the MBR, which is the reason why the BIOS can provide only four primary partitions.
- BIOS cannot generate good graphics/GUIs.
    - Now this is a generic statement, and it is used in comparison with UEFI. There are some BIOS vendors that have implemented web browsers outside of the OS, but such implementations are rare to see on normal desktop hardware.

    - Also, at Phoenix, some of the BIOS implementations has a FAT32 driver in it through which it manages to show icons inside a setup.
- You cannot use a mouse in the BIOS.
    - There are many BIOS vendors that have mouse support, but again it is rare to find in normal desktop systems.
- The maximum partition size is 2.2 TB.
    - The BIOS uses and supports an MS-DOS partition table, which is quite old, and it has its own drawbacks like 2.2 TB of maximum partition size.
- The BIOS is dumb because it does not understand the bootloader or the OS.
- It is slow because of the hardware limitations.
    - In terms of booting speed, the BIOS is slow since it takes time to initialize the hardware.
    - The BIOS takes almost 30 seconds to start the actual OS-level booting.
- It struggles to initialize the new-generation hardware devices.
- BIOS has limited preboot tools.
    - Compared to the UEFI firmware, the BIOS has very few preboot tools such as remote hardware diagnostics, etc.

So, to overcome all these BIOS limitations, Intel started an initiative in 1998 called Intel Boot Initiative (IBI); later it became Extensible Firmware Interface (EFI). Intel was joined by every other possible OS and hardware vendor (HP/Apple/Dell/Microsoft/IBM/Asus/AMD/American Megatrends /Phoenix Technologies). They made an open source forum for this project, and finally it became Unified Extensible Interface (UEFI).

The open source code is signed under the BSD license, but Intel's base code is still proprietary. UEFI is basically an open source framework, and vendors build their applications on top of it based on the specification provided by UEFI.org. For example, American Megatrends built APTIO, and Phoenix Technologies built the SecureCore UEFI firmware. Apple was the first that dared to launch systems with UEFI firmware in it. All the drawbacks that the BIOS has are because of its 16-bit instruction set. Since this 16-bit instruction set limits BIOS hardware usage to 1 MB of address space, UEFI targeted and resolved that limitation.

UEFI Advantages

UEFI supports 64-bit processors; hence, it does not face any of the hardware limitations that the BIOS faces.

- UEFI can use the full CPU. Unlike the BIOS (which is stuck with 16 bits of processor), UEFI can access up to 64 bits.
- UEFI can use a full RAM module. Unlike 1 MB of address space of the BIOS, UEFI can support and use terabytes of RAM.
- Instead of 64 bytes of a tiny MBR, UEFI uses the GPT (GUID) partition table, which will provide an infinite number of partitions, and all will be primary partitions. In fact, there is no concept of primary and logical partitions.
- A maximum partition size is 8 zettabytes.
- UEFI has enterprise management tools.
    a) You will be able to fix the computer remotely.
    b) You will be able to browse the Internet inside the UEFI firmware.
    c) You will be able to change the UEFI firmware behavior/settings from OS.
        i) To change the settings of BIOS, we have to reboot the system since OS runs in long mode, whereas BIOS runs in real mode, and real mode can only be possible at the time of boot.
- UEFI is a small OS.
    a) You will have full access to audio and video devices.
    b) You will be able to connect to WiFi.
    c) You will be able to use the mouse.

d) In terms of the GUI, UEFI will provide a rich graphics interface.

e) UEFI will have its own app store like we have for Android and Apple phones.

f) You will be able to download and use the applications from the UEFI app store, just like with Android and Apple phones. Hundreds of apps are available such as calendars, email clients, browser, games, shells, etc.

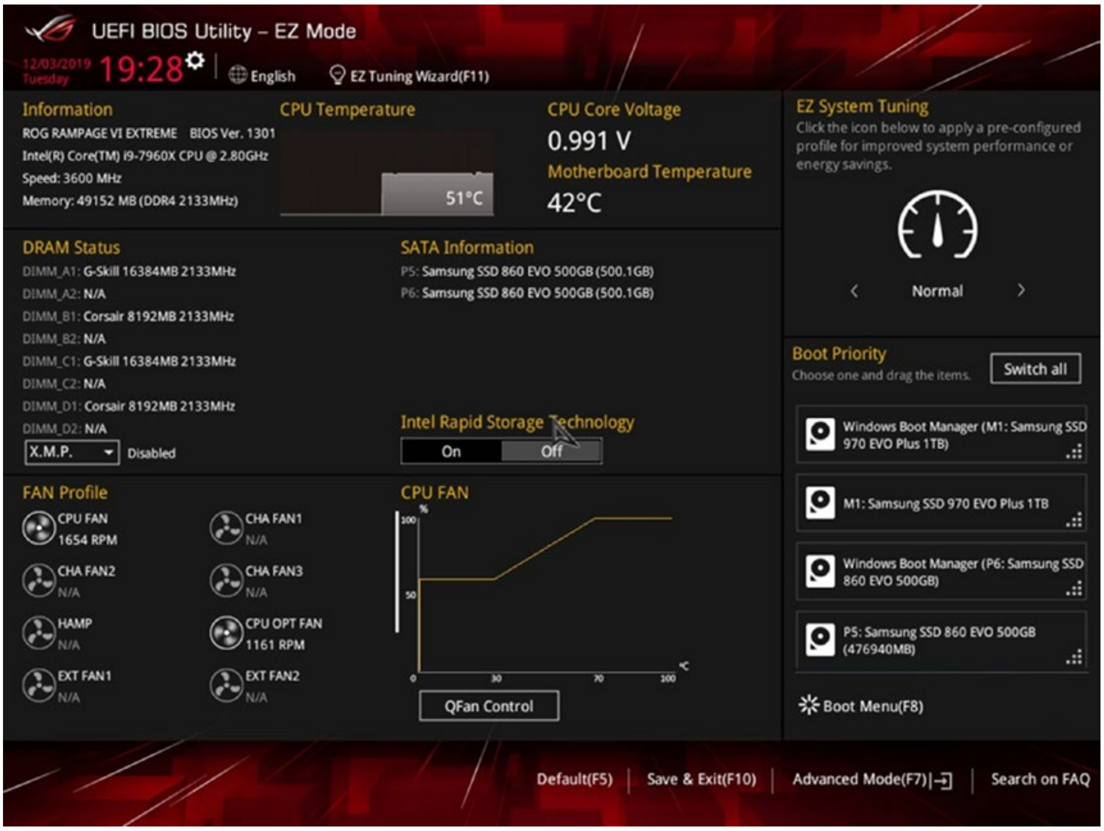
g) UEFI is able to run any binary that has an EFI executable format.

h) It boots operating systems securely with the help of the Secure Boot feature. We will discuss the Secure Boot feature in depth later in this book.

i) UEFI is backward compatible, meaning it will support the "BIOS way" of booting. In other words, operating systems that do not have UEFI support will also be able to boot with UEFI.

The GUI of UEFI

Figure 2-105 shows the GUI implementation of ASUS.



UEFI BIOS Utility – EZ Mode

12/03/2019 Tuesday 19:28 | English | EZ Tuning Wizard(F11)

Information
ROG RAMPAGE VI EXTREME BIOS Ver. 1301
Intel(R) Core(TM) i9-7960X CPU @ 2.80GHz
Speed: 3600 MHz
Memory: 49152 MB (DDR4 2133MHz)

CPU Temperature
51°C

CPU Core Voltage
0.991 V

Motherboard Temperature
42°C

EZ System Tuning
Click the icon below to apply a pre-configured profile for improved system performance or energy savings.
Normal

DRAM Status
DIMM_A1: G-Skill 16384MB 2133MHz
DIMM_A2: N/A
DIMM_B1: Corsair 8192MB 2133MHz
DIMM_B2: N/A
DIMM_C1: G-Skill 16384MB 2133MHz
DIMM_C2: N/A
DIMM_D1: Corsair 8192MB 2133MHz
DIMM_D2: N/A
X.M.P. Disabled

SATA Information
P5: Samsung SSD 860 EVO 500GB (500.1GB)
P6: Samsung SSD 860 EVO 500GB (500.1GB)

Intel Rapid Storage Technology
On Off

Boot Priority
Choose one and drag the items.
Switch all
Windows Boot Manager (M1: Samsung SSD 970 EVO Plus 1TB)
M1: Samsung SSD 970 EVO Plus 1TB
Windows Boot Manager (P6: Samsung SSD 860 EVO 500GB)
P5: Samsung SSD 860 EVO 500GB (476940MB)
Boot Menu(F8)

FAN Profile
CPU FAN 1654 RPM
CHA FAN1 N/A
CHA FAN2 N/A
CHA FAN3 N/A
HAMP N/A
CPU OPT FAN 1161 RPM
EXT FAN1 N/A
EXT FAN2 N/A

CPU FAN
QFan Control

Default(F5) | Save & Exit(F10) | Advanced Mode(F7) | Search on FAQ

Figure 2-105. *ASUS UEFI implementation*

Here are some things to notice:

- The rich GUI
- Mouse pointer
- Icons, buttons, scroll options, animations, graphs, drop-down options, etc.

Of course, you need to get an expensive motherboard to get such a rich UEFI implementation, but even the basic UEFI implementations are much better than the BIOS implementations.

UEFI Implementation

The UEFI forum releases the UEFI specification. The current UEFI specification when writing this book was 2.8 and can be downloaded from `https://uefi.org/specifications`. The current specification is 2,551 pages long, and every vendor (motherboard, OS, UEFI developer, etc.) has to agree to it. The specification forces regulations that every vendor has to follow. The following are some of the major UEFI regulations.

EFI System Partition (ESP)

Every OS vendor has to create one EPS partition, and the bootloader has to be installed in this partition only. It is not necessary to create ESP as a first partition; it could be created anywhere, but the ESP should have the FAT16/32 (preferably FAT32) filesystem. The recommended ESP size is a minimum of 256 MB. The OS vendor has to create the following directory structure in ESP:

```
EFI System Partition
      ├── EFI
      |     ├── <OS_vendor_name>
      |     |          ├── <boot_loader_files>
```

Once this structure is created, the OS has to install the bootloader inside the `/EFI/<os_vendor_name>/` location only. Figure 2-106 shows you the UEFI structure.

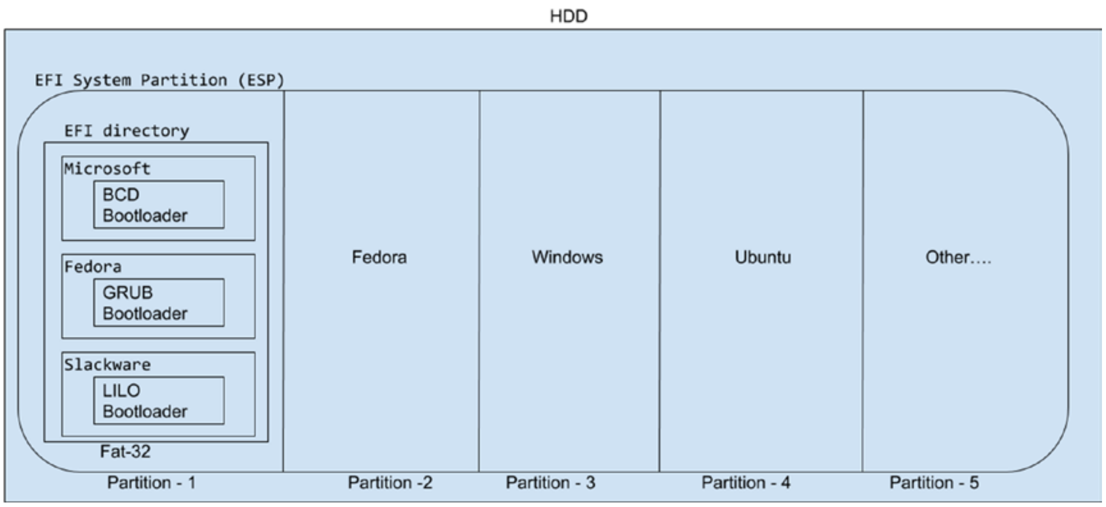


Figure 2-106. *The UEFI structure*

This means, like the 512 bytes + 31 KB space reserved for bootloaders, in the same way we have a 256 MB minimum dedicated space for bootloaders in UEFI. The ESP partition will be mounted in Linux under the mount point `/boot/efi`.

EFI

It's compulsory for every OS vendor to write bootloader files in the EFI executable format. Also, the files should have the `.efi` extension.

Secure Boot

One of the best features UEFI provides is Secure Boot. The feature was proposed by Microsoft and later added in the UEFI specification. Microsoft first used the Secure Boot feature in Windows 8. We will talk about Secure Boot in detail once we get familiarized with how UEFI works.

Partition Table

The recommended partition table is GPT, which is a GUID partition table, whereas the BIOS uses an MS-DOS partition table.

For a better understanding of UEFI, we will use the same approach that we used with the BIOS. We will use a new system named UEFI, which has the UEFI firmware on it, and we will install a couple of OSs in it.

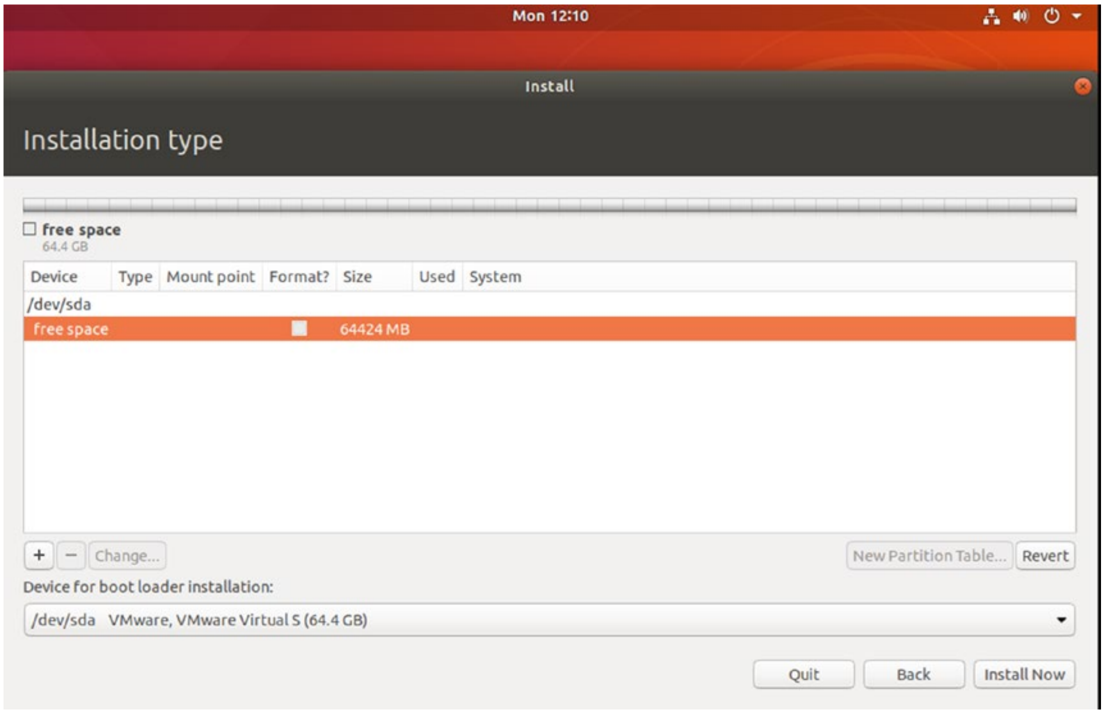
List of Operating Systems

As you know, UEFI uses a GPT partition table; hence, there is no primary or secondary/logical partition concept. This also means there is no particular priority to the installations of operating systems. You can install operating systems in any way you want. We will install the OSs in this order:

1) Ubuntu 18
2) Windows 10
3) Fedora 31

Ubuntu 18.04 LTS

We have almost 64.4 GB of HDD. It is not necessary to use a GParted-like tool to create the partition layout like we used with the BIOS. We will use a Ubuntu-provided default disk utility instead. See Figure 2-107.

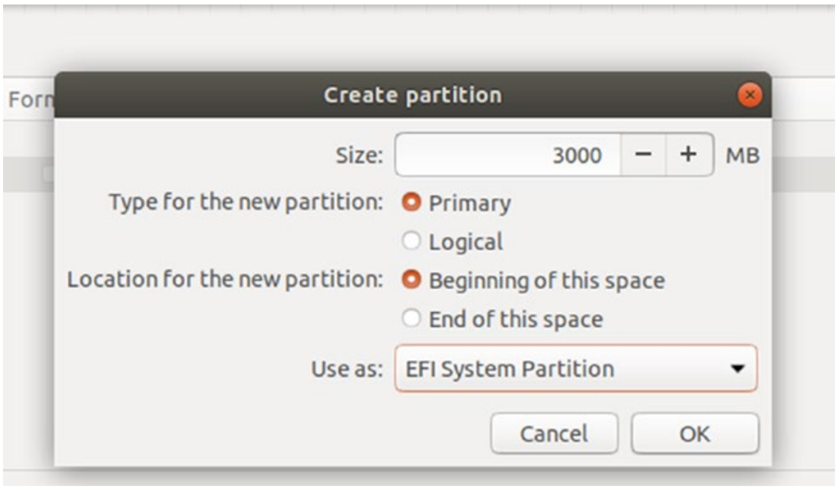


Device	Type	Mount point	Format?	Size	Used	System
/dev/sda						
free space			☐	64424 MB		

+
−
Change...
New Partition Table...
Revert
Device for boot loader installation:
/dev/sda VMware, VMware Virtual S (64.4 GB)
Quit
Back
Install Now

Figure 2-107. *The disk layout provided by Ubuntu*

As shown in Figure 2-108, we will create a 3 GB ESP partition first.



Create partition

Size: 3000 MB

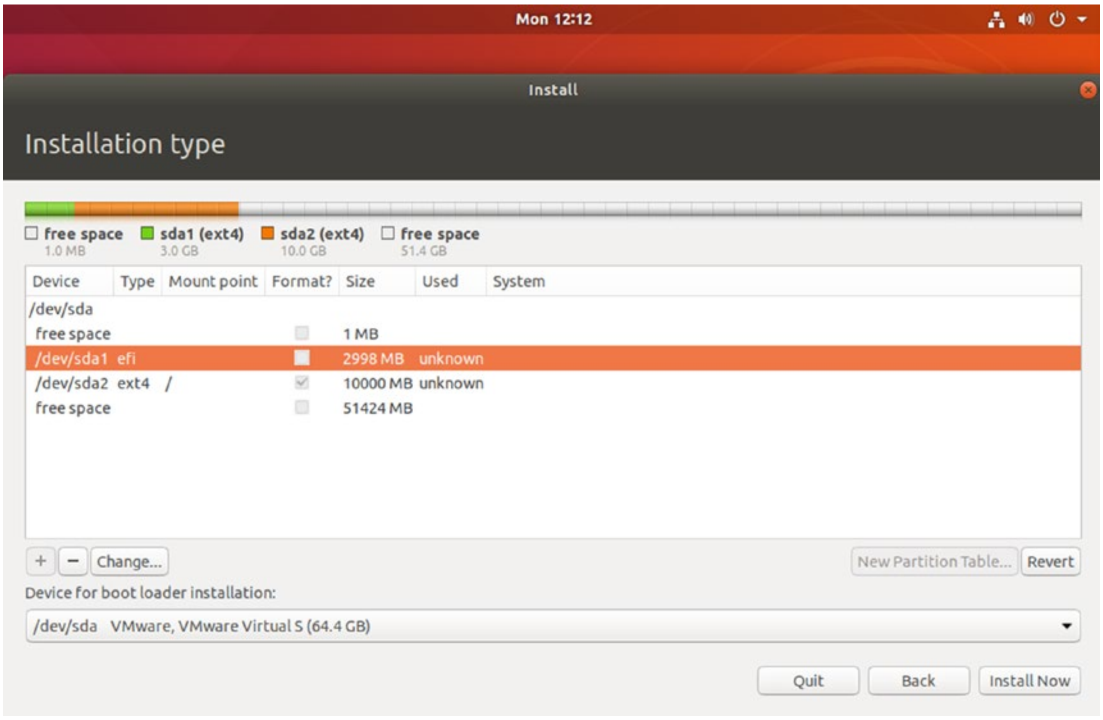
Type for the new partition: [✓ Primary] Logical

Location for the new partition: [✓ Beginning of this space] End of this space

Use as: EFI System Partition

Figure 2-108. *Creating the ESP partition*

Once ESP is created, we will make one more partition (10 GB) for Ubuntu's root filesystem. Figure 2-109 shows the final partition layout of Ubuntu.



Mon 12:12

Install

Installation type

☐ free space 1.0 MB · 🟩 sda1 (ext4) 3.0 GB · 🟧 sda2 (ext4) 10.0 GB · ☐ free space 51.4 GB

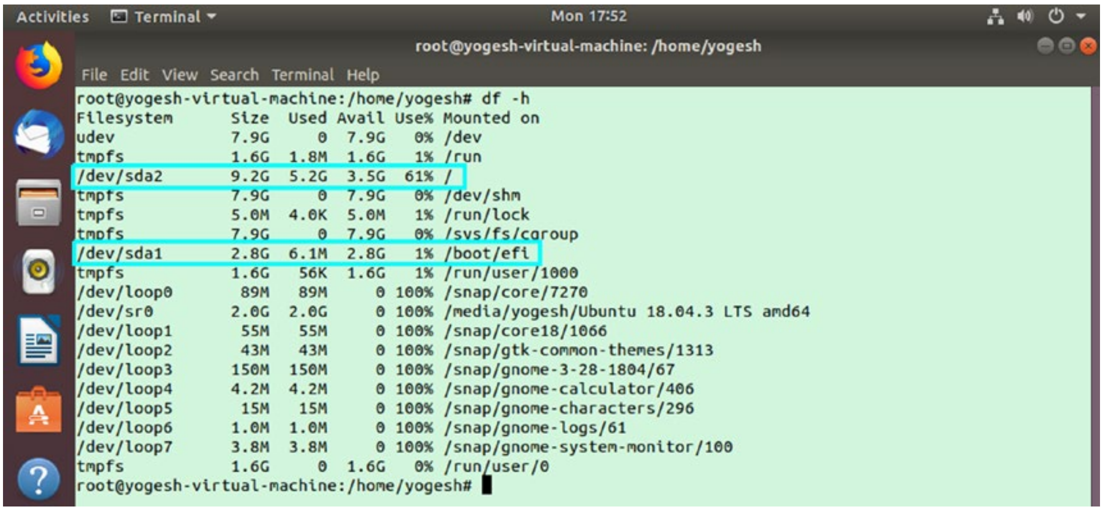
Device	Type	Mount point	Format?	Size	Used	System
/dev/sda						
free space			☐	1 MB		
/dev/sda1	efi		☐	2998 MB	unknown	
/dev/sda2	ext4	/	✓	10000 MB	unknown	
free space			☐	51424 MB		

Device for boot loader installation:

/dev/sda VMware, VMware Virtual S (64.4 GB)

Figure 2-109. *The partition layout of Ubuntu*

After the installation, you can see in Figure 2-110 that ESP is mounted on `/boot/efi` and the root filesystem is mounted on sda2.

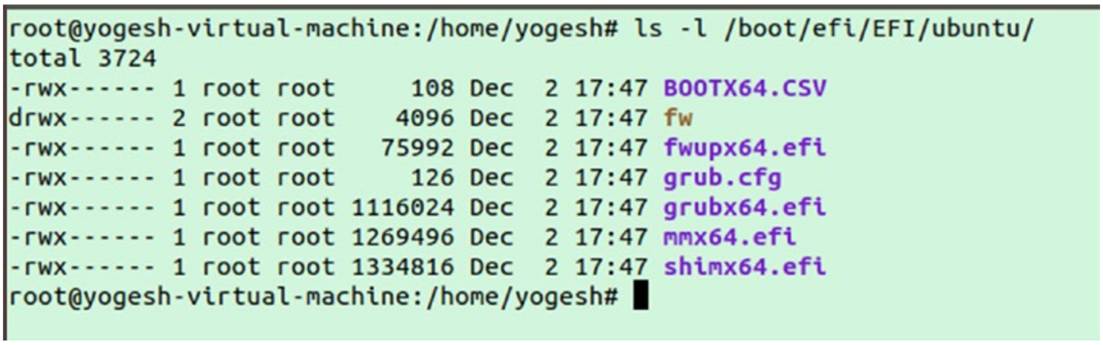


Activities
Terminal
Mon 17:52
root@yogesh-virtual-machine: /home/yogesh
File Edit View Search Terminal Help

```
root@yogesh-virtual-machine:/home/yogesh# df -h
Filesystem      Size  Used Avail Use% Mounted on
udev            7.9G     0  7.9G   0% /dev
tmpfs           1.6G  1.8M  1.6G   1% /run
/dev/sda2       9.2G  5.2G  3.5G  61% /
tmpfs           7.9G     0  7.9G   0% /dev/shm
tmpfs           5.0M  4.0K  5.0M   1% /run/lock
tmpfs           7.9G     0  7.9G   0% /sys/fs/cgroup
/dev/sda1       2.8G  6.1M  2.8G   1% /boot/efi
tmpfs           1.6G   56K  1.6G   1% /run/user/1000
/dev/loop0       89M   89M     0 100% /snap/core/7270
/dev/sr0        2.0G  2.0G     0 100% /media/yogesh/Ubuntu 18.04.3 LTS amd64
/dev/loop1       55M   55M     0 100% /snap/core18/1066
/dev/loop2       43M   43M     0 100% /snap/gtk-common-themes/1313
/dev/loop3      150M  150M     0 100% /snap/gnome-3-28-1804/67
/dev/loop4      4.2M  4.2M     0 100% /snap/gnome-calculator/406
/dev/loop5       15M   15M     0 100% /snap/gnome-characters/296
/dev/loop6      1.0M  1.0M     0 100% /snap/gnome-logs/61
/dev/loop7      3.8M  3.8M     0 100% /snap/gnome-system-monitor/100
tmpfs           1.6G     0  1.6G   0% /run/user/0
root@yogesh-virtual-machine:/home/yogesh# 
```

Figure 2-110. *The mount points*

Also, as per the UEFI specification, Ubuntu has created a directory structure of `/EFI/ubuntu` in the `/boot/efi` (sda1) mount point and installed the GRUB bootloader in it. See Figure 2-111.



```
root@yogesh-virtual-machine:/home/yogesh# ls -l /boot/efi/EFI/ubuntu/
total 3724
-rwx------ 1 root root     108 Dec  2 17:47 BOOTX64.CSV
drwx------ 2 root root    4096 Dec  2 17:47 fw
-rwx------ 1 root root   75992 Dec  2 17:47 fwupx64.efi
-rwx------ 1 root root     126 Dec  2 17:47 grub.cfg
-rwx------ 1 root root 1116024 Dec  2 17:47 grubx64.efi
-rwx------ 1 root root 1269496 Dec  2 17:47 mmx64.efi
-rwx------ 1 root root 1334816 Dec  2 17:47 shimx64.efi
root@yogesh-virtual-machine:/home/yogesh# 
```

Figure 2-111. *The EFI directory of Ubuntu*

Also notice the `.efi` extensions to the bootloader files. The following is the Ubuntu booting sequence on a UEFI system:

1) Power on the system.

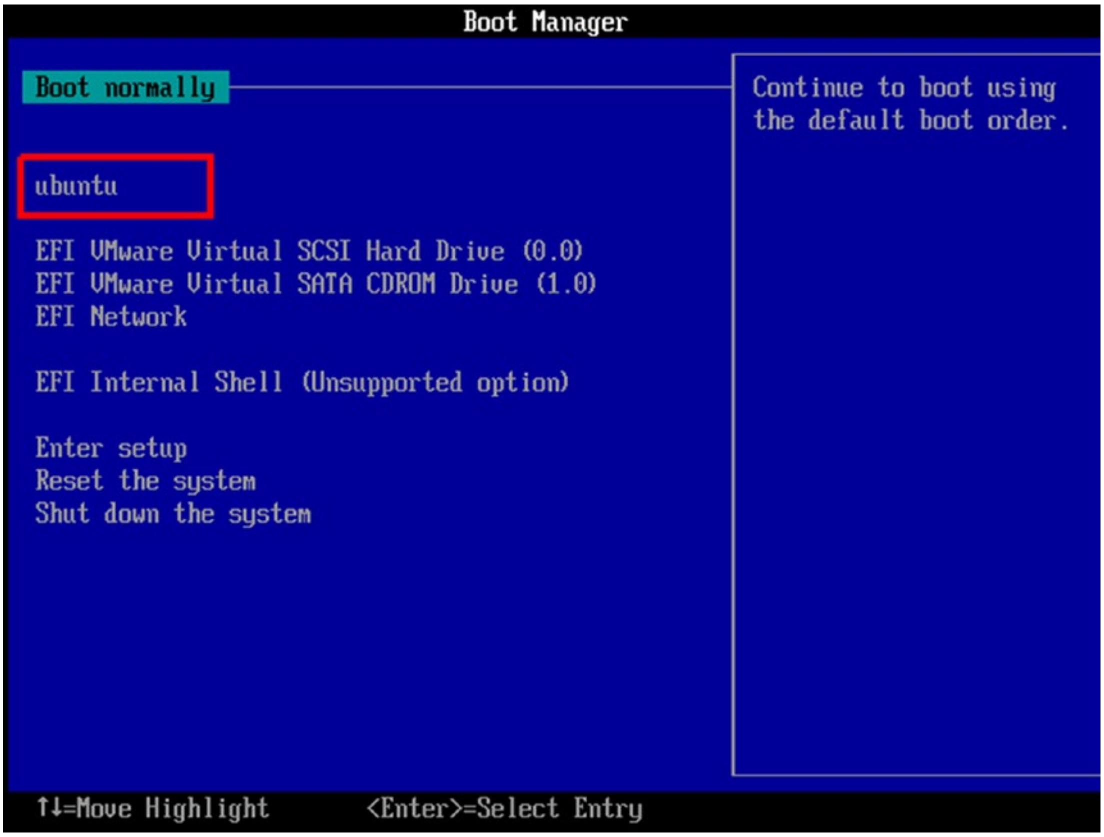
2) It goes to the UEFI firmware. UEFI launches POST.

3) POST checks the hardware and gives a healthy beep if everything is good.

4) POST goes back to UEFI.

5) UEFI is smart; instead of jumping to the first 512 bytes, UEFI finds the ESP partition.

6) It jumps inside ESP. Again, UEFI is smart, and it understands the bootloader. It lists the bootloader's name on the screen. In Ubuntu's case, it sees the `grubx64.efi` file; hence, it lists the Ubuntu name in the boot priority of UEFI. Please refer to Figure 2-112, where you can see the `ubuntu` entry inside UEFI's boot priority menu.

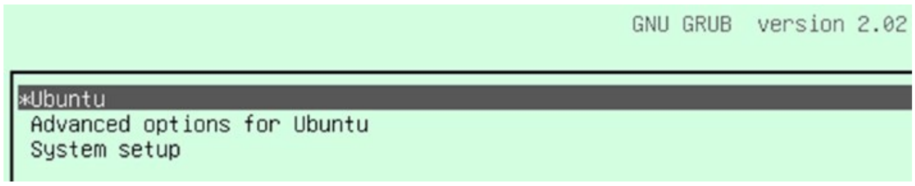


```
Boot Manager

Boot normally                              Continue to boot using
                                           the default boot order.
ubuntu

EFI VMware Virtual SCSI Hard Drive (0.0)
EFI VMware Virtual SATA CDROM Drive (1.0)
EFI Network

EFI Internal Shell (Unsupported option)

Enter setup
Reset the system
Shut down the system

↑↓=Move Highlight        <Enter>=Select Entry
```

Figure 2-112. *The boot priority window of UEFI*

7) Remember, the bootloader has not yet been called or started by UEFI. The BIOS used to show you only the available boot device names like CD-ROM, HDD, and PXE, but UEFI goes inside the device to check for the ESP partition and shows the OS name directly.

8) The moment the user chooses the Ubuntu option, UEFI will run `grubx64.efi` from the ESP partition. The absolute path will be `/boot/efi/EFI/ubuntu/grubx64.efi` Next, `grubx64.efi` will read `grub.cfg`, which is present in the same directory, and as shown in Figure 2-113, it will print the title entries.



```
                                     GNU GRUB  version 2.02

*Ubuntu
 Advanced options for Ubuntu
 System setup
```

Figure 2-113. *The welcome screen of Ubuntu*

With the BIOS, there used to be jumps like this:

a) Go to the fdisk signature, go to part-1 of the bootloader, and go to part-2 of the bootloader.

b) Go to part-3 of the bootloader and then go to the bootloader configuration file like `menu.lst` or `grub.cfg`.

c) Print the titles.

With UEFI, the (a) jump is skipped. UEFI directly jumps to (b). The BIOS used to have a bootloader divided into three parts because of space constraints, but UEFI does not have any space limitations. Hence, the entire bootloader is available in just one single binary. For example, in the case of Ubuntu, `grubx64.efi` has one, two, and three parts all added in a single binary, which is `grubx64.efi`.

The `grubx64.efi` file will eventually load the kernel (`vmlinuz`) and initramfs from `/boot` into the memory, and then Ubuntu's GRUB bootloaders job is done. Figure 2-114 shows the flowchart of Ubuntu's boot sequence.

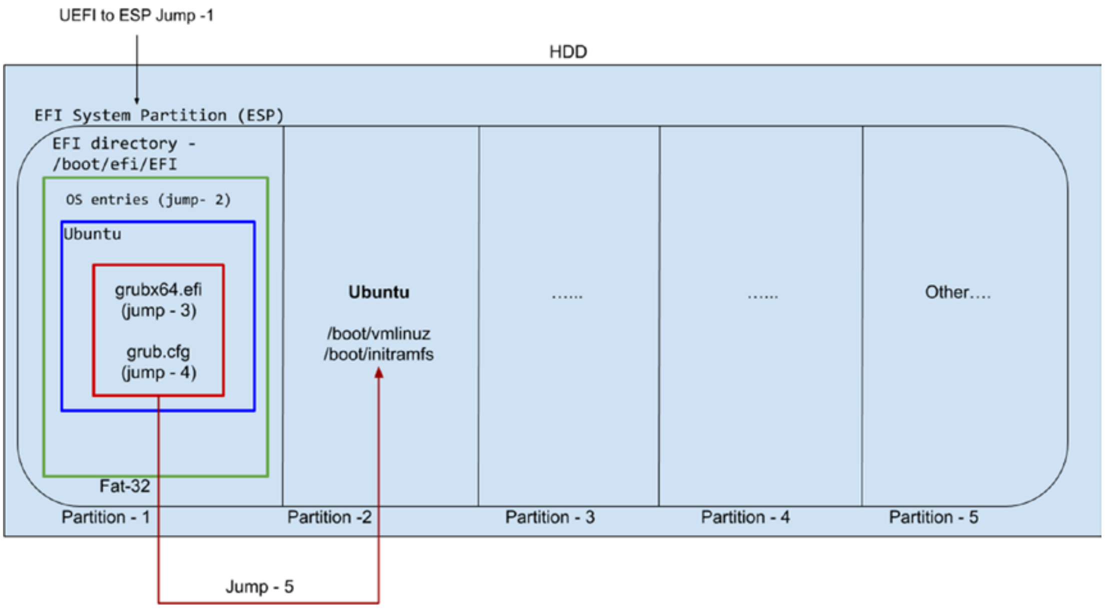
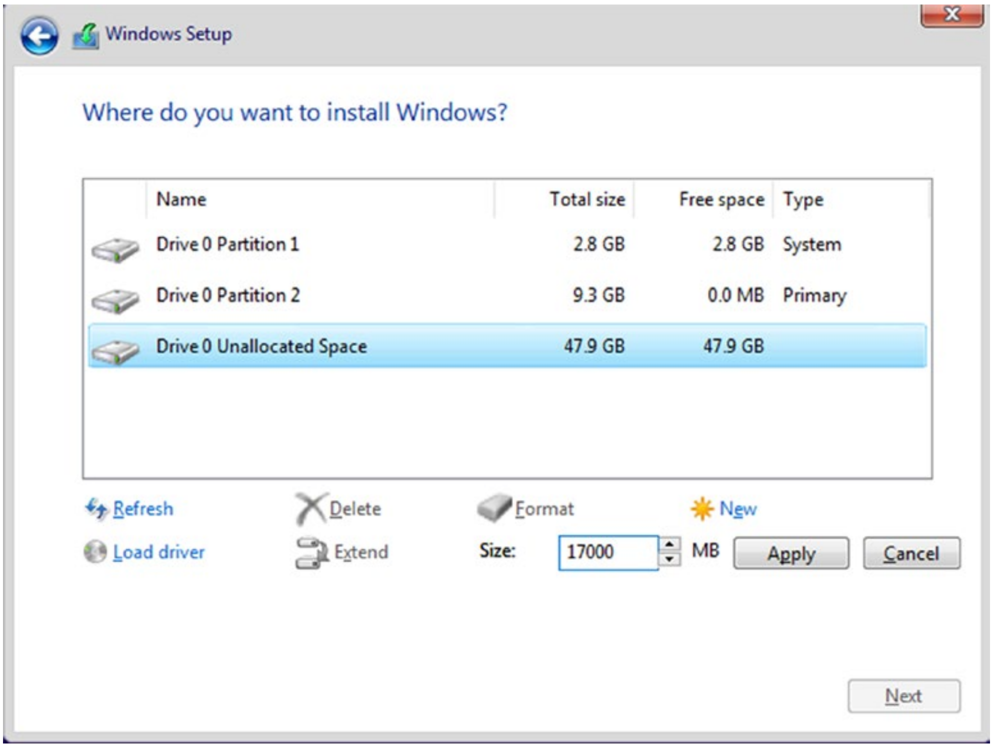


Figure 2-114. *Ubuntu's boot sequence*

Windows 10

As you can see in Figure 2-115, partition 1 is ESP, and partition 2 is the root (/) of Ubuntu.

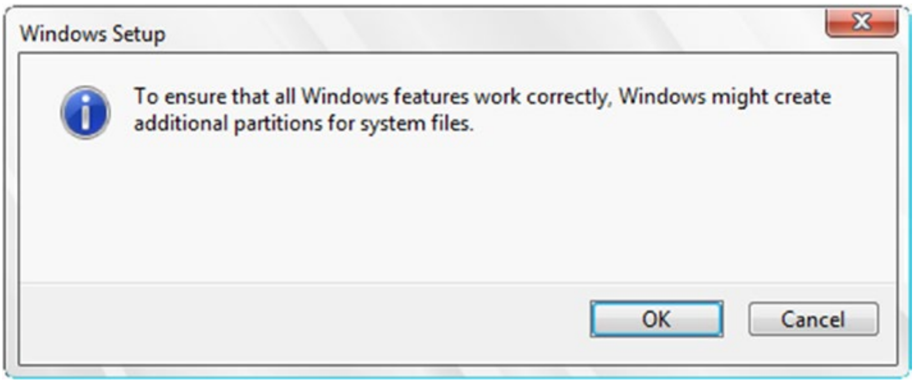


Where do you want to install Windows?

	Name	Total size	Free space	Type
	Drive 0 Partition 1	2.8 GB	2.8 GB	System
	Drive 0 Partition 2	9.3 GB	0.0 MB	Primary
	Drive 0 Unallocated Space	47.9 GB	47.9 GB	

Figure 2-115. *The partition layout shown by Windows 10*

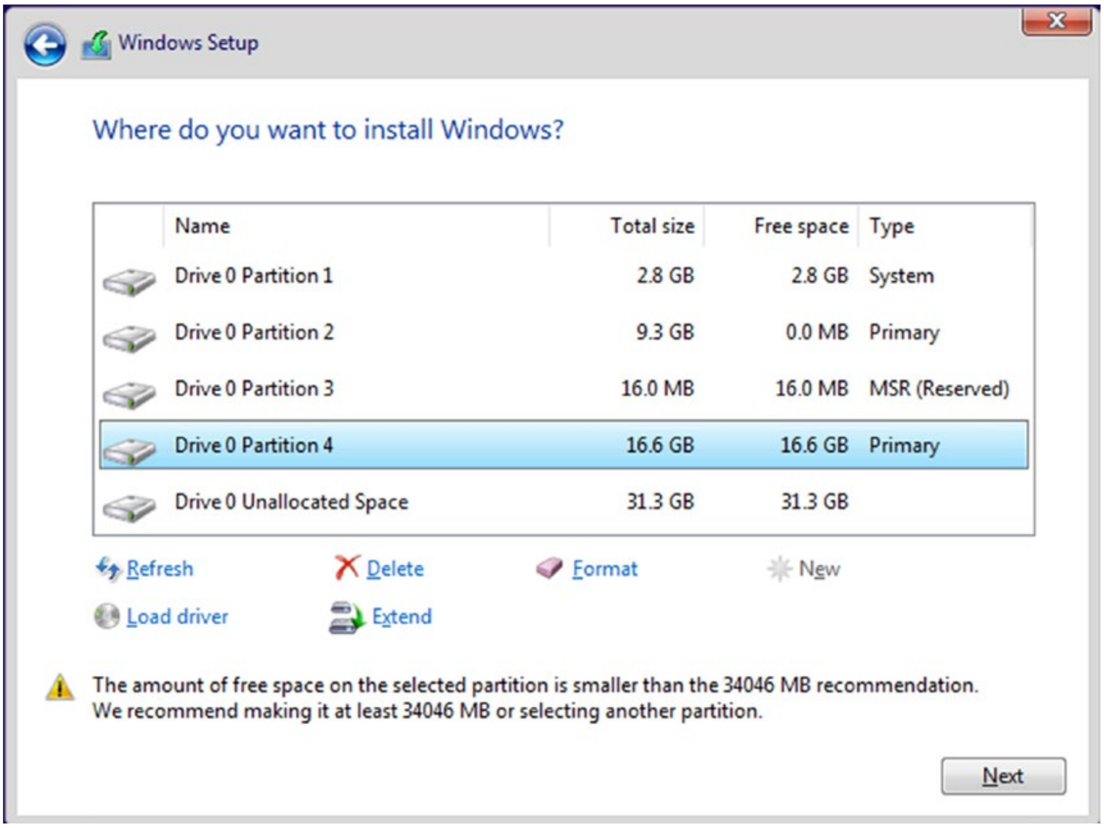
Now we will create a new partition for Windows. While creating a new partition, Windows will reserve some space for the Windows recovery tool called MSR (Microsoft Recovery, partition 3). See Figure 2-116.



To ensure that all Windows features work correctly, Windows might create additional partitions for system files.

Figure 2-116. *The MSR space reservation*

As shown in Figure 2-117, on the newly created partition 4, we will install Windows 10.


Windows Setup

Where do you want to install Windows?

	Name	Total size	Free space	Type
	Drive 0 Partition 1	2.8 GB	2.8 GB	System
	Drive 0 Partition 2	9.3 GB	0.0 MB	Primary
	Drive 0 Partition 3	16.0 MB	16.0 MB	MSR (Reserved)
	Drive 0 Partition 4	16.6 GB	16.6 GB	Primary
	Drive 0 Unallocated Space	31.3 GB	31.3 GB	

The amount of free space on the selected partition is smaller than the 34046 MB recommendation.
We recommend making it at least 34046 MB or selecting another partition.

Figure 2-117. *Installing Windows 10 on partition 4*

Windows will by default detect the ESP partition, and by following the UEFI specification, it will create a directory named `Microsoft` in it and will install its bootloader (BCD) in it. If Windows does not find ESP, then it will create one for us. Since Windows is mainly for desktop users, it will not show us the ESP partition (refer to Figure 2-118) the way Ubuntu shows it.

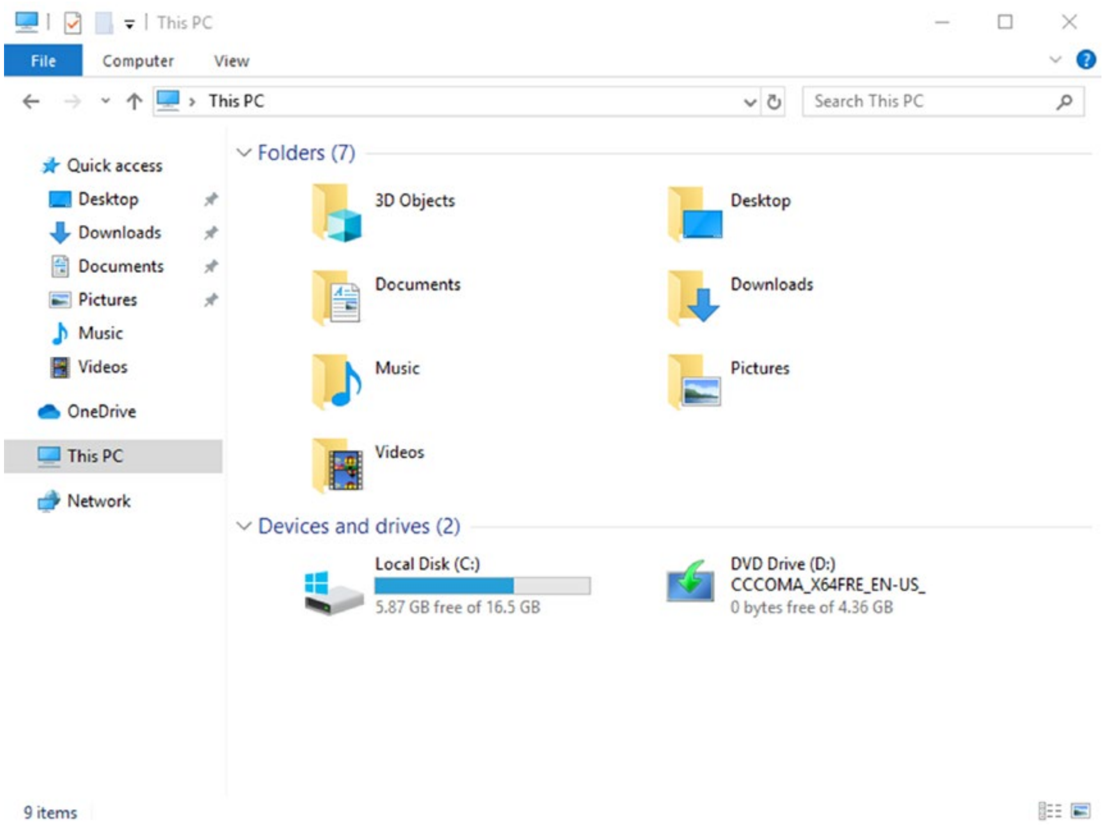
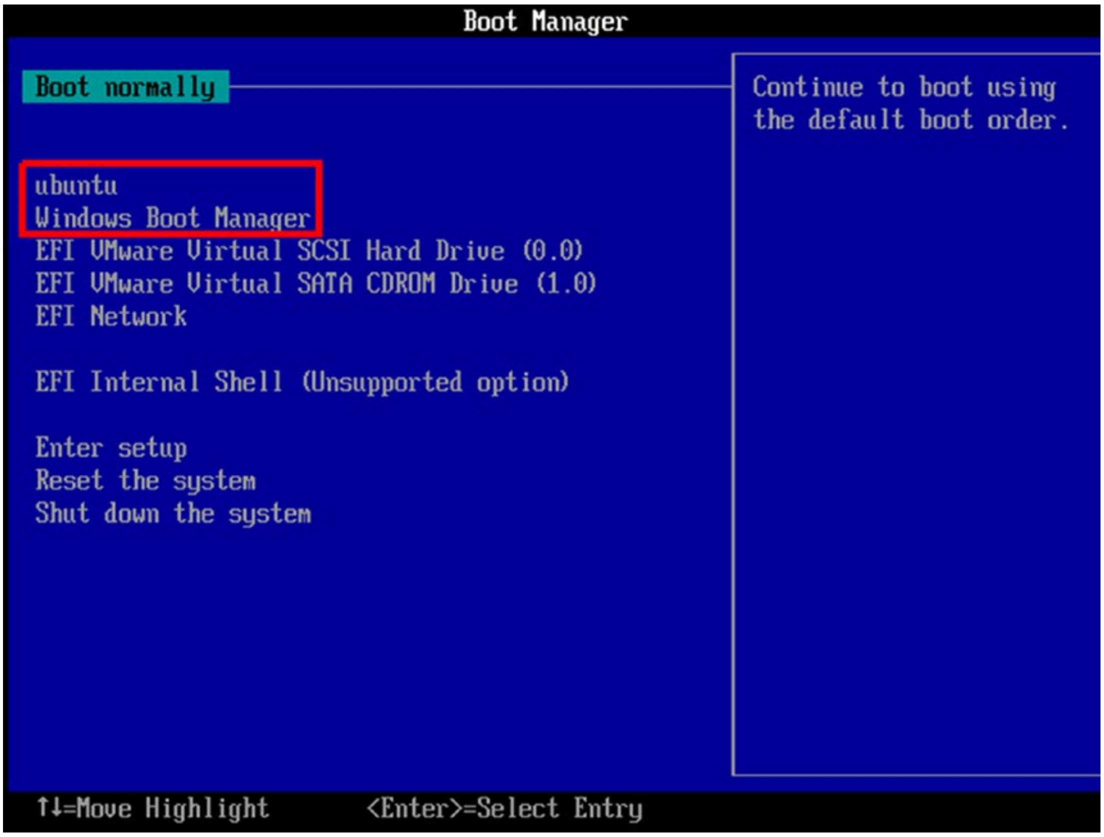


Figure 2-118. *ESP is hidden*

This is how Windows 10 will boot on a UEFI-based system:

1) Power on the system: first UEFI, then POST, then UEFI, and then ESP.

2) As visible in Figure 2-119, print the OS entries as per the directories found in ESP (`/boot/efi/EFI`).



```
                              Boot Manager

 Boot normally                                  Continue to boot using
                                                the default boot order.

 ubuntu
 Windows Boot Manager
 EFI VMware Virtual SCSI Hard Drive (0.0)
 EFI VMware Virtual SATA CDROM Drive (1.0)
 EFI Network

 EFI Internal Shell (Unsupported option)

 Enter setup
 Reset the system
 Shut down the system

 ↑↓=Move Highlight        <Enter>=Select Entry
```

Figure 2-119. *The OS entries inside UEFI*

3) The moment the user chooses Windows Boot Manager, UEFI will launch the `bootmgfw.efi` file from the `EFI/Microsoft` directory. On a Linux-based system, the same file's absolute path will be `/boot/efi/EFI/Microsoft/bootmgfw.efi`.

4) `bootmgfw.efi` will eventually load the kernel of Windows from `C:\windows\system32\`.

5) The Windows kernel will take care of the rest of the booting, and while doing that, a famous animation, shown in Figure 2-120, will be shown to users.

Figure 2-120. *The famous Windows loading screen*

6) As you can see from Figure 2-121, as of now, only one OS is booting, and that is Windows 10. But don't worry, because Windows 10 is bound to follow the UEFI specification, so it has not touched Ubuntu's directory and of course has not added Ubuntu's entry in its own bootloader file.

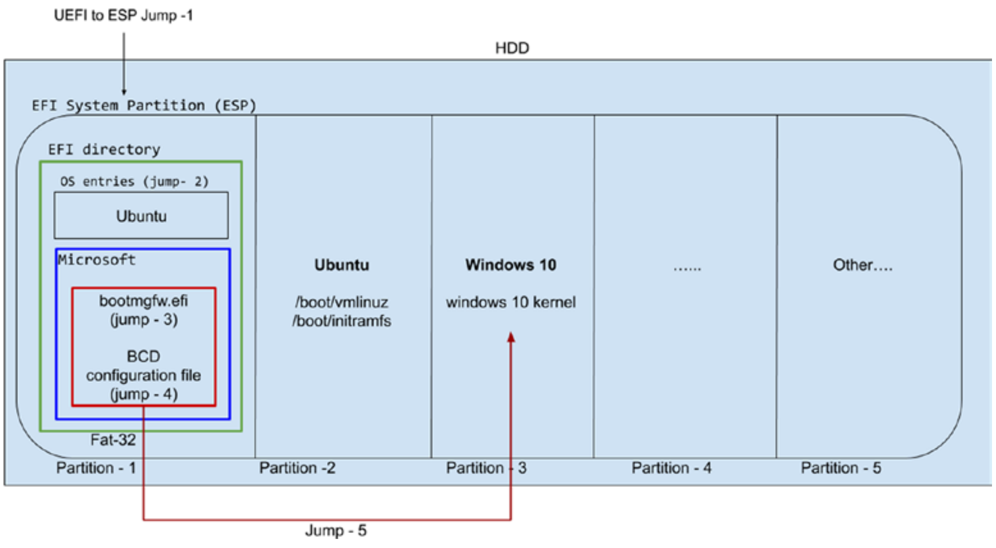


Figure 2-121. *The boot sequence of Windows 10*

Fedora 31

The final OS that we will install is Fedora 31. As shown in Figure 2-122, we will again create a standard partition, which is sda5, and we will mount `/dev/sda1` (ESP) on `/boot/efi`.

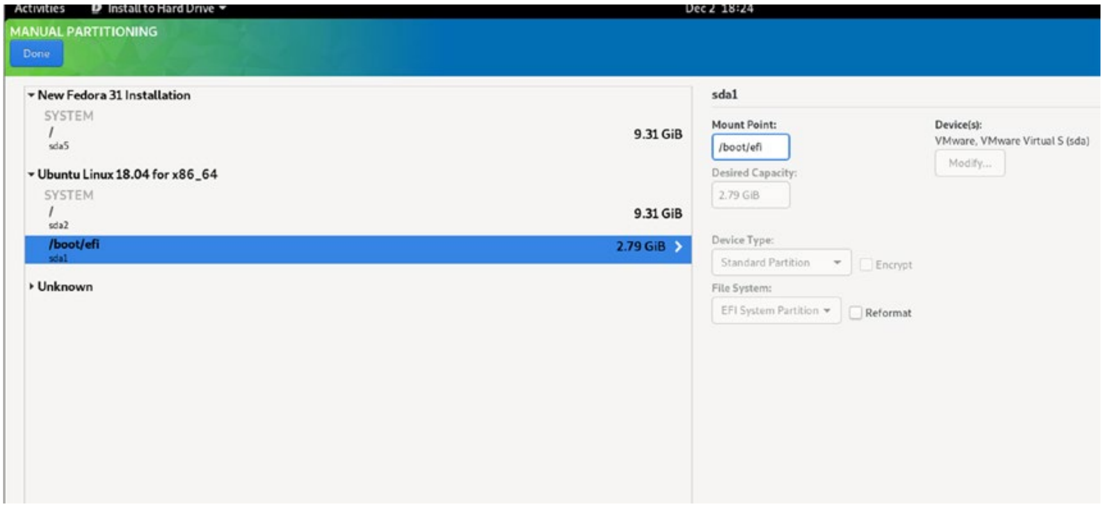
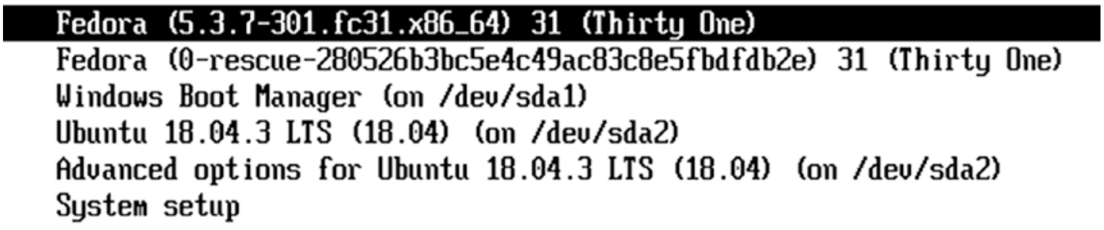


Figure 2-122. *The Fedora installation*

Remember, do not format sda1, which is ESP. Losing ESP means losing the bootloaders of Windows and Ubuntu. After installation, Fedora's GRUB will present us with the OS list (Figure 2-123).



```
Fedora (5.3.7-301.fc31.x86_64) 31 (Thirty One)
Fedora (0-rescue-280526b3bc5e4c49ac83c8e5fbdfdb2e) 31 (Thirty One)
Windows Boot Manager (on /dev/sda1)
Ubuntu 18.04.3 LTS (18.04) (on /dev/sda2)
Advanced options for Ubuntu 18.04.3 LTS (18.04) (on /dev/sda2)
System setup
```

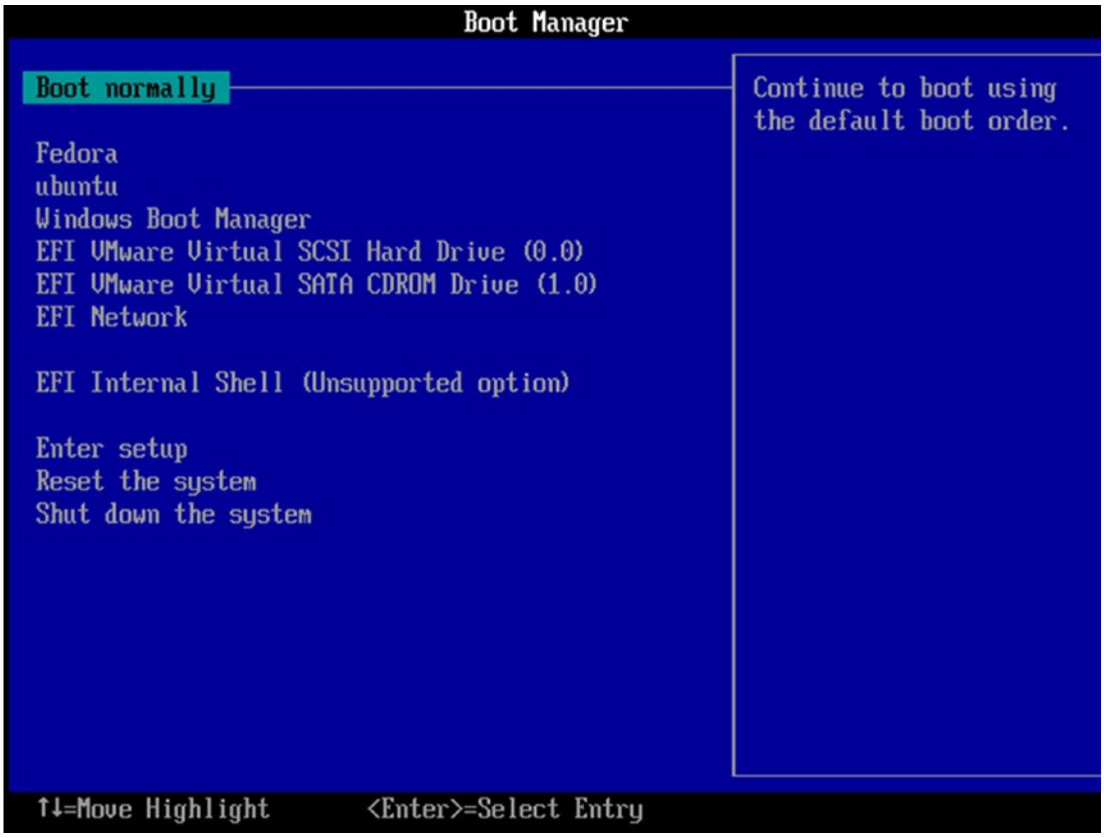
Figure 2-123. *The OS entries shown by Fedora*

While installing GRUB, the Fedora installer Anaconda detected other operating systems from ESP. To give them an equal chance to boot, Fedora added Ubuntu and Windows entries in `grub.cfg`. The following is the booting sequence of Fedora:

1) Power on the system: first UEFI, then POST, then UEFI.

2) UEFI will jump inside ESP.

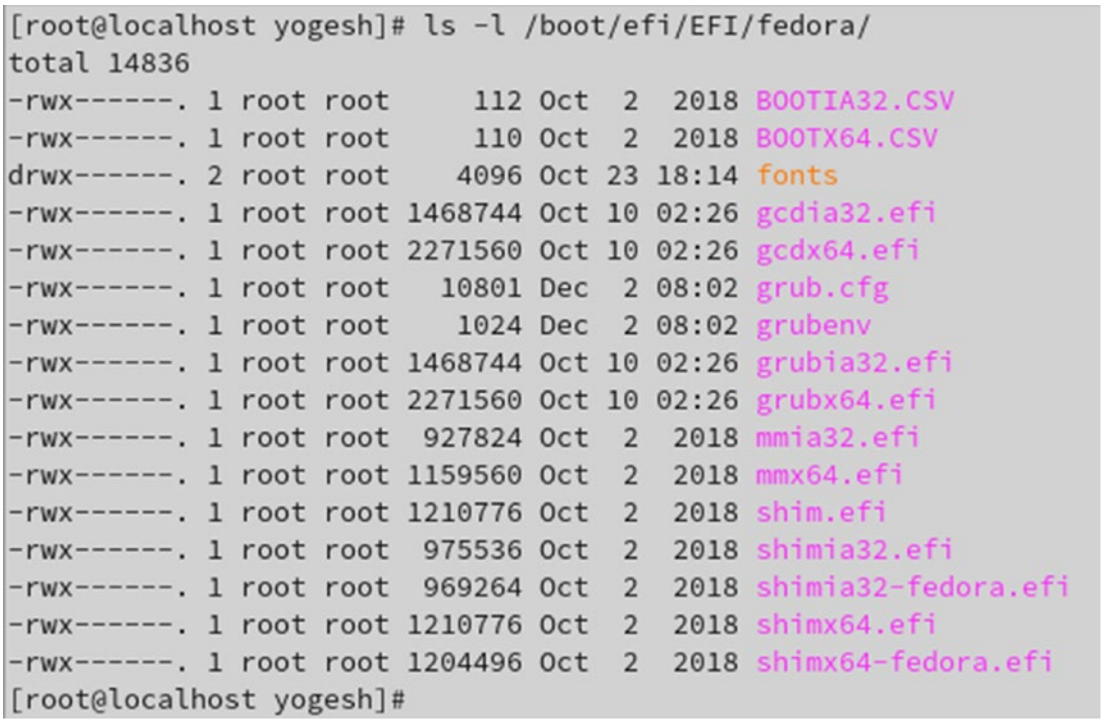
3) It will go inside an ESP directory and choose the OS to boot by checking the boot priority. As of now, the boot priority is set to Fedora. Check out Figure 2-124.



```
                              Boot Manager

 Boot normally                                  Continue to boot using
                                                the default boot order.
 Fedora
 ubuntu
 Windows Boot Manager
 EFI VMware Virtual SCSI Hard Drive (0.0)
 EFI VMware Virtual SATA CDROM Drive (1.0)
 EFI Network

 EFI Internal Shell (Unsupported option)

 Enter setup
 Reset the system
 Shut down the system

 ↑↓=Move Highlight        <Enter>=Select Entry
```

Figure 2-124. *The Fedora entry inside UEFI*

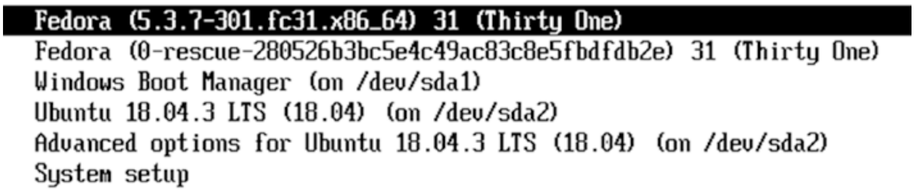
4) Since the boot priority is set to Fedora, UEFI will go inside the `/boot/efi/EFI/fedora` directory (refer Figure 2-125) and will launch the file `grubx64.efi`.



```
[root@localhost yogesh]# ls -l /boot/efi/EFI/fedora/
total 14836
-rwx------. 1 root root     112 Oct  2  2018 BOOTIA32.CSV
-rwx------. 1 root root     110 Oct  2  2018 BOOTX64.CSV
drwx------. 2 root root    4096 Oct 23 18:14 fonts
-rwx------. 1 root root 1468744 Oct 10 02:26 gcdia32.efi
-rwx------. 1 root root 2271560 Oct 10 02:26 gcdx64.efi
-rwx------. 1 root root   10801 Dec  2 08:02 grub.cfg
-rwx------. 1 root root    1024 Dec  2 08:02 grubenv
-rwx------. 1 root root 1468744 Oct 10 02:26 grubia32.efi
-rwx------. 1 root root 2271560 Oct 10 02:26 grubx64.efi
-rwx------. 1 root root  927824 Oct  2  2018 mmia32.efi
-rwx------. 1 root root 1159560 Oct  2  2018 mmx64.efi
-rwx------. 1 root root 1210776 Oct  2  2018 shim.efi
-rwx------. 1 root root  975536 Oct  2  2018 shimia32.efi
-rwx------. 1 root root  969264 Oct  2  2018 shimia32-fedora.efi
-rwx------. 1 root root 1210776 Oct  2  2018 shimx64.efi
-rwx------. 1 root root 1204496 Oct  2  2018 shimx64-fedora.efi
[root@localhost yogesh]#
```

Figure 2-125. *The Fedora EFI directory*

5) `grubx64.efi` will read the file `grub.cfg` and print the OS entries on-screen. Figure 2-126 shows this.



```
 Fedora (5.3.7-301.fc31.x86_64) 31 (Thirty One)
 Fedora (0-rescue-280526b3bc5e4c49ac83c8e5fbdfdb2e) 31 (Thirty One)
 Windows Boot Manager (on /dev/sda1)
 Ubuntu 18.04.3 LTS (18.04) (on /dev/sda2)
 Advanced options for Ubuntu 18.04.3 LTS (18.04) (on /dev/sda2)
 System setup
```

Figure 2-126. *The OS entries shown by Fedora*

6) The moment the user chooses Fedora, the same `grubx64.efi` will load `vmlinuz` and initramfs of Fedora from `/boot` (sda4) into memory. The Fedora kernel will take care of the rest of the booting sequence. Check out Figure 2-127 for the flowchart. The steps taken by the kernel will be discussed in much more detail in Chapter 4.

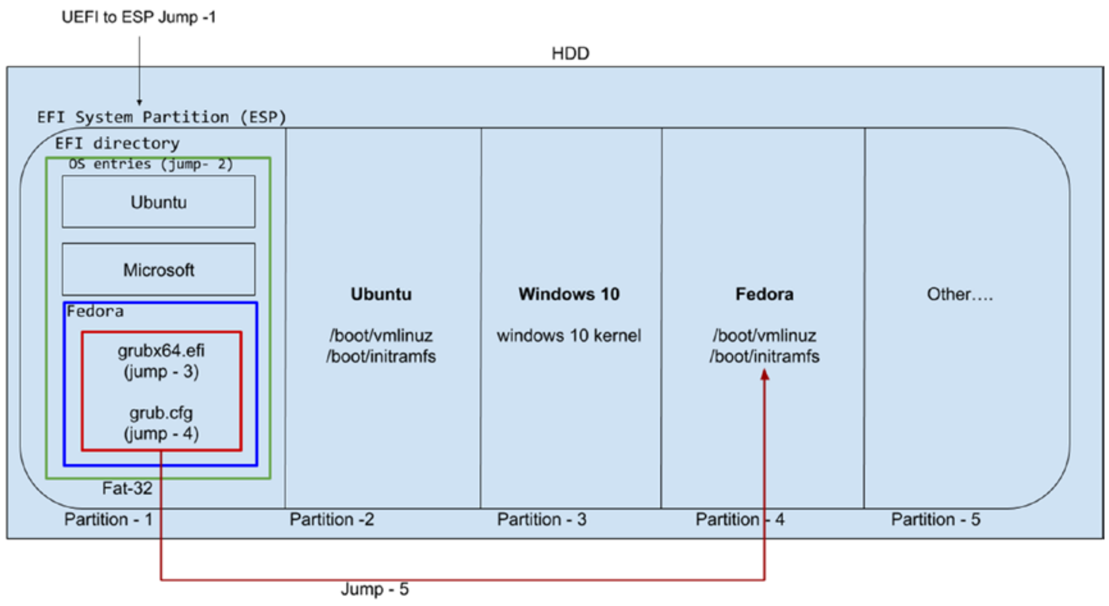
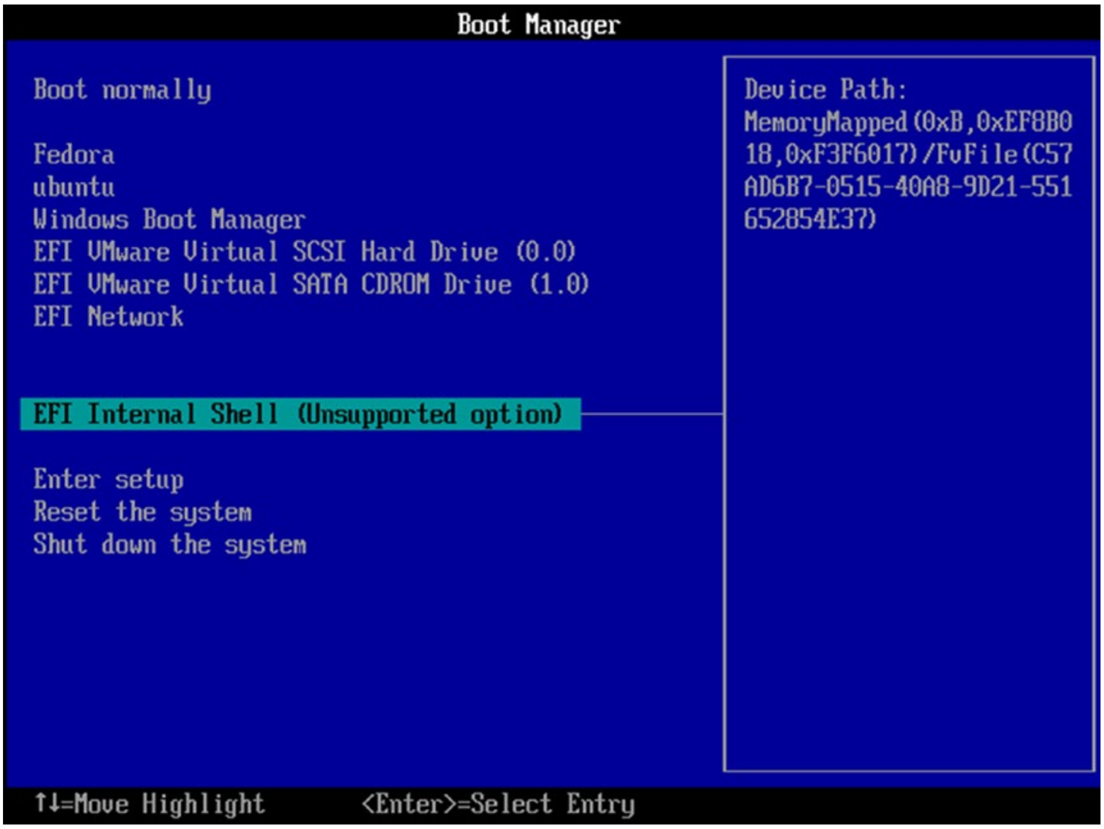


Figure 2-127. *The boot sequence of Fedora*

UEFI Shell

UEFI is a small operating system. Like normal operating systems, UEFI provides a required environment to run the applications. Of course, UEFI will not be able to run every binary, but the binaries that are built in the EFI executable format will easily be able to run. One of the best apps (application/binary) provided by UEFI is the shell. As shown in Figure 2-128, you can find it mostly in boot priority settings of UEFI.



```
                              Boot Manager
 Boot normally                                   Device Path:
                                                 MemoryMapped(0xB,0xEF8B0
 Fedora                                          18,0xF3F6017)/FvFile(C57
 ubuntu                                          AD6B7-0515-40A8-9D21-551
 Windows Boot Manager                            652854E37)
 EFI VMware Virtual SCSI Hard Drive (0.0)
 EFI VMware Virtual SATA CDROM Drive (1.0)
 EFI Network


 EFI Internal Shell (Unsupported option)

 Enter setup
 Reset the system
 Shut down the system

 ↑↓=Move Highlight        <Enter>=Select Entry
```

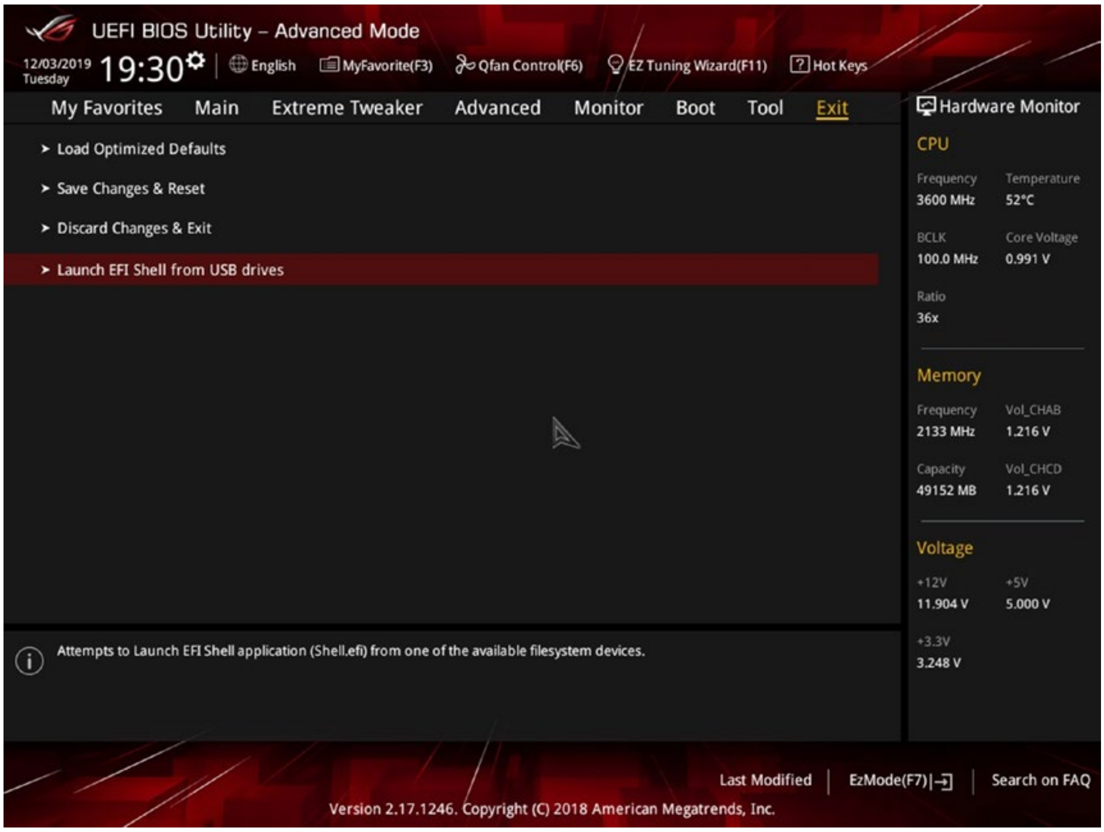
***Figure 2-128.** The built-in UEFI shell*

If your system's UEFI implementation does not provide the shell, then you can download the shell app from the TianoCore project site or from its EDK-II GitHub page.

`https://www.tianocore.org/`

`https://github.com/tianocore/edk2/blob/UDK2018/ShellBinPkg/UefiShell/X64/Shell.efi`

Format the USB device with the FAT32 filesystem and place the downloaded `Shell.efi` file in it. Boot back with the same USB device, and UEFI will present you a UEFI shell through its boot priority window. See Figure 2-129.



Load Optimized Defaults
Save Changes & Reset
Discard Changes & Exit
Launch EFI Shell from USB drives

Attempts to Launch EFI Shell application (Shell.efi) from one of the available filesystem devices.

CPU
Frequency 3600 MHz
Temperature 52°C
BCLK 100.0 MHz
Core Voltage 0.991 V
Ratio 36x

Memory
Frequency 2133 MHz
Vol_CHAB 1.216 V
Capacity 49152 MB
Vol_CHCD 1.216 V

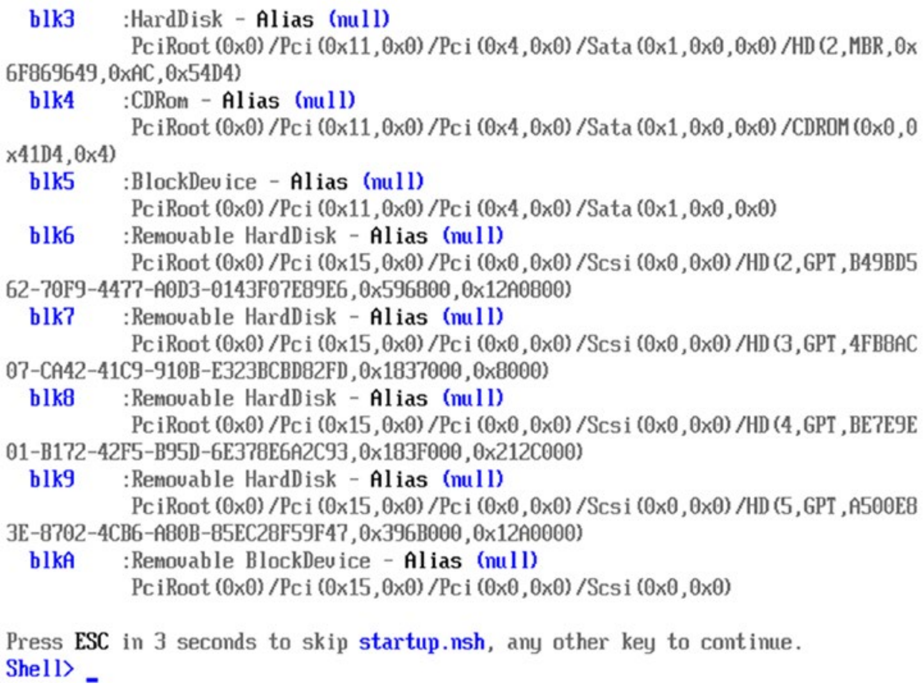
Voltage
+12V 11.904 V
+5V 5.000 V
+3.3V 3.248 V

Version 2.17.1246. Copyright (C) 2018 American Megatrends, Inc.

***Figure 2-129.** The UEFI shell loaded from USB*

The amazing thing to notice here is that UEFI did not show that the system has a USB device connected. Rather, UEFI went inside the USB device and saw the FAT32 filesystem. It saw the `shell.efi` file and realized this is not a normal EFI app; rather, it will provide the shell to the user. If it had been a BIOS, it would have only shown that system as USB disk connected, but here UEFI is showing you have a shell inside a USB-connected disk.

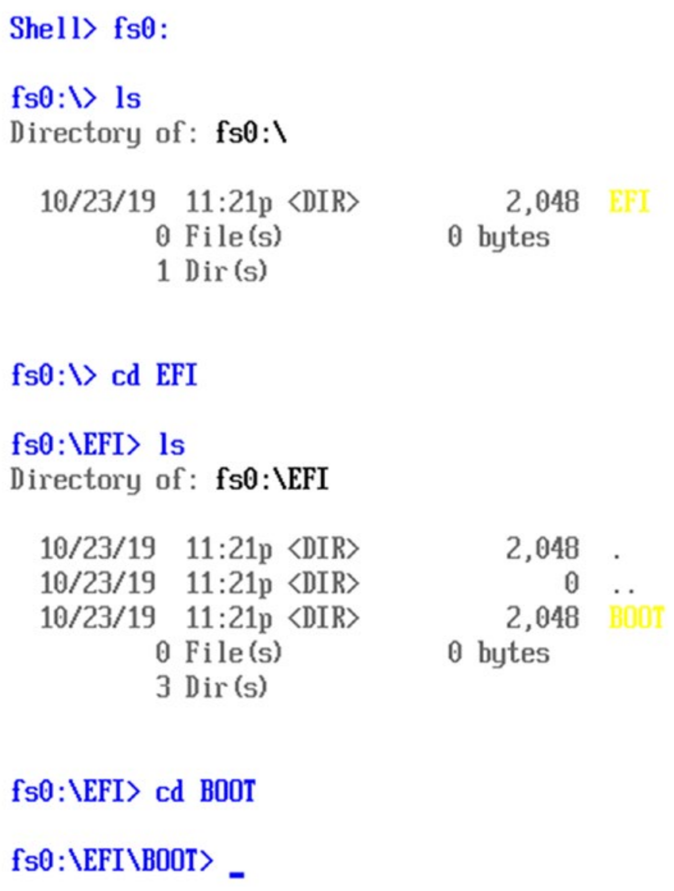
The moment you choose the option Launch EFI Shell from USB drives, it will execute the `shell.efi` file and will present you with a shell (Figure 2-130) when an OS is not present. That is remarkable.



```
  blk3     :HardDisk - Alias (null)
            PciRoot(0x0)/Pci(0x11,0x0)/Pci(0x4,0x0)/Sata(0x1,0x0,0x0)/HD(2,MBR,0x
6F869649,0xAC,0x54D4)
  blk4     :CDRom - Alias (null)
            PciRoot(0x0)/Pci(0x11,0x0)/Pci(0x4,0x0)/Sata(0x1,0x0,0x0)/CDROM(0x0,0
x41D4,0x4)
  blk5     :BlockDevice - Alias (null)
            PciRoot(0x0)/Pci(0x11,0x0)/Pci(0x4,0x0)/Sata(0x1,0x0,0x0)
  blk6     :Removable HardDisk - Alias (null)
            PciRoot(0x0)/Pci(0x15,0x0)/Pci(0x0,0x0)/Scsi(0x0,0x0)/HD(2,GPT,B49BD5
62-70F9-4477-A0D3-0143F07E89E6,0x596800,0x12A0800)
  blk7     :Removable HardDisk - Alias (null)
            PciRoot(0x0)/Pci(0x15,0x0)/Pci(0x0,0x0)/Scsi(0x0,0x0)/HD(3,GPT,4FB8AC
07-CA42-41C9-910B-E323BCBD82FD,0x1837000,0x8000)
  blk8     :Removable HardDisk - Alias (null)
            PciRoot(0x0)/Pci(0x15,0x0)/Pci(0x0,0x0)/Scsi(0x0,0x0)/HD(4,GPT,BE7E9E
01-B172-42F5-B95D-6E378E6A2C93,0x183F000,0x212C000)
  blk9     :Removable HardDisk - Alias (null)
            PciRoot(0x0)/Pci(0x15,0x0)/Pci(0x0,0x0)/Scsi(0x0,0x0)/HD(5,GPT,A500E8
3E-8702-4CB6-A80B-85EC28F59F47,0x396B000,0x12A0000)
  blkA     :Removable BlockDevice - Alias (null)
            PciRoot(0x0)/Pci(0x15,0x0)/Pci(0x0,0x0)/Scsi(0x0,0x0)

Press ESC in 3 seconds to skip startup.nsh, any other key to continue.
Shell> _
```

Figure 2-130. *The UEFI shell*

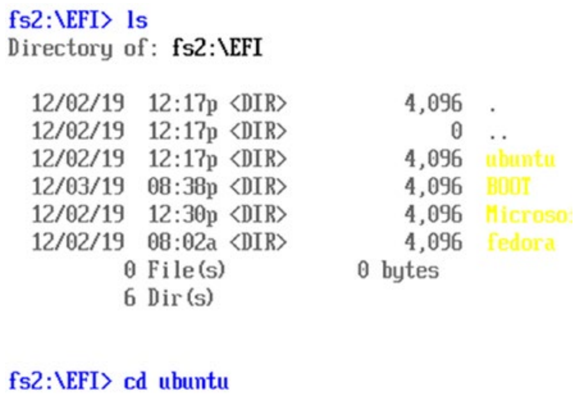
The `blk*` entries are the device names, whereas `fs*` is a filesystem naming convention. Since the UEFI shell is able to read the FAT32 filesystem (ESP partition), we can browse the ESP directory, as shown in Figure 2-131.



```
Shell> fs0:

fs0:\> ls
Directory of: fs0:\

  10/23/19  11:21p <DIR>          2,048  EFI
          0 File(s)           0 bytes
          1 Dir(s)


fs0:\> cd EFI

fs0:\EFI> ls
Directory of: fs0:\EFI

  10/23/19  11:21p <DIR>          2,048  .
  10/23/19  11:21p <DIR>              0  ..
  10/23/19  11:21p <DIR>          2,048  BOOT
          0 File(s)           0 bytes
          3 Dir(s)


fs0:\EFI> cd BOOT

fs0:\EFI\BOOT> _
```

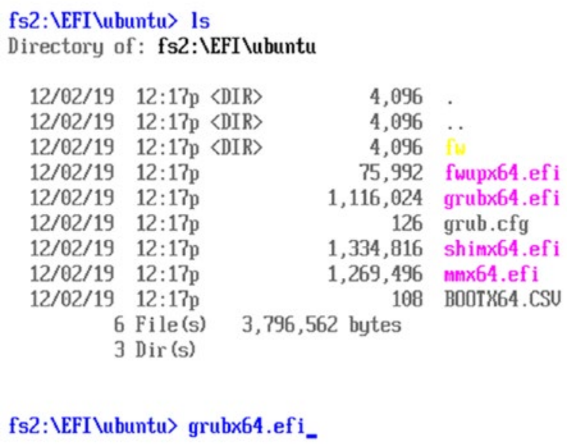
Figure 2-131. *Browsing the EFI directory*

The `fs0` stands for file system number 0. It is shell's internal command that we can use to change the partition. As you can see in Figure 2-132 and in Figure 2-133, `fs2` is our ESP.



```
fs2:\EFI> ls
Directory of: fs2:\EFI

  12/02/19  12:17p <DIR>          4,096  .
  12/02/19  12:17p <DIR>              0  ..
  12/02/19  12:17p <DIR>          4,096  ubuntu
  12/03/19  08:38p <DIR>          4,096  BOOT
  12/02/19  12:30p <DIR>          4,096  Microso
  12/02/19  08:02a <DIR>          4,096  fedora
          0 File(s)           0 bytes
          6 Dir(s)


fs2:\EFI> cd ubuntu
```

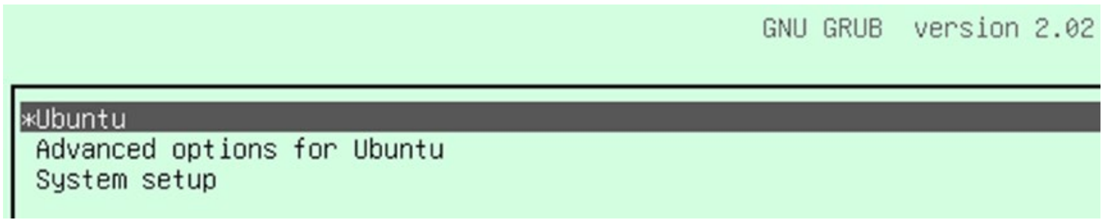
Figure 2-132. *The EFI directory*



```
fs2:\EFI\ubuntu> ls
Directory of: fs2:\EFI\ubuntu

  12/02/19  12:17p <DIR>          4,096  .
  12/02/19  12:17p <DIR>          4,096  ..
  12/02/19  12:17p <DIR>          4,096  fw
  12/02/19  12:17p               75,992  fwupx64.efi
  12/02/19  12:17p            1,116,024  grubx64.efi
  12/02/19  12:17p                  126  grub.cfg
  12/02/19  12:17p            1,334,816  shimx64.efi
  12/02/19  12:17p            1,269,496  mmx64.efi
  12/02/19  12:17p                  108  BOOTX64.CSV
          6 File(s)    3,796,562 bytes
          3 Dir(s)


fs2:\EFI\ubuntu> grubx64.efi_
```

Figure 2-133. *Ubuntu's bootloader directory*

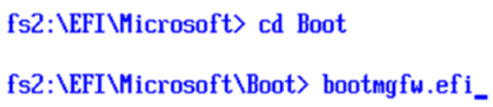
We can simply run the `grubx64.efi` file through the shell, and GRUB will appear on-screen. See Figure 2-134.



```
                                        GNU GRUB  version 2.02

*Ubuntu
 Advanced options for Ubuntu
 System setup
```

Figure 2-134. *The GRUB of Ubuntu*

For a UEFI shell, `grubx64.efi` is a simple app. In a similar way, as shown in Figure 2-135 we can launch the Windows bootloader too. See also Figure 2-136.

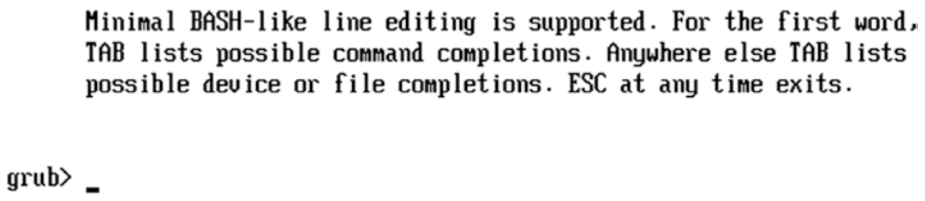


```
fs2:\EFI\Microsoft> cd Boot

fs2:\EFI\Microsoft\Boot> bootmgfw.efi_
```

Figure 2-135. *Launching the Windows bootloader from the UEFI shell*

Figure 2-136. *The famous Windows animation*

The shell can be useful in resolving the “can’t boot” scenarios. Consider the scenario shown in Figure 2-137 where the system is throwing an error on a GRUB prompt.



```
    Minimal BASH-like line editing is supported. For the first word,
    TAB lists possible command completions. Anywhere else TAB lists
    possible device or file completions. ESC at any time exits.


grub> _
```

Figure 2-137. *The system is unable to boot*

By using a UEFI shell, we are able to check whether GRUB-related files are present or not.

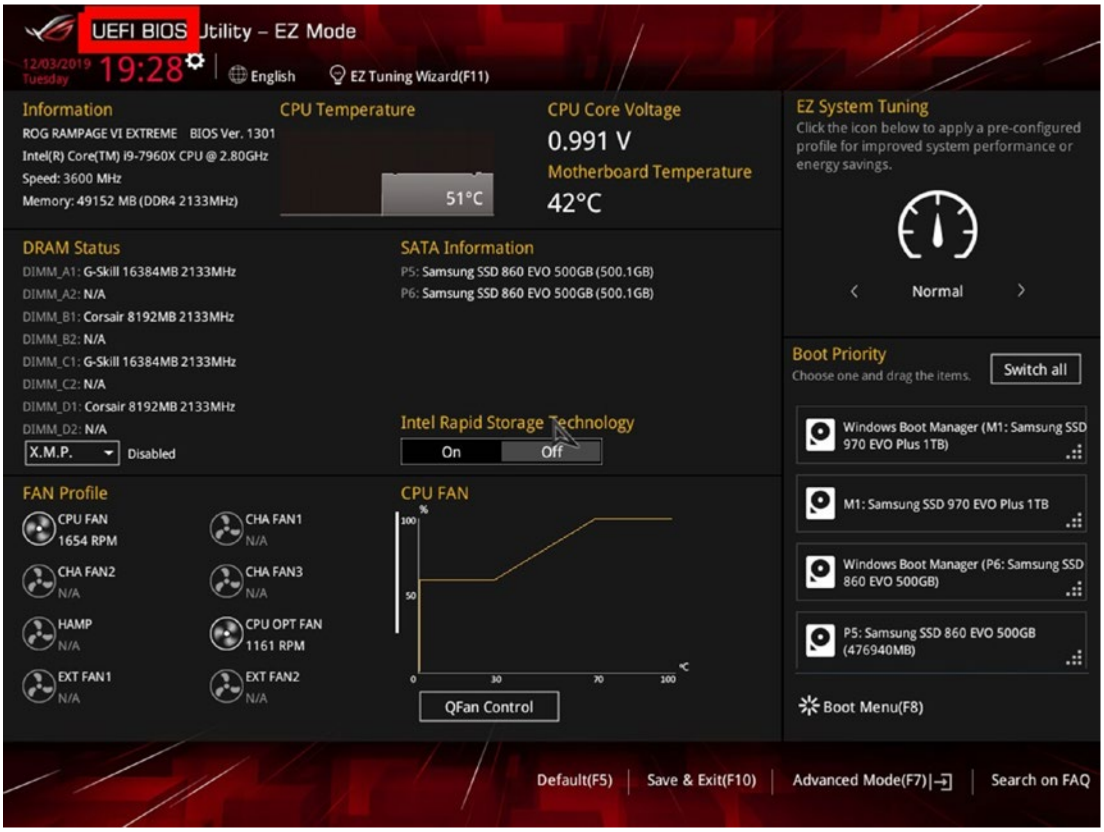
Misconceptions About UEFI

The following are some misconceptions about UEFI.

Misconception 1: UEFI Is a New BIOS or UEFI Is a BIOS

People keep saying that UEFI is a new BIOS. In fact, when you go inside the UEFI firmware, the firmware itself says it is a UEFI BIOS. Check out Figure 2-138.

No, UEFI is not a BIOS nor is it a new BIOS. UEFI is here to replace the BIOS. UEFI is a completely new firmware, and you cannot have a BIOS and UEFI on the same system. You have either UEFI or a BIOS.



UEFI BIOS Utility – EZ Mode

12/03/2019 Tuesday 19:28

Information
ROG RAMPAGE VI EXTREME BIOS Ver. 1301
Intel(R) Core(TM) i9-7960X CPU @ 2.80GHz
Speed: 3600 MHz
Memory: 49152 MB (DDR4 2133MHz)

CPU Temperature 51°C

CPU Core Voltage 0.991 V

Motherboard Temperature 42°C

EZ System Tuning
Click the icon below to apply a pre-configured profile for improved system performance or energy savings.
Normal

DRAM Status
DIMM_A1: G-Skill 16384MB 2133MHz
DIMM_A2: N/A
DIMM_B1: Corsair 8192MB 2133MHz
DIMM_B2: N/A
DIMM_C1: G-Skill 16384MB 2133MHz
DIMM_C2: N/A
DIMM_D1: Corsair 8192MB 2133MHz
DIMM_D2: N/A
X.M.P. Disabled

SATA Information
P5: Samsung SSD 860 EVO 500GB (500.1GB)
P6: Samsung SSD 860 EVO 500GB (500.1GB)

Intel Rapid Storage Technology On Off

Boot Priority
Choose one and drag the items.
Windows Boot Manager (M1: Samsung SSD 970 EVO Plus 1TB)
M1: Samsung SSD 970 EVO Plus 1TB
Windows Boot Manager (P6: Samsung SSD 860 EVO 500GB)
P5: Samsung SSD 860 EVO 500GB (476940MB)

FAN Profile
CPU FAN 1654 RPM
CHA FAN1 N/A
CHA FAN2 N/A
CHA FAN3 N/A
HAMP N/A
CPU OPT FAN 1161 RPM
EXT FAN1 N/A
EXT FAN2 N/A

Figure 2-138. *The UEFI is not a BIOS*

It is pretty simple to identify whether you have a BIOS or UEFI. If you can use a mouse inside the firmware, then you have UEFI, and if you see a rich GUI, then you have UEFI. The correct way to check is by using an `efibootmgr`-like command.

```
# efibootmgr -v

Fatal: Couldn't open either sysfs or procfs directories for accessing EFI
variables.
Try 'modprobe efivars' as root.
```

If you get output like this from the `efibootmgr` command on a Linux system, then you have a BIOS. If you get something like this, then you have UEFI:

```
# efibootmgr -v

BootCurrent: 0005
Timeout: 2 seconds
BootOrder: 0005,0004,0003,0000,0001,0002,0006,0007,000A
Boot0000* EFI VMware Virtual SCSI Hard Drive (0.0)
      PciRoot(0x0)/Pci(0x15,0x0)/Pci(0x0,0x0)/SCSI(0,0)
Boot0001* EFI VMware Virtual SATA CDROM Drive (1.0)
      PciRoot(0x0)/Pci(0x11,0x0)/Pci(0x4,0x0)/Sata(1,0,0)
```

This is the correct way of identifying what firmware your system has. Returning to our UEFI BIOS discussion, the vendors are using the UEFI and BIOS terms together because most users will not understand the term UEFI. For example, an article saying "change the parameters in your UEFI" might be confusing for most users, but saying "change the parameters in your BIOS" will be well understood by everyone. Hence, vendors are using the term UEFI/BIOS just for the sake of understanding, but remember you can have only one firmware at a time, not both.

Misconception 2: Microsoft Is Evil

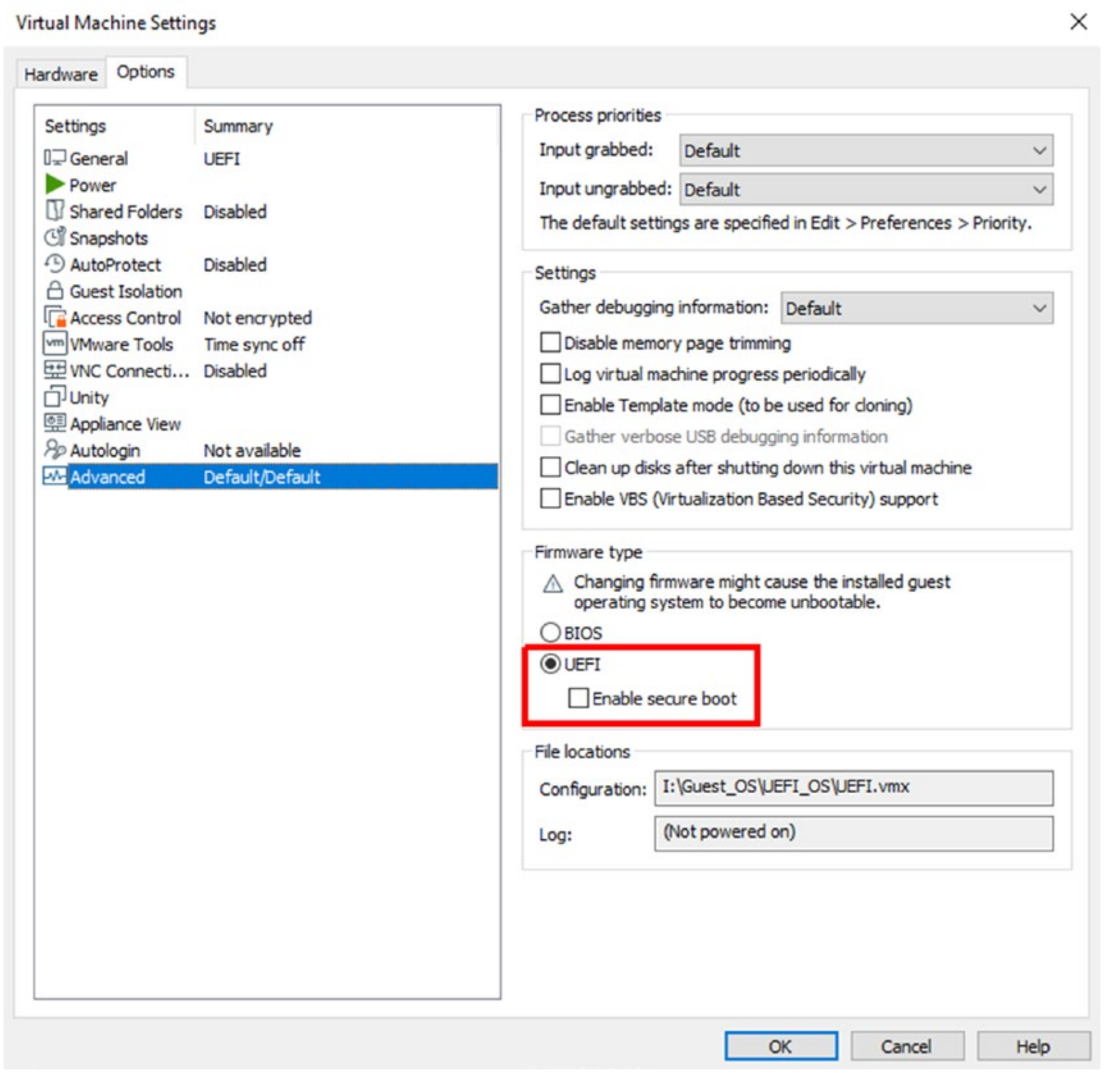
As we have seen, UEFI is a forum, and operating system vendors are part of it, including Microsoft. To make the booting more secure, Microsoft proposed a Secure Boot feature in UEFI. Secure Boot will stop the execution of unauthorized or compromised binaries at the time of the boot. This solves these three problems:

- It guarantees that `grubx64.efi`, which is about to run, is from an authentic source.
- It guarantees that BCD does not have any backdoor in it.
- It stops something from executing if it is unauthorized.

This is how Secure Boot works:

1) Microsoft will generate a key pair (public and private key).
2) Microsoft will digitally sign its bootloader or its files with the private key.
3) The public key of Microsoft will be kept inside the UEFI firmware.
4) The digital signature that was generated in step 2 will be regenerated by the public key of Microsoft, which is present inside the UEFI.
5) If the digital signature matches, then only UEFI will allow the `*.efi` file's execution.
6) If the digital signature does not match, then UEFI will consider that a harmful program, or at least it is not shipped by Microsoft, UEFI will halt the execution.

Pretty nice implementation by Microsoft, right? Yes, it is. But the problem will arise when the Secure Boot feature is enabled and you choose Linux to boot. UEFI will take out Microsoft's public key and will generate the digital signature of `grubx64.efi`. The generated digital signature will not, of course, match with Microsoft's bootloader files, so it will be considered an unauthorized program, and UEFI will stop the execution. In other words, Linux or any non-Windows OS will never be able to boot. So, what's the resolution to this? Simple: UEFI should provide an option to disable the Secure Boot feature, which it does. See Figure 2-139. In fact, the option to disable the Secure Boot feature has to be present in UEFI firmware. This is imposed in the UEFI specification.


Virtual Machine Settings

Hardware | Options

Settings	Summary
General	UEFI
Power	
Shared Folders	Disabled
Snapshots	
AutoProtect	Disabled
Guest Isolation	
Access Control	Not encrypted
VMware Tools	Time sync off
VNC Connecti...	Disabled
Unity	
Appliance View	
Autologin	Not available
Advanced	Default/Default

Process priorities
Input grabbed: Default
Input ungrabbed: Default
The default settings are specified in Edit > Preferences > Priority.

Settings
Gather debugging information: Default
☐ Disable memory page trimming
☐ Log virtual machine progress periodically
☐ Enable Template mode (to be used for cloning)
☐ Gather verbose USB debugging information
☐ Clean up disks after shutting down this virtual machine
☐ Enable VBS (Virtualization Based Security) support

Firmware type
Changing firmware might cause the installed guest operating system to become unbootable.
○ BIOS
● UEFI
☐ Enable secure boot

File locations
Configuration: I:\Guest_OS\UEFI_OS\UEFI.vmx
Log: (Not powered on)

Figure 2-139. *Disabling the Secure Boot feature*

But Microsoft has clearly called out that the only systems that will be certified are ones that have Secure Boot enabled. This means if you are hardware vendor and want your system to be certified for Windows, then it has to have Secure Boot enabled. This move was considered “evil” by some of industry leaders since non-Windows-based operating systems will not be able to boot on the same hardware. We will return to the discussion of whether Microsoft is evil or not later, but first let’s see what options non-Windows OSs have.

Linux Vendors Should Make Their Own Key Pair

Yes, every Linux OS vendor should make their own key pair and then sign their bootloaders with their private key and keep the public key in the UEFI firmware. Whenever a user chooses Windows to boot, UEFI will use the Windows public key, and whenever the user chooses Linux to boot, UEFI will use the Linux public key to regenerate the digital signature of the Linux bootloader's files. This seems to be an easy resolution, but this will not work. There are almost 200+ active Linux distributions on the market, and they generally have new versions released every six months. This means almost every six months you will have a newer version of Linux distro on the market. This means roughly that Linux vendors will have almost 400 keys a year, so obviously you cannot fit this many keys in UEFI. Even if you could, this will hamper one of the main mottos of UEFI design, which is speedy booting. So, in short, this cannot be a resolution.

All Linux Vendors Should Make Only One Key Pair

This also cannot be a resolution. There are 200+ active Linux distributions, and their offices are spread over the world. If all Linux vendors came together and made only one key pair, then this key pair would have to be shipped throughout the internet to the developers throughout the world. It would be a security nightmare. So in short, it would be difficult to maintain; hence, this is not a resolution.

Disable UEFI's Secure Boot Feature

This seems to be the only workable approach. UEFI does provide a facility to disable the Secure Boot feature, and Microsoft has no objection on providing such a facility. For example, say you have a dual-boot system, which has Windows 10 and Fedora 31 installed. If you want to boot Windows, then Secure Boot has to be enabled in UEFI, and if next time you want to boot Linux, then you have to go inside UEFI and change the enabled Secure Boot to a disabled state. You can consider this a workaround, but this is not practical; hence, it cannot be considered as a resolution.

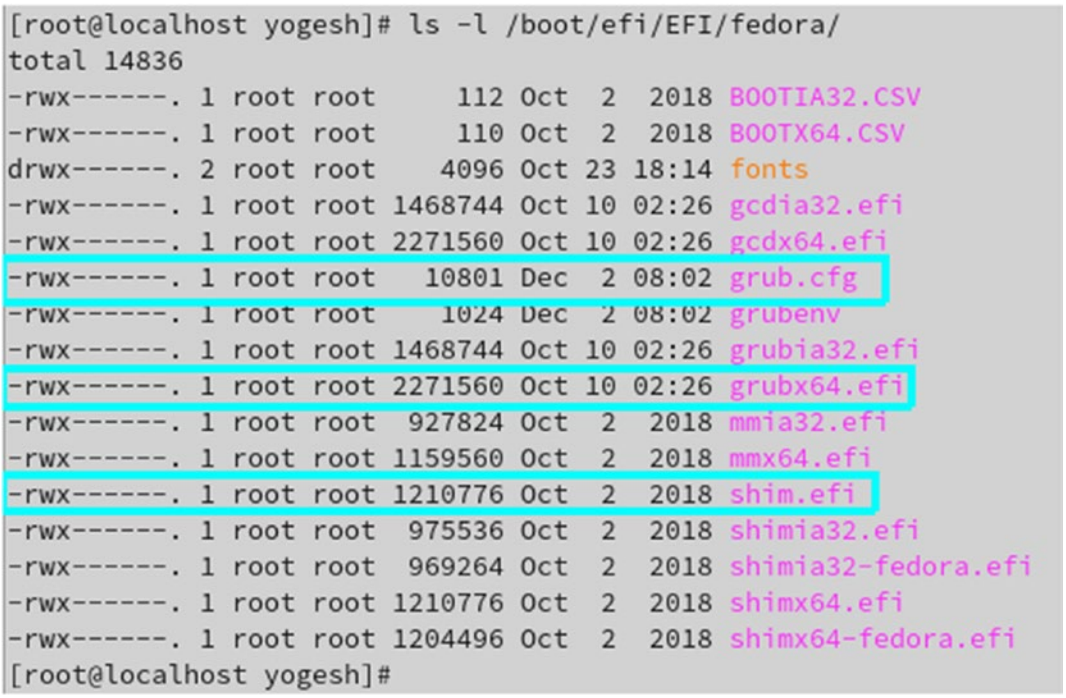
So, how can Linux take advantage of Secure Boot? There is only one resolution, and that is to use Microsoft's private key to digitally sign the Linux bootloader files, and guess what, Microsoft has agreed to this. So, at this stage, Linux is able to secure boot by using Microsoft's key pair, and hence Microsoft is certainly not evil. It just wanted to make its boot sequence secure.

But there is one problem in this arrangement; GRUB development will be dependent on Microsoft's key pair. If any new change is committed to GRUB, we need to re-sign it by using Microsoft's key. Ubuntu resolved this problem first by introducing a smaller bootloader called shim. This bootloader is supposed to get signed by Microsoft's key, and then this bootloader's job is to call the actual bootloader, which is GRUB. With this approach, the Linux world has broken Microsoft's signing dependency. Since shim will never change (at least it would be rare), GRUB development will continue the way it has.

So, if Secure Boot is enabled, then the boot sequence of Linux will be as follows:

1. Power on the system: first UEFI, then POST, and then UEFI.
2. ESP lists the operating systems and available bootable devices.
3. If the user chooses Linux, the boot process regenerates the digital signature of the `shim.efi` file by using Microsoft's public key.
4. If the digital signature matches, then allow execution of `shim.efi`.
5. `shim.efi` will call the original bootloader, which is `grubx64.efi`.
6. `grubx64.efi` will read the `grub.cfg` file from ESP and will present the available OS list.
7. If the user again chooses Linux, then the same `grubx64.efi` file will start loading the kernel and initramfs in memory.

Refer to Figure 2-140 to see the list of files involved in this boot sequence.



```
[root@localhost yogesh]# ls -l /boot/efi/EFI/fedora/
total 14836
-rwx------. 1 root root     112 Oct  2  2018 BOOTIA32.CSV
-rwx------. 1 root root     110 Oct  2  2018 BOOTX64.CSV
drwx------. 2 root root    4096 Oct 23 18:14 fonts
-rwx------. 1 root root 1468744 Oct 10 02:26 gcdia32.efi
-rwx------. 1 root root 2271560 Oct 10 02:26 gcdx64.efi
-rwx------. 1 root root   10801 Dec  2 08:02 grub.cfg
-rwx------. 1 root root    1024 Dec  2 08:02 grubenv
-rwx------. 1 root root 1468744 Oct 10 02:26 grubia32.efi
-rwx------. 1 root root 2271560 Oct 10 02:26 grubx64.efi
-rwx------. 1 root root  927824 Oct  2  2018 mmia32.efi
-rwx------. 1 root root 1159560 Oct  2  2018 mmx64.efi
-rwx------. 1 root root 1210776 Oct  2  2018 shim.efi
-rwx------. 1 root root  975536 Oct  2  2018 shimia32.efi
-rwx------. 1 root root  969264 Oct  2  2018 shimia32-fedora.efi
-rwx------. 1 root root 1210776 Oct  2  2018 shimx64.efi
-rwx------. 1 root root 1204496 Oct  2  2018 shimx64-fedora.efi
[root@localhost yogesh]#
```

Figure 2-140. *The files involved in the described boot sequence*

Misconception 3: Disable the UEFI

One of the biggest misconceptions is that you can disable UEFI and start the BIOS. No, you cannot disable the firmware of your system; also, you cannot have two firmware on one system. You have either UEFI or the BIOS. When people say "disable UEFI," it means they would like to say, let UEFI boot with the BIOS or in a legacy way. One of the biggest features of UEFI is that it is backward compatible, meaning it does understand the BIOS way of booting, which is the 512 bytes + 31KB approach. So, when you change the UEFI settings from the UEFI way to the legacy way, it only means that UEFI will not follow the ESP way of booting. Rather, the firmware will follow the BIOS way of booting, but this does not mean you are disabling the UEFI firmware. When you boot a UEFI system the BIOS way, then you lose all the features that UEFI provides.

Since you now have a better understanding of firmware and the way bootloaders work, it is the right time to dive deeper into the GRUB bootloader.

CHAPTER 3

GRUB Bootloader

The bootloader that Linux systems use these days is GRUB version 2. The first stable release of GRUB 2 was in 2012, but it started appearing in enterprise-level Linux in 2014 with Centos 7 and RHEL 7. After 2015, it saw wide adoption in almost every popular Linux distribution. Usually when users file bugs or ask for new features, developers listen to the feedback, prioritize the work, and eventually launch a new version of code. However, in the case of GRUB, it worked another way. The developers decided to change the entire structure of GRUB 2 when users were happy with GRUB Legacy (version 1).

> "GRUB Legacy has become unmaintainable, due to messy code and design failures. We received many feature requests, and extended GRUB beyond the original scope, without redesigning the framework. This resulted in the state that it was impossible to extend GRUB any further without rethinking everything from the ground."
>
> —GNU GRUB FAQ (`https://www.gnu.org/software/grub/grub-faq.html`)

Here are some of the features that GRUB 2 provides or are in development:

- Full USB support.
- Linux Unified Setup Key (LUKS) support. LUKS is the standard for Linux hard disk encryption.
- A fancy menu implementation that will have animations, colorful effects, style sheets, etc.
- A "parted" tool will be added inside the bootloader. When this is added, users will be able to edit the disk configuration at the time of boot.

© Yogesh Babar 2020
Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_3

This chapter will cover the following:

– How GRUB 2 is implemented for the BIOS and UEFI firmware

– The firmware-specific structural changes in GRUB 2

– The Bootloader Specification feature of GRUB 2

– The Secure Boot feature of UEFI and how it is implemented in GRUB 2

– Several bootloader-related issues and how we can fix them

GRUB 2 Implementation

As we have seen so far, GRUB takes control of the firmware. This means it has to deal with UEFI as well as the BIOS. Let's see how GRUB 2 has been implemented on BIOS-based systems first.

GRUB 2 on BIOS-Based Systems

GRUB 2 on a BIOS-based system keeps all of its files in three different locations.

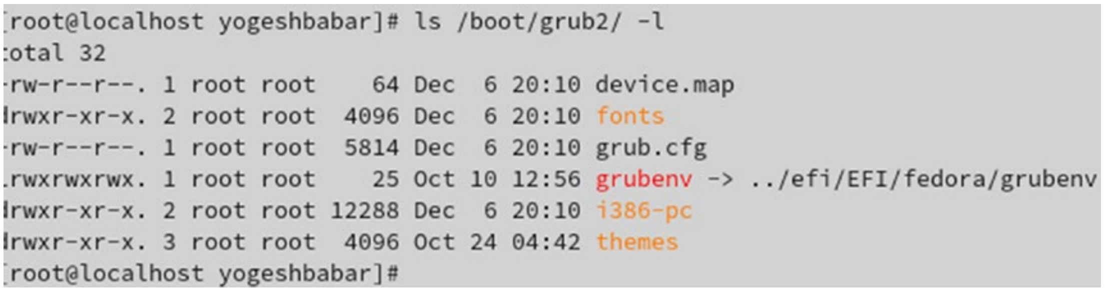
- `/boot/grub2/`
- `/etc/default/grub`
- `/etc/grub.d/`

In the case of Ubuntu, version 2 is not used in GRUB's name, so it will be `/boot/grub/` instead of `/boot/grub2/`, `grub-install` instead of `grub2-install`, or `grub-mkconfig` instead of `grub2-mkconfig`.

Let's discuss the locations and their contents.

/boot/grub2

This is the location where GRUB 2 will be installed. As you can see in Figure 3-1, the directory holds the bootloader's core files.



```
[root@localhost yogeshbabar]# ls /boot/grub2/ -l
:otal 32
-rw-r--r--. 1 root root    64 Dec  6 20:10 device.map
drwxr-xr-x. 2 root root  4096 Dec  6 20:10 fonts
-rw-r--r--. 1 root root  5814 Dec  6 20:10 grub.cfg
.rwxrwxrwx. 1 root root    25 Oct 10 12:56 grubenv -> ../efi/EFI/fedora/grubenv
drwxr-xr-x. 2 root root 12288 Dec  6 20:10 i386-pc
drwxr-xr-x. 3 root root  4096 Oct 24 04:42 themes
[root@localhost yogeshbabar]#
```

Figure 3-1. *The files present in /boot/grub2*

Device.map

GRUB does not understand disk names like sda or vda since these disk naming conventions were created by the SCSI drivers of operating systems. It is obvious that GRUB runs when the OS is not present, so it has its own disk naming convention. The following are GRUB's disk naming conventions:

GRUB Version	Disk Naming Convention	Meaning
2	`hd0, msdos1`	Hard disk number 0 and partition number 1, which has an MS-DOS partition table
2	`hd1, msdos3`	Hard disk number 2 and partition number 3, which has an MS-DOS partition table
2	`hd2, gpt1`	Hard disk number 3 and partition number 1, which has a GPT partition table
1	`hd0, 0`	Hard disk number 0 and partition number 1

In GRUB, the hard disk starts at 0, and the partition numbers start at 1, whereas the OS naming conventions of disks and partitions start at 1. Since the OS and GRUB disk naming conventions are different, there has to be a mapping for the users, and that is why the `device.map` file was created.

```
# cat /boot/grub2/device.map
      # this device map was generated by anaconda
      (hd0)      /dev/sda
```

The device.map file will be used by the grub2-install like commands to understand on which disk GRUB's core files are installed. Here's an example of this file:

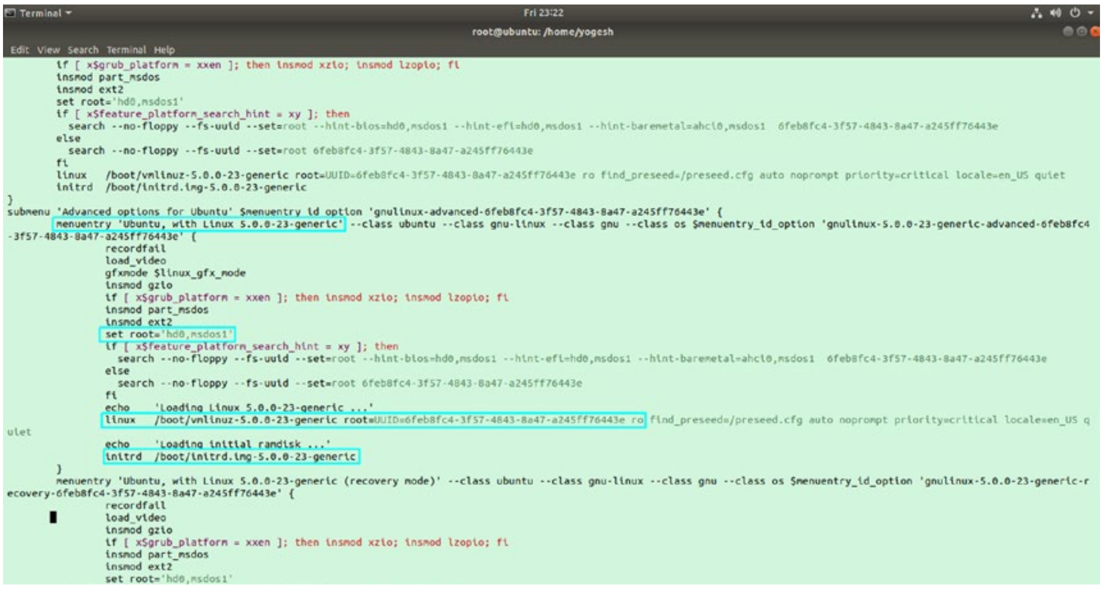
```
# strace -o delete_it.txt  grub2-install  /dev/sda
      Installing for i386-pc platform.
      Installation finished. No error reported.

# cat delete_it.txt | grep -i 'device.map'
      openat(AT_FDCWD, "/boot/grub2/device.map", O_RDONLY) = 3
      read(3, "# this device map was generated "..., 4096) = 64
      openat(AT_FDCWD, "/boot/grub2/device.map", O_RDONLY) = 3
      read(3, "# this device map was generated "..., 4096) = 64
```

The grub2-install command will take input in the form of the OS disk naming conventions since users are not aware of the GRUB disk naming conventions. During the execution, grub2-install will convert the SCSI disk naming conventions to the GRUB disk naming conventions by reading the device.map file.

grub.cfg

This is the main configuration file of GRUB. As you can see in Figure 3-2, it's a huge script file that is generated by referring to some other script files, which we will discuss soon. It is highly advisable not to change the contents of grub.cfg as doing so might make your Linux version unbootable. This is the file from which GRUB part-3 takes instructions like the following:

- Location of the kernel and initramfs
    - /boot/vmlinuz-<version>
    - /boot/initramfs-<version>
- Kernel command-line parameters
    - Root filesystem name and its location, etc.



```
        if [ x$grub_platform = xxen ]; then insmod xzio; insmod lzopio; fi
        insmod part_msdos
        insmod ext2
        set root='hd0,msdos1'
        if [ x$feature_platform_search_hint = xy ]; then
          search --no-floppy --fs-uuid --set=root --hint-bios=hd0,msdos1 --hint-efi=hd0,msdos1 --hint-baremetal=ahci0,msdos1  6feb8fc4-3f57-4843-8a47-a245ff76443e
        else
          search --no-floppy --fs-uuid --set=root 6feb8fc4-3f57-4843-8a47-a245ff76443e
        fi
        linux   /boot/vmlinuz-5.0.0-23-generic root=UUID=6feb8fc4-3f57-4843-8a47-a245ff76443e ro find_preseed=/preseed.cfg auto noprompt priority=critical locale=en_US quiet
        initrd  /boot/initrd.img-5.0.0-23-generic
}
submenu 'Advanced options for Ubuntu' $menuentry_id_option 'gnulinux-advanced-6feb8fc4-3f57-4843-8a47-a245ff76443e' {
        menuentry 'Ubuntu, with Linux 5.0.0-23-generic' --class ubuntu --class gnu-linux --class gnu --class os $menuentry_id_option 'gnulinux-5.0.0-23-generic-advanced-6feb8fc4
-3f57-4843-8a47-a245ff76443e' {
                recordfail
                load_video
                gfxmode $linux_gfx_mode
                insmod gzio
                if [ x$grub_platform = xxen ]; then insmod xzio; insmod lzopio; fi
                insmod part_msdos
                insmod ext2
                set root='hd0,msdos1'
                if [ x$feature_platform_search_hint = xy ]; then
                  search --no-floppy --fs-uuid --set=root --hint-bios=hd0,msdos1 --hint-efi=hd0,msdos1 --hint-baremetal=ahci0,msdos1  6feb8fc4-3f57-4843-8a47-a245ff76443e
                else
                  search --no-floppy --fs-uuid --set=root 6feb8fc4-3f57-4843-8a47-a245ff76443e
                fi
                echo    'Loading Linux 5.0.0-23-generic ...'
                linux   /boot/vmlinuz-5.0.0-23-generic root=UUID=6feb8fc4-3f57-4843-8a47-a245ff76443e ro find_preseed=/preseed.cfg auto noprompt priority=critical locale=en_US q
uiet
                echo    'Loading initial ramdisk ...'
                initrd  /boot/initrd.img-5.0.0-23-generic
        }
        menuentry 'Ubuntu, with Linux 5.0.0-23-generic (recovery mode)' --class ubuntu --class gnu-linux --class gnu --class os $menuentry_id_option 'gnulinux-5.0.0-23-generic-r
ecovery-6feb8fc4-3f57-4843-8a47-a245ff76443e' {
                recordfail
                load_video
                insmod gzio
                if [ x$grub_platform = xxen ]; then insmod xzio; insmod lzopio; fi
                insmod part_msdos
                insmod ext2
                set root='hd0,msdos1'
```

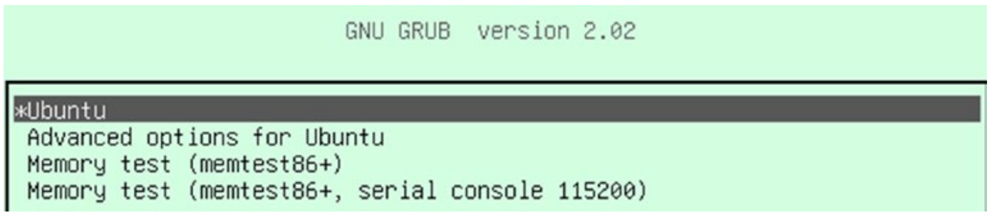
Figure 3-2. *The grub.cfg file*

GRUB has its own set of commands, as you can see here:

GRUB Command	Purpose
`menuentry`	This will print the title on-screen.
`set root`	This will provide the disk and partition names where the kernel and initramfs are stored.
`linux`	The absolute path of the Linux kernel file
`initrd`	The absolute path of the initramfs file of Linux

So, the booting sequence of GRUB 2 on a BIOS-based system of Fedora is as follows:

1. Power on a system: first BIOS, then POST, then BIOS, and then the first sector.
2. First is the bootstrap (part-1 of GRUB), then part-2 of GRUB, and then part-3 of GRUB.
3. Part-3 of GRUB will read the previously shown `grub.cfg` from `/boot/grub2/` (in the case of Ubuntu, it will be `/boot/grub/`) and will print the welcome screen, as shown in Figure 3-3.



```
                    GNU GRUB  version 2.02

*Ubuntu
 Advanced options for Ubuntu
 Memory test (memtest86+)
 Memory test (memtest86+, serial console 115200)
```

***Figure 3-3.** The welcome screen*

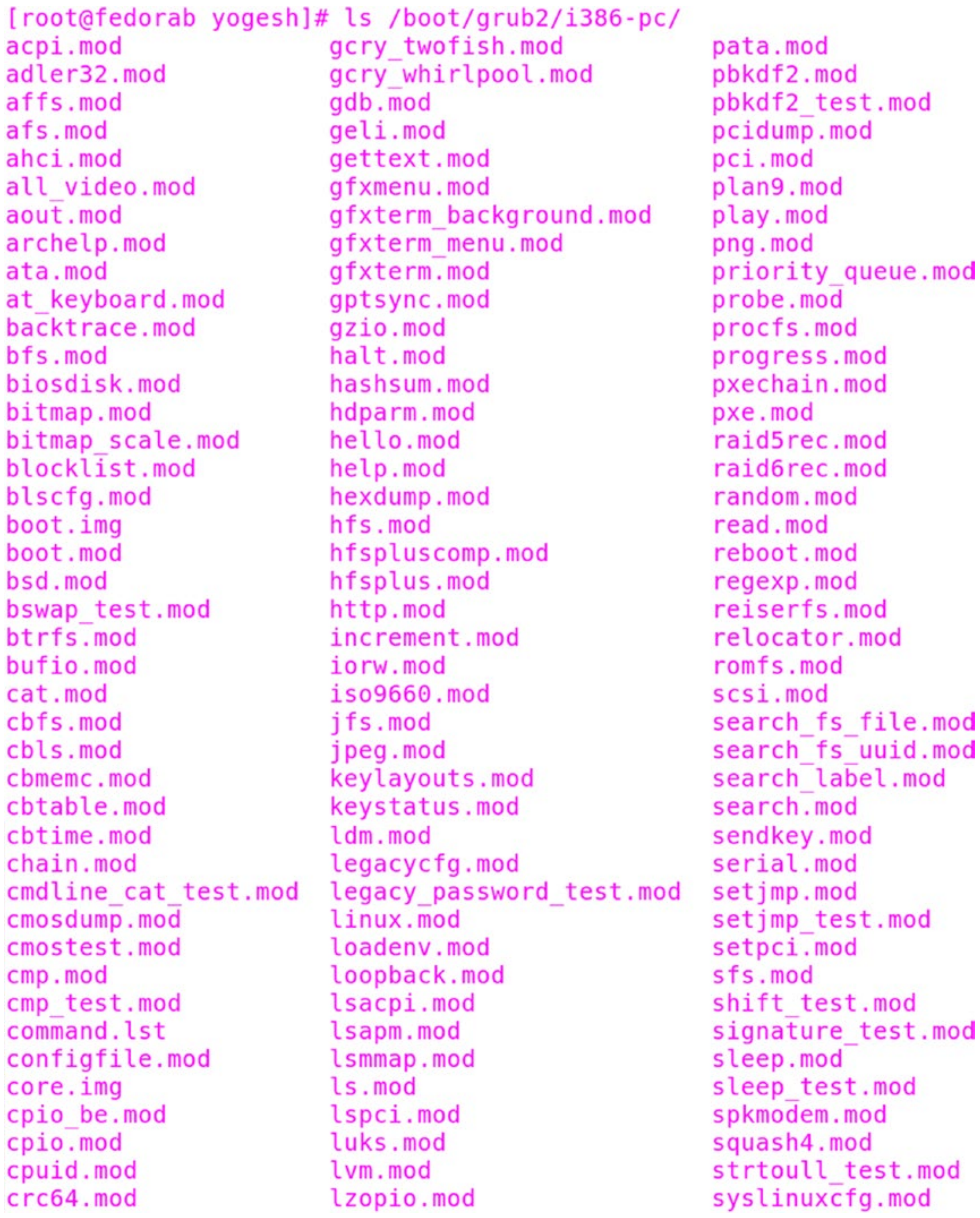
4. The moment the user chooses the Ubuntu `menuentry`, it will run the `set root`, `linux`, and `initrd` commands and will start loading the kernel and initramfs in memory.

5. In Fedora-like Linux distributions, you will find a different approach. There will be a `grub.cfg` file, but the `menuentry`, `set root`, `linux`, and `initrd` commands will not be available in `grub.cfg`. There has been a new development in a GRUB upstream project called BLS. We will cover that later in this chapter.

i386-pc

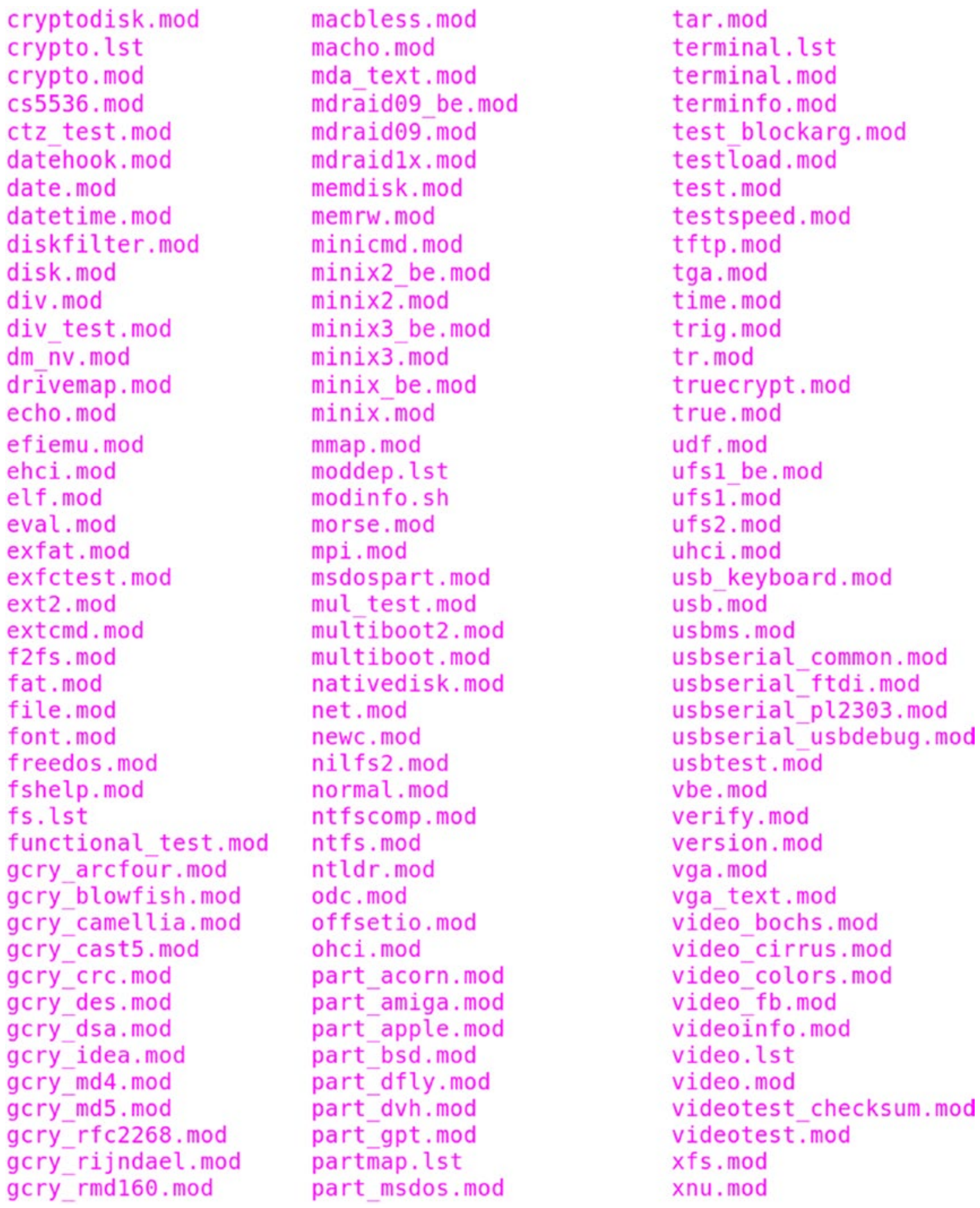
This directory has all the GRUB-supported filesystem modules (drivers) in it (please refer to Figure 3-4). All the `*.mod` files are the modules. By using these modules, GRUB can load the kernel and initramfs files in memory. For example, the `/boot` of this system has an ext4 filesystem, so obviously when exploring and loading the `vmlinuz` and initramfs files from `/boot`, GRUB needs the ext4 module, which it gets from the `ext4.mod` file. It's similar to `/boot` on the XFS or UFS filesystem; hence, the `xfs.mod` and `ufs.mod` files are present in `/boot/grub2/i386-pc`. At the same time, you will find modules like `http.mod` and `pxe.mod`. This means GRUB 2's part-3 can load the kernel and initramfs files from the `http` and `pxe` devices. In general, the `*.mod` files add features, not just devices. The features may include device support, filesystem support, or protocol support.

Earlier, `/boot` under LVM was not possible, and the reason was simple. GRUB had to understand the LVM devices. To understand and assemble the LVM device, GRUB would need the LVM module as well as LVM binaries such as `vgscan, vgchange, pvs, lvscan,` etc. It would increase the size of GRUB as a package; hence, the enterprise Linux system vendors have always avoided `/boot` under LVM devices. But since UEFI has been introduced, GRUB has started supporting `/boot` on LVM devices.



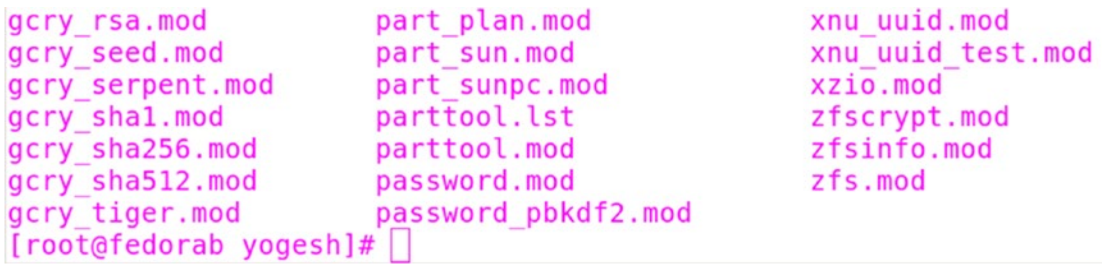
```
[root@fedorab yogesh]# ls /boot/grub2/i386-pc/
acpi.mod              gcry_twofish.mod          pata.mod
adler32.mod           gcry_whirlpool.mod        pbkdf2.mod
affs.mod              gdb.mod                   pbkdf2_test.mod
afs.mod               geli.mod                  pcidump.mod
ahci.mod              gettext.mod               pci.mod
all_video.mod         gfxmenu.mod               plan9.mod
aout.mod              gfxterm_background.mod    play.mod
archelp.mod           gfxterm_menu.mod          png.mod
ata.mod               gfxterm.mod               priority_queue.mod
at_keyboard.mod       gptsync.mod               probe.mod
backtrace.mod         gzio.mod                  procfs.mod
bfs.mod               halt.mod                  progress.mod
biosdisk.mod          hashsum.mod               pxechain.mod
bitmap.mod            hdparm.mod                pxe.mod
bitmap_scale.mod      hello.mod                 raid5rec.mod
blocklist.mod         help.mod                  raid6rec.mod
blscfg.mod            hexdump.mod               random.mod
boot.img              hfs.mod                   read.mod
boot.mod              hfspluscomp.mod           reboot.mod
bsd.mod               hfsplus.mod               regexp.mod
bswap_test.mod        http.mod                  reiserfs.mod
btrfs.mod             increment.mod             relocator.mod
bufio.mod             iorw.mod                  romfs.mod
cat.mod               iso9660.mod               scsi.mod
cbfs.mod              jfs.mod                   search_fs_file.mod
cbls.mod              jpeg.mod                  search_fs_uuid.mod
cbmemc.mod            keylayouts.mod            search_label.mod
cbtable.mod           keystatus.mod             search.mod
cbtime.mod            ldm.mod                   sendkey.mod
chain.mod             legacycfg.mod             serial.mod
cmdline_cat_test.mod  legacy_password_test.mod  setjmp.mod
cmosdump.mod          linux.mod                 setjmp_test.mod
cmostest.mod          loadenv.mod               setpci.mod
cmp.mod               loopback.mod              sfs.mod
cmp_test.mod          lsacpi.mod                shift_test.mod
command.lst           lsapm.mod                 signature_test.mod
configfile.mod        lsmmap.mod                sleep.mod
core.img              ls.mod                    sleep_test.mod
cpio_be.mod           lspci.mod                 spkmodem.mod
cpio.mod              luks.mod                  squash4.mod
cpuid.mod             lvm.mod                   strtoull_test.mod
crc64.mod             lzopio.mod                syslinuxcfg.mod
```

Figure 3-4. *The .mod* files from /boot/grub2/i386-pc*



```
cryptodisk.mod        macbless.mod          tar.mod
crypto.lst            macho.mod             terminal.lst
crypto.mod            mda_text.mod          terminal.mod
cs5536.mod            mdraid09_be.mod       terminfo.mod
ctz_test.mod          mdraid09.mod          test_blockarg.mod
datehook.mod          mdraid1x.mod          testload.mod
date.mod              memdisk.mod           test.mod
datetime.mod          memrw.mod             testspeed.mod
diskfilter.mod        minicmd.mod           tftp.mod
disk.mod              minix2_be.mod         tga.mod
div.mod               minix2.mod            time.mod
div_test.mod          minix3_be.mod         trig.mod
dm_nv.mod             minix3.mod            tr.mod
drivemap.mod          minix_be.mod          truecrypt.mod
echo.mod              minix.mod             true.mod
efiemu.mod            mmap.mod              udf.mod
ehci.mod              moddep.lst            ufs1_be.mod
elf.mod               modinfo.sh            ufs1.mod
eval.mod              morse.mod             ufs2.mod
exfat.mod             mpi.mod               uhci.mod
exfctest.mod          msdospart.mod         usb_keyboard.mod
ext2.mod              mul_test.mod          usb.mod
extcmd.mod            multiboot2.mod        usbms.mod
f2fs.mod              multiboot.mod         usbserial_common.mod
fat.mod               nativedisk.mod        usbserial_ftdi.mod
file.mod              net.mod               usbserial_pl2303.mod
font.mod              newc.mod              usbserial_usbdebug.mod
freedos.mod           nilfs2.mod            usbtest.mod
fshelp.mod            normal.mod            vbe.mod
fs.lst                ntfscomp.mod          verify.mod
functional_test.mod   ntfs.mod              version.mod
gcry_arcfour.mod      ntldr.mod             vga.mod
gcry_blowfish.mod     odc.mod               vga_text.mod
gcry_camellia.mod     offsetio.mod          video_bochs.mod
gcry_cast5.mod        ohci.mod              video_cirrus.mod
gcry_crc.mod          part_acorn.mod        video_colors.mod
gcry_des.mod          part_amiga.mod        video_fb.mod
gcry_dsa.mod          part_apple.mod        videoinfo.mod
gcry_idea.mod         part_bsd.mod          video.lst
gcry_md4.mod          part_dfly.mod         video.mod
gcry_md5.mod          part_dvh.mod          videotest_checksum.mod
gcry_rfc2268.mod      part_gpt.mod          videotest.mod
gcry_rijndael.mod     partmap.lst           xfs.mod
gcry_rmd160.mod       part_msdos.mod        xnu.mod
```

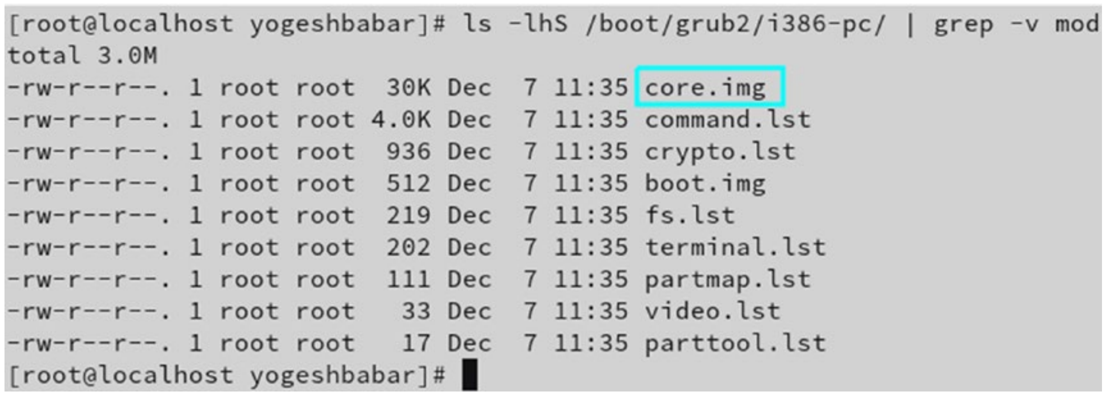
Figure 3-4. *(continued)*



```
gcry_rsa.mod            part_plan.mod              xnu_uuid.mod
gcry_seed.mod           part_sun.mod               xnu_uuid_test.mod
gcry_serpent.mod        part_sunpc.mod             xzio.mod
gcry_sha1.mod           parttool.lst               zfscrypt.mod
gcry_sha256.mod         parttool.mod               zfsinfo.mod
gcry_sha512.mod         password.mod               zfs.mod
gcry_tiger.mod          password_pbkdf2.mod
[root@fedorab yogesh]#
```

Figure 3-4. *(continued)*

As you can see in Figure 3-5, along with these `*.mod` files, you will find a couple of other files in the `/boot/grub2/i386-pc/` location.



```
[root@localhost yogeshbabar]# ls -lhS /boot/grub2/i386-pc/ | grep -v mod
total 3.0M
-rw-r--r--. 1 root root  30K Dec  7 11:35 core.img
-rw-r--r--. 1 root root 4.0K Dec  7 11:35 command.lst
-rw-r--r--. 1 root root  936 Dec  7 11:35 crypto.lst
-rw-r--r--. 1 root root  512 Dec  7 11:35 boot.img
-rw-r--r--. 1 root root  219 Dec  7 11:35 fs.lst
-rw-r--r--. 1 root root  202 Dec  7 11:35 terminal.lst
-rw-r--r--. 1 root root  111 Dec  7 11:35 partmap.lst
-rw-r--r--. 1 root root   33 Dec  7 11:35 video.lst
-rw-r--r--. 1 root root   17 Dec  7 11:35 parttool.lst
[root@localhost yogeshbabar]#
```

Figure 3-5. *The files in addition to *.mod*

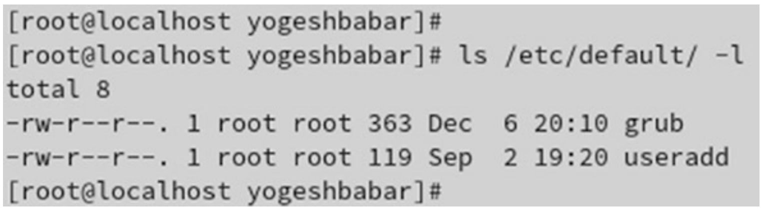
The `core.img` file is part-3 of GRUB 2. So, the Linux booting sequence becomes as follows:

```
-> Power on -> BIOS -> POST -> BIOS ->
-> part-1 of GRUB2 -> Part-2 of GRUB2 -> core3.img -> grub.cfg ->
-> if /boot is on an xfs filesystem -> /boot/grub2/i386-pc/xfs.mod ->
-> load vmlinuz & initramfs in main memory.
```

Once the kernel is in memory, GRUB 2's job is done. The rest of the booting sequence will be carried out by the kernel, which we will discuss in Chapter 4.

/etc/default/grub

Another important file is, of course, `/etc/default/grub`. Please see Figure 3-6.



```
[root@localhost yogeshbabar]#
[root@localhost yogeshbabar]# ls /etc/default/ -l
total 8
-rw-r--r--. 1 root root 363 Dec  6 20:10 grub
-rw-r--r--. 1 root root 119 Sep  2 19:20 useradd
[root@localhost yogeshbabar]#
```

Figure 3-6. *The contents of the /etc/default directory*

This file is used by GRUB to accept the cosmetic and kernel command-line changes from the user.

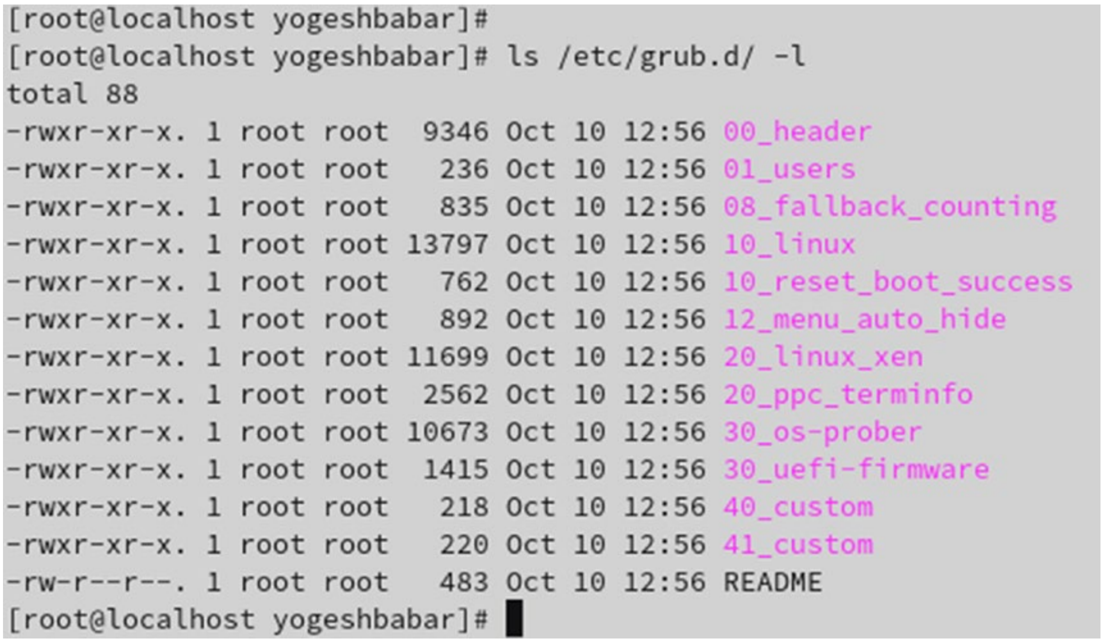
```
$ cat /etc/default/grub
GRUB_TIMEOUT=10
GRUB_DISTRIBUTOR="$(sed 's, release .*$,,g' /etc/system-release)"
GRUB_DEFAULT=saved
GRUB_DISABLE_SUBMENU=true
GRUB_TERMINAL_OUTPUT="console"
GRUB_CMDLINE_LINUX="resume=/dev/mapper/root_vg-swap rd.lvm.lv=root_vg/root
rd.lvm.lv=root_vg/swap console=ttyS0,115200 console=tty0"
GRUB_DISABLE_RECOVERY="true"
GRUB_ENABLE_BLSCFG=true
```

As you can see, in this file, we can change the default timeout of the GRUB welcome screen, the font, the submenus, and the default kernel command-line parameters like the root device name, the swap device name, etc.

/etc/grub.d/

Now this is where things get really interesting about GRUB 2.

GRUB 2 has a command called `grub2-mkconfig`. The name of command suggests that it will make the GRUB configuration file `grub.cfg`, which will be referred by part-3 of GRUB to show the welcome screen. The `grub2-mkconfig` file will first take the cosmetic and kernel command-line parameter inputs from `/etc/default/grub` and run the script files listed in Figure 3-7 from the `/etc/grub.d/` directory.



```
[root@localhost yogeshbabar]#
[root@localhost yogeshbabar]# ls /etc/grub.d/ -l
total 88
-rwxr-xr-x. 1 root root  9346 Oct 10 12:56 00_header
-rwxr-xr-x. 1 root root   236 Oct 10 12:56 01_users
-rwxr-xr-x. 1 root root   835 Oct 10 12:56 08_fallback_counting
-rwxr-xr-x. 1 root root 13797 Oct 10 12:56 10_linux
-rwxr-xr-x. 1 root root   762 Oct 10 12:56 10_reset_boot_success
-rwxr-xr-x. 1 root root   892 Oct 10 12:56 12_menu_auto_hide
-rwxr-xr-x. 1 root root 11699 Oct 10 12:56 20_linux_xen
-rwxr-xr-x. 1 root root  2562 Oct 10 12:56 20_ppc_terminfo
-rwxr-xr-x. 1 root root 10673 Oct 10 12:56 30_os-prober
-rwxr-xr-x. 1 root root  1415 Oct 10 12:56 30_uefi-firmware
-rwxr-xr-x. 1 root root   218 Oct 10 12:56 40_custom
-rwxr-xr-x. 1 root root   220 Oct 10 12:56 41_custom
-rw-r--r--. 1 root root   483 Oct 10 12:56 README
[root@localhost yogeshbabar]#
```

Figure 3-7. *The contents of the /etc/grub.d/ directory*

As you can see, the files have numbers assigned with them. This means they will run in order.

The `00_header`, `01_users`, `08_fallback_counting`, `10_reset_boot_success`, and `12_menu_auto_hide` script files do the housekeeping work. For instance, the `00_header` script file is responsible for adding a header to the `grub.cfg` file. For example, on Fedora Linux, the following header will be added in `grub.cfg` after running the `grub2-mkconfig` file:

```
### BEGIN /etc/grub.d/00_header ###
set pager=1

if [ -f ${config_directory}/grubenv ]; then
  load_env -f ${config_directory}/grubenv
elif [ -s $prefix/grubenv ]; then
  load_env
fi
if [ "${next_entry}" ] ; then
   set default="${next_entry}"
   set next_entry=
   save_env next_entry
   set boot_once=true
else
   set default="${saved_entry}"
fi

if [ x"${feature_menuentry_id}" = xy ]; then
  menuentry_id_option="--id"
else
  menuentry_id_option=""
fi

export menuentry_id_option

if [ "${prev_saved_entry}" ]; then
  set saved_entry="${prev_saved_entry}"
  save_env saved_entry
  set prev_saved_entry=
  save_env prev_saved_entry
  set boot_once=true
fi
function savedefault {
  if [ -z "${boot_once}" ]; then
    saved_entry="${chosen}"
    save_env saved_entry
  fi
}

function load_video {
  if [ x$feature_all_video_module = xy ]; then
    insmod all_video
  else
    insmod efi_gop
    insmod efi_uga
    insmod ieee1275_fb
    insmod vbe
    insmod vga
    insmod video_bochs
    insmod video_cirrus
  fi
}

terminal_output console
if [ x$feature_timeout_style = xy ] ; then
  set timeout_style=menu
  set timeout=5
# Fallback normal timeout code in case the timeout_style feature is
# unavailable.
else
  set timeout=5
fi
### END /etc/grub.d/00_header ###
```

The `08_fallback_counting` script file will add the following contents in `grub.cfg`:

```
### BEGIN /etc/grub.d/08_fallback_counting ###
insmod increment
# Check if boot_counter exists and boot_success=0 to activate this
behaviour.
if [ -n "${boot_counter}" -a "${boot_success}" = "0" ]; then
  # if countdown has ended, choose to boot rollback deployment,
  # i.e. default=1 on OSTree-based systems.
  if  [ "${boot_counter}" = "0" -o "${boot_counter}" = "-1" ]; then
    set default=1
    set boot_counter=-1
  # otherwise decrement boot_counter
  else
    decrement boot_counter
  fi
  save_env boot_counter
fi
### END /etc/grub.d/08_fallback_counting ###
```

As you can see, the file adds the code that will watch the default timeout value of a GRUB's welcome screen, the same way the rest of the files (`10_reset_boot_success` and `menu_auto_hide`) will do the housekeeping work for GRUB. Let's look at the script files that make GRUB 2 one of the best bootloaders for multibooting.

10_linux

This file contains almost 500 lines of a bash script file. Whenever a user executes the `grub2-mkconfig` command, it will run this script. The `10_linux` file will find out what other Linux distributions you have installed on your system. It will literally go partition by partition and find all the other Linux versions that have been installed on your system. If there are any others, then it will make a `menuentry` of it in `grub.cfg`. Along with `menuentry`, it will add the respective kernel and initramfs entries. Isn't that amazing?

Consider you installed Ubuntu first and then Fedora; now you don't have to add the entries of Ubuntu manually into Fedora's `grub.cfg`. You have to just run `grub2-mkconfig`. The command will run `10_linux` for us, and it will eventually find out that Ubuntu is installed and will add the appropriate entry for it.

20_linux_xen

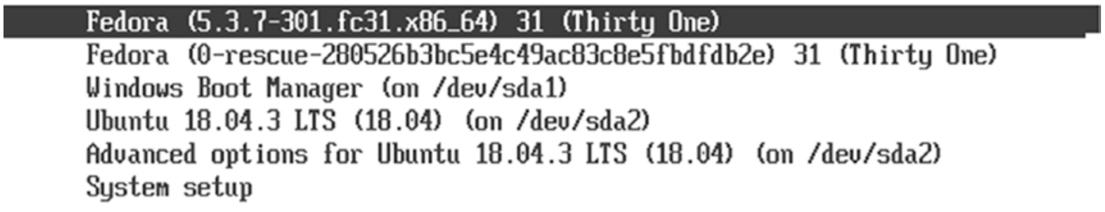
After `grub2-mkconfig`, this script file will find out whether your system has the XEN kernel installed. If it does, then it will add the appropriate entry for it in `grub.cfg`. Most of the Linux distributors ship XEN as a separate kernel package. XEN is mostly used by hypervisors.

20_ppc_terminfo

If your system has PPC or a PowerPC architecture from IBM, then this script file will find the respective kernel for it and will add the appropriate entry into `grub.cfg`.

30_os_prober

If you have any non-Linux-based OS installed on your HDD, then this script file will find that OS and will make the appropriate entry for it. In other words, if you have Windows installed on your system, it will automatically find that out and will make an appropriate entry for it in `grub.cfg`. This is the reason that, after installing our third OS (Fedora 31) on a UEFI system, we got the list of operating systems without doing anything. You can see the welcome screen presented by Fedora 31 in Figure 3-8.



```
Fedora (5.3.7-301.fc31.x86_64) 31 (Thirty One)
Fedora (0-rescue-280526b3bc5e4c49ac83c8e5fbdfdb2e) 31 (Thirty One)
Windows Boot Manager (on /dev/sda1)
Ubuntu 18.04.3 LTS (18.04) (on /dev/sda2)
Advanced options for Ubuntu 18.04.3 LTS (18.04) (on /dev/sda2)
System setup
```

Figure 3-8. *The welcome screen*

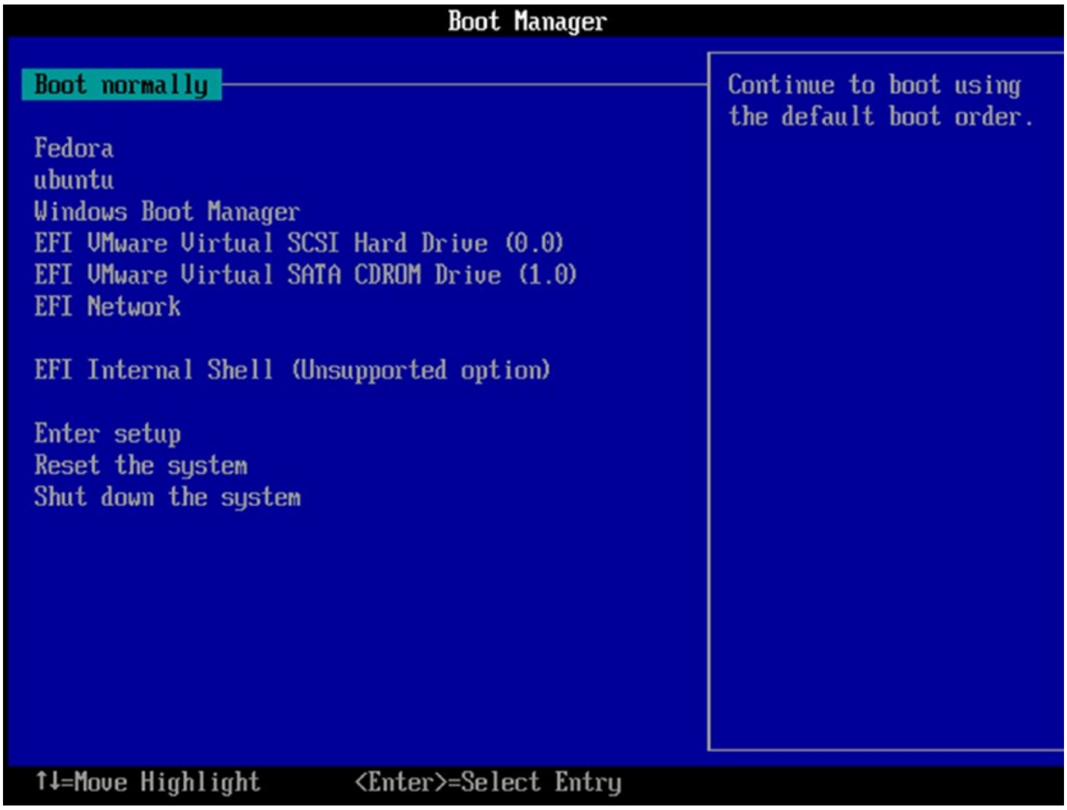
After the Fedora installation, Anaconda ran `grub2-mkconfig` in the background, which eventually ran `30_os_prober`, and it found the Windows installation and made the appropriate entry for it in `grub.cfg`.

30_uefi-firmware

This script will run successfully only if you have a UEFI system. The job of this script file is to add the appropriate entries of UEFI firmware in `grub.cfg`. As you can see in Figure 3-8, the `System setup` entry has been added by the `30_uefi-firmware` script file.

```
### BEGIN /etc/grub.d/30_uefi-firmware ###
menuentry 'System setup' $menuentry_id_option 'uefi-firmware' {
        fwsetup
}
### END /etc/grub.d/30_uefi-firmware ###
```

If the user chooses the "System setup" option, then it will boot back to the UEFI firmware. You can see the UEFI firmware interface in Figure 3-9.



```
                         Boot Manager

Boot normally                                    Continue to boot using
                                                 the default boot order.
Fedora
ubuntu
Windows Boot Manager
EFI VMware Virtual SCSI Hard Drive (0.0)
EFI VMware Virtual SATA CDROM Drive (1.0)
EFI Network

EFI Internal Shell (Unsupported option)

Enter setup
Reset the system
Shut down the system

↑↓=Move Highlight        <Enter>=Select Entry
```

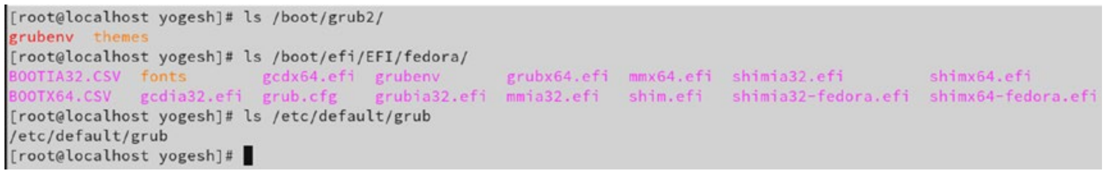
Figure 3-9. *The UEFI firmware*

40_custom and 41_custom

These are given to the user in case the user wants to add some custom entries to `grub.cfg`. For example, if `grub2-mkconfig` fails to add any of the installed OS as entries, then users can add a custom entry to these two custom files. You can make your own custom files, but you need to make sure each has a number assigned to it and has executable permission.

GRUB 2 on UEFI-Based System

Again, there are three locations where GRUB 2 stores its files. Figure 3-10 shows the directories and its files.



```
[root@localhost yogesh]# ls /boot/grub2/
grubenv  themes
[root@localhost yogesh]# ls /boot/efi/EFI/fedora/
BOOTIA32.CSV  fonts        gcdx64.efi  grubenv       grubx64.efi  mmx64.efi  shimia32.efi         shimx64.efi
BOOTX64.CSV   gcdia32.efi  grub.cfg    grubia32.efi  mmia32.efi   shim.efi   shimia32-fedora.efi  shimx64-fedora.efi
[root@localhost yogesh]# ls /etc/default/grub
/etc/default/grub
[root@localhost yogesh]# 
```

Figure 3-10. *The GRUB 2 locations on a UEFI-based system*

The `grub.cfg` file that was shown earlier in `/boot/grub2/` has been shifted inside ESP (`/boot/efi/EFI/fedora/`). Also, as you can see, there is no `i386-pc` directory. This is because of the rich device and filesystem support provided by EFI. Inside ESP, you will find a couple of `*.efi` files, including our `shim.efi` and `grubx64.efi` binaries. The `etc/default/grub` file, which is responsible for GRUB's cosmetic changes and for kernel command-line parameters, is still at the same location. The `device.map` file is not available since the `grub2-install` command does not have significance on a UEFI system. We will talk about this command later in the chapter.

Boot Loader Specification (BLS)

The BLS is a new development on GRUB upstream projects that hasn't been adopted by many mainstream distributions yet. Specifically, this scheme has been adopted by Fedora-based operating systems such as RHEL, Fedora, Centos, Oracle Linux, etc., but not by Debian-based distributions such as Ubuntu, Mint, etc.

On BIOS-based systems, whichever OS has control of the first 512 bytes has control of all the operating systems' booting sequences, which is why every OS tries to get hold of the first 512 bytes. This situation arises because the BIOS always lands in the first 512 bytes of the HDD and calls part-1 of the bootloader (bootstrap). The part-1 to part-2 and part-2 to part-3 transitions happen later, and then at the end part-3 reads the bootloader-specific configuration file (`bcdedit` in the case of Windows, `grub.cfg` in the case of Linux). If that configuration file has the entries for other installed OSs, then they will get a chance to boot. So, long story short: whoever has control of the first 512 bytes controls the entire booting sequence. But with ESP, every OS gets an equal chance to boot because UEFI checks the ESP directories and lists all the available OS entries. Developers started wondering if they could get something like this in a BIOS-based system, and they came up with BLS.

In BLS, a new location (the fifth one) has been introduced to store the bootloader-related files, and that is `/boot/loader/.` So, we have now five locations where GRUB will store its files.

- `/boot/grub2/`
- `/etc/default/grub`
- `/etc/grub.d`
- `/boot/efi/EFI/<OS_vendor>/` (in the case of UEFI only)
- `/boot/loader/` (BLS files will be stored here)

The idea is that after the new kernel installation, the kernel itself with its post-scripts (something like the `kernel-core` package in the case of Fedora) will create an entry for a new kernel in the `/boot/loader/` directory. For example, we have this kernel package installed:

```
# rpm -q kernel

Kernel-5.3.7-301.fc31.x86_64
```

This is the same package that will provide the `/boot/vmlinuz` and `/boot/initramfs` files. Once this kernel is installed, it prepares the following file:

```
# cat /boot/loader/entries/36543031048348f9965e3e12e48bd2b1-5.3.7-301.fc31.
x86_64.conf

title Fedora (5.3.7-301.fc31.x86_64) 31 (Thirty One)
version 5.3.7-301.fc31.x86_64
linux /vmlinuz-5.3.7-301.fc31.x86_64
initrd /initramfs-5.3.7-301.fc31.x86_64.img
options $kernelopts
grub_users $grub_users
grub_arg --unrestricted
grub_class kernel
```

As you can see, the file has four entries.

- The title that will be printed by part-3 of GRUB
- The location and name of the kernel file

- The location and name of the initramfs file
- The `$kernelopts` variable that has been declared in the `/boot/grub2/grubenv` file

```
# cat /boot/grub2/grubenv

# GRUB Environment Block
saved_entry=2058a9f13f9e489dba29c477a8ae2493-5.3.7-301.fc31.x86_64
menu_auto_hide=1
boot_success=0
kernelopts=root=/dev/mapper/fedora_localhost--live-root ro resume=/dev/
mapper/fedora_localhost--live-swap rd.lvm.lv=fedora_localhost-live/root
rd.lvm.lv=fedora_localhost-live/swap rhgb quiet
boot_indeterminate=0
```

Basically, `kernelopts` provides the kernel command-line parameters like the name of the root filesystem (`/dev/mapper/fedora_localhost--live-root`) and in which mode it has to be mounted (`ro - read only`).

So, the booting sequence becomes like this:

1) BIOS -> POST -> BIOS
2) Part-1 of GRUB -> part-2 of GRUB -> part-3 of GRUB
3) Part-3 of GRUB -> read `grub.cfg`
4) Part-3 of GRUB -> reads `/boot/loader/entries/*`
5) Prints all the file titles that are present in `/boot/loader/entries`

For an example, consider a new OS has been installed or a new kernel has been installed. It has to generate its own entry file and place it in the first primary partition's `/boot/loader/entries/` directory. This way, every time the first primary OS's GRUB part-3 reads the entry, the other OS will have a chance to boot. The entry file can be created by using Fedora's `kernel-install` command.

```
#kernel-install add 5.3.7-301.fc31.x86_64 /lib/modules/5.3.7-301.fc31.
x86_64/vmlinuz
```

The command will make the appropriate entry for `kernel-5.3.7-301.fc31.x86_64` in `/boot/loader/entries/`, as shown here:

```
# ls /boot/loader/entries/ -l
total 8
-rw-r--r--. 1 root root 329 Dec  9 10:18 2058a9f13f9e489dba29c477a8ae2493-
0-rescue.conf
-rw-r--r--. 1 root root 249 Oct 22 01:04
2058a9f13f9e489dba29c477a8ae2493-5.3.7-301.fc31.x86_64.conf
```

The number associated with the `*.conf` file is unique. The BLS has its own advantages and disadvantages.

Here are the advantages:

- Every OS will get an equal chance to boot.
- It works irrespective of the BIOS and UEFI firmware.
- In the case of the BIOS, the latest Linux installation removes part-1 and part-2 of the earlier installed operating system, which has become obsolete since the latest Linux installation will make its own entry through the `kernel-install` command on earlier OSs.

Here are the disadvantages:

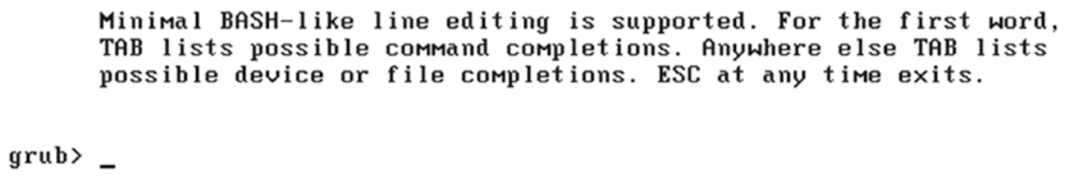
- The BLS is not completely implemented yet. If the second OS wants to make its entry in the first OS, then `/boot` of the first OS has to be shared. That is not the case as of now. So, I consider this as a half-implementation.
- The BLS unnecessarily complicates the booting sequence since we have two configuration files to refer to: `grub.conf` and `<uniq_no><kernel_version>.conf` from `/boot/loader/entries/`. The BLS especially makes life difficult in the case of resolving the “can’t boot” issues.
- Except Fedora-based distros, no one has adopted the BLS yet, which seems to be a wise decision. It looks like Fedora is the most committed to the upstream project; hence, the BLS has been implemented in Fedora.

Common Bootloader Issues

Based on this knowledge, let's try to resolve some of the most common bootloader-related "can't boot" issues.

"Can't Boot" Issue 1 (Bootloader)

Issue: After powering up the system, it is dropping you on the GRUB prompt, as shown in Figure 3-11.



```
          Minimal BASH-like line editing is supported. For the first word,
          TAB lists possible command completions. Anywhere else TAB lists
          possible device or file completions. ESC at any time exits.


 grub> _
```

Figure 3-11. *The GRUB 2 prompt*

This is what you see on your screen. You must have encountered this error at least once in your life. Let's try to resolve it.

1) You will be able to resolve the issue only if you know what the issue is all about. Right now, though, we have no idea what the problem is since we just started the system and this is what we get.

2) The screen is called a GRUB prompt. When this is called a prompt, it means you can execute commands at it. Remember, this is a GRUB command prompt, which means it can accept only GRUB commands.

3) By looking at Figure 3-11, out of three parts of GRUB, which part of GRUB has provided us with the GRUB prompt?

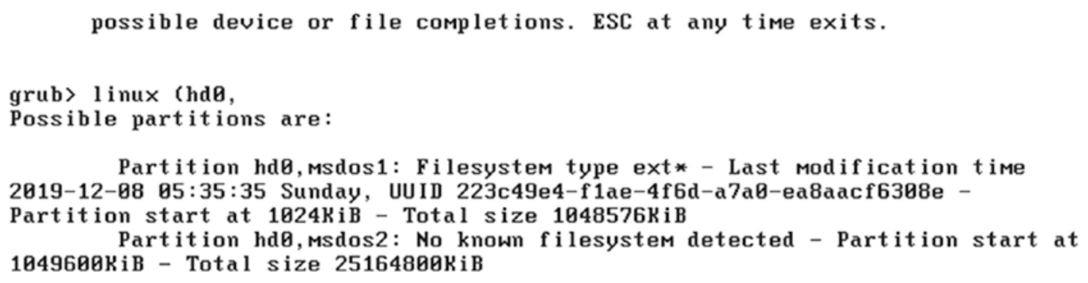
4) Of course, it must be part-3 because part-1 and part-2 have very little space, so they cannot fit such functionality. So, we have successfully reached part-3 of GRUB, and most important, it does not matter whether this system has UEFI or the BIOS. Since we have reached part-3, it means we have left the firmware environment. That's the crucial input. Now we cannot concentrate on part-3 only.

5) What is the purpose of part-3 of GRUB? Simple. It reads `grub.cfg`, and from there it gets the kernel and initramfs locations. If it is a BLS-enabled system, then it gets the kernel and initramfs names from the `/boot/loader/entries/` directories. For this example, we will assume this system is not BLS-aware. Part-3 then loads `vmlinuz` and initramfs in memory.

6) Since part-3 has provided us with the GRUB prompt but failed to load the OS, it means either the kernel and initramfs files are not present or the `grub.cfg` file is not pointing out the correct location of these files.

7) So, in such a situation we can try to boot Fedora manually. Manually means we will provide the kernel and initramfs files with absolute paths by using the GRUB prompt. This is how it can be done.

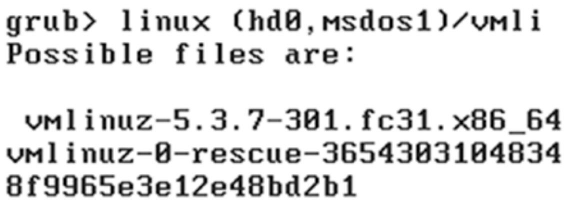
8) `linux` is a GRUB command through which we need to give the absolute path of the kernel (`vmlinuz`) file. As we know, the `vmlinuz` file is at `/boot`, and GRUB follows its own disk naming convention. So, the path of `/boot` will be hard disk number 0 and partition number 1. Of course, you might not be aware on which HDD or partition `/boot` has been stored. In that case, you can get the help of the autocomplete feature of GRUB. You can press Tab twice, and GRUB will prompt you for the available options. Let's find out the HDD and partition number of `/boot`. Please refer to Figure 3-12.



```
      possible device or file completions. ESC at any time exits.


grub> linux (hd0,
Possible partitions are:

        Partition hd0,msdos1: Filesystem type ext* - Last modification time
2019-12-08 05:35:35 Sunday, UUID 223c49e4-f1ae-4f6d-a7a0-ea8aacf6308e -
Partition start at 1024KiB - Total size 1048576KiB
        Partition hd0,msdos2: No known filesystem detected - Partition start at
1049600KiB - Total size 25164800KiB
```

Figure 3-12. *The available partitions on hard disk number 0*

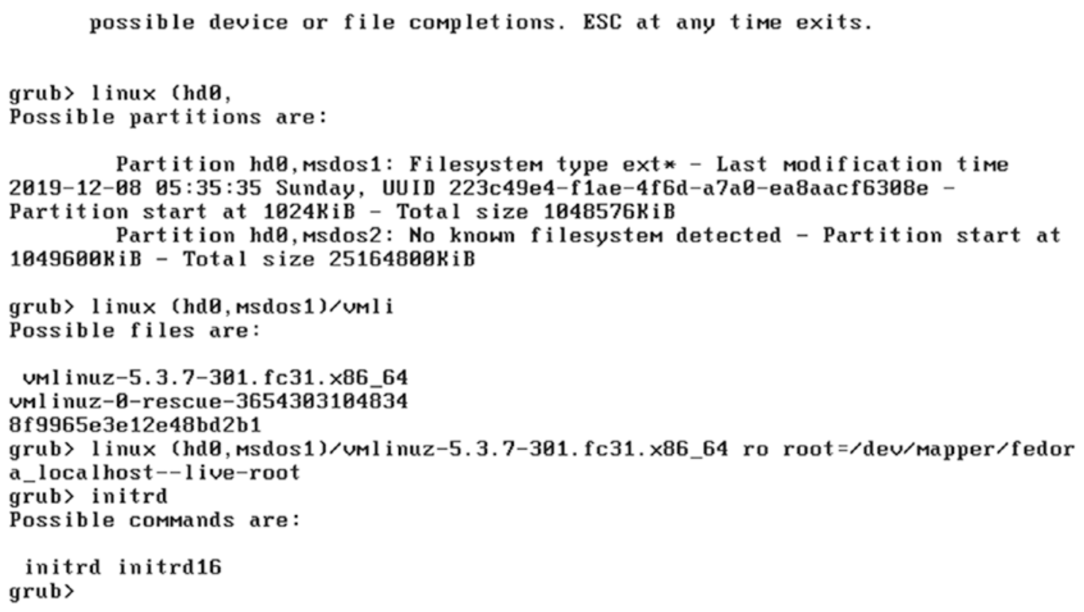
The first tab after `hd0` showed us that there are two partitions available under the hard disk number 0. The second partition is not readable to GRUB, so of course the second partition cannot be `/boot`. Hence, we will choose the `msdos1` partition. Then, as shown in Figure 3-13, we will start looking for the `vmlinuz` file in it with the help of autocomplete.



```
grub> linux (hd0,msdos1)/vmli
Possible files are:

 vmlinuz-5.3.7-301.fc31.x86_64
vmlinuz-0-rescue-3654303104834
8f9965e3e12e48bd2b1
```

Figure 3-13. *The vmlinuz file*

As you can see inside HDD number 0 and partition number 1, we found two `vmlinuz` files; one is of a rescue kernel, and another one is the normal kernel file of Fedora 31. As shown in Figure 3-14, we will choose the normal kernel and will provide the root filesystem name to it. If you are unaware of the root filesystem name of your system, then you can boot the system with the rescue or live image and check the `/etc/fstab` entries. We will talk about the rescue mode in Chapter 10.



```
       possible device or file completions. ESC at any time exits.


grub> linux (hd0,
Possible partitions are:

        Partition hd0,msdos1: Filesystem type ext* - Last modification time
2019-12-08 05:35:35 Sunday, UUID 223c49e4-f1ae-4f6d-a7a0-ea8aacf6308e -
Partition start at 1024KiB - Total size 1048576KiB
        Partition hd0,msdos2: No known filesystem detected - Partition start at
1049600KiB - Total size 25164800KiB

grub> linux (hd0,msdos1)/vmli
Possible files are:

 vmlinuz-5.3.7-301.fc31.x86_64
vmlinuz-0-rescue-3654303104834
8f9965e3e12e48bd2b1
grub> linux (hd0,msdos1)/vmlinuz-5.3.7-301.fc31.x86_64 ro root=/dev/mapper/fedor
a_localhost--live-root
grub> initrd
Possible commands are:

 initrd initrd16
grub>
```

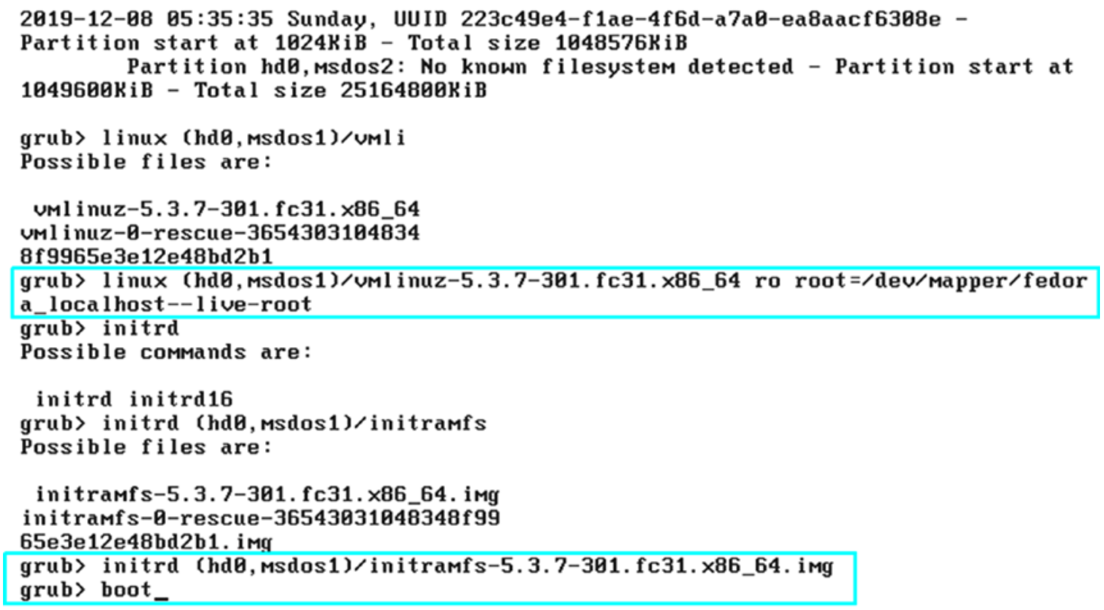
***Figure 3-14.** The root filesystem name and the ro flag*

The absolute path of the `vmlinuz` file is `(hd0,msdos1)/vmlinuz-5.3.7-301.fc31.x86_64`. Next to it is the `ro` kernel command-line parameter, which stands for "read-only." After `ro`, we have a `root` kernel command-line parameter to which we have passed our system's root filesystem name, which is - `/dev/mapper/fedora_localhost--live-root.` It's an `lvm` device.

```
grub> linux (hd0,msdos1)/vmlinuz-5.3.7-301.fc31.x86_64 ro
     root=/dev/mapper/fedora_localhost--live-root
```

After successfully executing the `linux` command, we need to pass on the initramfs name. We have two commands available that we can use: `initrd` and `initrd16`. Please refer to Figure 3-15.

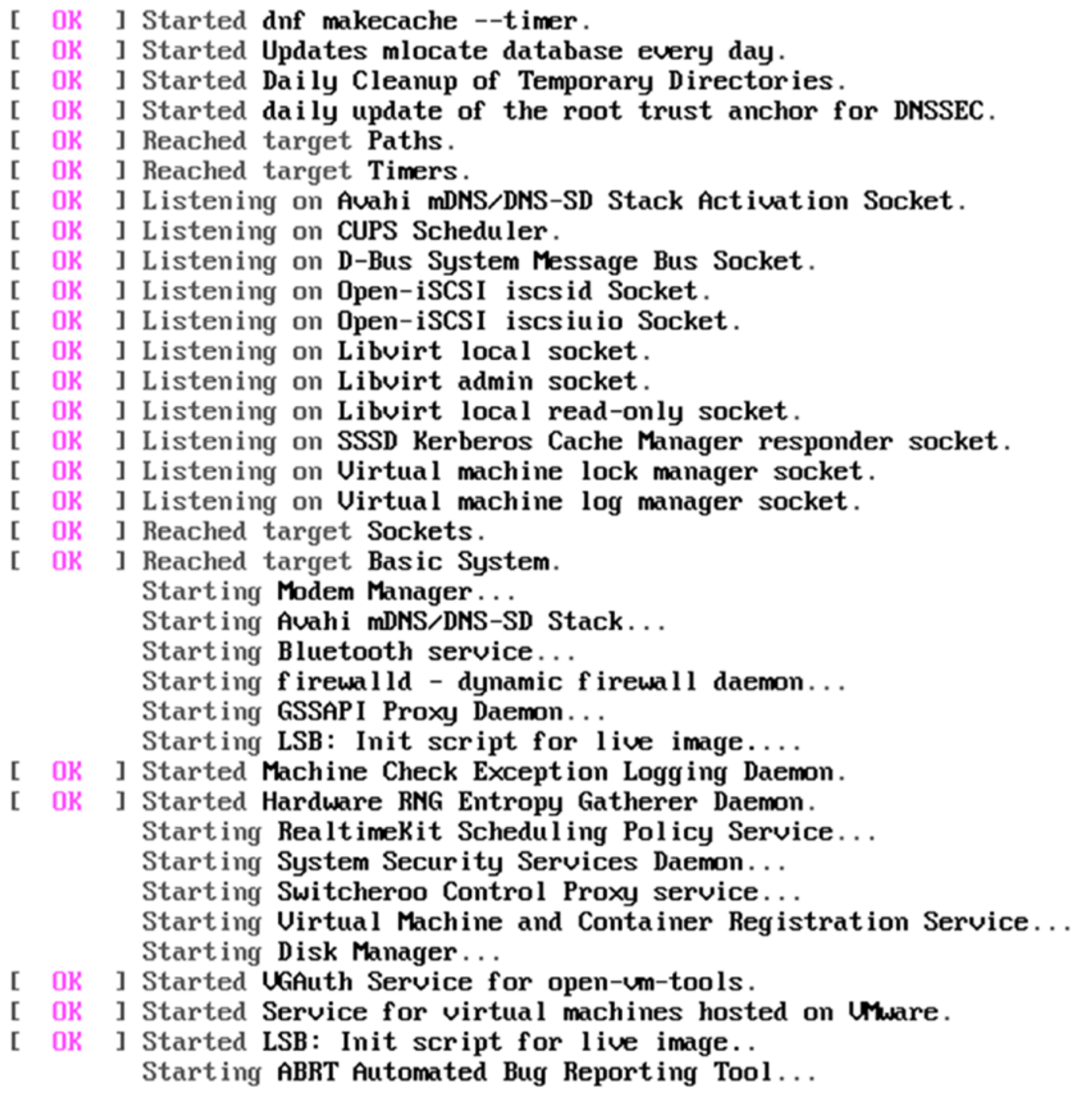
```
grub> initrd (hd0,msdos1)/initramfs-5.3.7-301.fc31.x86_64.img
```



```
2019-12-08 05:35:35 Sunday, UUID 223c49e4-f1ae-4f6d-a7a0-ea8aacf6308e -
Partition start at 1024KiB - Total size 1048576KiB
        Partition hd0,msdos2: No known filesystem detected - Partition start at
1049600KiB - Total size 25164800KiB

grub> linux (hd0,msdos1)/vmli
Possible files are:

 vmlinuz-5.3.7-301.fc31.x86_64
vmlinuz-0-rescue-3654303104834
8f9965e3e12e48bd2b1
grub> linux (hd0,msdos1)/vmlinuz-5.3.7-301.fc31.x86_64 ro root=/dev/mapper/fedor
a_localhost--live-root
grub> initrd
Possible commands are:

 initrd initrd16
grub> initrd (hd0,msdos1)/initramfs
Possible files are:

 initramfs-5.3.7-301.fc31.x86_64.img
initramfs-0-rescue-36543031048348f99
65e3e12e48bd2b1.img
grub> initrd (hd0,msdos1)/initramfs-5.3.7-301.fc31.x86_64.img
grub> boot_
```

Figure 3-15. *The linux, initrd, and boot commands in action*

9) The moment you execute the `boot` command, as shown in Figure 3-16 and in Figure 3-17, GRUB's part-3 will take these inputs and load `/boot/vmlinuz-5.3.7-301.fc31.x86_64` from `sda1 (hd0,msdos1)`. Then it will load `/boot/initramfs-5.3.7-301.fc31.x86_64.img` and give control to the kernel. The kernel will eventually mount the root (`/`) filesystem from `/dev/mapper/fedora_locahost--live-root` on the `/` directory and will show the login screen.



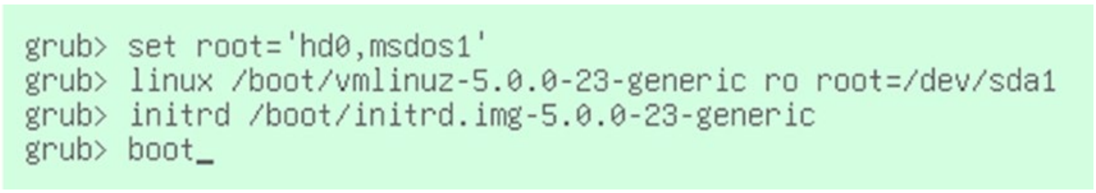
```
[  OK  ] Started dnf makecache --timer.
[  OK  ] Started Updates mlocate database every day.
[  OK  ] Started Daily Cleanup of Temporary Directories.
[  OK  ] Started daily update of the root trust anchor for DNSSEC.
[  OK  ] Reached target Paths.
[  OK  ] Reached target Timers.
[  OK  ] Listening on Avahi mDNS/DNS-SD Stack Activation Socket.
[  OK  ] Listening on CUPS Scheduler.
[  OK  ] Listening on D-Bus System Message Bus Socket.
[  OK  ] Listening on Open-iSCSI iscsid Socket.
[  OK  ] Listening on Open-iSCSI iscsiuio Socket.
[  OK  ] Listening on Libvirt local socket.
[  OK  ] Listening on Libvirt admin socket.
[  OK  ] Listening on Libvirt local read-only socket.
[  OK  ] Listening on SSSD Kerberos Cache Manager responder socket.
[  OK  ] Listening on Virtual machine lock manager socket.
[  OK  ] Listening on Virtual machine log manager socket.
[  OK  ] Reached target Sockets.
[  OK  ] Reached target Basic System.
         Starting Modem Manager...
         Starting Avahi mDNS/DNS-SD Stack...
         Starting Bluetooth service...
         Starting firewalld - dynamic firewall daemon...
         Starting GSSAPI Proxy Daemon...
         Starting LSB: Init script for live image....
[  OK  ] Started Machine Check Exception Logging Daemon.
[  OK  ] Started Hardware RNG Entropy Gatherer Daemon.
         Starting RealtimeKit Scheduling Policy Service...
         Starting System Security Services Daemon...
         Starting Switcheroo Control Proxy service...
         Starting Virtual Machine and Container Registration Service...
         Starting Disk Manager...
[  OK  ] Started VGAuth Service for open-vm-tools.
[  OK  ] Started Service for virtual machines hosted on VMware.
[  OK  ] Started LSB: Init script for live image..
         Starting ABRT Automated Bug Reporting Tool...
```

Figure 3-16. *The console messages while booting*

***Figure 3-17.** The login screen*

10) In the case of Ubuntu 18, the commands are slightly different. On Fedora 31, we gave the `/boot` partition's address directly to the `linux` command, whereas in Ubuntu we have a separate GRUB command called `set root` for it.

As you can see in Figure 3-18, the root filesystem name of the Ubuntu 18 system is `/dev/sda1`. It's a standard partition unlike the `lvm` device of Fedora 31.



```
grub> set root='hd0,msdos1'
grub> linux /boot/vmlinuz-5.0.0-23-generic ro root=/dev/sda1
grub> initrd /boot/initrd.img-5.0.0-23-generic
grub> boot_
```

***Figure 3-18.** Ubuntu has a slightly different approach*

As soon as we provide the proper inputs to GRUB 2, it leads us to the login screen. You can see the login screen of Ubuntu in Figure 3-19.

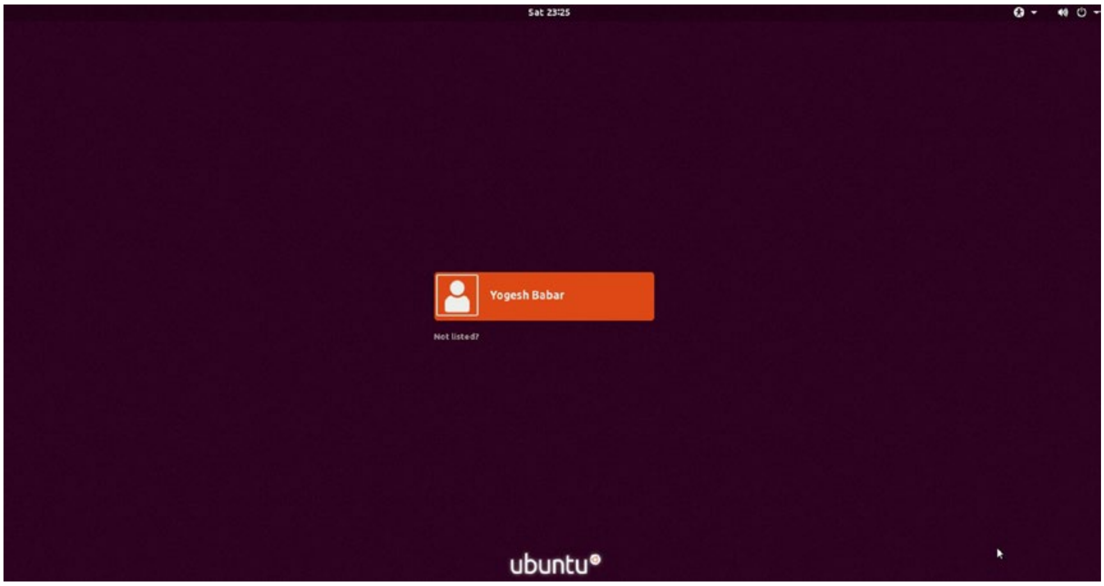
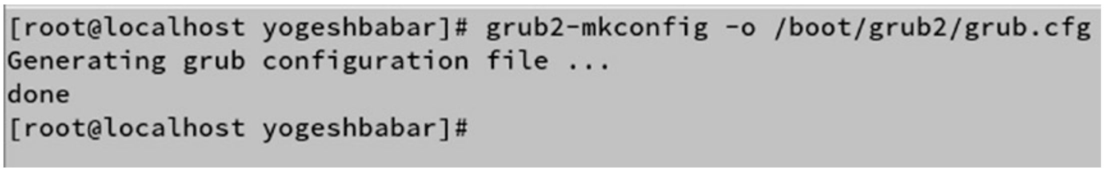


Figure 3-19. *The login screen presented by Ubuntu*

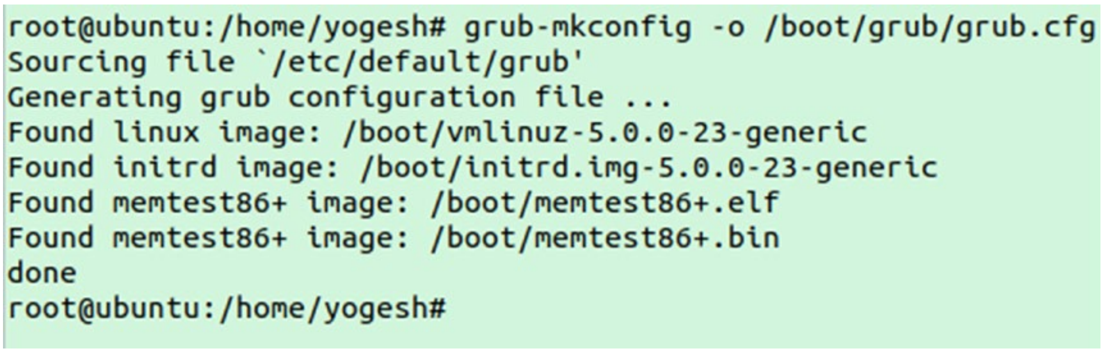
11) Coming back to our Fedora system, since it has been booted now, we can regenerate the `grub.cfg` file by using the `grub2-mkconfig` command, as shown in Figure 3-20.



```
[root@localhost yogeshbabar]# grub2-mkconfig -o /boot/grub2/grub.cfg
Generating grub configuration file ...
done
[root@localhost yogeshbabar]#
```

Figure 3-20. *grub2-mkconfig command*

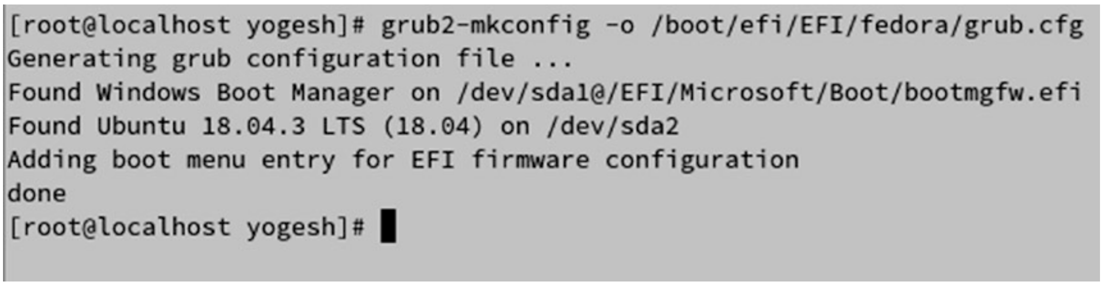
We can execute `grub-mkconfig` in case of Ubuntu. Please refer to Figure 3-21.



```
root@ubuntu:/home/yogesh# grub-mkconfig -o /boot/grub/grub.cfg
Sourcing file `/etc/default/grub'
Generating grub configuration file ...
Found linux image: /boot/vmlinuz-5.0.0-23-generic
Found initrd image: /boot/initrd.img-5.0.0-23-generic
Found memtest86+ image: /boot/memtest86+.elf
Found memtest86+ image: /boot/memtest86+.bin
done
root@ubuntu:/home/yogesh#
```

***Figure 3-21.** The grub-mkconfig command of Ubuntu*

But if it is a UEFI system and you want to regenerate `grub.cfg`, then, as shown in Figure 3-22, the location of `grub.cfg` would be ESP.



```
[root@localhost yogesh]# grub2-mkconfig -o /boot/efi/EFI/fedora/grub.cfg
Generating grub configuration file ...
Found Windows Boot Manager on /dev/sda1@/EFI/Microsoft/Boot/bootmgfw.efi
Found Ubuntu 18.04.3 LTS (18.04) on /dev/sda2
Adding boot menu entry for EFI firmware configuration
done
[root@localhost yogesh]#
```

***Figure 3-22.** grub2-mkconfig on a UEFI-based system*

12) Once `grub.cfg` is generated, we need to regenerate the BLS entries for Fedora.

```
#kernel-install add 5.3.7-301.fc31.x86_64 /lib/modules/5.3.7-301.fc31.x86_64/vmlinuz
```

The command will make the appropriate entry for `kernel-5.3.7-301.fc31.x86_64` in `/boot/loader/entries/`.

```
# ls /boot/loader/entries/ -l
total 8
-rw-r--r--. 1 root root 329 Dec  9 10:18
2058a9f13f9e489dba29c477a8ae2493-0-rescue.conf
-rw-r--r--. 1 root root 249 Oct 22 01:04
2058a9f13f9e489dba29c477a8ae2493-5.3.7-301.fc31.x86_64.conf
```

13) If Fedora is on a UEFI system, then the BLS step remains the same.

14) After rebooting, Fedora is able to boot smoothly, and the "can't boot" issue has been fixed.

"Can't Boot" Issue 2 (Bootloader)

Issue: After powering on the system, it passes the firmware stage, but after that, as you can see in Figure 3-23, there is nothing on the screen.

Figure 3-23. *The blank screen*

Resolution for a BIOS-Based System

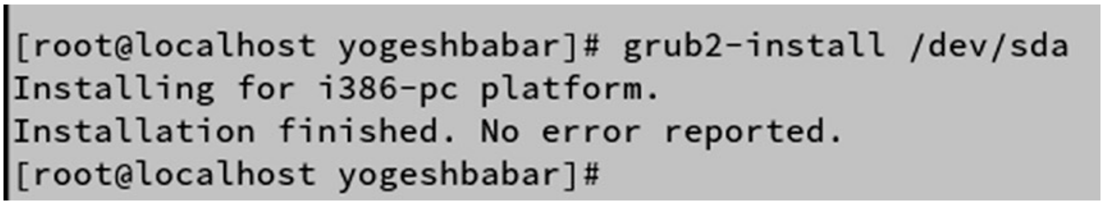
Here are the steps to solve this:

1. Since the BIOS firmware stage has been passed, it means something is wrong at the bootloader level.

2. Since we are not getting anything on the screen, it means part-1 or part-2 of GRUB is missing or at least they are corrupted (512 bytes + 31 KB). If it had reached part-3, then we would have gotten at least the GRUB prompt. So, the issue has been isolated, and the plan of action is to replace part-1 and part-2 of GRUB.

3. This can be done with the `grub2-install` command. First either boot with live medium of the same Linux distro or, if available, boot in rescue mode. The live image and rescue mode will be explained in Chapter 10.

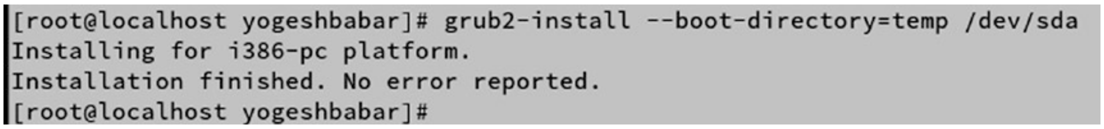
As you can see in Figure 3-24, `grub2-install` takes the device name as an input. Please note that the device name should not be a partition number; rather, it should be a disk name. This is because part-1 and part-2 of GRUB has to be installed on the first 512 bytes + 31 KB of a disk, not inside a partition. You need to replace sda with your disk name.



```
[root@localhost yogeshbabar]# grub2-install /dev/sda
Installing for i386-pc platform.
Installation finished. No error reported.
[root@localhost yogeshbabar]#
```

Figure 3-24. *The grub2-install command*

Along with part-1 and part-2 of the bootloader files, `grub2-install` repairs or re-installs the `i386-pc` directory, which has all the modules of the GRUB 2 bootloader. We can cross-verify this by installing the modules in a custom directory. Please see Figure 3-25.



```
[root@localhost yogeshbabar]# grub2-install --boot-directory=temp /dev/sda
Installing for i386-pc platform.
Installation finished. No error reported.
[root@localhost yogeshbabar]#
```

Figure 3-25. *Installing grub2 in a temporary directory*

You can see that all the GRUB 2 files have been restored along with GRUB's module files.

```
# ls temp/grub2/
       fonts  grubenv  i386-pc
# ls -l temp/grub2/i386-pc/ | wc -l
       279
```

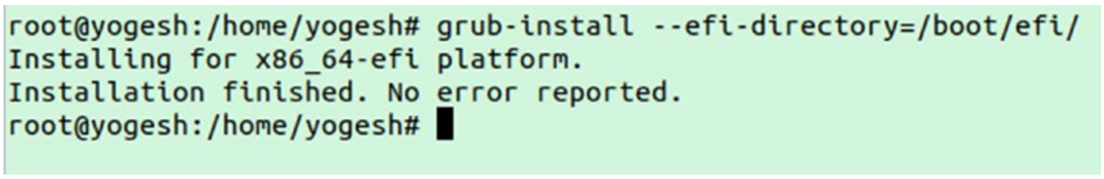
After rebooting, Fedora should boot normally, and the "can't boot" issue should have been fixed. If GRUB drops you on a command prompt, then you need to follow the steps mentioned for issue 1 since `grub2-install` repairs the binaries, but it does not regenerate the `grub.cfg` file.

But what if you face a similar problem on a UEFI-based system?

Resolution for a UEFI-Based System

Here are the steps:

1. As you might have guessed, we have to just change the passed device name of the `grub2-install` command, as shown in Figure 3-26. The device name should be ESP.



```
root@yogesh:/home/yogesh# grub-install --efi-directory=/boot/efi/
Installing for x86_64-efi platform.
Installation finished. No error reported.
root@yogesh:/home/yogesh# █
```

Figure 3-26. *The grub-install command on a UEFI-based system*

"Can't Boot" Issue 3 (Bootloader + Kernel)

Issue: The complete `/boot` is missing.

Resolution for BIOS-Based Systems

Here are the steps:

1. Recovering the lost `/boot` is not possible (or at least it's outside the scope of this book).
2. Boot in rescue mode or boot with a live image and mount our "can't boot" system's root filesystem. The rescue mode and how it works are discussed in Chapter 10.
3. First make a new `/boot` directory and set the proper permissions on it.
   - **`#mkdir /boot`**
   - **`#chmod 555 /boot`**
   - **`#chown root:root /boot`**
   - If `/boot` is supposed to be a separate partition, then mount it with the correct partition.

4. As we know, `/boot` is where we store the files of the bootloader, kernel, and initramfs. Since `/boot` is missing, we need to create every file for it.
   - **`#dnf reinstall kernel`**
     - This is for a Fedora-based system. If it is a Debian-based system, then you can use the `apt-get` command and can reinstall the kernel.
     - This will install the `vmlinuz` file and will also regenerate the initramfs file for it.
5. Now we need to install GRUB.
   - **`#grub2-install /dev/<disk_name>`**
     - In our case, the command is `#grub2-install /dev/sda.`
   - This will repair GRUB's part-1 , part-2, and `i386-pc` directory from `/boot/grub2`.
   - To repair part-3 of GRUB and to have some GRUB-provided tools, we need to install two packages on a Fedora-based system.
     - **`#dnf reinstall grub2 grub2-tools`**
     - As the name suggests, the `grub2` package will provide part-3 of GRUB, and `grub2-tools` will provide some of the tools like `grub2-install`.
   - Now it's time to regenerate the GRUB configuration file.
     - **`#grub2-mkconfig -o /boot/grub2/grub.cfg`**
   - Finally, fix the BLS.
     - **`#kernel-install add 5.3.7-301.fc31.x86_64 /lib/modules/5.3.7-301.fc31.x86_64/vmlinuz`**

Resolution for UEFI-Based Systems

Here are the steps:

- `/boot and /boot/efi/` are separate mount points.
    - **`# mkdir /boot`**
    - **`# chmod 555 /boot`**
    - **`# chown root:root /boot`**
    - **`# yum reinstall kernel`**
- Now we need to create an ESP partition, and as we know, it has to be a VFAT partition. Then assign an ESP partition type to it.
    - **`#mkdir /boot/efi`**
    - **`#mount /dev/sda2 /boot/efi`**
        - In our case, the partition that I have created for ESP is sda2.
    - **`#grub2-install --efi-directory=/boot/efi`**
        - This will install the `grubx64.efi` file in ESP.
    - The rest of the required files are provided by the `grub2-efi`, `shim`, and `grub2-tools` packages.
        - **`#yum reinstall grub2-efi shim grub2-tools`**
    - Regenerate the configuration files.
        - **`#grub2-mkconfig -o /boot/efi/EFI/redhat/grub.cfg`**
        - **`#kernel-install add 5.3.7-301.fc31.x86_64 /lib/modules/5.3.7-301.fc31.x86_64/vmlinuz`**

After rebooting the system, it is able to boot without any issue.

Now it's time to shed some more light on UEFI's Secure Boot environment.

Secure Boot Feature of UEFI

Secure Boot is an amazing feature of UEFI. It makes sure no untrusted binary will run while booting. So far, we have seen the following:

- The digital signature is a unique string.
    - The digital signature of any file will be generated from a private key.
    - The same digital signature can be regenerated from the public key.
    - If the file is not altered, then the digital signature should match.
- Microsoft made its key pair (public and private keys).
- Microsoft digitally signed its bootloader-related files (BCD) with its private key.
- Microsoft's public key is present inside UEFI.
- While booting, UEFI will regenerate the digital signature of the bootloader by using the available public key. If the digital signatures do not match, then UEFI will discard the execution of `.efi` files.
- To use this feature in the Linux environment, a new bootloader has been created called `shim`, and it has been signed by Microsoft's private key so that UEFI will allow the `shim.efi` execution.
- `Shim.efi`'s job is to call the actual GRUB file, which is `grubx64.efi`.

But Secure Boot does not stop here. Because there is a possibility that `grubx64.efi` itself has been compromised, or in fact any code that runs after the bootloader could have been compromised, securing the booting environment up to the bootloader level only is not sufficient; hence, these days the Secure Boot feature secures the entire booting procedure of Linux. This is how it works:

1. Fedora will prepare its own key pair and will sign the GRUB files with Fedora's private key.
2. The public key of Fedora will be kept inside the `shim.efi` file.

3. As the booting sequence continues, GRUB's digital signature will be regenerated by using the public key that is inside `shim.efi`.
4. If the signature matches then `grubx64.efi` and other bootloader files will be allowed to run by UEFI.
5. GRUB's ultimate job is to load the kernel (`/boot/vmlinuz`).
6. This `vmlinuz` file can also be compromised, so to avoid that, the kernel will be signed by the same private key that was used to sign GRUB.
7. `Vmlinuz'`s digital signature will be regenerated by using the public key that is inside `shim.efi`.
8. Once the digital signature matches, the kernel takes control of the booting sequence.
9. But the kernel uses a lot of modules/drivers that are eventually inserted inside the kernel. So, these modules that are again binaries could be compromised, and since they are going to become part of kernel/`vmlinuz`, then eventually the kernel itself will be compromised.
10. So, the kernel as a package will prepare its own key pair. All the modules will be signed by this kernel's private key, and the public key will be shipped with the kernel package itself. The private key of a kernel package will be destroyed later.
11. At the time of the booting, while inserting the modules in the kernel, the digital signature of the module will be regenerated by using the public key, which is with the kernel.
12. By following the steps mentioned, the Secure Boot feature makes sure that only binaries from trusted parties are executed.

The block diagrams shown Figure 3-27 will simplify the booting procedure even more.

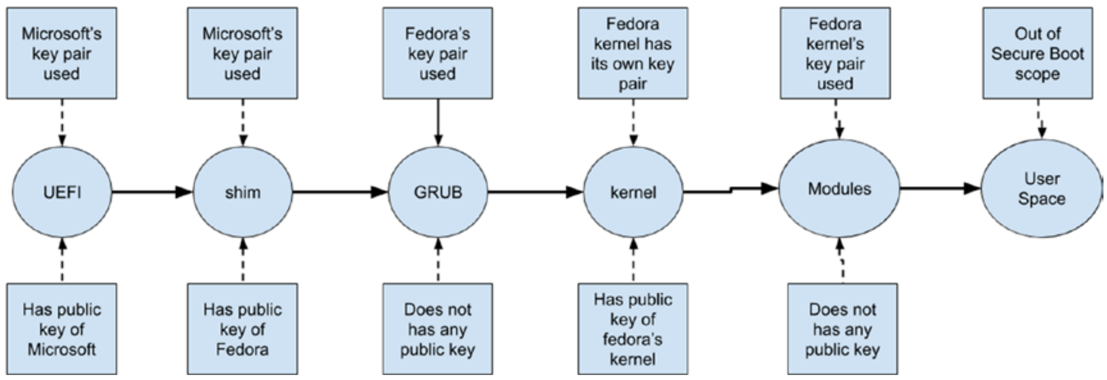

Microsoft's key pair used
Microsoft's key pair used
Fedora's key pair used
Fedora kernel has its own key pair
Fedora kernel's key pair used
Out of Secure Boot scope
UEFI
shim
GRUB
kernel
Modules
User Space
Has public key of Microsoft
Has public key of Fedora
Does not has any public key
Has public key of fedora's kernel
Does not has any public key

Figure 3-27. *The Secure Boot procedure*

100 OS Multiboot Project

One of my students asked me a question: how many operating systems can we install on one system and multiboot them with one bootloader? I didn't know the answer, but I decided to try to find out. I decided that I would use a GRUB 2 bootloader to boot every operating system that I have installed. I have been installing and multibooting the operating systems for almost two years now. I have installed 106 operating systems so far. This is our third system, which I named Jarvis. Here are the hardware and software details of Jarvis:

- UEFI firmware.
- Two disks attached (sda and sdb).
- The booting method is UEFI.
- sda is formatted with an MS-DOS partition table.
- sdb is formatted with a GPT partition table.
- All the operating systems are identified and booted by the GRUB 2 bootloader.

The operating systems that are installed on the sda disk were installed by setting the booting method to UEFI, and it has all the new operating systems. The operating systems that are on sdb were installed by setting the booting method of the firmware to legacy. sdb hosts most of the old-generation operating systems or at least those operating systems that do not have UEFI support. Here are the details:

Partition	Operating System	Filesystem	Size
sda-1	ESP (EFI System Partition)	FAT32	20 GB
sda-2	MSR (Microsoft Recovery)	MSR	16 MB
sda-3	Windows 10	NTFS	9.7 GB
sda-4	Swap	Swap	2.01 GB
sda-5	openSUSE Linux 13.2	EXT4	10 GB
sda-6	Mint Linux 17.2	EXT4	10 GB
sda-7	Oracle OpenSolaris 11.2	ZFS	10 GB
sda-8	Sabayon Linux 15.06	EXT4	10 GB
sda-9	Some random free space	N/A	8.4 MB
sda-10	Kali Linux 2.0	EXT4	10 GB
sda-11	Arch Linux 2015-8.1	EXT4	10 GB
sda-12	Debian Linux 8.1	EXT4	10 GB
sda-13	Semplice Linux 7.0.1	EXT4	10 GB
sda-14	Slackware 14.1 Linux	EXT4	10 GB
sda-15	Openmandriva 2014.2	EXT4	10 GB
sda-16	Mate Ubuntu Linux15.04	EXT4	10 GB
sda-17	Steam OS beta	EXT4	10 GB
sda-18	Manjaro Linux 0.8.13.1	EXT4	10 GB
sda-19	Netrunner Linux 16	EXT4	10 GB
sda-20	Windows 8	NTFS	10 GB
sda-21	Korora Linux 22	EXT4	10 GB
sda-22	KaOS Linux 2015.08	EXT4	10 GB
sda-23	Lubuntu Linux 15.04	EXT4	10 GB
sda-24	Sonar Linux 2015.2	EXT4	10 GB
sda-25	Antergos Linux 2015.08.18	EXT4	10 GB
sda-26	Mythbuntu Linux 14.04.2	EXT4	10 GB

(*continued*)

Partition	Operating System	Filesystem	Size
sda-27	Rosa Linux fresh R5	EXT4	10 GB
sda-28	SparkyLinux 4.0	EXT4	10 GB
sda-29	Vinux Linux 4.0	EXT4	10 GB
sda-30	Xubuntu Linux 14.04.3	EXT4	10 GB
sda-31	Ubuntu Studio 14.04.3	EXT4	10 GB
sda-32	Suse Enterprise 12	EXT4	10 GB
sda-33	Ubuntu Linux 14.04	EXT4	10 GB
sda-34	Ubuntu Linux 15.04	EXT4	10 GB
sda-35	Scientific Linux 7	EXT4	10 GB
sda-36	CentOS Linux 7	EXT4	10 GB
sda-37	Solus Linux Daily	EXT4	10 GB
sda-38	Ubuntu Server 14 Linux	EXT4	10 GB
sda-39	Fedora 21 Linux	EXT4	10 GB
sda-40	Fedora 22 Linux	EXT4	10 GB
sda-41	BlackArch 2015.07.31	EXT4	10 GB
sda-42	Gentoo Linux multilib 20140826	EXT4	10 GB
sda-43	Calculate Linux 14.16.2	EXT4	10 GB
sda-44	Fedora 20 Linux	EXT4	10 GB
sda-45	Fedora 23 Linux	EXT4	10 GB
sda-46	Manjaro Linux 15-0.9	EXT4	10 GB
sda-47	Ubuntu Linux 16.04	EXT4	10 GB
sda-48	chapeau Linux 23	EXT4	10 GB
sda-49	Arquetype Linux 22	EXT4	10 GB
sda-50	Fx64 Linux 22	EXT4	10 GB
sda-51	Viperr Linux 7	EXT4	10 GB
sda-52	Hanthana Linux 21	EXT4	10 GB

(*continued*)

Partition	Operating System	Filesystem	Size
sda-53	Qubes R3.1 Linux	EXT4	10 GB
sda-54	Fedora 24	EXT4	10 GB
sda-55	Korora-23	EXT4	10 GB
sda-56	sabayon-16	EXT4	10 GB
sda-57	Korora-24	EXT4	10 GB
sda-58	Sonar 16 Linux	EXT4	10 GB
sda-59	Viper 9 Linux	EXT4	10 GB
sda-60	Arquetype Linux 23	EXT4	10 GB
sda-61	Manjaro Linux 16	EXT4	10 GB
sda-62	Manjaro Linux Gaming 16	EXT4	10 GB
sda-63	Calculate Linux 15	EXT4	10 GB

So, the total number of UEFI OS installations on the sda disk is 59 since four partitions are reserved for ESP- and MSR-like stuff. The following are the sdb disk installations details:

Partition	Operating System	Filesystem	Size
sdb-1	PCBSD 10.1.2	ZFS	10 GB
sdb-2	Magia 2 Linux	EXT4	10 GB
sdb-3	Magia 3 Linux	EXt4	10 GB
sdb-4	Extended/secondary	N/A	970 GB approximately
sdb-5	Q4OS Linux 1.2.8	EXT4	10 GB
sdb-6	Qubes R2 Linux	EXT4	10 GB
sdb-7	Pardus Linux 2013	EXT4	10 GB
sdb-8	GoboLinux 015	EXT4	10 GB
sdb-9	Crux Linux 3.1	EXT4	10 GB
sdb-10	Point Linux 3.0	EXT4	10 GB

(*continued*)

Partition	Operating System	Filesystem	Size
sdb-11	Extix Linux 15.3	EXT4	10 GB
sdb-12	Bodhi Linux 3.0	EXT4	10 GB
sdb-13	Debian Linux 7.0	EXT4	10 GB
sdb-14	Debian Linux 6.0	EXT4	10 GB
sdb-15	BOSS Linux 6.1	EXT4	10 GB
sdb-16	CrunchBang rc1 Linux	EXT4	10 GB
sdb-17	Handy Linux 2.1	EXT4	10 GB
sdb-18	Lite Linux 2.4	EXT4	10 GB
sdb-19	WattOS Linux R9	EXT4	10 GB
sdb-20	PinGuy OS 14.04.3 Linux	EXT4	10 GB
sdb-21	SuperX 3.0 Linux	EXT4	10 GB
sdb-22	JuLinux 10X Rev 3.1 Linux	EXT4	10 GB
sdb-23	Black Lab Linux 2015.7	EXT4	10 GB
sdb-24	Hamara Linux 1.0.3	EXT4	10 GB
sdb-25	Peppermint LInux 20150518	EXT4	10 GB
sdb-26	Ubuntu 13.10 Linux	EXT4	10 GB
sdb-27	LinuxMint 13 mate	EXT4	10 GB
sdb-28	Linux Mint 14.1 cinnamon	EXT4	10 GB
sdb-29	LinuxMint 15 xfce	EXT4	10 GB
sdb-30	LinuxMint 16 KDE	EXT4	10 GB
sdb-31	Peppermint 4 20131113	EXT4	10 GB
sdb-32	Peppermint 5 20140623	EXT4	10 GB
sdb-33	Fedora 12	EXT4	10 GB
sdb-34	Trisquel 7 Linux	EXT4	10 GB
sdb-35	Oracle Linux 7.1	EXT4	10 GB
sdb-36	Fedora 14 Linux	EXT4	10 GB

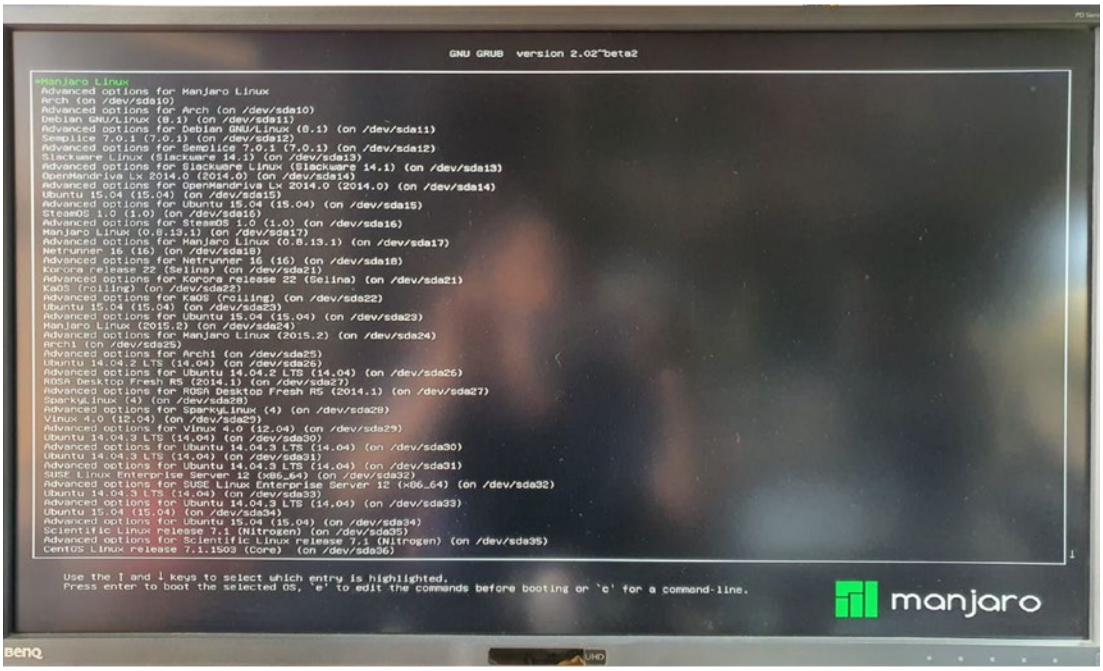
(*continued*)

Partition	Operating System	Filesystem	Size
sdb-37	Fedora 15 Linux	EXT4	10 GB
sdb-38	Fedora 17 Linux	EXT4	10 GB
sdb-39	Fedora 19 Linux	EXT4	10 GB
sdb-40	RHEL 6.5 Linux	EXT4	10 GB
sdb-41	SolydX 201506	EXT4	10 GB
sdb-42	Oracle Linux 6.7	EXT4	10 GB
sdb-43	OpenSuse 11.3	EXT4	10 GB
sdb-44	LMDE (Linux Mint 2 Debian edition)	EXT4	10 GB
sdb-45	Centrych Linux 12.04	EXT4	10 GB
sdb-46	Elementary OS 2013	EXT4	10 GB
sdb-47	Elementary OS 2015	EXT4	10 GB
sdb-48	Sabayon 13.08 Linux	EXT4	10 GB
sdb-49	Deepin 2013 Linux	EXT4	10 GB
sdb-50	Deepin 15.1 Linux	EXT4	10 GB

The total number of operating systems booting the BIOS way on the sdb disks is 50 – 2 = 48.

Two partitions are reserved for swap and the extended partition.

So, the total number of installations on the Jarvis system is 106, and as you can see in Figure 3-28, all of these OSs are multibooted by using the GRUB 2 bootloader. With this project I have realized that there is no end to this. The GRUB 2 and UEFI combination can handle *n* number of operating systems.



```
GNU GRUB  version 2.02~beta2

*Manjaro Linux
 Advanced options for Manjaro Linux
 Arch (on /dev/sda10)
 Advanced options for Arch (on /dev/sda10)
 Debian GNU/Linux (8.1) (on /dev/sda11)
 Advanced options for Debian GNU/Linux (8.1) (on /dev/sda11)
 Semplice 7.0.1 (7.0.1) (on /dev/sda12)
 Advanced options for Semplice 7.0.1 (7.0.1) (on /dev/sda12)
 Slackware Linux (Slackware 14.1) (on /dev/sda13)
 Advanced options for Slackware Linux (Slackware 14.1) (on /dev/sda13)
 OpenMandriva Lx 2014.0 (2014.0) (on /dev/sda14)
 Advanced options for OpenMandriva Lx 2014.0 (2014.0) (on /dev/sda14)
 Ubuntu 15.04 (15.04) (on /dev/sda15)
 Advanced options for Ubuntu 15.04 (15.04) (on /dev/sda15)
 SteamOS 1.0 (1.0) (on /dev/sda16)
 Advanced options for SteamOS 1.0 (1.0) (on /dev/sda16)
 Manjaro Linux (0.8.13.1) (on /dev/sda17)
 Advanced options for Manjaro Linux (0.8.13.1) (on /dev/sda17)
 Netrunner 16 (16) (on /dev/sda18)
 Advanced options for Netrunner 16 (16) (on /dev/sda18)
 Korora release 22 (Selina) (on /dev/sda21)
 Advanced options for Korora release 22 (Selina) (on /dev/sda21)
 KaOS (rolling) (on /dev/sda22)
 Advanced options for KaOS (rolling) (on /dev/sda22)
 Ubuntu 15.04 (15.04) (on /dev/sda23)
 Advanced options for Ubuntu 15.04 (15.04) (on /dev/sda23)
 Manjaro Linux (2015.2) (on /dev/sda24)
 Advanced options for Manjaro Linux (2015.2) (on /dev/sda24)
 Arch1 (on /dev/sda25)
 Advanced options for Arch1 (on /dev/sda25)
 Ubuntu 14.04.2 LTS (14.04) (on /dev/sda26)
 Advanced options for Ubuntu 14.04.2 LTS (14.04) (on /dev/sda26)
 ROSA Desktop Fresh R5 (2014.1) (on /dev/sda27)
 Advanced options for ROSA Desktop Fresh R5 (2014.1) (on /dev/sda27)
 SparkyLinux (4) (on /dev/sda28)
 Advanced options for SparkyLinux (4) (on /dev/sda28)
 Vinux 4.0 (12.04) (on /dev/sda29)
 Advanced options for Vinux 4.0 (12.04) (on /dev/sda29)
 Ubuntu 14.04.3 LTS (14.04) (on /dev/sda30)
 Advanced options for Ubuntu 14.04.3 LTS (14.04) (on /dev/sda30)
 Ubuntu 14.04.3 LTS (14.04) (on /dev/sda31)
 Advanced options for Ubuntu 14.04.3 LTS (14.04) (on /dev/sda31)
 SUSE Linux Enterprise Server 12 (x86_64) (on /dev/sda32)
 Advanced options for SUSE Linux Enterprise Server 12 (x86_64) (on /dev/sda32)
 Ubuntu 14.04.3 LTS (14.04) (on /dev/sda33)
 Advanced options for Ubuntu 14.04.3 LTS (14.04) (on /dev/sda33)
 Ubuntu 15.04 (15.04) (on /dev/sda34)
 Advanced options for Ubuntu 15.04 (15.04) (on /dev/sda34)
 Scientific Linux release 7.1 (Nitrogen) (on /dev/sda35)
 Advanced options for Scientific Linux release 7.1 (Nitrogen) (on /dev/sda35)
 CentOS Linux release 7.1.1503 (Core)  (on /dev/sda36)

   Use the ↑ and ↓ keys to select which entry is highlighted.
   Press enter to boot the selected OS, `e' to edit the commands before booting or `c' for a command-line.
```

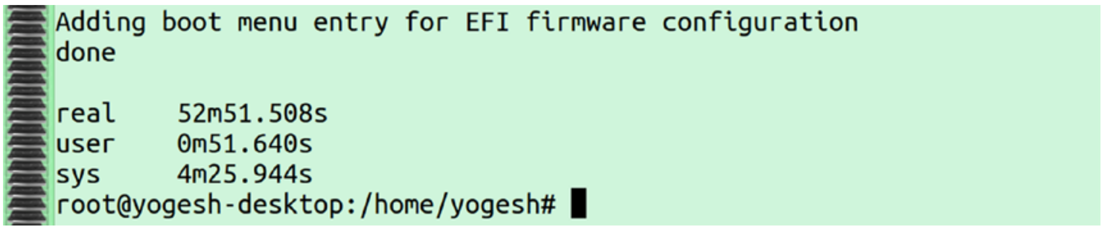
Figure 3-28. *The 106 operating systems listed by GRUB 2*

How did I manage to install this many operating systems? Simple. I fired the `grub-mkconfig` command after every new OS installation, which found all the operating systems from all the attached disks.

```
# time grub-mkconfig -o multiboot_grub.cfg
```

The previous command is used after installing Ubuntu 18, which was the 106th OS in the list.

As you can see in Figure 3-29, when I installed the 106th OS, `grub-mkconfig` took almost one hour to complete, and the resulting GRUB configuration file had 5,500 lines in it.



```
Adding boot menu entry for EFI firmware configuration
done

real    52m51.508s
user    0m51.640s
sys     4m25.944s
root@yogesh-desktop:/home/yogesh# 
```

Figure 3-29. *The time taken by the grub-mkconfig command*

A Dummy Small Bootloader

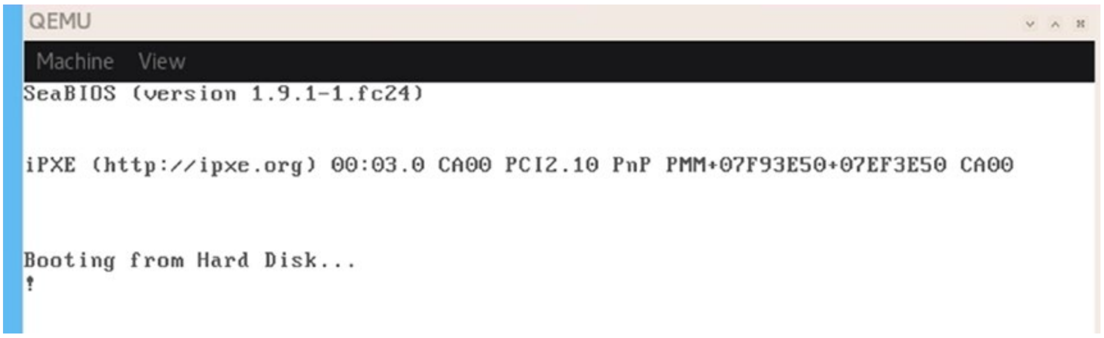
We know that the BIOS jumps to the first 512 bytes and calls the GRUB 2 bootloader. To understand how exactly BIOS calls the bootloader, we will make our own bootloader. Our bootloader will be very tiny compared to GRUB 2. Our bootloader will just print `!` on the screen. But with this example, you will be able to understand how the BIOS jumps to the bootloaders as with GRUB 2, as shown here:

#cat boot.nasm

```
    ;
    ; Note: this example is written in Intel Assembly syntax
    ;
     [BITS 16]
     [ORG 0x7c00]

    boot:
        mov al, '!'       <<-- Character for interrupt
        mov ah, 0x0e      <<-- Display character
        mov bh, 0x00      <<-- Set video mode
        mov bl, 0x07      <<-- Clear/Scroll screen down
        int 0x10          <<--- BIOS interrupt 10 which is taking inputs
                          from al, ah, bh, bl
        jmp $
        times 510-($-$$) db 0      <<--- Out of 512 bytes first 510 bytes
                                   are filled  with 0's.
                                   In the real world it will be filled with
                                   grub's boot strap.
        db 0x55           <<-- &
        db 0xaa           <<-- | tells BIOS that this is the device which
                          is active/fdisk sign/boot flag.
```

#nasm -f bin boot.nasm && qemu-system-x86_64 boot

This will make a boot disk (disk image) from the `boot.nasm` file, and it will be an input to qemu, which will execute it. As you can see in Figure 3-30, you will see `!` printed on the screen.



```
SeaBIOS (version 1.9.1-1.fc24)


iPXE (http://ipxe.org) 00:03.0 CA00 PCI2.10 PnP PMM+07F93E50+07EF3E50 CA00


Booting from Hard Disk...
!
```

Figure 3-30. Our small tiny bootloader

Basically, the qemu machine is considering boot as a disk, and whenever the qemu machine finishes its BIOS stage, the BIOS drops at the first 512 bytes of the boot disk. Here you will find that the first 510 bytes are written as 0 and the in last 2 bytes we have ! (the bootloader), and it will be printed on our screen.

So far, we have gotten a good overview of GRUB 2; now going further in the next section, we will discuss what really happens inside GRUB 2.

GRUB 2 at a Low level

While writing this book, the latest available source code of GRUB was GRUB 2.04, which I have been using here. The bootstrap binary (if the system is BIOS based) from the first 440 bytes of 512 bytes is called `boot.img`, which is available at `/usr/lib/grub/i386-pc/boot.img`.

```
# ls -lh /usr/lib/grub/i386-pc/boot.img
-rw-r--r--. 1 root root 512 Mar 28  2019 /usr/lib/grub/i386-pc/boot.img
```

```
# file  /usr/lib/grub/i386-pc/boot.img
/usr/lib/grub/i386-pc/boot.img: DOS/MBR boot sector
```

The `boot.img` file is created from the source code written in the file `/GRUB 2.04/grub-core/boot/i386/pc/boot.S`.

The following is a snippet of it:

```
<snip>
/* -*-Asm-*- */
/*
 *  GRUB  --  GRand Unified Bootloader
 *  Copyright (C) 1999,2000,2001,2002,2005,2006,2007,2008,2009  Free Software Foundation, Inc.
 *
 *  GRUB is free software: you can redistribute it and/or modify
 *  it under the terms of the GNU General Public License as published by
 *  the Free Software Foundation, either version 3 of the License, or
 *  (at your option) any later version.
 *
 *  GRUB is distributed in the hope that it will be useful,
 *  but WITHOUT ANY WARRANTY; without even the implied warranty of
 *  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 *  GNU General Public License for more details.
 *
 *  You should have received a copy of the GNU General Public License
 *  along with GRUB.  If not, see <http://www.gnu.org/licenses/>.
 */

#include <grub/symbol.h>
#include <grub/machine/boot.h>

/*
 *  defines for the code go here
 */

        /* Print message string */
#define MSG(x)  movw $x, %si; call LOCAL(message)
#define ERR(x)  movw $x, %si; jmp LOCAL(error_message)

```

```
        .macro floppy
part_start:

LOCAL(probe_values):
        .byte   36, 18, 15, 9, 0

LOCAL(floppy_probe):
        pushw   %dx
/*
 *  Perform floppy probe.
 */
#ifdef __APPLE__
        LOCAL(probe_values_minus_one) = LOCAL(probe_values) - 1
        movw    MACRO_DOLLAR(LOCAL(probe_values_minus_one)), %si
#else
        movw    MACRO_DOLLAR(LOCAL(probe_values)) - 1, %si
#endif

LOCAL(probe_loop):
        /* reset floppy controller INT 13h AH=0 */
        xorw    %ax, %ax
        int     MACRO_DOLLAR(0x13)
</snip>
```

You can consider `boot.img` as a first stage of the bootloader or part-1 of GRUB. This `boot.img` file transfers control to `diskboot.img`, which is part-2 of GRUB.

```
# ls -lh /usr/lib/grub/i386-pc/diskboot.img
-rw-r--r--. 1 root root 512 Mar 28  2019 /usr/lib/grub/i386-pc/diskboot.img
```

```
# file /usr/lib/grub/i386-pc/diskboot.img
/usr/lib/grub/i386-pc/diskboot.img: data
```

The diskboot.img file is made from the source code of grub-2.04/grub-core/boot/i386/pc/diskboot.S. The following is a snippet of it:

```
<snip>
/*
 *  GRUB  --  GRand Unified Bootloader
 * Copyright (C) 1999,2000,2001,2002,2006,2007,2009,2010 Free Software Foundation, Inc.
 *
 *  GRUB is free software: you can redistribute it and/or modify
 *  it under the terms of the GNU General Public License as published by
 *  the Free Software Foundation, either version 3 of the License, or
 *  (at your option) any later version.
 *
 *  GRUB is distributed in the hope that it will be useful,
 *  but WITHOUT ANY WARRANTY; without even the implied warranty of
 *  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
 *  GNU General Public License for more details.
 *
 *  You should have received a copy of the GNU General Public License
 *  along with GRUB.  If not, see <http://www.gnu.org/licenses/>.
 */

#include <grub/symbol.h>
#include <grub/machine/boot.h>

/*
 *  defines for the code go here
 */

#define MSG(x)  movw $x, %si; call LOCAL(message)

        .file   "diskboot.S"

        .text

        /* Tell GAS to generate 16-bit instructions so that this code works
           in real mode. */
        .code16

        .globl  start, _start
start:
_start:
        /*
         * _start is loaded at 0x8000 and is jumped to with
         * CS:IP 0:0x8000 in kernel.
         */
</snip>
```

The `diskboot.img` file then loads the actual core part of GRUB 2, which is part-3 of GRUB. You can also consider that part-3 of GRUB is a kernel of the bootloader. At this stage, GRUB 2 will be capable of reading the filesystem.

```
# ls /boot/grub2/i386-pc/core.img -lh
-rw-r--r--. 1 root root 30K Dec  9 10:18 /boot/grub2/i386-pc/core.img
```

From `/GRUB 2.00/grub-core/kern/main.c`, GRUB 2 sets the root device name, reads `grub.cfg`, and at the end shows the operating system list to choose.

I hope you understand how GRUB 2 works now. The following is a quick summary of what we have discussed so far:

a. The bootloader is the first code that runs after the firmware.

b. The bootloader/GRUB copies the kernel in memory.

c. The bootloader loads the initramfs image in memory and gives the kernel a pointer to it.

d. The bootloader hand overs control to the kernel.

CHAPTER 4

Kernel

This chapter will cover the kernel.

Loading the Kernel in Memory

This is an interesting chapter. So far, we have seen that up to this stage GRUB 2 had full control of the booting procedure. Now it has to hand over control to the kernel. In this chapter, we will see how and where the bootloader loads the kernel. In other words, how is the kernel extracted? Then we will see the booting-related tasks achieved by the Linux kernel and at the end how the kernel starts systemd.

Note The source code of the kernel that is used in this chapter is version `kernel-5.4.4`. When I was writing this book, that was the latest stable code available; see `https://www.kernel.org/`. An excellent resource on this subject is the *Inside Linux* book, written by 0xAX. I have learned a lot from it, and I'm sure you will too. You can find the book at `https://0xax.gitbooks.io/linux-insides/`.

To hand over the control to the kernel, the bootloader has to achieve two major things.

- Load the kernel into memory
- Set some of the fields of the kernel as per the boot protocol

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Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_4

The complete boot protocol is available at `https://www.kernel.org/doc/Documentation/x86/boot.txt`. The original boot protocol was defined by none other than Linus Torvalds.

```
         ~                                ~
         |  Protected-mode kernel         |
 100000  +--------------------------------+
         |  I/O memory hole               |
 0A0000  +--------------------------------+
         |  Reserved for BIOS             | Leave as much as possible unused
         ~                                ~
         |  Command line                  | (Can also be below the X+10000
                                            mark)
X+10000  +--------------------------------+
         |  Stack/heap                    | For use by the kernel real-mode
                                            code.
X+08000  +--------------------------------+
         |  Kernel setup                  | The kernel real-mode code.
         |  Kernel boot sector            | The kernel legacy boot sector.
      X  +--------------------------------+
         |  Boot loader                   | <- Boot sector entry point
                                            0000:7C00. You will see the same
         |                                | address location at our boot.asm
                                            file which we created above.
  001000 +--------------------------------+
         |  Reserved for MBR/BIOS         |
 000800  +--------------------------------+
         |  Typically used by MBR         |
 000600  +--------------------------------+
         |  BIOS use only                 |
 000000  +--------------------------------+
```

As per the boot protocol, it's the duty of a bootloader to pass on or set some of the fields of the kernel header. The fields are the root device name, mount options like `ro` or `rw`, the initramfs name, the initramfs size, etc. These same fields are called *kernel command-line parameters*, and we already know that the kernel command-line parameters are passed by GRUB/the bootloader to the kernel.

GRUB will not load the kernel (`/boot/vmlinuz`) at any random location; it will always be loaded at a special location. The special location will vary as per the Linux distribution and version you are using and as per the CPU architecture of the system. `vmlinuz` is an archive file, and the archive is made from three parts.

```
Vmlinuz (bZimage) =  Header   + kernel setup code + vmlinux (actual
compressed kernel)
                     (part-1)   (part-2)             (part-3)
```

After Loading the Kernel in Memory

We need to imagine here that GRUB 2 has loaded the kernel in memory at the special location. Here are the initial-level steps carried out by the kernel archive file `vmlinuz` as soon as it loaded in memory:

1) As soon as the bootloader loads the kernel in memory at a specific location, the binary made from the file `arch/x86/boot/header.S` runs.

2) Confusion occurs if `vmlinuz` is an archive and the bootloader has not extracted it yet. The bootloader has just loaded the kernel at a specific location. Then why is the code that is inside the `vmlinuz` archive file able to run?

3) We will see the short answer first, and the long answer will be discussed in the "What Extracts vmlinuz?" section of this chapter. So, the short answer is a binary made from the `arch/x86/boot/header.S` file is not in the archive; rather, it is part of a header that does a `kernel_setup` task. The header is outside of an archive.

```
Vmlinuz (bZimage) = Header + kernel setup code + vmlinux (actual compressed kernel)
                    --->Outside of archive<--- + -------->Inside archive<----
                    --->header.s file is here<---
```

4) Let's consider for now that `vmlinuz` has been extracted, and let's continue our booting sequence. So far, we have seen that GRUB has loaded the kernel in memory at a special location and runs the binary made from `arch/x86/boot/header.S.` This binary is responsible for the `Kernel_setup` part. The `kernel_setup` file does the following tasks:

   a) Align the segment registers

   b) Set up the stack and BSS

   In every chapter, a flowchart will give us a clear idea about what we have learned and, in terms of booting, where we have reached. Figure 4-1 shows the start of the flowchart that we will build in this chapter as we progress. It shows the actions performed by the `kernel_setup` code of `header.s`.

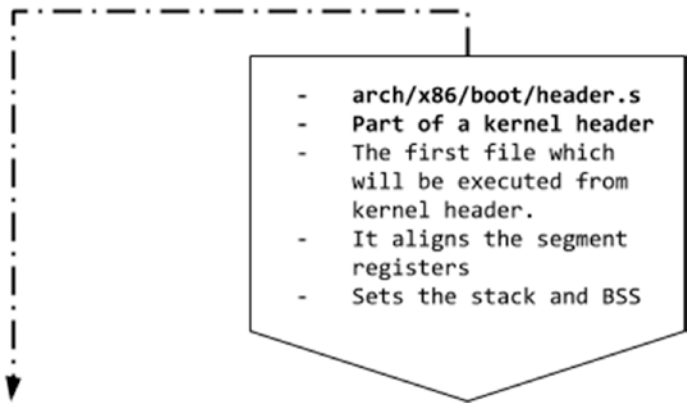

- arch/x86/boot/header.s
- Part of a kernel header
- The first file which will be executed from kernel header.
- It aligns the segment registers
- Sets the stack and BSS

Figure 4-1. *Steps taken by kernel_setup*

5) Then it jumps to the `main()` function at `arch/x86/boot/main.c`. The `main.c` file is also part of a kernel header, and the header is outside the actual archive.

Vmlinuz (bZimage) = Header + kernel setup code + vmlinux (actual compressed kernel)

```
                   --->Outside of archive<--- + -------->Inside archive<---------
                  --->main.c file is here<---
```

```
#vim arch/x86/boot/main.c
<snip>
void main(void)
{
        /* First, copy the boot header into the "zeropage" */
        copy_boot_params();

        /* Initialize the early-boot console */
        console_init();
        if (cmdline_find_option_bool("debug"))
                puts("early console in setup code\n");

        /* End of heap check */
        init_heap();

        /* Make sure we have all the proper CPU support */
        if (validate_cpu()) {
                puts("Unable to boot - please use a kernel
                      appropriate "
                     "for your CPU.\n");
                die();
        }

        /* Tell the BIOS what CPU mode we intend to run in. */
        set_bios_mode();

        /* Detect memory layout */
        detect_memory();

        /* Set keyboard repeat rate (why?) and query the lock flags */
        keyboard_init();

        /* Query Intel SpeedStep (IST) information */
        query_ist();

        /* Query APM information */
#if defined(CONFIG_APM) || defined(CONFIG_APM_MODULE)
        query_apm_bios();
#endif

        /* Query EDD information */
#if defined(CONFIG_EDD) || defined(CONFIG_EDD_MODULE)
        query_edd();
#endif

        /* Set the video mode */
        set_video();

        /* Do the last things and invoke protected mode */
        go_to_protected_mode();
}
</snip>
```

As you can see, the `main.c` source code is responsible for the following:

1) It copies the boot parameters (the kernel command-line parameters) from the bootloader. The `copy_boot_params` function will be used to copy the following boot parameters passed by the bootloader:

   `debug, earlyprintk, ro, root, ramdisk_image, ramdisk_size etc.`

2) It initializes the console and checks whether the `debug`-like kernel command-line parameter has been passed by the user. If it has, the kernel will show the verbose-level messages on the screen.

3) It initializes the heap.

4) If the CPU cannot be validated, then it throws an error message through the `validate_cpu()` function. Distributions like Fedora and Ubuntu customize the error message, from `'unable to boot - please use the kernel appropriate for your cpu'` to something like `'The CPU is not supported'`. The customization will also panic the kernel, and the booting will be halted.

5) Then it detects the memory layout and prints it on-screen at an early stage of booting. The same memory layout messages can be seen after the boot by using the `'dmesg'` command, as shown here:

```
[    0.000000] BIOS-provided physical RAM map:
[    0.000000] BIOS-e820: [mem 0x0000000000000000-0x0000000000057fff] usable
[    0.000000] BIOS-e820: [mem 0x0000000000058000-0x0000000000058fff] reserved
[    0.000000] BIOS-e820: [mem 0x0000000000059000-0x000000000009cfff] usable
[    0.000000] BIOS-e820: [mem 0x000000000009d000-0x00000000000fffff] reserved
[    0.000000] BIOS-e820: [mem 0x0000000000100000-0x000000007e5f7fff] usable
[    0.000000] BIOS-e820: [mem 0x000000007e5f8000-0x000000007e5f8fff] ACPI NVS
[    0.000000] BIOS-e820: [mem 0x000000007e5f9000-0x000000007e5f9fff] reserved
[    0.000000] BIOS-e820: [mem 0x000000007e5fa000-0x0000000087f62fff] usable
[    0.000000] BIOS-e820: [mem 0x0000000087f63000-0x000000008952bfff] reserved
[    0.000000] BIOS-e820: [mem 0x000000008952c000-0x0000000089599fff] ACPI NVS
[    0.000000] BIOS-e820: [mem 0x000000008959a000-0x00000000895fefff] ACPI data
[    0.000000] BIOS-e820: [mem 0x00000000895ff000-0x00000000895fffff] usable
[    0.000000] BIOS-e820: [mem 0x0000000089600000-0x000000008f7fffff] reserved
[    0.000000] BIOS-e820: [mem 0x00000000f0000000-0x00000000f7ffffff] reserved
[    0.000000] BIOS-e820: [mem 0x00000000fe010000-0x00000000fe010fff] reserved
[    0.000000] BIOS-e820: [mem 0x0000000100000000-0x000000086e7fffff] usable
```

6) Initialize the keyboard and its layout.

7) Set the basic video mode.

8) Jump to the protected mode through the `go_to_protected_mode()` function. Please refer to Figure 4-2 for a better understanding.

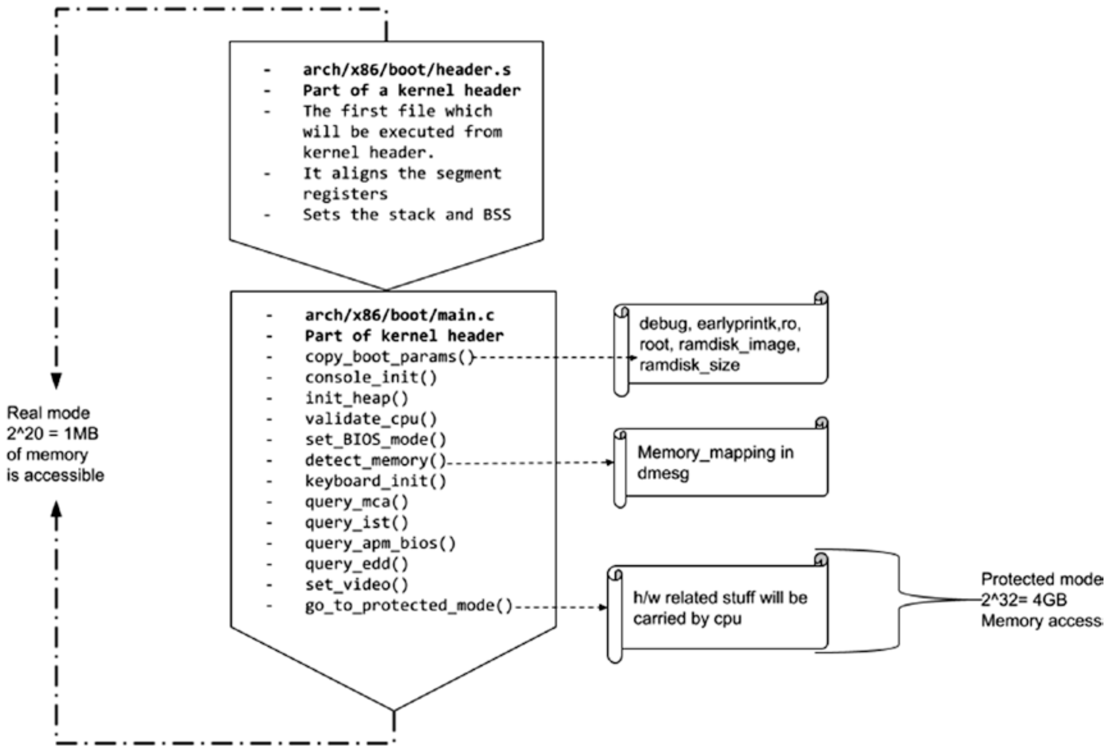


Figure 4-2. *The flowchart*

Protected Mode

Up to this point, we have worked in real mode, which has 20-bit address limitations because of that we can access up to 1 MB of memory. With the `go_to_protected_mode()` function, the kernel has switched the CPU from real mode to the protected mode. Protected mode has a 32-bit address limitation, so the CPU can access up to 4 GB of memory. In simple terms, in real mode only those programs will run that have a 16-bit instruction set, for example, the BIOS. In protected mode, only the 32-bit programs will run. The kernel does some hardware-related tasks in protected mode and then launches a CPU in long mode.

Please note that this book follows Intel's X86 architecture, and the real, protected, and long mode discussions are based on Intel's 64-bit architecture.

Long Mode

Long mode does not put any memory restrictions on the CPU. It can use all the installed memory. Placing the CPU in long mode will be achieved by the `head_64.S` file from `arch/x86/boot/compressed/head_64.S`. It is responsible for the following:

1) Preparing for long mode means it will check whether it supports long mode or not.

2) Enter into long mode.

3) Decompress the kernel.

The following are functions that get called from the `head_64.S` assembly file:

```
$ cat arch/x86/boot/compressed/head_64.S | grep -i call
    call    1f
    call    verify_cpu
    call    get_sev_encryption_bit
    call    1f
    call    1f
    call    .Ladjust_got
     * this function call.
    call    paging_prepare
     * this function call.
    call    cleanup_trampoline
    call    1f
    call    .Ladjust_got
    call    1f
     * Relocate efi_config->call().
    call    make_boot_params
    call    1f
     * Relocate efi_config->call().
    call    efi_main
    call    extract_kernel    /* returns kernel location in %rax */
    .quad    efi_call
```

Function	Working
verify_cpu	This will make sure the CPU has a long mode.
make_boot_params	This will take care of the bootloader-passed boot-time parameters.
efi_main	UEFI firmware-related stuff.
extract_kernel	The function is defined in `arch/x86/boot/compressed_misc.c`. This is the function that will decompress `vmlinux` from `vmlinuz`.

For a better understanding, please refer to the flowchart shown in Figure 4-3.

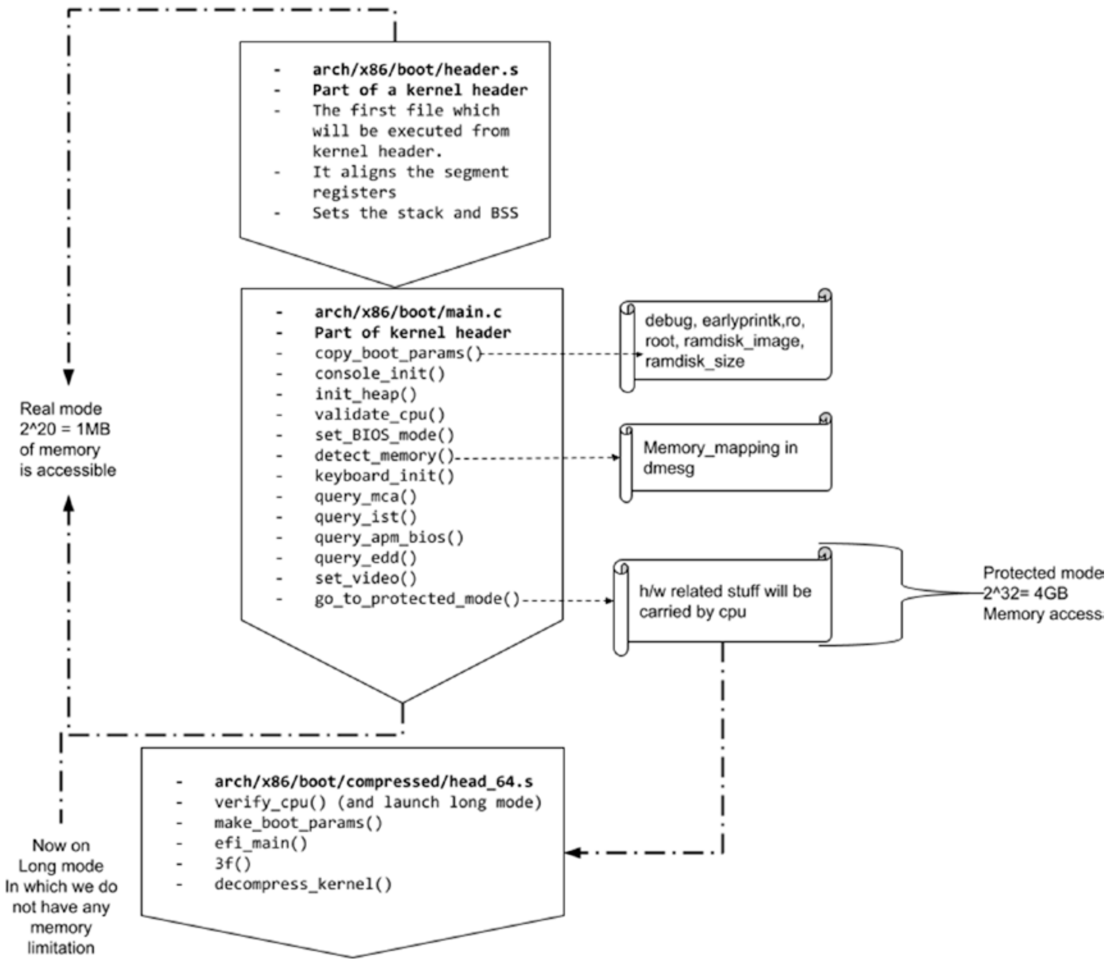

- arch/x86/boot/header.s
- Part of a kernel header
- The first file which will be executed from kernel header.
- It aligns the segment registers
- Sets the stack and BSS
- arch/x86/boot/main.c
- Part of kernel header
- copy_boot_params()
- console_init()
- init_heap()
- validate_cpu()
- set_BIOS_mode()
- detect_memory()
- keyboard_init()
- query_mca()
- query_ist()
- query_apm_bios()
- query_edd()
- set_video()
- go_to_protected_mode()
debug, earlyprintk,ro, root, ramdisk_image, ramdisk_size
Memory_mapping in dmesg
h/w related stuff will be carried by cpu
Protected mode 2^32= 4GB Memory access
Real mode 2^20 = 1MB of memory is accessible
- arch/x86/boot/compressed/head_64.s
- verify_cpu() (and launch long mode)
- make_boot_params()
- efi_main()
- 3f()
- decompress_kernel()
Now on Long mode In which we do not have any memory limitation

Figure 4-3. The flowchart, updated

Wait a minute: if the kernel is not yet decompressed, then how come we proceed at this point? Here comes the long answer.

What Extracts vmlinuz?

So far, we understand that it's GRUB that loads the kernel in memory, but at the same time, we noticed that the `vmlinuz` image is an archive. So, what extracts this image? Is it GRUB?

No, it is not GRUB. Rather, it's the kernel that extracts itself. Yes, I said it's the kernel that extracts the kernel. The `vmlinuz` could be the operating system world's only file that extracts itself. But how is it possible to extract yourself? To understand this, let's get some more insight about `vmlinuz` first.

The "vm" of `vmlinuz` stands for "virtual memory." In the earlier stages of Linux development, the virtual memory concept was not yet developed, so when it was added, the "vm" characters were added to the name of the Linux kernel. The "z" stands for a zipped file.

```
$ file vmlinuz-5.0.9-301.fc30.x86_64

vmlinuz-5.0.9-301.fc30.x86_64: Linux kernel x86 boot executable bzImage,
version 5.0.9-301.fc30.x86_64 (mockbuild@bkernel04.phx2.fedoraproject.org)
#1 SMP Tue Apr 23 23:57:35 U, RO-rootFS, swap_dev 0x8, Normal VGA
```

As you can see, `vmlinuz` is `bzImage` (`bzImage` stands for "big zimage"). `vmlinuz` is a compressed file of the actual kernel's binary `vmlinux`. You cannot decompress this file with `gunzip/bunzip` or even with `tar`. The easiest way to extract `vmlinuz` and to get the `vmlinux` file is to use the `extract-vmlinux` script file provided by the `kernel-devel` package (in the case of Fedora). The file will be present at `/usr/src/kernels/<kernel_version>/scripts/extract-vmlinux`.

```
# ./extract-vmlinux /boot/vmlinuz-5.3.7-301.fc31.x86_64 >> /boot/temp/
   vmlinux

# file /boot/temp/*
/boot/temp/vmlinux: ELF 64-bit LSB executable, x86-64, version 1 (SYSV),
statically linked, BuildID[sha1]=ec96b29d8e4079950644230c0b7868942bb70366,
stripped
```

There are various ways to open the `vmlinux` and `vmlinuz` kernel files.

```
$ xxd vmlinux | less
$ objdump vmlinux | less
$ objdump vmlinux -D | less
$ hexdump vmlinux | less
$ od vmlinux | less
```

We will use the `od` command with some of the switches to open the `vmlinuz` file.

```
    $ od -A d -t x1 vmlinuz-5.0.9-301.fc30.x86_64 | less
<snip>
0000000 4d 5a ea 07 00 c0 07 8c c8 8e d8 8e c0 8e d0 31
0000016 e4 fb fc be 40 00 ac 20 c0 74 09 b4 0e bb 07 00
0000032 cd 10 eb f2 31 c0 cd 16 cd 19 ea f0 ff 00 f0 00
0000048 00 00 00 00 00 00 00 00 00 00 00 00 82 00 00 00
0000064 55 73 65 20 61 20 62 6f 6f 74 20 6c 6f 61 64 65
0000080 72 2e 0d 0a 0a 52 65 6d 6f 76 65 20 64 69 73 6b
0000096 20 61 6e 64 20 70 72 65 73 73 20 61 6e 79 20 6b
0000112 65 79 20 74 6f 20 72 65 62 6f 6f 74 2e 2e 2e 0d
0000128 0a 00 50 45 00 00 64 86 04 00 00 00 00 00 00 00
0000144 00 00 01 00 00 00 a0 00 06 02 0b 02 02 14 80 37
0000160 8e 00 00 00 00 00 80 86 26 02 f0 48 00 00 00 02
0000176 00 00 00 00 00 00 00 00 00 00 20 00 00 00 20 00
0000192 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000208 00 00 00 c0 b4 02 00 02 00 00 00 00 00 00 0a 00
0000224 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
*
0000256 00 00 00 00 00 00 06 00 00 00 00 00 00 00 00 00
0000272 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000288 00 00 00 00 00 00 00 00 00 00 80 39 8e 00 48 09
0000304 00 00 00 00 00 00 00 00 00 00 2e 73 65 74 75 70
0000320 00 00 e0 43 00 00 00 02 00 00 e0 43 00 00 00 02
0000336 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00
0000352 50 60 2e 72 65 6c 6f 63 00 00 20 00 00 00 e0 45
0000368 00 00 20 00 00 00 e0 45 00 00 00 00 00 00 00 00
0000384 00 00 00 00 00 00 40 00 10 42 2e 74 65 78 74 00
```

```
0000400 00 00 80 f3 8d 00 00 46 00 00 80 f3 8d 00 00 46
0000416 00 00 00 00 00 00 00 00 00 00 00 00 00 00 20 00
0000432 50 60 2e 62 73 73 00 00 00 00 80 86 26 02 80 39
0000448 8e 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000464 00 00 00 00 00 00 80 00 00 c8 00 00 00 00 00 00
0000480 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ff
0000496 ff 22 01 00 38 df 08 00 00 00 ff ff 00 00 55 aa
0000512 eb 66 48 64 72 53 0d 02 00 00 00 00 00 10 c0 37
0000528 00 01 00 80 00 00 10 00 00 00 00 00 00 00 00 00
0000544 00 00 00 00 50 5a 00 00 00 00 00 00 ff ff ff 7f
0000560 00 00 00 01 01 15 3f 00 ff 07 00 00 00 00 00 00
0000576 00 00 00 00 00 00 00 00 b1 03 00 00 11 f3 89 00
0000592 00 00 00 00 00 00 00 00 00 00 00 01 00 00 00 00
0000608 00 c0 b4 02 90 01 00 00 8c d8 8e c0 fc 8c d2 39
0000624 c2 89 e2 74 16 ba 50 58 f6 06 11 02 80 74 04 8b
</snip>
```

```
# od -A d -t x1 /boot/vmlinuz-5.3.7-301.fc31.x86_64 | grep -i '1f 8b 08 00'
0018864 8f 1f 8b 08 00 00 00 00 00 02 03 ec fd 79 7c 54
```

So, on 0018864, the actual kernel (vmlinux) starts, whereas the vmlinuz file starts at 0000000. This means from 0000000 to 0018864, what we have is the header of the file, such as header.S, misc.c, etc. This will extract the actual kernel (vmlinux) from vmlinuz. You can consider a header to be like a cap on a vmlinux binary, and when this cap is available, it becomes vmlinuz. In the following sections, we will see how the kernel routine extracts vmlinuz.

extract_kernel

Let's get back to the extract_kernel function from arch/x86/boot/compressed/misc.c.

```
asmlinkage __visible void *extract_kernel(void *rmode, memptr heap,
                                          unsigned char *input_data,
                                          unsigned long input_len,
                                          unsigned char *output,
                                          unsigned long output_len)
```

As you can see, the function will accept seven arguments.

Argument	Purpose
rmode	A pointer to the `boot_params` structure that is filled by the bootloader
heap	A pointer to the `boot_heap` file that represents the start address of the early boot heap
input_data	A pointer to the start of the compressed kernel or in other words a pointer to `arch/x86/boot/compressed/vmlinux.bin.bz2`
input_len	The size of the compressed kernel
output	The start address of the future decompressed kernel
output_len	The size of decompressed kernel
run_size	The amount of space needed to run the kernel including `.bss` and `.brk` sections

Along with the kernel, the bootloader will also load initramfs in memory. We will talk about initramfs in Chapter 5. So, before extracting the kernel image, the header or the kernel routine has to take care that the `vmlinuz` extraction will not overwrite or overlap the already loaded initramfs image. So, the `extract_kernel` function will also take care of calculating the initramfs address space and will adjust the kernel image decompression accordingly. Once we get the correct address where the header can decompress `vmlinuz`, it will extract the kernel there.

```
asmlinkage __visible void *extract_kernel(void *rmode, memptr heap,
                                  unsigned char *input_data,
                                  unsigned long input_len,
                                  unsigned char *output,
                                  unsigned long output_len)
{
        const unsigned long kernel_total_size = VO__end - VO__text;
        unsigned long virt_addr = LOAD_PHYSICAL_ADDR;
        unsigned long needed_size;

        /* Retain x86 boot parameters pointer passed from
        startup_32/64. */
        boot_params = rmode;

        /* Clear flags intended for solely in-kernel use. */
        boot_params->hdr.loadflags &= ~KASLR_FLAG;

        sanitize_boot_params(boot_params);

        if (boot_params->screen_info.orig_video_mode == 7) {
                vidmem = (char *) 0xb0000;
                vidport = 0x3b4;
        } else {
                vidmem = (char *) 0xb8000;
                vidport = 0x3d4;
        }

        lines = boot_params->screen_info.orig_video_lines;
        cols = boot_params->screen_info.orig_video_cols;

        console_init();

        /*
         * Save RSDP address for later use. Have this after console_init()
         * so that early debugging output from the RSDP parsing code can be
         * collected.
         */
        boot_params->acpi_rsdp_addr = get_rsdp_addr();

        debug_putstr("early console in extract_kernel\n");

        free_mem_ptr     = heap;        /* Heap */
        free_mem_end_ptr = heap + BOOT_HEAP_SIZE;

        /*
```

```
         * The memory hole needed for the kernel is the larger of either
         * the entire decompressed kernel plus relocation table, or the
         * entire decompressed kernel plus .bss and .brk sections.
         *
         * On X86_64, the memory is mapped with PMD pages. Round the
         * size up so that the full extent of PMD pages mapped is
         * included in the check against the valid memory table
         * entries. This ensures the full mapped area is usable RAM
         * and doesnt include any reserved areas.
         */
        needed_size = max(output_len, kernel_total_size);
#ifdef CONFIG_X86_64
        needed_size = ALIGN(needed_size, MIN_KERNEL_ALIGN);
#endif

        /* Report initial kernel position details. */
        debug_putaddr(input_data);
        debug_putaddr(input_len);
        debug_putaddr(output);
        debug_putaddr(output_len);
        debug_putaddr(kernel_total_size);
        debug_putaddr(needed_size);

#ifdef CONFIG_X86_64
        /* Report address of 32-bit trampoline */
        debug_putaddr(trampoline_32bit);
#endif

        choose_random_location((unsigned long)input_data, input_len,
                                (unsigned long *)&output,
                                needed_size,
                                &virt_addr);

        /* Validate memory location choices. */
        if ((unsigned long)output & (MIN_KERNEL_ALIGN - 1))
                error("Destination physical address inappropriately aligned");
        if (virt_addr & (MIN_KERNEL_ALIGN - 1))
                error("Destination virtual address inappropriately aligned");
#ifdef CONFIG_X86_64
        if (heap > 0x3fffffffffffUL)
                error("Destination address too large");
        if (virt_addr + max(output_len, kernel_total_size) > KERNEL_IMAGE_SIZE)
                error("Destination virtual address is beyond the kernel mapping area");
#else
        if (heap > ((-__PAGE_OFFSET-(128<<20)-1) & 0x7fffffff))
                error("Destination address too large");
#endif
#ifndef CONFIG_RELOCATABLE
        if ((unsigned long)output != LOAD_PHYSICAL_ADDR)
                error("Destination address does not match LOAD_PHYSICAL_ADDR");
        if (virt_addr != LOAD_PHYSICAL_ADDR)
                error("Destination virtual address changed when not relocatable");
#endif

        debug_putstr("\nDecompressing Linux... ");
        __decompress(input_data, input_len, NULL, NULL, output, output_len,
                        NULL, error);
        parse_elf(output);
        handle_relocations(output, output_len, virt_addr);
        debug_putstr("done.\nBooting the kernel.\n");
        return output;
}
```

The decompression method will be chosen according to the compression algorithm used at the time of kernel compilation. The decompression methods can be seen in the same `misc.c` file.

```
        <snip from misc.c>
#ifdef CONFIG_KERNEL_GZIP
#include "../../../../lib/decompress_inflate.c"
#endif

#ifdef CONFIG_KERNEL_BZIP2
#include "../../../../lib/decompress_bunzip2.c"
#endif

#ifdef CONFIG_KERNEL_LZMA
#include "../../../../lib/decompress_unlzma.c"
#endif

#ifdef CONFIG_KERNEL_XZ
#include "../../../../lib/decompress_unxz.c"
#endif

#ifdef CONFIG_KERNEL_LZO
#include "../../../../lib/decompress_unlzo.c"
#endif
  </snip>
```

Once the kernel is decompressed in memory, the entry point of the extracted kernel will be obtained from the `extract_kernel` function, and the CPU will jump inside a kernel.

Inside the Kernel

The kernel does numerous things, but I will list what is of most interest to you as someone learning about booting.

- The kernel will set the kernel stack size to 16 KB if the architecture is 64-bit. This means every new process will get its own kernel stack which will be 16 KB in size.

- page_size will be set to 4 KB, which is the default page size on an Intel 64-bit architecture.
- The kernel will prepare the interrupt and exception handling mechanism also called the *interrupt descriptor table* (IDT).
- The kernel will set the page fault handling mechanism.
- The kernel will collect the initramfs file details such as file name, size, address, relocation address, major and minor numbers of a new root device, etc., from /arch/x86/kernel/setup.c.
- Then it extracts initramfs from the source code file init/initramfs.c.
- Finally, it launches systemd by using the start_kernel function of init/main.c.

You will notice that this is the first time we came outside of the arch directory. That means we can consider this code as architecture independent. Once the kernel is launched, it does numerous things, and it is almost impossible to cover all of it in this book. In terms of booting, the kernel's motto is to launch systemd from initramfs. Since initramfs has already been loaded in memory by the bootloader, extracting the initramfs kernel requires the initramfs file details, which the kernel will get from /arch/x86/kernel/setup.c.

```
Initramfs file name,
Initramfs file size,
Initramfs files address,
Initramfs files relocation address,
Major and minor numbers on which initramfs will be mounted.
```

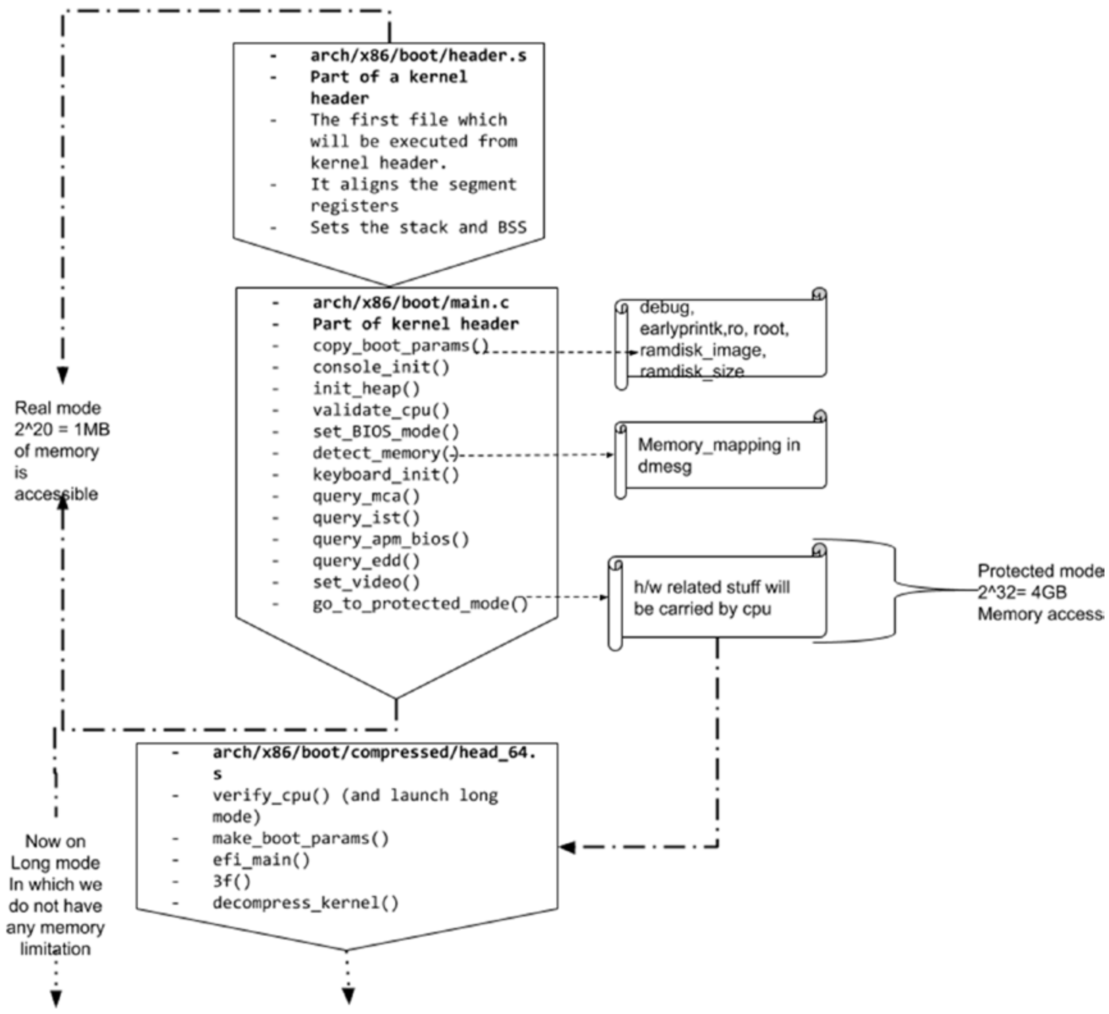
Once the kernel receives the details of the initramfs file, it will extract the initramfs archive from the init/initramfs.c file. We will discuss how exactly the kernel extracts initramfs in memory in Chapter 5. To mount initramfs as a root device, it needs virtual filesystems like proc, sys, dev, etc., so the kernel accordingly prepares them.

```
err = register_filesystem(&proc_fs_type);
    if (err)
    return;
```

The kernel will later mount the extracted initramfs as a root with the help of the `do_mount_root` function of `init/do_mounts.c`. Once the initramfs is mounted in memory, the kernel will launch systemd from it. systemd will be launched through the same `start_kernel` function of an `init/main.c` file.

```
asmlinkage void __init start_kernel(void)
```

Basically, once the root filesystem is ready, it will get inside the root filesystem and will create two threads: PID 1 is a systemd process, and PID 2 is a kthread. For better understanding, please refer to the flowchart shown in Figure 4-4.



- arch/x86/boot/header.s
- Part of a kernel header
- The first file which will be executed from kernel header.
- It aligns the segment registers
- Sets the stack and BSS
- arch/x86/boot/main.c
- Part of kernel header
- copy_boot_params()
- console_init()
- init_heap()
- validate_cpu()
- set_BIOS_mode()
- detect_memory()
- keyboard_init()
- query_mca()
- query_ist()
- query_apm_bios()
- query_edd()
- set_video()
- go_to_protected_mode()
debug, earlyprintk,ro, root, ramdisk_image, ramdisk_size
Memory_mapping in dmesg
h/w related stuff will be carried by cpu
Protected mode 2^32= 4GB Memory access
Real mode 2^20 = 1MB of memory is accessible
- arch/x86/boot/compressed/head_64.s
- verify_cpu() (and launch long mode)
- make_boot_params()
- efi_main()
- 3f()
- decompress_kernel()
Now on Long mode In which we do not have any memory limitation

Figure 4-4. *The flowchart, updated again*

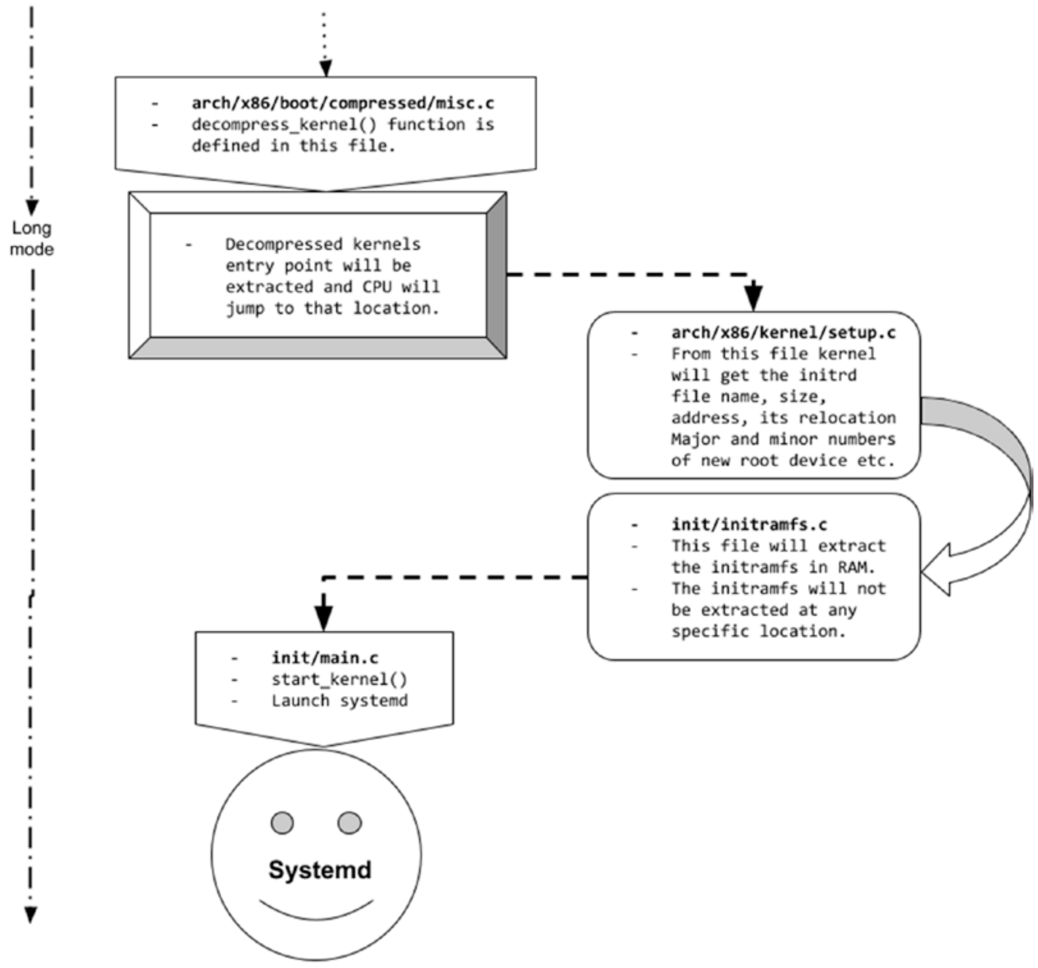

- arch/x86/boot/compressed/misc.c
- decompress_kernel() function is defined in this file.
- Decompressed kernels entry point will be extracted and CPU will jump to that location.
Long mode
- arch/x86/kernel/setup.c
- From this file kernel will get the initrd file name, size, address, its relocation Major and minor numbers of new root device etc.
- init/initramfs.c
- This file will extract the initramfs in RAM.
- The initramfs will not be extracted at any specific location.
- init/main.c
- start_kernel()
- Launch systemd
Systemd

Figure 4.4. *(continued)*

Figure 4-5 shows the complete boot sequence that we have discussed so far.

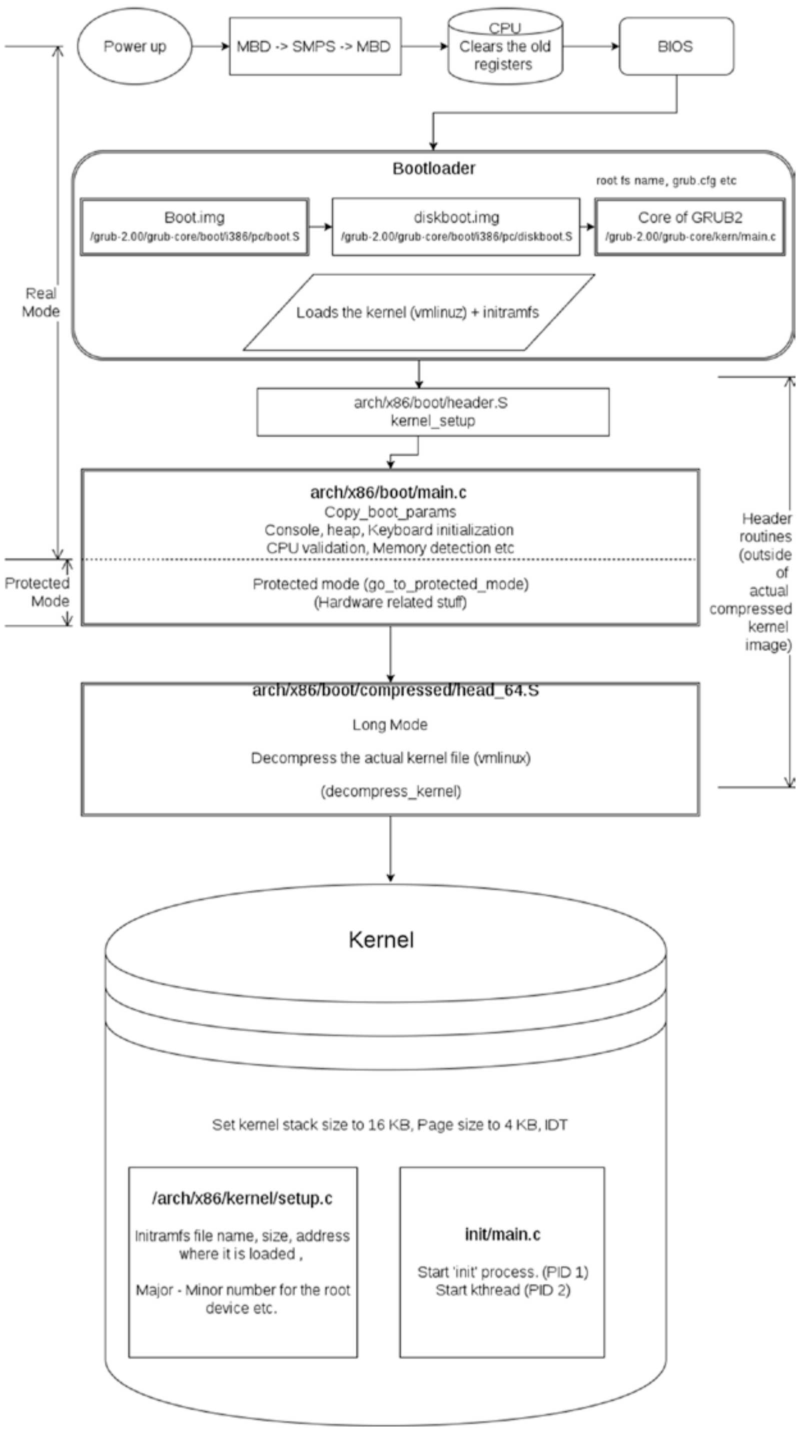

Power up
MBD -> SMPS -> MBD
CPU
Clears the old registers
BIOS
Bootloader
root fs name, grub.cfg etc
Boot.img
/grub-2.00/grub-core/boot/i386/pc/boot.S
diskboot.img
/grub-2.00/grub-core/boot/i386/pc/diskboot.S
Core of GRUB2
/grub-2.00/grub-core/kern/main.c
Loads the kernel (vmlinuz) + initramfs
Real Mode
arch/x86/boot/header.S
kernel_setup
arch/x86/boot/main.c
Copy_boot_params
Console, heap, Keyboard initialization
CPU validation, Memory detection etc
Protected Mode
Protected mode (go_to_protected_mode)
(Hardware related stuff)
Header routines (outside of actual compressed kernel image)
arch/x86/boot/compressed/head_64.S
Long Mode
Decompress the actual kernel file (vmlinux)
(decompress_kernel)
Kernel
Set kernel stack size to 16 KB, Page size to 4 KB, IDT
/arch/x86/kernel/setup.c
Initramfs file name, size, address where it is loaded ,
Major - Minor number for the root device etc.
init/main.c
Start 'init' process. (PID 1)
Start kthread (PID 2)

Figure 4-5. *The boot sequence in a block diagram*

Before we continue and look at how the kernel extracts initramfs and runs systemd from it, we need to understand the basics of initramfs such as why we need it, what its structure is, etc. Once we understand the importance and basics of initramfs, we will continue our booting sequence with systemd's role in the boot sequence.

CHAPTER 5

initramfs

In this chapter, we will discuss why we really need initramfs and why it's important in the booting procedure. We know that initramfs is loaded into memory by the bootloader, but we haven't discussed yet how initramfs is extracted. This chapter will address that. We will also see the steps to extract, rebuild, and customize initramfs. Later, we will see the structure of initramfs as well as the booting sequence of a system inside initramfs.

Why initramfs?

The aim of the booting procedure is to present the user with their own files that reside in the root filesystem. In other words, it is the kernel's duty to find, mount, and present the user's root filesystem to the user. To achieve this goal, the kernel has to run the systemd binary, which again resides in the user's root filesystem. Now this has become a chicken-and-egg problem. To run a systemd process, first we have to mount the root filesystem, and to mount the root filesystem, we have to run systemd from the root filesystem. Also, along with the actual root filesystem, users might have files on some other filesystems such as NFS, CIFS, etc., and that list of other filesystems is also inside the root filesystem (`/etc/fstab`).

So, to solve this chicken-and-egg problem, the developers came up with a resolution called initramfs (which means "initial RAM filesystem"). initramfs is a temporary root filesystem (inside the main memory) that will be used to mount the actual root filesystem (from the hard disk or network). So, the whole purpose of initramfs is to mount the user's root filesystem from the HDD/network. Ideally, the kernel is capable enough to mount the root filesystem from disk on its own without initramfs, but these days a user's root filesystem could be anywhere. It could be on RAID, on an LVM, or on a multipath device. It could be on *n* number of filesystem types like XFS, BTRFS, ext4, ext3, NFS, etc. It could even be on an encrypted filesystem like LUKS. So, it is almost

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impossible for a kernel to incorporate all these scenarios in its own `vmlinux` binary. Let me provide some real-life scenarios in this section.

Let's say the root file system is on NFS and there is no initramfs concept. That means the kernel has to mount the user's root filesystem from NFS on its own. In such a case, the kernel has to achieve the following tasks:

1. Bring up the primary network interface.
2. Invoke a DHCP client and get an IP address from the DHCP server.
3. Find the NFS share and associated NFS server.
4. Mount the NFS share (the root filesystem).

To achieve these steps, the kernel needs to have the following binaries: `NetworkManager`, `dhclient`, `mount`, etc.

Now let's say the root filesystem is on a software RAID device. Then the kernel has to do the following tasks:

1. Find the RAID disks first with `mdadm --examine --scan`.
2. Once the underlying disks on which the software RAID is spanned are identified, it has to assemble the RAID with `mdadm --assemble --scan`.
3. To achieve this, the kernel needs to have the `mount` and `mdadm` binaries and some configuration files of the software RAID devices.

Now let's say the root file system is on a logical volume. Then the kernel has to finish the following tasks on its own:

1. Find the physical volumes with `pvs`.
2. Find the volume group with `vgscan` and then activate it with `vgchange`.
3. Scan the LVS with `lvscan`.
4. Finally, once the `root lv` is populated, mount it as a root filesystem.
5. To achieve this, the kernel needs to have `pvscan`, `pvs`, `lvscan`, `vgscan`, `lvs`, and `vgchange`-like binaries.

Let's say the root filesystem is on an encrypted block device. Then the kernel has to complete the following tasks:

1. Collect a password from the user and/or insert a hardware token (such as a smart card or a USB security dongle).
2. Create a decryption target with the device mapper.

To achieve all of this, the kernel needs LUKS-related binaries.

For a kernel, it is not possible to incorporate all of these root filesystem possibilities; hence, developers have come up with the initramfs concept whose sole purpose is to mount the root filesystem.

The kernel can still perform all of the steps we have discussed. For example, if you build a simple command-line Linux system from LFS (`www.linuxfromscratch.org/`), you don't need initramfs to mount a root filesystem, as the kernel itself is capable enough to mount the root filesystem. But the moment you try to add a GUI into it through BLFS, you need initramfs.

So, the conclusion is that the kernel can mount the root filesystem on its own, but for that, the kernel has to keep all of the discussed binaries, supportive libraries, configuration files, etc., in the `vmlinuz` file. This will create a lot of issues.

- It will spoil the main motive of the kernel binary.
- The kernel binary will be huge in size. The bigger size of the binary will be difficult to maintain.
- The huge binary is difficult to manage, upgrade, share, and handle on servers (in terms of RPM packages).
- The approach won't be as per the KISS rule (keep it simple, stupid).

Infrastructure

To understand the initramfs structure, we need to first understand three different filesystems.

ramfs

For ease of understanding, we will compare ramfs to the kernel's caching mechanism. Linux has a unique feature called a *page cache*. Whenever you perform any I/O transactions, it caches those transactions in pages. Caching pages in memory is always good. This will save our future I/O transactions. And whenever the system encounters a low-memory situation, the kernel just discards these cached pages from memory. ramfs is just like our cache memory. But the issue with ramfs is that it does not have backing storage; hence, it cannot swap out the pages (swap is again a storage device). So, obviously, the kernel will not be able to free this memory as there is no place to save these pages. Hence, ramfs will keep growing, and you cannot really put a limit on its size. What we can do is allow only root users to write into ramfs to ease the situation.

tmpfs

tmpfs is just like ramfs but with a few additions. We can put a limit on the size of tmpfs, which we were not able to do in ramfs. Also, tmpfs pages can use swap space.

rootfs

rootfs is a tmpfs that is an instance of ramfs. The advantage of rootfs is you cannot unmount it. This is because of the same reason you can't kill the `systemd` process.

initramfs uses ramfs as a filesystem, and the space occupied by initramfs in memory will be released once the user's root filesystem has been mounted.

```
# dmesg | grep Free

[    0.813330] Freeing SMP alternatives memory: 36K
[    3.675187] Freeing initrd memory: 32548K    <<<=======<<<<<<===== NOTE
[    5.762702] Freeing unused decrypted memory: 2040K
[    5.767001] Freeing unused kernel image memory: 2272K
[    5.776841] Freeing unused kernel image memory: 2016K
[    5.783116] Freeing unused kernel image memory: 1580K
```

Earlier, instead of initramfs, Linux used to use `initrd` (initial RAM disk), but `initrd` is deprecated now, and hence we will list only a few important points for comparison with initramfs.

initrd

- Being formatted/treated as a block device means `initrd` cannot scale. That means once you bring `initrd` in memory and consider it as a block device, you cannot increase or decrease its size.
- We will waste some of the memory in cache as `initrd` is considered as a block device, because the Linux kernel is designed to keep the block device contents in cache to reduce I/O transactions. In short, unnecessarily the kernel will cache the `initrd` contents, which are already in memory.

Initramfs

- In `initrd`, there will always be the overhead of the filesystem driver and its binaries like `mke2fs`. The `mke2fs` command is used to create ext2/3/4 filesystems. This means some of the RAM area will first be formatted, with the ext2/3/4 filesystem by `mke2fs`, and then `initrd` will be extracted on it, whereas initramfs is just like tmpfs, which you can grow or shrink any time on the fly.
- There is no duplication of data between block devices and cache.
- To use initramfs as the root filesystem, the kernel does not need any driver or binary like `mke2fs` as the initramfs archive will be extracted in main memory as it is.

```
# ls -lh /boot/initramfs-5.3.7-301.fc31.x86_64.img

-rw-------. 1 root root 32M Dec  9 10:19 /boot/initramfs-5.3.7-301.fc31.
x86_64.img
```

We can use the `lsinitrd` tool to see the contents of initramfs, or we can extract initramfs with the help of the `skipcpio` tool.

```
#lsinitrd
<snip>
Image: /boot/initramfs-5.3.7-301.fc31.x86_64.img: 32M
========================================================================
Early CPIO image
========================================================================
drwxr-xr-x   3 root     root            0 Jul 25  2019 .
-rw-r--r--   1 root     root            2 Jul 25  2019 early_cpio
drwxr-xr-x   3 root     root            0 Jul 25  2019 kernel
drwxr-xr-x   3 root     root            0 Jul 25  2019 kernel/x86
drwxr-xr-x   2 root     root            0 Jul 25  2019 kernel/x86/microcode
-rw-r--r--   1 root     root       100352 Jul 25  2019 kernel/x86/
microcode/GenuineIntel.bin
========================================================================
Version: dracut-049-27.git20181204.fc31.1

Arguments: -f

dracut modules:
bash
systemd
systemd-initrd
nss-softokn
i18n
network-manager
network
ifcfg
drm
plymouth
dm
kernel-modules
kernel-modules-extra
kernel-network-modules
lvm
```

```
qemu
qemu-net
resume
rootfs-block
terminfo
udev-rules
dracut-systemd
usrmount
base
fs-lib
shutdown
========================================================================
drwxr-xr-x  12 root     root            0 Jul 25  2019 .
crw-r--r--   1 root     root       5,   1 Jul 25  2019 dev/console
crw-r--r--   1 root     root       1,  11 Jul 25  2019 dev/kmsg
crw-r--r--   1 root     root       1,   3 Jul 25  2019 dev/null
crw-r--r--   1 root     root       1,   8 Jul 25  2019 dev/random
crw-r--r--   1 root     root       1,   9 Jul 25  2019 dev/urandom
lrwxrwxrwx   1 root     root            7 Jul 25  2019 bin -> usr/bin
drwxr-xr-x   2 root     root            0 Jul 25  2019 dev
drwxr-xr-x  11 root     root            0 Jul 25  2019 etc
drwxr-xr-x   2 root     root            0 Jul 25  2019 etc/cmdline.d
drwxr-xr-x   2 root     root            0 Jul 25  2019 etc/conf.d
-rw-r--r--   1 root     root          124 Jul 25  2019 etc/conf.d/systemd.
                                      conf
-rw-r--r--   1 root     root            0 Jul 25  2019 etc/fstab.empty
-rw-r--r--   1 root     root          240 Jul 25  2019 etc/group
-rw-r--r--   1 root     root           22 Jul 25  2019 etc/hostname
lrwxrwxrwx   1 root     root           25 Jul 25  2019 etc/initrd-release
                                       -> ../usr/lib/initrd-release
-rw-r--r--   1 root     root         8581 Jul 25  2019 etc/ld.so.cache
-rw-r--r--   1 root     root           28 Jul 25  2019 etc/ld.so.conf
drwxr-xr-x   2 root     root            0 Jul 25  2019 etc/ld.so.conf.d
-rw-r--r--   1 root     root           17 Jul 25  2019 etc/ld.so.conf.d/
                                       libiscsi-x86_64.conf
```

```
-rw-rw-r--   1 root     root           19 Jul 25  2019 etc/locale.conf
drwxr-xr-x   2 root     root            0 Jul 25  2019 etc/lvm
-rw-r--r--   1 root     root       102256 Jul 25  2019 etc/lvm/lvm.conf
-rw-r--r--   1 root     root         2301 Jul 25  2019 etc/lvm/lvmlocal.conf
-r--r--r--   1 root     root           33 Jul 25  2019 etc/machine-id
drwxr-xr-x   2 root     root            0 Jul 25  2019 etc/modprobe.d
</snip>
```

To extract the contents of initramfs, use the `skipcpio` binary from `/usr/lib/dracut/skipcpio/`. The `skipcpio` is provided by the dracut tool. We will cover dracut in Chapter 6.

```
#/usr/lib/dracut/skipcpio initramfs-5.3.7-301.fc31.x86_64.img | gunzip -c |
cpio -idv
```

If you look at the extracted initramfs contents, you will be surprised to know that it looks just like the user's root filesystem. Please note that we have extracted initramfs into the `/root/boot` directory.

```
# ls -lh /root/boot/
total 44K
lrwxrwxrwx.  1 root root    7 Mar 26 18:03 bin -> usr/bin
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 dev
drwxr-xr-x. 11 root root 4.0K Mar 26 18:03 etc
lrwxrwxrwx.  1 root root   23 Mar 26 18:03 init -> usr/lib/systemd/systemd
lrwxrwxrwx.  1 root root    7 Mar 26 18:03 lib -> usr/lib
lrwxrwxrwx.  1 root root    9 Mar 26 18:03 lib64 -> usr/lib64
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 proc
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 root
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 run
lrwxrwxrwx.  1 root root    8 Mar 26 18:03 sbin -> usr/sbin
-rwxr-xr-x.  1 root root 3.1K Mar 26 18:03 shutdown
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 sys
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 sysroot
drwxr-xr-x.  2 root root 4.0K Mar 26 18:03 tmp
drwxr-xr-x.  8 root root 4.0K Mar 26 18:03 usr
drwxr-xr-x.  3 root root 4.0K Mar 26 18:03 var
```

You will find `bin`, `sbin`, `usr`, `etc`, `var`, `lib`, and `lib64`-like directories that we used to see in our user's root filesystem. Along with that, you will notice the virtual filesystem directories such as `dev`, `run`, `proc`, `sys`, etc. So, initramfs is just like the user's root filesystem. Let's explore each directory for the better understanding of the initramfs implementation.

initramfs Implementation

Now we will look as the contents of initramfs and how exactly initramfs is organized. Through this section, you will realize that initramfs is nothing but a small root filesystem.

bin

Normal Binaries

We can use all the following binaries on a system that has finished its booting procedure. Since all these binaries are available inside initramfs, when the system is still booting, we will be able to use all these commands at the time of the boot.

`cat, chown, cp, dmesg, echo, grep, gzip, less, ln, mkdir, mv, ps, rm, sed, sleep, umount, uname, vi, loadkeys, kbd_mode, flock, tr, true, stty, mount, sort etc.`

```
[root@fedorab boot]# ls -la bin/

total 7208
drwxr-xr-x. 2 root root    4096 Jan 10 12:01 .
drwxr-xr-x. 8 root root    4096 Dec 19 14:30 ..
-rwxr-xr-x. 1 root root 1237376 Dec 19 14:30 bash
-rwxr-xr-x. 1 root root   50160 Dec 19 14:30 cat
-rwxr-xr-x. 1 root root   82688 Dec 19 14:30 chown
-rwxr-xr-x. 1 root root  177144 Dec 19 14:30 cp
-rwxr-xr-x. 1 root root   89344 Dec 19 14:30 dmesg
-rwxr-xr-x. 1 root root    2666 Dec 19 14:30 dracut-cmdline
-rwxr-xr-x. 1 root root     422 Dec 19 14:30 dracut-cmdline-ask
-rwxr-xr-x. 1 root root    1386 Dec 19 14:30 dracut-emergency
-rwxr-xr-x. 1 root root    2151 Dec 19 14:30 dracut-initqueue
```

```
-rwxr-xr-x. 1 root root    1056 Jan 10 12:01 dracut-mount
-rwxr-xr-x. 1 root root     517 Dec 19 14:30 dracut-pre-mount
-rwxr-xr-x. 1 root root     928 Dec 19 14:30 dracut-pre-pivot
-rwxr-xr-x. 1 root root     482 Dec 19 14:30 dracut-pre-trigger
-rwxr-xr-x. 1 root root    1417 Dec 19 14:30 dracut-pre-udev
-rwxr-xr-x. 1 root root   45112 Dec 19 14:30 echo
-rwxr-xr-x. 1 root root   76768 Dec 19 14:30 findmnt
-rwxr-xr-x. 1 root root   38472 Dec 19 14:30 flock
-rwxr-xr-x. 1 root root  173656 Dec 19 14:30 grep
-rwxr-xr-x. 1 root root  107768 Dec 19 14:30 gzip
-rwxr-xr-x. 1 root root   78112 Dec 19 14:30 journalctl
-rwxr-xr-x. 1 root root   17248 Dec 19 14:30 kbd_mode
-rwxr-xr-x. 1 root root  387504 Dec 19 14:30 kmod
-rwxr-xr-x. 1 root root  192512 Dec 19 14:30 less
-rwxr-xr-x. 1 root root   85992 Dec 19 14:30 ln
-rwxr-xr-x. 1 root root  222616 Dec 19 14:30 loadkeys
lrwxrwxrwx. 1 root root       4 Dec 19 14:30 loginctl -> true
-rwxr-xr-x. 1 root root  158056 Dec 19 14:30 ls
-rwxr-xr-x. 1 root root   99080 Dec 19 14:30 mkdir
-rwxr-xr-x. 1 root root   80264 Dec 19 14:30 mkfifo
-rwxr-xr-x. 1 root root   84560 Dec 19 14:30 mknod
-rwsr-xr-x. 1 root root   58984 Dec 19 14:30 mount
-rwxr-xr-x. 1 root root  169400 Dec 19 14:30 mv
-rwxr-xr-x. 1 root root   50416 Dec 19 14:30 plymouth
-rwxr-xr-x. 1 root root  143408 Dec 19 14:30 ps
-rwxr-xr-x. 1 root root   60376 Dec 19 14:30 readlink
-rwxr-xr-x. 1 root root   83856 Dec 19 14:30 rm
-rwxr-xr-x. 1 root root  127192 Dec 19 14:30 sed
-rwxr-xr-x. 1 root root   52272 Dec 19 14:30 setfont
-rwxr-xr-x. 1 root root   16568 Dec 19 14:30 setsid
lrwxrwxrwx. 1 root root       4 Dec 19 14:30 sh -> bash
-rwxr-xr-x. 1 root root   46608 Dec 19 14:30 sleep
-rwxr-xr-x. 1 root root  140672 Dec 19 14:30 sort
-rwxr-xr-x. 1 root root   96312 Dec 19 14:30 stat
```

```
-rwxr-xr-x. 1 root root   92576 Dec 19 14:30 stty
-rwxr-xr-x. 1 root root  240384 Dec 19 14:30 systemctl
-rwxr-xr-x. 1 root root   20792 Dec 19 14:30 systemd-cgls
-rwxr-xr-x. 1 root root   19704 Dec 19 14:30 systemd-escape
-rwxr-xr-x. 1 root root   62008 Dec 19 14:30 systemd-run
-rwxr-xr-x. 1 root root   95168 Dec 19 14:30 systemd-tmpfiles
-rwxr-xr-x. 1 root root  173752 Dec 19 14:30 teamd
-rwxr-xr-x. 1 root root   58400 Dec 19 14:30 tr
-rwxr-xr-x. 1 root root   45112 Dec 19 14:30 true
-rwxr-xr-x. 1 root root  442552 Dec 19 14:30 udevadm
-rwsr-xr-x. 1 root root   41912 Dec 19 14:30 umount
-rwxr-xr-x. 1 root root   45120 Dec 19 14:30 uname
-rwxr-xr-x. 1 root root 1353704 Dec 19 14:30 vi
```

Special Binaries

Special Binary	Purpose
bash	initramfs will provide us with a shell at the time of boot.
mknod	We will be able to create devices.
udevadm	We will be able to manage devices. dracut uses `udev`, an event-driven tool, which will launch certain programs such as `lvm`, `mdadm`, etc., when certain `udev` rules are matched. For example, whenever certain `udev` rules are matched, storage volumes and network card device files will appear under `/dev`.
kmod	A tool to manage the kernel modules.

Networking Binaries

There is only one network related binary available under bin and that is teamd (initramfs can handle the teaming network devices).

Hooks

We will discuss hooks in Chapters 7 and 9.

`dracut-cmdline`	`dracut-cmdline-ask`
`dracut-emergency`	`dracut -initqueue`
`dracut-mount`	`dracut -pre-pivot`
`dracut - pre-trigger`	`dracut -pre-udev`

Systemd Binaries

Binary	Purpose
`systemd`	This is the parent of every process that is a replacement of `init`. This is the first process, which runs the moment we enter initramfs.
`systemctl`	Systemd's service manager.
`systemd-cgls`	This will list the existing control groups (cgroups).
`systemd-escape`	This will convert the string in systemd unit format, also called escaping.
`systemd-run`	This can run the programs as a service but in transient scope.
`systemd-tmpfiles`	This creates, deletes, and cleans up volatile and temporary files and directories.
`journalctl`	A tool to deal with systemd journal.

Sbin

Filesystem and Storage-Related Binaries

Binary	Purpose
`blkid`	To read device attributes
`chroot`	To change the root filesystem device
`e2fsck`	To check ext2/3/4 filesystems
`fsck, fsck.ext4`	To check and repair the filesystem
`swapoff`	In case you want to stop the swap device

(*continued*)

Binary	Purpose
dmsetup	A device mapper tool for LVM management
dmeventd	A device mapper event daemon
lvm	An LVM management tool that will provide `lvscan`, `vgscan`, `vgchange`, `pvs`, etc., commands
lvm_scan	A script to find the LVM devices

Networking Binaries

Binaries	Purpose
dhclient	To get the IP from the DHCP server
losetup	To set the `loop` device
Netroot	A support for a root over the network
NetworkManager	A tool to manage the network devices

Special Binaries

Binaries	Purpose
depmod	To generate `modules.dep` (symlink of `kmod`)
lsmod	To list the loaded modules (symlink of `kmod`)
modinfo	To print the module's information (symlink of `kmod`)
modprobe	To load or insert the modules (symlink of `kmod`)
rmmod	To remove the loaded module (symlink of `kmod`)
init / systemd	A first process
kexec	A kexec kernel that is used by the Kdump
udevadm	Udev manager

Basic Binaries

Finally, here are the basic binaries:

`Halt, poweroff, reboot`

```
 [root@fedorab boot]# **ls -lah sbin/**
total 13M
drwxr-xr-x. 2 root root 4.0K Dec 19 14:30 .
drwxr-xr-x. 8 root root 4.0K Dec 19 14:30 ..
-rwxr-xr-x. 1 root root 126K Dec 19 14:30 blkid
-rwxr-xr-x. 1 root root  50K Dec 19 14:30 chroot
lrwxrwxrwx. 1 root root   11 Dec 19 14:30 depmod -> ../bin/kmod
-rwxr-xr-x. 1 root root 2.9M Dec 19 14:30 dhclient
-r-xr-xr-x. 1 root root  45K Dec 19 14:30 dmeventd
-r-xr-xr-x. 1 root root 159K Dec 19 14:30 dmsetup
-rwxr-xr-x. 2 root root 340K Dec 19 14:30 e2fsck
-rwxr-xr-x. 1 root root  58K Dec 19 14:30 fsck
-rwxr-xr-x. 2 root root 340K Dec 19 14:30 fsck.ext4
lrwxrwxrwx. 1 root root   16 Dec 19 14:30 halt -> ../bin/systemctl
lrwxrwxrwx. 1 root root   22 Dec 19 14:30 init -> ../lib/systemd/systemd
-rwxr-xr-x. 1 root root 1.2K Dec 19 14:30 initqueue
lrwxrwxrwx. 1 root root   11 Dec 19 14:30 insmod -> ../bin/kmod
-rwxr-xr-x. 1 root root  197 Dec 19 14:30 insmodpost.sh
-rwxr-xr-x. 1 root root 203K Dec 19 14:30 kexec
-rwxr-xr-x. 1 root root  496 Dec 19 14:30 loginit
-rwxr-xr-x. 1 root root 117K Dec 19 14:30 losetup
lrwxrwxrwx. 1 root root   11 Dec 19 14:30 lsmod -> ../bin/kmod
-r-xr-xr-x. 1 root root 2.4M Dec 19 14:30 lvm
-rwxr-xr-x. 1 root root 3.5K Dec 19 14:30 lvm_scan
lrwxrwxrwx. 1 root root   11 Dec 19 14:30 modinfo -> ../bin/kmod
lrwxrwxrwx. 1 root root   11 Dec 19 14:30 modprobe -> ../bin/kmod
-rwxr-xr-x. 1 root root 2.7K Dec 19 14:30 netroot
-rwxr-xr-x. 1 root root 5.3M Dec 19 14:30 NetworkManager
-rwxr-xr-x. 1 root root  16K Dec 19 14:30 nologin
-rwxr-xr-x. 1 root root 150K Dec 19 14:30 plymouthd
lrwxrwxrwx. 1 root root   16 Dec 19 14:30 poweroff -> ../bin/systemctl
```

```
-rwxr-xr-x. 1 root root 1.4K Dec 19 14:30 rdsosreport
lrwxrwxrwx. 1 root root   16 Dec 19 14:30 reboot -> ../bin/systemctl
lrwxrwxrwx. 1 root root   11 Dec 19 14:30 rmmod -> ../bin/kmod
-rwxr-xr-x. 1 root root  25K Dec 19 14:30 swapoff
-rwxr-xr-x. 1 root root 6.0K Dec 19 14:30 tracekomem
lrwxrwxrwx. 1 root root   14 Dec 19 14:30 udevadm -> ../bin/udevadm
```

Isn't it amazing to see that without having an actual user's root filesystem we will be able to use and manage the shell, network, modules, devices, etc.? In other words, you do not really need a user's root filesystem, unless a user wants to access their private files, that is. Just kidding.

Now a question comes to mind: where and how can we use all of these commands? These binaries or commands will be automatically used by initramfs. Or, to say it correctly, these binaries or commands will be used by the systemd of initramfs to mount the user's actual root filesystem, but if systemd fails to do so, it will provide us with a shell, and we will be able to use these commands and troubleshoot further. We will discuss this in Chapters 7, 8, and 9.

etc

The binaries from the `bin` and `sbin` directories will have their own configuration files, and they will be stored in the `etc` directory of initramfs.

```
 [root@fedorab boot]# tree etc/
etc/
├── cmdline.d
├── conf.d
│   └── systemd.conf
├── fstab.empty
├── group
├── hostname
├── initrd-release -> ../usr/lib/initrd-release
├── ld.so.cache
├── ld.so.conf
├── ld.so.conf.d
│   └── libiscsi-x86_64.conf
```

```
├── locale.conf
├── lvm
│   ├── lvm.conf
│   └── lvmlocal.conf
├── machine-id
├── modprobe.d
│   ├── firewalld-sysctls.conf
│   ├── kvm.conf
│   ├── lockd.conf
│   ├── mlx4.conf
│   ├── nvdimm-security.conf
│   └── truescale.conf
├── mtab -> /proc/self/mounts
├── os-release -> initrd-release
├── passwd
├── plymouth
│   └── plymouthd.conf
├── sysctl.conf
├── sysctl.d
│   └── 99-sysctl.conf -> ../sysctl.conf
├── systemd
│   ├── journald.conf
│   └── system.conf
├── system-release -> ../usr/lib/fedora-release
├── udev
│   ├── rules.d
│   │   ├── 11-dm.rules
│   │   ├── 59-persistent-storage-dm.rules
│   │   ├── 59-persistent-storage.rules
│   │   ├── 61-persistent-storage.rules
│   │   └── 64-lvm.rules
│   └── udev.conf
├── vconsole.conf
└── virc

10 directories, 35 files
```

Virtual Filesystems

Virtual filesystems are the kind of filesystems whose files are not really present on disk; rather, the entire filesystem is available in memory. This has its own advantages and disadvantages; for example, you get a very high throughput, but the filesystem cannot store the data permanently. There are three virtual filesystems available inside initramfs, which are `dev`, `proc`, and `sys`. Here I have given a brief introduction to the filesystems, but we will talk about them in detail in the next chapters:

```
[root@fedorab boot]# ls -lah dev
total 8.0K
drwxr-xr-x.  2 root root  4.0K Dec 19 14:30 .
drwxr-xr-x. 12 root root  4.0K Dec 19 14:33 ..
crw-r--r--.  1 root root 5,  1 Dec 19 14:30 console
crw-r--r--.  1 root root 1, 11 Dec 19 14:30 kmsg
crw-r--r--.  1 root root 1,  3 Dec 19 14:30 null
crw-r--r--.  1 root root 1,  8 Dec 19 14:30 random
crw-r--r--.  1 root root 1,  9 Dec 19 14:30 urandom

[root@fedorab boot]# ls -lah proc/
total 8.0K
drwxr-xr-x.  2 root root 4.0K Dec 19 14:30 .
drwxr-xr-x. 12 root root 4.0K Dec 19 14:33 ..

[root@fedorab boot]# ls -lah sys/
total 8.0K
drwxr-xr-x.  2 root root 4.0K Dec 19 14:30 .
drwxr-xr-x. 12 root root 4.0K Dec 19 14:33 ..
```

dev

As of now, there are only five default device files, but as the system boots up, `udev` will fully populate this directory. The `console`, `kmsg`, `null`, `random`, and `urandom` devices files will be created by the kernel itself, or in other words, these device files are handcrafted by using the `mknod` command, but the rest of the device files will be populated by `udev`.

proc and sys

As soon as the kernel takes control of the booting procedure, the kernel will create and populate these directories. The `proc` filesystem will hold all the processes' related information such as `/proc/1/status`, whereas `sys` will hold the device and its driver-related information such as `/sys/fs/ext4/sda5/errors_count`.

usr, var

As we all know, these days `usr` is a separate filesystem hierarchy in the root filesystem. Our `/bin`, `/sbin`, `/lib`, and `/lib64` are nothing but symlinks to `usr/bin`, `usr/sbin`, `usr/lib`, and `usr/lib64`.

```
# ls -l bin
lrwxrwxrwx. 1 root root 7 Dec 21 12:19 bin -> usr/bin

# ls -l sbin
lrwxrwxrwx. 1 root root 8 Dec 21 12:19 sbin -> usr/sbin

# ls -la usr
total 40
drwxr-xr-x.  8 root root  4096 Dec 21 12:19 .
drwxr-xr-x. 12 root root  4096 Dec 21 12:19 ..
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 bin
drwxr-xr-x. 12 root root  4096 Dec 21 12:19 lib
drwxr-xr-x.  4 root root 12288 Dec 21 12:19 lib64
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 libexec
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 sbin
drwxr-xr-x.  5 root root  4096 Dec 21 12:19 share

# ls -la var
total 12
drwxr-xr-x.  3 root root 4096 Dec 21 12:19 .
drwxr-xr-x. 12 root root 4096 Dec 21 12:19 ..
lrwxrwxrwx.  1 root root   11 Dec 21 12:19 lock -> ../run/lock
lrwxrwxrwx.  1 root root    6 Dec 21 12:19 run -> ../run
drwxr-xr-x.  2 root root 4096 Dec 21 12:19 tmp
```

lib, lib64

There are almost 200 libraries, and almost all of them are provided by `glibc`, such as `libc.so.6`.

The `lib` and `lib64` directories are the symlinks of `usr/lib` and `usr/lib64`.

```
# ls -l lib
lrwxrwxrwx. 1 root root 7 Dec 21 12:19 lib -> usr/lib

# ls -l lib64
lrwxrwxrwx. 1 root root 9 Dec 21 12:19 lib64 -> usr/lib64

# ls -la lib/
total 128
drwxr-xr-x. 12 root root  4096 Dec 21 12:19 .
drwxr-xr-x.  8 root root  4096 Dec 21 12:19 ..
drwxr-xr-x.  3 root root  4096 Dec 21 12:19 dracut
-rwxr-xr-x.  1 root root 34169 Dec 21 12:19 dracut-lib.sh
-rw-r--r--.  1 root root    31 Dec 21 12:19 fedora-release
drwxr-xr-x.  6 root root  4096 Dec 21 12:19 firmware
-rwxr-xr-x.  1 root root  6400 Dec 21 12:19 fs-lib.sh
-rw-r--r--.  1 root root   238 Dec 21 12:19 initrd-release
drwxr-xr-x.  6 root root  4096 Dec 21 12:19 kbd
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 modprobe.d
drwxr-xr-x.  3 root root  4096 Dec 21 12:19 modules
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 modules-load.d
-rwxr-xr-x.  1 root root 25295 Dec 21 12:19 net-lib.sh
lrwxrwxrwx.  1 root root    14 Dec 21 12:19 os-release -> initrd-release
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 sysctl.d
drwxr-xr-x.  5 root root  4096 Dec 21 12:19 systemd
drwxr-xr-x.  2 root root  4096 Dec 21 12:19 tmpfiles.d
drwxr-xr-x.  3 root root  4096 Dec 21 12:19 udev

# ls -la lib64/libc.so.6
lrwxrwxrwx. 1 root root 12 Dec 21 12:19 lib64/libc.so.6 -> libc-2.30.so
```

```
# dnf whatprovides lib64/libc.so.6
glibc-2.30-5.fc31.x86_64 : The GNU libc libraries
Repo        : @System
Matched from:
Filename    : /lib64/libc.so.6
```

initramfs Booting

The basic flow of booting sequence inside initramfs is easy to understand:

1) Since initramfs is a root filesystem (`temporary`), it will create the environment that is necessary to run the processes. initramfs will be mounted as a root filesystem (temporary `/`), and programs like systemd will be started from it.

2) Afterward, a new user's root filesystem from your HDD or network will be mounted on a temporary directory inside initramfs.

3) Once the user's root filesystem is mounted inside initramfs, the kernel will start the `init` binary, which is a symlink to `systemd`, the first process of the operating system.

   ```
   # ls init -l
   lrwxrwxrwx. 1 root root 23 Dec 21 12:19 init -> usr/lib/systemd/systemd
   ```

4) Once everything is good, the temporary root filesystem (initramfs root filesystem) will be unmounted, and systemd will take care of the rest of the booting sequence. Chapter 7 will cover systemd booting.

We can cross-verify whether the kernel really launches the `init/systemd` process as soon as it extracts initramfs. We can modify the `init` script for this, but the hurdle is that systemd is a binary, whereas `init` used to be a script. We can edit `init` easily since it is a script file, but we cannot edit the systemd binary. However, to have good understanding and to verify our booting sequence to see whether systemd is getting called as soon as the kernel extracts initramfs, we will use an `init`-based system. This would be a fair example since systemd is here to replace the `init` system. Also, `init` is still a symlink to systemd. We will use a Centos 6 system, which is an `init`-based Linux distribution.

First extract initramfs.

```
# zcat  initramfs-2.6.32-573.el6.x86_64.img  |  cpio -idv
```

```
[root@localhost initramfs]# ls -lah
total 120K
drwxr-xr-x. 26 root root 4.0K Mar 27 12:56 .
drwxr-xr-x.  3 root root 4.0K Mar 27 12:56 ..
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 bin
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 cmdline
drwxr-xr-x.  3 root root 4.0K Mar 27 12:56 dev
-rw-r--r--.  1 root root   19 Mar 27 12:56 dracut-004-388.el6
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 emergency
drwxr-xr-x.  8 root root 4.0K Mar 27 12:56 etc
-rwxr-xr-x.  1 root root 8.8K Mar 27 12:56 init
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 initqueue
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 initqueue-finished
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 initqueue-settled
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 initqueue-timeout
drwxr-xr-x.  7 root root 4.0K Mar 27 12:56 lib
drwxr-xr-x.  3 root root 4.0K Mar 27 12:56 lib64
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 mount
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 netroot
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 pre-mount
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 pre-pivot
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 pre-trigger
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 pre-udev
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 proc
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 sbin
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 sys
drwxr-xr-x.  2 root root 4.0K Mar 27 12:56 sysroot
drwxrwxrwt.  2 root root 4.0K Mar 27 12:56 tmp
drwxr-xr-x.  8 root root 4.0K Mar 27 12:56 usr
drwxr-xr-x.  4 root root 4.0K Mar 27 12:56 var
```

Open an init file and add the following banner in it:

```
#vim init
   "We are inside the init process. Init is replaced by Systemd"
<snip>
#!/bin/sh
#
# Licensed under the GPLv2
#
# Copyright 2008-2009, Red Hat, Inc.
# Harald Hoyer <harald@redhat.com>
# Jeremy Katz <katzj@redhat.com>
echo "we are inside the init process. Init is replaced by Systemd"
wait_for_loginit()
{
    if getarg rdinitdebug; then
        set +x
        exec 0<>/dev/console 1<>/dev/console 2<>/dev/console
        # wait for loginit
        i=0
        while [ $i -lt 10 ]; do
.
.
.
</snip>
```

Repack initramfs with the test.img name.

```
[root@localhost initramfs]# find . | cpio -o -c | gzip -9 > /boot/test.img
163584 blocks

# ls -lh /boot/
total 66M
-rw-r--r--. 1 root root 105K Jul 23  2015 config-2.6.32-573.el6.x86_64
drwxr-xr-x. 3 root root 1.0K Aug  7  2015 efi
-rw-r--r--. 1 root root 163K Jul 20  2011 elf-memtest86+-4.10
drwxr-xr-x. 2 root root 1.0K Dec 21 16:12 grub
```

```
-rw-------. 1 root root  27M Dec 21 15:55 initramfs-2.6.32-573.el6.
x86_64.img
-rw-------. 1 root root 5.3M Dec 21 16:03 initrd-2.6.32-573.el6.
x86_64kdump.img
drwx------. 2 root root  12K Dec 21 15:54 lost+found
-rw-r--r--. 1 root root 162K Jul 20  2011 memtest86+-4.10
-rw-r--r--. 1 root root 202K Jul 23  2015 symvers-2.6.32-573.el6.x86_64.gz
-rw-r--r--. 1 root root 2.5M Jul 23  2015 System.map-2.6.32-573.el6.x86_64
-rw-r--r--. 1 root root  27M Mar 27 13:16 test.img
-rwxr-xr-x. 1 root root 4.1M Jul 23  2015 vmlinuz-2.6.32-573.el6.x86_64
```

Boot with the new `test.img` initramfs, and you will notice right after unpacking initramfs that our banner is getting printed.

```
<snip>
.
.
.
cpuidle: using governor ladder
cpuidle: using governor menu
EFI Variables Facility v0.08 2004-May-17
usbcore: registered new interface driver hiddev
usbcore: registered new interface driver usbhid
usbhid: v2.6:USB HID core driver
GRE over IPv4 demultiplexor driver
TCP cubic registered
Initializing XFRM netlink socket
NET: Registered protocol family 17
registered taskstats version 1
rtc_cmos 00:01: setting system clock to 2020-03-27 07:53:44 UTC (1585295624)
Initalizing network drop monitor service
Freeing unused kernel memory: 1296k freed
Write protecting the kernel read-only data: 10240k
Freeing unused kernel memory: 732k freed
Freeing unused kernel memory: 1576k freed
we are inside the init process. Init is replaced by Systemd
dracut: dracut-004-388.el6
```

```
dracut: rd_NO_LUKS: removing cryptoluks activation
device-mapper: uevent: version 1.0.3
device-mapper: ioctl: 4.29.0-ioctl (2014-10-28) initialised:
dm-devel@redhat.com
udev: starting version 147
dracut: Starting plymouth daemon
.
.
</snip>
```

How Does the Kernel Extract initramfs from Memory?

Let's take a minute and try to recall whatever we have learned so far.

1) The bootloader runs first.
2) The bootloader copies the kernel and initramfs in memory.
3) The kernel extracts itself.
4) The bootloader passes on the location of initramfs to the kernel.
5) The kernel extracts initramfs in memory.
6) The kernel runs systemd from the extracted initramfs.

The extraction takes place in the kernel's `init/initramfs.c` file. The `populate_rootfs` function is responsible for the extraction.

populate_rootfs function:

```
<snip>
.
.
static int __init populate_rootfs(void)
{
        /* Load the built in initramfs */
        char *err = unpack_to_rootfs(__initramfs_start, __initramfs_
        size);
        if (err)
```

```
                panic("%s", err); /* Failed to decompress INTERNAL initramfs */

        if (!initrd_start || IS_ENABLED(CONFIG_INITRAMFS_FORCE))
                goto done;

        if (IS_ENABLED(CONFIG_BLK_DEV_RAM))
                printk(KERN_INFO "Trying to unpack rootfs image as initramfs...\n");
        else
                printk(KERN_INFO "Unpacking initramfs...\n");

        err = unpack_to_rootfs((char *)initrd_start, initrd_end - initrd_start);
        if (err) {
                clean_rootfs();
                populate_initrd_image(err);
        }

done:
        /*
         * If the initrd region is overlapped with crashkernel reserved region,
         * free only memory that is not part of crashkernel region.
         */
        if (!do_retain_initrd && initrd_start && !kexec_free_initrd())
                free_initrd_mem(initrd_start, initrd_end);
        initrd_start = 0;
        initrd_end = 0;

        flush_delayed_fput();
        return 0;
}
.
.
</snip>
```

unpack_to_rootfs function:

```
<snip>
.
.
static char * __init unpack_to_rootfs(char *buf, unsigned long len)
{
        long written;
        decompress_fn decompress;
        const char *compress_name;
        static __initdata char msg_buf[64];

        header_buf = kmalloc(110, GFP_KERNEL);
        symlink_buf = kmalloc(PATH_MAX + N_ALIGN(PATH_MAX) + 1,
        GFP_KERNEL);
        name_buf = kmalloc(N_ALIGN(PATH_MAX), GFP_KERNEL);

        if (!header_buf || !symlink_buf || !name_buf)
                panic("can't allocate buffers");

        state = Start;
        this_header = 0;
        message = NULL;
        while (!message && len) {
                loff_t saved_offset = this_header;
                if (*buf == '0' && !(this_header & 3)) {
                        state = Start;
                        written = write_buffer(buf, len);
                        buf += written;
                        len -= written;
                        continue;
                }
                if (!*buf) {
                        buf++;
                        len--;
                        this_header++;
                        continue;
                }
                this_header = 0;
                decompress = decompress_method(buf, len, &compress_name);
                pr_debug("Detected %s compressed data\n", compress_name);
                if (decompress) {
                        int res = decompress(buf, len, NULL, flush_buffer, NULL,
                                   &my_inptr, error);
                        if (res)
                                error("decompressor failed");
                } else if (compress_name) {
                        if (!message) {
                                snprintf(msg_buf, sizeof msg_buf,
                                         "compression method %s not configured",
                                         compress_name);
                                message = msg_buf;
                        }
                } else
                        error("invalid magic at start of compressed archive");
                if (state != Reset)
                        error("junk at the end of compressed archive");
                this_header = saved_offset + my_inptr;
                buf += my_inptr;
                len -= my_inptr;
        }
        dir_utime();
        kfree(name_buf);
        kfree(symlink_buf);
        kfree(header_buf);
        return message;
}
.
.
</snip>
```

Inside the `populate_rootfs` function there is a `unpack_to_rootfs` function. This is the worker function that unpacks initramfs and returns 0 for failure and 1 for success. Also note the interesting function parameters.

- **`__initramfs_start:`** This is the exact location/address of a loaded initramfs (initramfs will be loaded by the bootloader, so obviously the address location is also provided by the bootloader through `boot_protocol`).
- **`__initramfs_size:`** This is the size of the initramfs image.

How Does the Kernel Mount initramfs as Root?

The initramfs blob is just an (optionally compressed) `cpio` file. The kernel extracts it by creating a tmpfs/ramfs filesystem in memory as the root filesystem. So, there's not really a fixed location; the kernel just allocates memory for the extracted files as it goes along. We have already seen that GRUB 2/the bootloader places the kernel at a specific location that will be architecture dependent, but initramfs image extraction does not take place at any specific location.

Now before we proceed further with our booting sequence, we need to understand the dracut tool, which generates initramfs. This tool will provide us with a better understanding of initramfs and systemd.

CHAPTER 6

dracut

Put simply, dracut is a tool that creates the initramfs filesystem on Fedora-based systems. Debian- and Ubuntu-based systems use a similar tool called *update-initramfs*. If you want to generate, regenerate, or customize the existing initramfs, then you should know how to use the dracut tool. This chapter will explain how dracut works along with how to generate and customize initramfs. Also, you will learn some of the most common "can't boot" issues related to initramfs.

Getting Started

Every kernel has its own initramfs file, but you might be wondering why you never had to use the `dracut` command to create initramfs while installing a new kernel. Instead, you just found the respective initramfs in the `/boot` location. Well, when you install a new kernel, the `post-scripts` command of the kernel's `rpm` package calls dracut and makes initramfs for you. Let's see how it works on a Fedora-based system:

```
# rpm -q --scripts kernel-core-5.3.7-301.fc31.x86_64
postinstall scriptlet (using /bin/sh):

if [ `uname -i` == "x86_64" -o `uname -i` == "i386" ] &&
   [ -f /etc/sysconfig/kernel ]; then
  /bin/sed -r -i -e 's/^DEFAULTKERNEL=kernel-smp$/DEFAULTKERNEL=kernel/' /
  etc/sysconfig/kernel || exit $?
fi
preuninstall scriptlet (using /bin/sh):
/bin/kernel-install remove 5.3.7-301.fc31.x86_64 /lib/modules/5.3.7-301.
fc31.x86_64/vmlinuz || exit $?
posttrans scriptlet (using /bin/sh):
/bin/kernel-install add 5.3.7-301.fc31.x86_64 /lib/modules/5.3.7-301.fc31.
x86_64/vmlinuz || exit $?
```

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Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_6

As you can see, the `post-scripts` command of the kernel package calls the `kernel-install` script. The `kernel-install` script executes all the scripts that are available at `/usr/lib/kernel/install.d`.

# vim /bin/kernel-install

```
if ! [[ $MACHINE_ID ]]; then
    ENTRY_DIR_ABS=$(mktemp -d /tmp/kernel-install.XXXXX) || exit 1
    trap "rm -rf '$ENTRY_DIR_ABS'" EXIT INT QUIT PIPE
elif [[ -d /efi/loader/entries ]] || [[ -d /efi/$MACHINE_ID ]]; then
    ENTRY_DIR_ABS="/efi/$MACHINE_ID/$KERNEL_VERSION"
elif [[ -d /boot/loader/entries ]] || [[ -d /boot/$MACHINE_ID ]]; then
    ENTRY_DIR_ABS="/boot/$MACHINE_ID/$KERNEL_VERSION"
elif [[ -d /boot/efi/loader/entries ]] || [[ -d /boot/efi/$MACHINE_ID ]]; then
    ENTRY_DIR_ABS="/boot/efi/$MACHINE_ID/$KERNEL_VERSION"
elif mountpoint -q /efi; then
    ENTRY_DIR_ABS="/efi/$MACHINE_ID/$KERNEL_VERSION"
elif mountpoint -q /boot/efi; then
    ENTRY_DIR_ABS="/boot/efi/$MACHINE_ID/$KERNEL_VERSION"
else
    ENTRY_DIR_ABS="/boot/$MACHINE_ID/$KERNEL_VERSION"
fi

export KERNEL_INSTALL_MACHINE_ID=$MACHINE_ID

ret=0

readarray -t PLUGINS <<<"$(
    dropindirs_sort ".install" \
        "/etc/kernel/install.d" \
        "/usr/lib/kernel/install.d"
)"
```

Here you can see the scripts executed by kernel-install:

```
# ls /usr/lib/kernel/install.d/ -lh
total 36K
-rwxr-xr-x. 1 root root  744 Oct 10 18:26 00-entry-directory.install
-rwxr-xr-x. 1 root root 1.9K Oct 19 07:46 20-grubby.install
-rwxr-xr-x. 1 root root 6.6K Oct 10 13:05 20-grub.install
-rwxr-xr-x. 1 root root  829 Oct 10 18:26 50-depmod.install
-rwxr-xr-x. 1 root root 1.7K Jul 25  2019 50-dracut.install
-rwxr-xr-x. 1 root root 3.4K Jul 25  2019 51-dracut-rescue.install
-rwxr-xr-x. 1 root root 3.4K Oct 10 18:26 90-loaderentry.install
-rwxr-xr-x. 1 root root 1.1K Oct 10 13:05 99-grub-mkconfig.install
```

As you can see, this executes the 50-dracut.install script. This particular script executes the dracut command and makes initramfs for a particular kernel.

```
        for ((i=0; i < "${#BOOT_OPTIONS[@]}"; i++)); do
            if [[ ${BOOT_OPTIONS[$i]} == root\=PARTUUID\=* ]]; then
                noimageifnotneeded="yes"
                break
            fi
        done
        dracut -f ${noimageifnotneeded:+--noimageifnotneeded}
        "$BOOT_DIR_ABS/$INITRD" "$KERNEL_VERSION"
        ret=$?
        ;;
    remove)
        rm -f -- "$BOOT_DIR_ABS/$INITRD"
        ret=$?
        ;;
esac
exit $ret
```

Similarly, there is the script 51-dracut-rescue.install, which will make initramfs for the rescue kernel.

```
        if [[ ! -f "$BOOT_DIR_ABS/$INITRD" ]]; then
            dracut -f --no-hostonly -a "rescue" "$BOOT_DIR_ABS/$INITRD" "$KERNEL_VERSION"
            ((ret+=$?))
        fi

        if [[ "${BOOT_DIR_ABS}" != "/boot" ]]; then
            {
                echo "title      $PRETTY_NAME - Rescue Image"
                echo "version    $KERNEL_VERSION"
                echo "machine-id $MACHINE_ID"
                echo "options    ${BOOT_OPTIONS[@]} rd.auto=1"
                echo "linux      $BOOT_DIR/linux"
                echo "initrd     $BOOT_DIR/initrd"
            } > $LOADER_ENTRY
        else
            cp -aT "${KERNEL_IMAGE%/*}/bls.conf" $LOADER_ENTRY
            sed -i 's/'$KERNEL_VERSION'/0-rescue-'${MACHINE_ID}'/' $LOADER_ENTRY
        fi
```

Hence, every kernel will have its own initramfs file.

```
# ls -lh /boot | grep -e vmlinuz -e initramfs

-rw-------. 1 root root  80M Dec  2 18:32 initramfs-0-rescue-280526b3bc5e4c49ac83c8e5fbdfdb2e.img
-rw-------. 1 root root  28M Dec 23 06:37 initramfs-5.3.16-300.fc31.x86_64.img
-rw-------. 1 root root  30M Dec  2 18:33 initramfs-5.3.7-301.fc31.x86_64.img
-rwxr-xr-x. 1 root root 8.9M Dec  2 18:32 vmlinuz-0-rescue-280526b3bc5e4c49ac83c8e5fbdfdb2e
-rwxr-xr-x. 1 root root 8.9M Dec 13 23:51 vmlinuz-5.3.16-300.fc31.x86_64
-rwxr-xr-x. 1 root root 8.9M Oct 22 01:04 vmlinuz-5.3.7-301.fc31.x86_64
```

Note the size of the kernel (`vmlinuz`) file and its associated initramfs file size. The initramfs file is much bigger than the kernel.

Making an initramfs Image

First check which kernel has been installed on your system with this command:

```
# rpm -qa | grep -i kernel-5

kernel-5.3.16-300.fc31.x86_64
kernel-5.3.7-301.fc31.x86_64
```

Choose the kernel version for which you want to generate a new initramfs image and pass it to dracut.

```
# dracut /boot/new.img 5.3.7-301.fc31.x86_64 -v
<snip>
dracut: Executing: /usr/bin/dracut /boot/new.img 5.3.7-301.fc31.x86_64 -v
dracut: dracut module 'busybox' will not be installed, because command
'busybox' could not be found!
dracut: dracut module 'stratis' will not be installed, because command
'stratisd-init' could not be found!
dracut: dracut module 'biosdevname' will not be installed, because command
'biosdevname' could not be found!
dracut: dracut module 'busybox' will not be installed, because command
'busybox' could not be found!
dracut: dracut module 'stratis' will not be installed, because command
'stratisd-init' could not be found!
dracut: *** Including module: bash ***
dracut: *** Including module: systemd ***
dracut: *** Including module: systemd-initrd ***
dracut: *** Including module: nss-softokn ***
dracut: *** Including module: i18n ***
dracut: *** Including module: network-manager ***
dracut: *** Including module: network ***
dracut: *** Including module: ifcfg ***
dracut: *** Including module: drm ***
dracut: *** Including module: plymouth ***
.
.
</snip>
```

In the previous code, dracut will create an initramfs file called `new.img` in the current directory for the 64-bit Fedora kernel, `Kernel-5.3.7-301.fc31.x86_64`.

```
# ls -lh new.img
-rw-------. 1 root root 28M Dec 23 08:16 new.img
```

If the kernel version is not provided, then dracut will make initramfs for the kernel through which the system has been booted. The kernel version that has been passed to dracut must match the kernel directory present in the `/lib/modules/` location.

```
# ls /lib/modules/ -l
total 4
drwxr-xr-x. 6 root root 4096 Dec  9 10:18 5.3.7-301.fc31.x86_64
```

```
# ls /lib/modules/5.3.7-301.fc31.x86_64/ -l
total 18084
-rw-r--r--.  1 root root     249 Oct 22 01:04 bls.conf
lrwxrwxrwx.  1 root root      38 Oct 22 01:04 build -> /usr/src/
kernels/5.3.7-301.fc31.x86_64
-rw-r--r--.  1 root root  213315 Oct 22 01:03 config
drwxr-xr-x.  5 root root    4096 Oct 24 04:44 extra
drwxr-xr-x. 13 root root    4096 Oct 24 04:43 kernel
-rw-r--r--.  1 root root 1127438 Dec  9 10:18 modules.alias
-rw-r--r--.  1 root root 1101059 Dec  9 10:18 modules.alias.bin
-rw-r--r--.  1 root root    1688 Oct 22 01:04 modules.block
-rw-r--r--.  1 root root    8324 Oct 22 01:04 modules.builtin
-rw-r--r--.  1 root root   10669 Dec  9 10:18 modules.builtin.bin
-rw-r--r--.  1 root root   60853 Oct 22 01:04 modules.builtin.modinfo
-rw-r--r--.  1 root root  415475 Dec  9 10:18 modules.dep
-rw-r--r--.  1 root root  574502 Dec  9 10:18 modules.dep.bin
-rw-r--r--.  1 root root     381 Dec  9 10:18 modules.devname
-rw-r--r--.  1 root root     153 Oct 22 01:04 modules.drm
-rw-r--r--.  1 root root      59 Oct 22 01:04 modules.modesetting
-rw-r--r--.  1 root root    2697 Oct 22 01:04 modules.networking
-rw-r--r--.  1 root root  139947 Oct 22 01:04 modules.order
```

```
-rw-r--r--.  1 root root     700 Dec  9 10:18 modules.softdep
-rw-r--r--.  1 root root  468520 Dec  9 10:18 modules.symbols
-rw-r--r--.  1 root root  572778 Dec  9 10:18 modules.symbols.bin
lrwxrwxrwx.  1 root root       5 Oct 22 01:04 source -> build
-rw-------.  1 root root 4426726 Oct 22 01:03 System.map
drwxr-xr-x.  2 root root    4096 Oct 22 01:02 updates
drwxr-xr-x.  2 root root    4096 Oct 24 04:43 vdso
-rwxr-xr-x.  1 root root 9323208 Oct 22 01:04 vmlinuz
```

As we know, initramfs is a temporary root filesystem, and its main purpose is to provide an environment that will help mount the user's root filesystem. The user's root filesystem could be a local to a system, or it could be a network device, and to use that device, the kernel should have drivers (modules) for that hardware and, while booting, get these modules from initramfs.

For example, say the user's root filesystem is a locally connected hard disk, and the HDD is a SCSI device. So, initramfs has to have the SCSI drivers added in its archive.

```
# lsinitrd | grep -i scsi | awk '{ print $9 }'
etc/ld.so.conf.d/libiscsi-x86_64.conf
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/firmware/iscsi_ibft.
ko.xz
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/iscsi_boot_sysfs.
ko.xz
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/libiscsi.ko.xz
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/qla4xxx
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/qla4xxx/qla4xxx.
ko.xz
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/scsi_transport_
iscsi.ko.xz
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/scsi_transport_
srp.ko.xz
usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/virtio_scsi.ko.xz
usr/lib/udev/scsi_id
```

On top of the SCSI device, users might have configured a RAID device. If they have, then the kernel needs to have RAID device drivers to identify and assemble the RAID device. Similarly, some of the users' HDDs could be connected through an HBA card. In such situations, the kernel needs a `qlaXxxx`-like modules.

```
# lsinitrd | grep -i qla

        usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/qla4xxx
        usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/qla4xxx/
        qla4xxx.ko.xz
```

Please note that these days `'/lib'` is a symlink to `'/usr/lib/'`.

In the case of some users, the HDD could be coming from Fiber Channel over Ethernet. Then the kernel needs FCOE modules. In a virtualized environment, the HDD could be a virtual disk exposed by a hypervisor. In that case, to mount the user's root filesystem, the `virtIO` module is necessary. This way, the list of hardware and their respective modules goes on.

Obviously, the kernel cannot store all of these necessary module files (`.ko`) in its own binary (`vmlinuz`). Hence, one of the main jobs of initramfs is to store all the modules that are necessary to mount the user's root filesystem. This is also one of the reasons why the initramfs file size is much bigger compared to the kernel file. But remember, initramfs is not the source of the modules. The modules will always be provided by the kernel and archived in initramfs by dracut. The kernel (`vmlinuz`) is the source of all the modules, but as you can rightly guess, the kernel size will be huge if the kernel stores all the modules in its `vmlinuz` binary. Hence, along with a `kernel` package, a new package named `kernel-modules` has been introduced, and this package provides all the modules that are present at the `/lib/modules/<kernel-version-arch>` location; dracut pulls only those modules (`.ko` files) that are necessary for mounting the user's root filesystem.

```
# rpm -qa | grep -i kernel

        Kernel-headers-5.3.6-300.fc31.x86_64
        kernel-modules-extra-5.3.7-301.fc31.x86_64
        kernel-modules-5.3.7-301.fc31.x86_64
        kernel-core-5.3.16-300.fc31.x86_64
        kernel-core-5.3.7-301.fc31.x86_64
        kernel-5.3.16-300.fc31.x86_64
        abrt-addon-kerneloops-2.12.2-1.fc31.x86_64
        kernel-5.3.7-301.fc31.x86_64
        libreport-plugin-kerneloops-2.10.1-2.fc31.x86_64
        Kernel-modules-5.3.16-300.fc31.x86_64

# rpm -ql kernel-modules-5.3.7-301.fc31.x86_64 | wc -l
    1698

    # rpm -ql kernel-modules-5.3.7-301.fc31.x86_64
    <snip>
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/atmtcp.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/eni.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/firestream.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/he.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/nicstar.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/solos-pci.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/atm/suni.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/auxdisplay/cfag12864b.
    ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/auxdisplay/cfag12864bfb.
    ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/auxdisplay/charlcd.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/auxdisplay/hd44780.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/auxdisplay/ks0108.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bcma/bcma.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bluetooth/ath3k.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bluetooth/bcm203x.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bluetooth/bfusb.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bluetooth/bluecard_
    cs.ko.xz
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bluetooth/bpa10x.ko.xz
    .
    .
    </snip>
```

As you can see, the kernel-modules package that came with kernel-5.3.7-301 provides almost 1,698 modules. Also, the kernel-module package will be a dependency of the kernel package; hence, whenever kernel is installed, kernel-modules will be pulled and installed by a Fedora-based operating system.

Dracut and Modules

We'll now review the dracut modules.

How Does dracut Select Modules?

To understand how dracut pulls the modules in initramfs, first we need to understand the depmod command. depmod analyzes all the kernel modules in the /lib/modules/<kernel-version-arch> location and makes a list of all the modules along with their dependency modules. It keeps this list in the modules.dep file. (Note that on Fedora-based systems, it is good to refer to the module's location as /usr/lib/modules/<kernel_version>/*.) Here's an example:

```
# vim /lib/modules/5.3.7-301.fc31.x86_64/modules.dep
<snip>
.
.
kernel/arch/x86/kernel/cpu/mce/mce-inject.ko.xz:
kernel/arch/x86/crypto/des3_ede-x86_64.ko.xz: kernel/crypto/des_generic.ko.xz
kernel/arch/x86/crypto/camellia-x86_64.ko.xz:
kernel/arch/x86/crypto/blowfish-x86_64.ko.xz: kernel/crypto/blowfish_
common.ko.xz
kernel/arch/x86/crypto/twofish-x86_64.ko.xz: kernel/crypto/twofish_common.
ko.xz
.
.
</snip>
```

In this code, you can see that the module named des3_ede needs the module des_generic to work properly. In another example, you can see that the blowfish modules have a `blowfish_comman` module as a dependency. So, dracut reads the `modules.dep` file and starts pulling the kernel modules in the initramfs image from the `/lib/modules/5.3.7-301.fc31.x86_64/kernel/` location.

```
# ls /lib/modules/5.3.7-301.fc31.x86_64/kernel/ -l
total 44
drwxr-xr-x.  3 root root 4096 Oct 24 04:43 arch
drwxr-xr-x.  4 root root 4096 Oct 24 04:43 crypto
drwxr-xr-x. 80 root root 4096 Oct 24 04:43 drivers
drwxr-xr-x. 43 root root 4096 Oct 24 04:43 fs
drwxr-xr-x.  4 root root 4096 Oct 24 04:43 kernel
drwxr-xr-x.  8 root root 4096 Oct 24 04:43 lib
drwxr-xr-x.  2 root root 4096 Oct 24 04:43 mm
drwxr-xr-x. 51 root root 4096 Oct 24 04:43 net
drwxr-xr-x.  3 root root 4096 Oct 24 04:43 security
drwxr-xr-x. 13 root root 4096 Oct 24 04:43 sound
drwxr-xr-x.  3 root root 4096 Oct 24 04:43 virt
```

The kernel provides thousands of modules, but every module does not need to be added in initramfs. Hence, while collecting the modules, dracut pulls very specific modules.

```
# find /lib/modules/5.3.7-301.fc31.x86_64/ -name '*.ko.xz' | wc -l
3539
```

If dracut pulled every module, then the size of initramfs would be large. Also, why pull every module when it is not necessary? So, dracut pulls only those modules that are necessary to mount the user's root filesystem on that system.

```
# lsinitrd | grep -i '.ko.xz'  | wc -l
221
```

As you can see, initramfs has only 221 modules, whereas the kernel has almost 3,539 modules in it.

If we include 3,539 modules in initramfs, it would make initramfs huge, which will eventually slow down the booting performance because the initramfs archive loading and decompression time will be high. Also, we need to understand that initramfs' main task is to mount the user's root filesystem. Therefore, it makes sense to include only those modules that are necessary to mount the root filesystem. For example, the Bluetooth-related modules are not necessary to add in initramfs since the root filesystem will never be coming from a Bluetooth-connected device. So, you will not find any Bluetooth-related modules in initramfs, even though there are a couple of `bluetooth` modules provided by the kernel (`kernel-modules`).

```
# find /lib/modules/5.3.7-301.fc31.x86_64/ -name 'bluetooth'
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/net/bluetooth
    /lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/bluetooth

# lsinitrd | grep -i blue
    <no_output>
```

By default, dracut will add only host-specific modules in initramfs. It does this by inspecting the current system state and the modules that are currently used by the system. Being host-specific is the default approach of every leading Linux distribution. Fedora and Ubuntu-like systems also create a generic initramfs image, called a *rescue initramfs image*. The rescue initramfs includes all possible modules for devices on which users can possibly make a root filesystem. The idea is that the generic initramfs should be applicable to all the systems. Therefore, the rescue initramfs will always be bigger in size compared to the host-specific initramfs. dracut has a bunch of logic to decide which modules are needed to mount the root filesystem. This is what man page of dracut says, but remember in Fedora-based Linux, `--hostonly` is the default.

> *"If you want to create lighter, smaller initramfs images, you may want to specify the --hostonly or -H option. Using this option, the resulting image will contain only those dracut modules, kernel modules and filesystems, which are needed to boot this specific machine. This has the drawback, that you can't put the disk on another controller or machine, and that you can't switch to another root filesystem, without recreating the initramfs image. The usage of the --hostonly option is only for experts and you will have to keep the broken pieces. At least keep a copy of a general purpose image (and corresponding kernel) as a fallback to rescue your system."*

In the Chapter 5 we saw that there are a number of binaries, modules, and configuration files that were chosen by dracut and added in initramfs, but how does dracut choose files from the user's large root filesystem?

The files are chosen by running the scripts in the location `/usr/lib/dracut/modules.d`. This is the place where all the scripts of dracut are stored. dracut runs these scripts while generating initramfs, as shown here:

```
# ls /usr/lib/dracut/modules.d/ -l
total 288
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 00bash
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 00systemd
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 00warpclock
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 01fips
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 01systemd-initrd
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 02systemd-networkd
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 03modsign
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 03rescue
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 04watchdog
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 05busybox
drwxr-xr-x. 2 root root 4096 Oct 24 04:42 05nss-softokn
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 05rdma
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 10i18n
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 30convertfs
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 35network-legacy
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 35network-manager
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 40network
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 45ifcfg
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 45url-lib
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 50drm
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 50plymouth
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 80lvmmerge
drwxr-xr-x. 2 root root 4096 Oct 24 04:42 90bcache
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90btrfs
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90crypt
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90dm
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90dmraid
drwxr-xr-x. 2 root root 4096 Oct 24 04:44 90dmsquash-live
drwxr-xr-x. 2 root root 4096 Oct 24 04:44 90dmsquash-live-ntfs
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90kernel-modules
```

```
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90kernel-modules-extra
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90kernel-network-modules
drwxr-xr-x. 2 root root 4096 Oct 24 04:44 90livenet
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90lvm
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90mdraid
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90multipath
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90qemu
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90qemu-net
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 90stratis
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 91crypt-gpg
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 91crypt-loop
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95cifs
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95debug
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95fcoe
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95fcoe-uefi
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95fstab-sys
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95iscsi
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95lunmask
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95nbd
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95nfs
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95resume
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95rootfs-block
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95ssh-client
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95terminfo
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95udev-rules
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 95virtfs
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 97biosdevname
drwxr-xr-x. 2 root root 4096 Jan  6 12:42 98dracut-systemd
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 98ecryptfs
drwxr-xr-x. 2 root root 4096 Oct 24 04:44 98ostree
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 98pollcdrom
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 98selinux
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 98syslog
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 98usrmount
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99base
```

```
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99earlykdump
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99fs-lib
drwxr-xr-x. 2 root root 4096 Oct 24 04:44 99img-lib
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99kdumpbase
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99shutdown
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99squash
drwxr-xr-x. 2 root root 4096 Oct 24 04:43 99uefi-lib
```

The same output can be viewed by using `#dracut --list-modules`.

Whenever we try to make an initramfs filesystem, dracut starts executing the `module-setup.sh` script files in each directory in `/usr/lib/dracut/modules.d/`.

```
# find /usr/lib/dracut/modules.d/ -name 'module-setup.sh'

/usr/lib/dracut/modules.d/95iscsi/module-setup.sh
/usr/lib/dracut/modules.d/98ecryptfs/module-setup.sh
/usr/lib/dracut/modules.d/30convertfs/module-setup.sh
/usr/lib/dracut/modules.d/90crypt/module-setup.sh
/usr/lib/dracut/modules.d/10i18n/module-setup.sh
/usr/lib/dracut/modules.d/99earlykdump/module-setup.sh
/usr/lib/dracut/modules.d/95nbd/module-setup.sh
.
.
.
/usr/lib/dracut/modules.d/04watchdog/module-setup.sh
/usr/lib/dracut/modules.d/90lvm/module-setup.sh
/usr/lib/dracut/modules.d/35network-legacy/module-setup.sh
/usr/lib/dracut/modules.d/01systemd-initrd/module-setup.sh
/usr/lib/dracut/modules.d/99squash/module-setup.sh
/usr/lib/dracut/modules.d/05busybox/module-setup.sh
/usr/lib/dracut/modules.d/50drm/module-setup.sh
```

This `module-setup.sh` script will pick the module, binary, and configuration files that are specific to that host. For example, the first `module-setup.sh` script, which will run from the `00bash` directory, will include the `bash` binary in initramfs.

```
# vim /usr/lib/dracut/modules.d/00bash/module-setup.sh
```

```
#!/usr/bin/bash

# called by dracut
check() {
    require_binaries /bin/bash
}

# called by dracut
depends() {
    return 0
}

# called by dracut
install() {
    # If another shell is already installed, do not use bash
    [[ -x $initdir/bin/sh ]] && return

    # Prefer bash as /bin/sh if it is available.
    inst /bin/bash && ln -sf bash "${initdir}/bin/sh"
}

```

As you can see, the script file is adding the /bin/bash binary in initramfs. Let's look at another example, this one of plymouth.

```
# vim /usr/lib/dracut/modules.d/50plymouth/module-setup.sh
```

```
#!/usr/bin/bash

pkglib_dir() {
    local _dirs="/usr/lib/plymouth /usr/libexec/plymouth/"
    if type -P dpkg-architecture &>/dev/null; then
        _dirs+=" /usr/lib/$(dpkg-architecture -qDEB_HOST_MULTIARCH)/plymouth"
    fi
    for _dir in $_dirs; do
```

```
        if [ -x $_dir/plymouth-populate-initrd ]; then
            echo $_dir
            return
        fi
    done
}

# called by dracut
check() {
    [[ "$mount_needs" ]] && return 1
    [ -z $(pkglib_dir) ] && return 1

    require_binaries plymouthd plymouth plymouth-set-default-theme
}

# called by dracut
depends() {
    echo drm
}

# called by dracut
install() {
    PKGLIBDIR=$(pkglib_dir)
    if grep -q nash ${PKGLIBDIR}/plymouth-populate-initrd \
        || [ ! -x ${PKGLIBDIR}/plymouth-populate-initrd ]; then
        . "$moddir"/plymouth-populate-initrd.sh
    else
        PLYMOUTH_POPULATE_SOURCE_FUNCTIONS="$dracutfunctions" \
            ${PKGLIBDIR}/plymouth-populate-initrd -t "$initdir"
    fi

    inst_hook emergency 50 "$moddir"/plymouth-emergency.sh

    inst_multiple readlink

    if ! dracut_module_included "systemd"; then
        inst_hook pre-trigger 10 "$moddir"/plymouth-pretrigger.sh
        inst_hook pre-pivot 90 "$moddir"/plymouth-newroot.sh
    fi
}
```

Simply grepping require_binaries will show all the binaries that dracut will add in the generic initramfs.

```
# grep -ir "require_binaries" /usr/lib/dracut/modules.d/
/usr/lib/dracut/modules.d/90mdraid/module-setup.sh:    require_binaries
mdadm expr || return 1
/usr/lib/dracut/modules.d/80lvmmerge/module-setup.sh:    require_binaries
lvm dd swapoff || return 1
/usr/lib/dracut/modules.d/95cifs/module-setup.sh:    require_binaries
mount.cifs || return 1
/usr/lib/dracut/modules.d/91crypt-gpg/module-setup.sh:    require_binaries
gpg || return 1
/usr/lib/dracut/modules.d/91crypt-gpg/module-setup.sh:       require_
binaries gpg-agent &&
/usr/lib/dracut/modules.d/91crypt-gpg/module-setup.sh:       require_
binaries gpg-connect-agent &&
/usr/lib/dracut/modules.d/91crypt-gpg/module-setup.sh:       require_
binaries /usr/libexec/scdaemon &&
/usr/lib/dracut/modules.d/45url-lib/module-setup.sh:    require_binaries
curl || return 1
/usr/lib/dracut/modules.d/90stratis/module-setup.sh:    require_binaries
stratisd-init thin_check thin_repair mkfs.xfs xfs_admin xfs_growfs ||
return 1
/usr/lib/dracut/modules.d/90multipath/module-setup.sh:    require_binaries
multipath || return 1
/usr/lib/dracut/modules.d/95iscsi/module-setup.sh:    require_binaries
iscsi-iname iscsiadm iscsid || return 1
/usr/lib/dracut/modules.d/95ssh-client/module-setup.sh:    require_binaries
ssh scp  || return 1
```

```
/usr/lib/dracut/modules.d/35network-manager/module-setup.sh:    require_
binaries sed grep || return 1
/usr/lib/dracut/modules.d/90dmsquash-live-ntfs/module-setup.sh:    require_
binaries ntfs-3g || return 1
/usr/lib/dracut/modules.d/91crypt-loop/module-setup.sh:    require_binaries
losetup || return 1
/usr/lib/dracut/modules.d/05busybox/module-setup.sh:    require_binaries
busybox || return 1
/usr/lib/dracut/modules.d/99img-lib/module-setup.sh:    require_binaries
tar gzip dd bash || return 1
/usr/lib/dracut/modules.d/90dm/module-setup.sh:    require_binaries dmsetup
|| return 1
/usr/lib/dracut/modules.d/03modsign/module-setup.sh:    require_binaries
keyctl || return 1
/usr/lib/dracut/modules.d/97biosdevname/module-setup.sh:    require_
binaries biosdevname || return 1
/usr/lib/dracut/modules.d/95nfs/module-setup.sh:    require_binaries rpc.
statd mount.nfs mount.nfs4 umount || return 1
/usr/lib/dracut/modules.d/90dmraid/module-setup.sh:    require_binaries
dmraid || return 1
/usr/lib/dracut/modules.d/95fcoe/module-setup.sh:    require_binaries
dcbtool fipvlan lldpad ip readlink fcoemon fcoeadm || return 1
/usr/lib/dracut/modules.d/00warpclock/module-setup.sh:    require_binaries
/sbin/hwclock || return 1
/usr/lib/dracut/modules.d/35network-legacy/module-setup.sh:    require_
binaries ip dhclient sed awk grep || return 1
/usr/lib/dracut/modules.d/00bash/module-setup.sh:    require_binaries /bin/
bash
/usr/lib/dracut/modules.d/95nbd/module-setup.sh:    require_binaries nbd-
client || return 1
/usr/lib/dracut/modules.d/90btrfs/module-setup.sh:    require_binaries
btrfs || return 1
/usr/lib/dracut/modules.d/00systemd/module-setup.sh:    if require_binaries
$systemdutildir/systemd; then
```

```
/usr/lib/dracut/modules.d/10i18n/module-setup.sh:    require_binaries
setfont loadkeys kbd_mode || return 1
/usr/lib/dracut/modules.d/90lvm/module-setup.sh:    require_binaries lvm ||
return 1
/usr/lib/dracut/modules.d/50plymouth/module-setup.sh:    require_binaries
plymouthd plymouth plymouth-set-default-theme
/usr/lib/dracut/modules.d/95fcoe-uefi/module-setup.sh:    require_binaries
dcbtool fipvlan lldpad ip readlink || return 1
```

Once again, dracut does not include every module from `/usr/lib/dracut/modules.d`. It includes only host-specific modules. In the following section, you will learn how to add or omit specific modules from initramfs.

Customizing initramfs

Dracut also has its own modules. The kernel modules and dracut modules are different. Dracut collects the host-specific binaries, the associated libraries, the configuration files, and the hardware device modules and groups them under the name *dracut modules*. The kernel modules consist of the `.ko` files of the hardware device. You can see the dracut modules list either from `/usr/lib/dracut/modules.d/` or from the `dracut --list-modules` command.

```
# dracut --list-modules | xargs -n6
bash systemd warpclock fips systemd-initrd systemd-networkd
modsign rescue watchdog busybox nss-softokn rdma
i18n convertfs network-legacy network-manager network ifcfg
url-lib drm plymouth lvmmerge bcache btrfs
crypt dm dmraid dmsquash-live dmsquash-live-ntfs kernel-modules
kernel-modules-extra kernel-network-modules livenet lvm mdraid multipath
qemu qemu-net stratis crypt-gpg crypt-loop cifs
debug fcoe fcoe-uefi fstab-sys iscsi lunmask
nbd nfs resume rootfs-block ssh-client terminfo
udev-rules virtfs biosdevname dracut-systemd ecryptfs ostree
pollcdrom selinux syslog usrmount base earlykdump
fs-lib img-lib kdumpbase shutdown squash uefi-lib
```

If you want to add or omit specific dracut modules (not the hardware device module) from initramfs, then `dracut.conf` plays a vital role here. Note that `dracut.conf` is a configuration file of dracut, not of initramfs; hence, it will not be available inside initramfs.

```
# lsinitrd | grep -i 'dracut.conf'
    <no output>
```

dracut will refer to the `dracut.conf file` while generating initramfs. By default it will be an empty file.

```
# cat /etc/dracut.conf
    # PUT YOUR CONFIG IN separate files
    # in /etc/dracut.conf.d named "<name>.conf"
    # SEE man dracut.conf(5) for options
```

There are various options provided by `dracut.conf` that you can use to add or omit the module.

Suppose you want to omit the `plymouth`-related files (binaries, configuration files, modules, etc.) from initramfs; then you can either add a `omit_dracutmodules+=plymouth` in `dracut.conf` or use the `omit` (`-o`) switch of the `dracut` binary. Here's an example:

```
# lsinitrd | grep -i plymouth | wc -l
    118
```

There are almost 118 `plymouth`-related files present in the currently booted kernel. Let's try to omit `plymouth`-related files now.

```
# dracut -o plymouth /root/new.img

# lsinitrd /root/new.img | grep -i plymouth | wc -l
    4
```

As you can clearly see, all `plymouth`-related dracut modules have been eliminated from our newly built initramfs. Therefore, the `plymouth`-related binaries, configuration files, libraries, and hardware device modules (if available) will not be captured by dracut in initramfs. The same result can be achieved by adding `omit_dracutmodules+= plymouth` in `dracut.conf`.

```
# cat /etc/dracut.conf | grep -v '#'
    omit_dracutmodules+=plymouth

# dracut /root/new.img --force

# lsinitrd /root/new.img | grep -i plymouth
-rw-r--r--   1 root     root          454 Jul 25  2019 usr/lib/systemd/
system/systemd-ask-password-plymouth.path
-rw-r--r--   1 root     root          435 Jul 25  2019 usr/lib/systemd/
system/systemd-ask-password-plymouth.service
drwxr-xr-x   2 root     root            0 Jul 25  2019 usr/lib/systemd/
system/systemd-ask-password-plymouth.service.wants
lrwxrwxrwx   1 root     root           33 Jul 25  2019 usr/lib/systemd/
system/systemd-ask-password-plymouth.service.wants/systemd-vconsole-setup.
service -> ../systemd-vconsole-setup.service
```

The following comes from the `man` page:

> *Omitting dracut Modules*
>
> *Sometimes you don't want a dracut module to be included for reasons of speed, size or functionality. To do this, either specify the omit_dracutmodules variable in the dracut.conf or /etc/dracut.conf.d/myconf.conf configuration file (see dracut.conf(5)), or use the -o or --omit option on the command line: # dracut -o "multipath lvm" no-multipath-lvm.img*

Like when we omitted the dracut module, we can add any module that is available in `/usr/lib/dracut/modules.d`. We can use the `--add` switch of dracut or can use `add_dracutmodules+= in dracut.conf`. For example, you can see that we do not have NFS modules/files/binaries added in our `new.img` initramfs because my test system is not booting from NFS and not using any NFS mount point in it. Obviously, dracut will skip the `nfs` module from `/usr/lib/dracut/modules.d`. So, let's add it in our initramfs.

```
#lsinitrd | grep -i nfs
<no_output>

# cat /etc/dracut.conf
    # PUT YOUR CONFIG IN separate files
    # in /etc/dracut.conf.d named "<name>.conf"
    # SEE man dracut.conf(5) for options
    #omit_dracutmodules+=plymouth
    add_dracutmodules+=nfs

# dracut /root/new.img --force
# lsinitrd /root/new.img | grep -i nfs | wc -l
    33
```

We can also achieve this by using the dracut command with the --add switch.

```
# lsinitrd /root/new.img | grep -i nfs
# dracut --add nfs /root/new.img --force
# lsinitrd /root/new.img | grep -i nfs
Arguments: --add 'nfs' --force
nfs
-rw-r--r--   1 root     root           15 Jul 25  2019 etc/modprobe.d/nfs.conf
drwxr-xr-x   2 root     root            0 Jul 25  2019 usr/lib64/libnfsidmap
-rwxr-xr-x   1 root     root        50416 Jul 25  2019 usr/lib64/
libnfsidmap/nsswitch.so
-rwxr-xr-x   1 root     root        54584 Jul 25  2019 usr/lib64/
libnfsidmap.so.1.0.0
lrwxrwxrwx   1 root     root           20 Jul 25  2019 usr/lib64/
libnfsidmap.so.1 -> libnfsidmap.so.1.0.0
-rwxr-xr-x   1 root     root        42744 Jul 25  2019 usr/lib64/
libnfsidmap/sss.so
-rwxr-xr-x   1 root     root        46088 Jul 25  2019 usr/lib64/
libnfsidmap/static.so
-rwxr-xr-x   1 root     root        62600 Jul 25  2019 usr/lib64/
libnfsidmap/umich_ldap.so
-rwxr-xr-x   1 root     root          849 Oct  8  2018 usr/lib/dracut/hooks/
cleanup/99-nfsroot-cleanup.sh
-rwxr-xr-x   1 root     root         3337 Oct  8  2018 usr/lib/dracut/hooks/
cmdline/90-parse-nfsroot.sh
-rwxr-xr-x   1 root     root          874 Oct  8  2018 usr/lib/dracut/hooks/
pre-udev/99-nfs-start-rpc.sh
drwxr-xr-x   5 root     root            0 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs
```

```
drwxr-xr-x   2 root     root            0 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/blocklayout
-rw-r--r--   1 root     root        16488 Jul 25  2019 usr/lib/modules/
5.3.7-301.fc31.x86_64/kernel/fs/nfs/blocklayout/blocklayoutdriver.ko.xz
drwxr-xr-x   2 root     root            0 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs_common
-rw-r--r--   1 root     root         2584 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs_common/grace.ko.xz
-rw-r--r--   1 root     root         3160 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs_common/nfs_acl.ko.xz
drwxr-xr-x   2 root     root            0 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/filelayout
-rw-r--r--   1 root     root        11220 Jul 25  2019 usr/lib/modules/
5.3.7-301.fc31.x86_64/kernel/fs/nfs/filelayout/nfs_layout_nfsv41_files.ko.xz
drwxr-xr-x   2 root     root            0 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/flexfilelayout
-rw-r--r--   1 root     root        20872 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/flexfilelayout/nfs_layout_
flexfiles.ko.xz
-rw-r--r--   1 root     root       109684 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/nfs.ko.xz
-rw-r--r--   1 root     root        18028 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/nfsv3.ko.xz
-rw-r--r--   1 root     root       182756 Jul 25  2019 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/fs/nfs/nfsv4.ko.xz
-rwxr-xr-x   1 root     root         4648 Oct  8  2018 usr/lib/nfs-lib.sh
-rwsr-xr-x   1 root     root       187680 Jul 25  2019 usr/sbin/mount.nfs
lrwxrwxrwx   1 root     root            9 Jul 25  2019 usr/sbin/mount.nfs4
-> mount.nfs
-rwxr-xr-x   1 root     root          719 Oct  8  2018 usr/sbin/nfsroot
drwxr-xr-x   4 root     root            0 Jul 25  2019 var/lib/nfs
drwxr-xr-x   2 root     root            0 Jul 25  2019 var/lib/nfs/rpc_pipefs
drwxr-xr-x   3 root     root            0 Jul 25  2019 var/lib/nfs/statd
drwxr-xr-x   2 root     root            0 Jul 25  2019 var/lib/nfs/statd/sm
```

Like we added the extra `nfs` dracut module in our initramfs, the same way we can have only the `nfs` module in our initramfs with the help of adding `dracutmodules+=` in `dracut.conf`. This means the resultant initramfs will have only the `nfs` module in it. The rest of the modules from `/usr/lib/dracut/modules.d/` will be discarded.

```
# cat /etc/dracut.conf
    #omit_dracutmodules+=plymouth
    #add_dracutmodules+=nfs
    dracutmodules+=nfs

# dracut /root/new.img –force

# lsinitrd /root/new.img

Image: /root/new.img: 20M
========================================================================
Early CPIO image
========================================================================
drwxr-xr-x  3 root     root       0 Jul 25  2019 .
-rw-r—r--   1 root     root       2 Jul 25  2019 early_cpio
drwxr-xr-x  3 root     root       0 Jul 25  2019 kernel
drwxr-xr-x  3 root     root       0 Jul 25  2019 kernel/x86
drwxr-xr-x  2 root     root       0 Jul 25  2019 kernel/x86/microcode
-rw-r—r--   1 root     root       100352 Jul 25  2019 kernel/x86/microcode/
GenuineIntel.bin
========================================================================
Version:

Arguments: --force

dracut modules:
nss-softokn
network-manager
network
kernel-network-modules
nfs
=======================================================================
```

As you can see, only the nfs module has been added along with its dependencies like the network dracut module. Also, notice the size difference between both versions of initramfs.

```
# ls -lh initramfs-5.3.16-300.fc31.x86_64.img
    -rw-------. 1 root root 28M Dec 23 06:37 initramfs-5.3.16-300.fc31.
    x86_64.img

# ls -lh /root/new.img
    -rw-------. 1 root root 20M Dec 24 11:05 /root/new.img
```

The same can be achieved by using the -m or --modules switch of dracut.

```
# dracut -m nfs /root/new.img --force
```

If you want to add only the hardware device module, then please note that *hardware device module* means the *.ko files provided by the kernel-modules package at /lib/modules/<kernel-version>/drivers/<module-name>. Then the --add switch of dracut or add_dracutmodules+= will not help because these two switches add the dracut modules and not the kernel module (.ko) file. So, to add the kernel module, we need to use either a --add-drivers switch of dracut or drivers+= or add_drivers+= in dracut.conf. Here's an example:

```
# lsinitrd /root/new.img | grep -i ath3k
```

The Bluetooth-related module named ath3k is not present in our initramfs, but it is one of the modules provided by the kernel.

```
#ls -lh /lib/modules/5.3.16-300.fc31.x86_64/kernel/drivers/bluetooth/ath3k.
ko.xz
```

Let's add it, as shown here:

```
# dracut --add-drivers ath3k /root/new.img --force
```

Now it has been added, as shown here:

```
# lsinitrd /root/new.img | grep -i ath3k
Arguments: --add-drivers 'ath3k' --force
-rw-r--r-- 1 root  root 246804 Jul 25 03:54 usr/lib/firmware/ath3k-1.fw
-rw-r--r-- 1 root  root   5652 Jul 25 03:54 usr/lib/modules/5.3.7-301.fc31.
x86_64/kernel/drivers/bluetooth/ath3k.ko.xz
```

As you can see, the ath3k.ko module has been added in initramfs.

dracut Module or Kernel Module?

Let’s examine when to add a dracut module and when to add a kernel module. Here’s a scenario: your host root filesystem is on a normal SCSI device. So, obviously, your initramfs has neither a `multipath.ko` kernel module nor a `multipath.conf`-like configuration file for it.

1) All of sudden you decide to shift your root filesystem from the normal local disk to a SAN (I would never recommend such change on a production system), and the SAN is connected through a multipath device.

2) To get the entire environment of the multipath device, you need to add the multipath dracut module here so that the entire environment of multipath will be pulled into initramfs.

3) After a few days, you add a new NIC card on the same system, and the NIC card vendor has provided drivers for it. A driver is nothing but a `.ko` file (kernel object). To add this module in your initramfs, you have to choose to add the `kernel module` option. This will add the driver of only the NIC card, not the entire environment.

But what if you want to add some specific file to the initramfs, which is neither a kernel module nor a dracut module? dracut provides the `install_items+=` and `--include` variables of `dracut.conf` through which we can add specific files. The files could be anything from a normal text to a binary file, etc.

```
#lsinitrd /root/new.img | grep -i date
    <no_output>
```

The `date` binary is not by default present in initramfs. But to add a binary, we can use an `install_itsems+` switch.

```
# cat /etc/dracut.conf
    # PUT YOUR CONFIG IN separate files
    # in /etc/dracut.conf.d named "<name>.conf"
    # SEE man dracut.conf(5) for options
    #omit_dracutmodules+=plymouth
    #add_dracutmodules+=nfs
    #dracutmodules+=nfs
    install_items+=date
```

```
# dracut /root/new.img --force

# lsinitrd /root/new.img | grep -i date
-rwxr-xr-x   1 root     root       122456 Jul 25 02:36 usr/bin/date
```

As you can see, the `date` binary has been added, but the most important thing is it does not only add the binary; rather, it also adds the library that is necessary to run the `date` command. The same can be achieved with the `--install` switch of the `dracut` command. But this has a limitation; it cannot add the user-made custom binaries. To do that, we need to use the `--include` switch of dracut. With `--include`, you can include the normal files, directories, or even a binary in initramfs. In the case of the binary, if your binary needs a supporting library, then you have to specify that library name with its absolute path.

"Can't Boot" Issue 4 (initramfs)

Issue: A Linux production system has been rebooted after four months for regular maintenance, and it has stopped booting. It keeps throwing this error message on the screen:

```
<snip>
.
dracut-initqueue[444]: warning: dracut-initqueue timeout - starting timeout
scripts
dracut-initqueue[444]: warning: dracut-initqueue timeout - starting timeout
scripts
dracut-initqueue[444]: warning: dracut-initqueue timeout - starting timeout
scripts
dracut-initqueue[444]: warning: dracut-initqueue timeout - starting timeout
scripts
.
</snip>
```

Resolution: Here are the steps to resolve the issue:

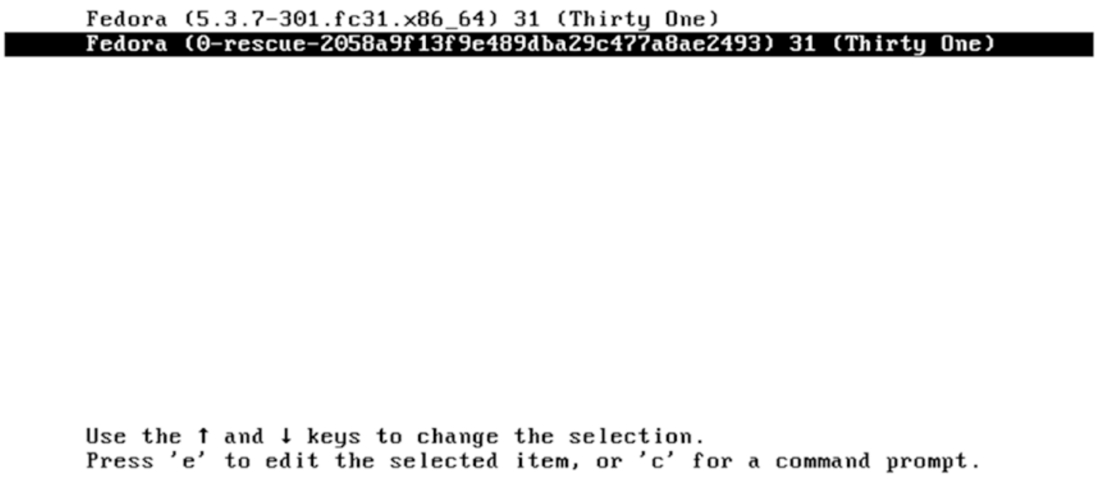
1. The error message starts by saying it is not able to reach the swap device, and then the process times out.

   ```
   [TIME] Timed out waiting for device /dev/mapper/fedora_localhost--live-swap
   ```

   This is a crucial piece of information since this tells you that something is wrong with this system's filesystems.

2. The swap device is based on an HDD, and the swap filesystem has been created on it. Now the swap device itself is missing. So, either the underlying disk itself is not accessible or the swap filesystem is corrupted. With this understanding, we can now concentrate on the storage side only. The isolation of the issue is important since the "can't boot" issue has thousands of situations that could cause the system to stop booting.

3. Either we will boot with rescue mode or we can use a live image of the same distribution and version. This is a Fedora 31 system, and as shown in Figure 6-1, I will use the rescue option from GRUB.



```
Fedora (5.3.7-301.fc31.x86_64) 31 (Thirty One)
Fedora (0-rescue-2058a9f13f9e489dba29c477a8ae2493) 31 (Thirty One)

Use the ↑ and ↓ keys to change the selection.
Press 'e' to edit the selected item, or 'c' for a command prompt.
```

Figure 6-1. *The GRUB splash screen*

4. Once we boot into rescue mode, we will mount the user's root filesystem and `chroot` into it. Now why is rescue mode able to boot when the normal kernel is not able to boot on the same system? This is a valid question, and the answer will be covered in Chapter 10.

5. Since we are able to mount the root filesystem in a rescue kernel but not able to mount the root filesystem with the normal kernel, that means something is wrong with the initramfs image. Maybe some module that is necessary to handle the HDD is missing. Let's verify this theory.

6. This is a virtualized system, which means it has a virtual disk. This can be seen from the `/dev` directory.

   ```
   #ls /dev/vd*
   vda vda1 vda2
   ```

7. To handle the virtualized disks, we need to have a `virtio_blk` module present in initramfs.

   ```
   #lsinitrd /boot/new.img | grep -i virt
   Arguments: --omit-drivers virtio_blk
   -rw-r--r-- 1 root  root   14132 Jul 25 03:54
       usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/char/
       virtio_console.ko.xz
   -rw-r--r-- 1 root  root   25028 Jul 25 03:54
       usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/net/
       virtio_net.ko.xz
   -rw-r--r-- 1 root  root   7780 Jul 25 03:54
       usr/lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/
       virtio_scsi.ko.xz
   -rw-r--r-- 1 root  root   499 Feb 26  2018 usr/lib/sysctl.d/60-
   libvirtd.conf
   ```

   As you can see, the `virtio_blk` module is missing.

8. Since `virtio_blk` is missing, obviously the kernel cannot detect and access the `vda` disk, which is where the user has the root filesystem as well as the swap filesystem.

9. To fix this issue, we need to add the missing `virtio_blk` module in initramfs.

```
#dracut --add-drivers=virtio_blk /boot/new.img --force

# lsinitrd | grep -i virtio_blk
    -rw-r--r--   1 root     root         8356 Jul 25 03:54 usr/
    lib/modules/5.3.7-301.fc31.x86_64/kernel/drivers/block/virtio_
    blk.ko.xz
```

10. We will boot by using our `new.img` initramfs. How to boot the system manually with the help of the GRUB command prompt was already discussed in "can't boot" issue 1.

11. After adding the missing `virtio_blk` module, the "can't boot" issue has been fixed. You can see the successfully booted system in Figure 6-2.

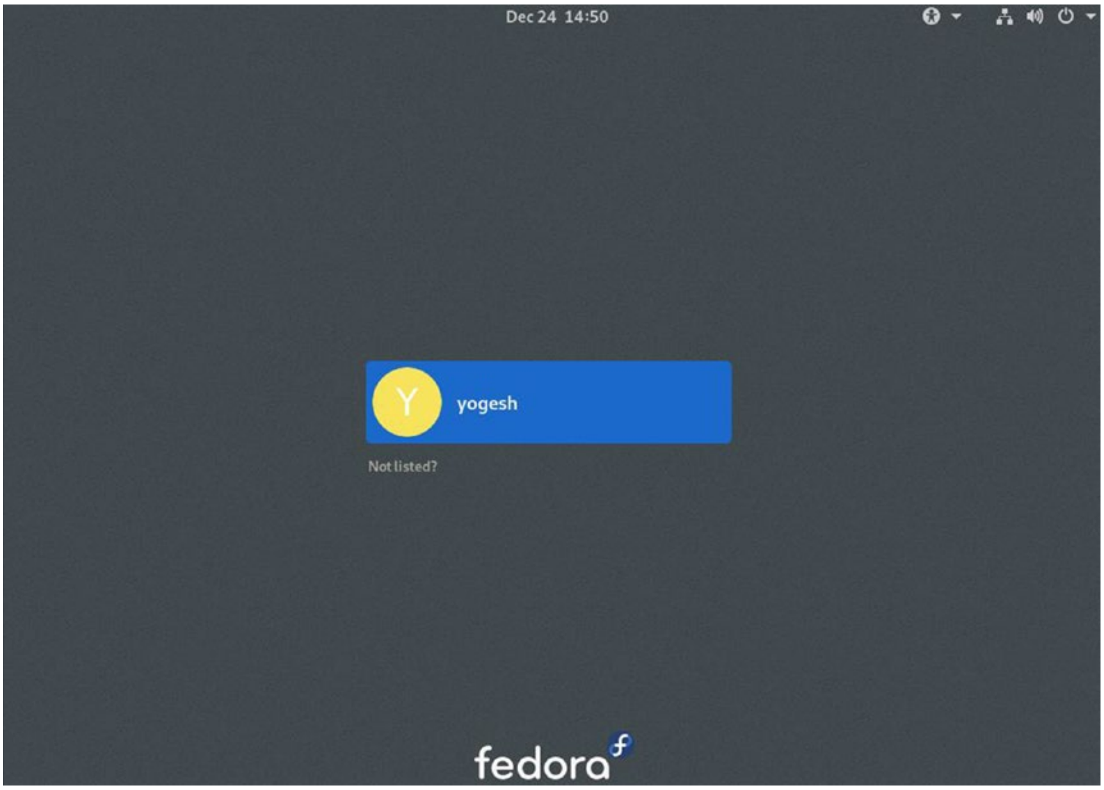


Figure 6-2. *The login screen of Fedora*

“Can’t Boot” Issue 5 (initramfs)

Issue: Figure 6-3 shows what is visible on-screen.

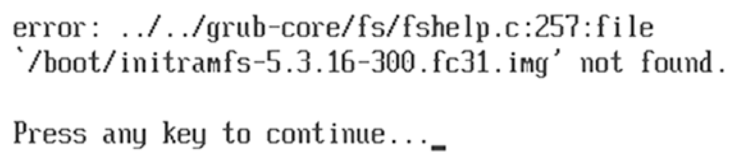

```
error: ../../grub-core/fs/fshelp.c:257:file
`/boot/initramfs-5.3.16-300.fc31.img' not found.

Press any key to continue..._
```

Figure 6-3. *The console messages*

Resolution: Here are the steps to resolve the issue:

1) Now this is easy to understand and to resolve.
2) The error message is self-explanatory; the initramfs file itself is missing.
3) Either the initramfs itself is missing or it’s just that the `/boot/loader/entries/*` file has a wrong entry in it. In this case, initramfs itself is missing.
4) So, we need to boot in rescue mode and mount the user’s root filesystem.
5) Either reinstall the kernel’s `rpm` package so that the `postscripts` part of the package will regenerate the missing initramfs and will also update the BLS entries accordingly.
6) Or you can regenerate initramfs with the help of the `dracut` command.

Kernel Command-Line Options

As we have already seen, GRUB accepts kernel command-line parameters and passes them to the kernel. The kernel has hundreds of command-line parameters, and it is almost impossible for anyone to cover each and every parameter. So, we will focus only on those parameters that are necessary while booting the operating system. If you are interested in all of the kernel command-line parameters, then visit the following page: https://www.kernel.org/doc/html/v4.14/admin-guide/kernel-parameters.html.

The list of parameters on that page are of the series 4 of kernels, but most of the parameter explanations are applicable to series 5 kernels as well. The best option is to always look at the kernel documentation at `/usr/share/doc/`.

root

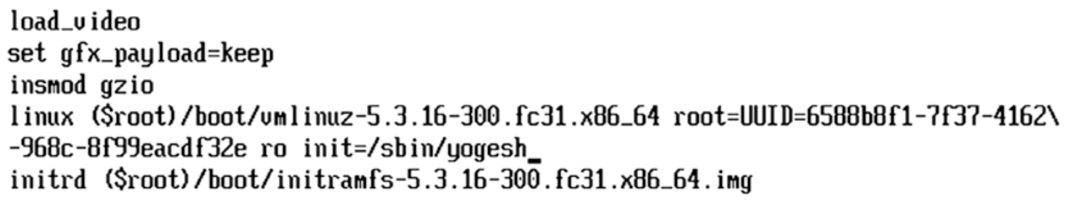
- This is one of the main kernel's command-line parameters. The ultimate aim of booting is to mount the user's root filesystem. The `root` kernel command-line parameter provides the name of the user's root filesystem, which the kernel is supposed to mount.
- On behalf of the kernel, systemd, which ran from initramfs, mounts the user's root filesystem.
- If the user's root filesystem is not available or if the kernel is not able to mount it, then it will be considered a panic situation for the kernel.

init

- The kernel runs systemd from initramfs, and that becomes the first process. It's also called PID-1 and is the parent of every process.
- But if you are a developer and you want to run your own binary instead of systemd, then you can use the `init` kernel command-line parameter. Here's an example:

  ```
  init=/sbin/yogesh
  ```

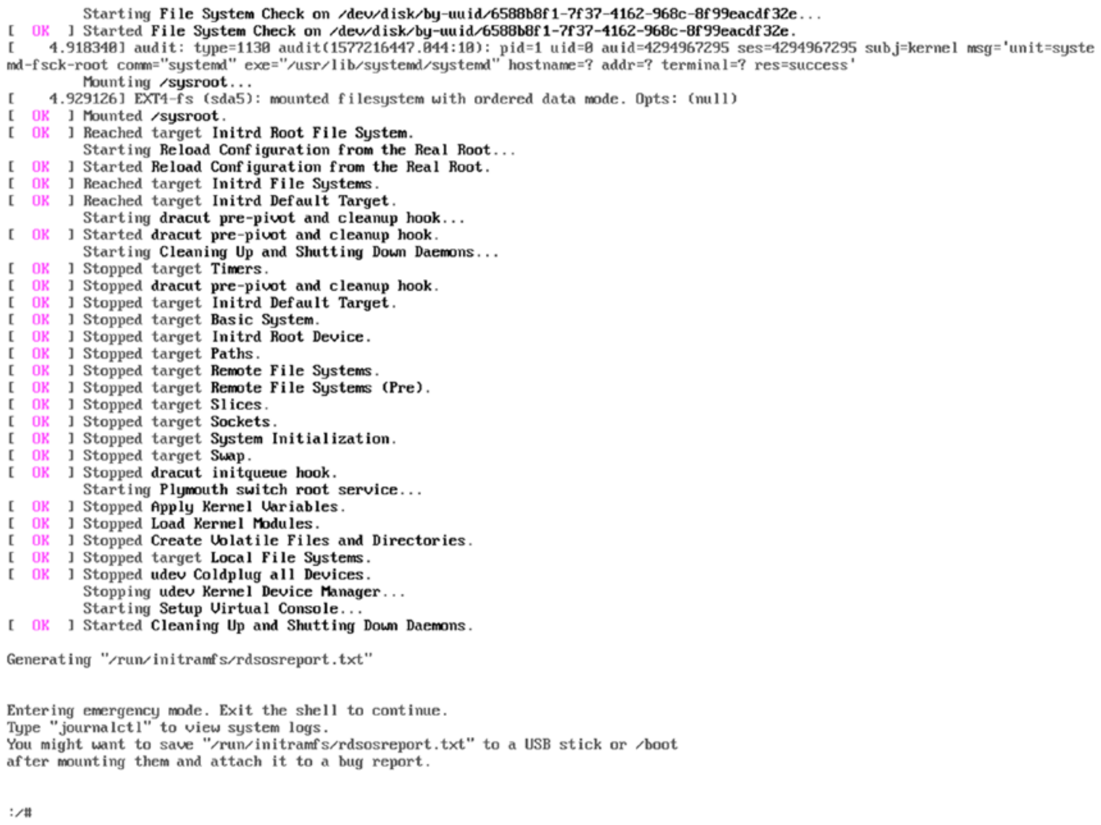
As you can see in Figure 6-4, this will run the `yogesh` binary instead of systemd.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro init=/sbin/yogesh_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 6-4. *The kernel command-line parameters*

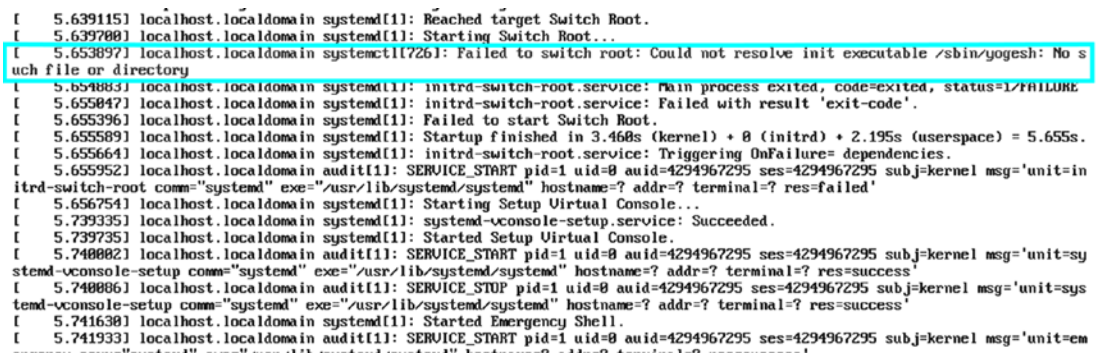
But `yogesh` is not available on the actual root filesystem; hence, as shown in Figure 6-5, it will fail to boot.



```
         Starting File System Check on /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e...
[  OK  ] Started File System Check on /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e.
[    4.918340] audit: type=1130 audit(1577216447.044:10): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=syste
md-fsck-root comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
         Mounting /sysroot...
[    4.929126] EXT4-fs (sda5): mounted filesystem with ordered data mode. Opts: (null)
[  OK  ] Mounted /sysroot.
[  OK  ] Reached target Initrd Root File System.
         Starting Reload Configuration from the Real Root...
[  OK  ] Started Reload Configuration from the Real Root.
[  OK  ] Reached target Initrd File Systems.
[  OK  ] Reached target Initrd Default Target.
         Starting dracut pre-pivot and cleanup hook...
[  OK  ] Started dracut pre-pivot and cleanup hook.
         Starting Cleaning Up and Shutting Down Daemons...
[  OK  ] Stopped target Timers.
[  OK  ] Stopped dracut pre-pivot and cleanup hook.
[  OK  ] Stopped target Initrd Default Target.
[  OK  ] Stopped target Basic System.
[  OK  ] Stopped target Initrd Root Device.
[  OK  ] Stopped target Paths.
[  OK  ] Stopped target Remote File Systems.
[  OK  ] Stopped target Remote File Systems (Pre).
[  OK  ] Stopped target Slices.
[  OK  ] Stopped target Sockets.
[  OK  ] Stopped target System Initialization.
[  OK  ] Stopped target Swap.
[  OK  ] Stopped dracut initqueue hook.
         Starting Plymouth switch root service...
[  OK  ] Stopped Apply Kernel Variables.
[  OK  ] Stopped Load Kernel Modules.
[  OK  ] Stopped Create Volatile Files and Directories.
[  OK  ] Stopped target Local File Systems.
[  OK  ] Stopped udev Coldplug all Devices.
         Stopping udev Kernel Device Manager...
         Starting Setup Virtual Console...
[  OK  ] Started Cleaning Up and Shutting Down Daemons.

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


:/#
```

Figure 6-5. *The emergency shell*

- The system has dropped us in the emergency shell. Refer to Chapter 8 for a detailed discussion about debugging shells.
- The reason for dropping us in the emergency shell and the reason for the "can't boot" issue is mentioned in `/run/initramfs/rdsosreport.txt`. Figure 6-6 shows a snippet of the `rdsosreport.txt` file.



```
[    5.639115] localhost.localdomain systemd[1]: Reached target Switch Root.
[    5.639700] localhost.localdomain systemd[1]: Starting Switch Root...
[    5.653897] localhost.localdomain systemctl[726]: Failed to switch root: Could not resolve init executable /sbin/yogesh: No s
uch file or directory
[    5.654883] localhost.localdomain systemd[1]: initrd-switch-root.service: Main process exited, code=exited, status=1/FAILURE
[    5.655047] localhost.localdomain systemd[1]: initrd-switch-root.service: Failed with result 'exit-code'.
[    5.655396] localhost.localdomain systemd[1]: Failed to start Switch Root.
[    5.655589] localhost.localdomain systemd[1]: Startup finished in 3.460s (kernel) + 0 (initrd) + 2.195s (userspace) = 5.655s.
[    5.655664] localhost.localdomain systemd[1]: initrd-switch-root.service: Triggering OnFailure= dependencies.
[    5.655952] localhost.localdomain audit[1]: SERVICE_START pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=in
itrd-switch-root comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=failed'
[    5.656754] localhost.localdomain systemd[1]: Starting Setup Virtual Console...
[    5.739335] localhost.localdomain systemd[1]: systemd-vconsole-setup.service: Succeeded.
[    5.739735] localhost.localdomain systemd[1]: Started Setup Virtual Console.
[    5.740002] localhost.localdomain audit[1]: SERVICE_START pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=sy
stemd-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[    5.740086] localhost.localdomain audit[1]: SERVICE_STOP pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=sys
temd-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[    5.741630] localhost.localdomain systemd[1]: Started Emergency Shell.
[    5.741933] localhost.localdomain audit[1]: SERVICE_START pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=em
```

Figure 6-6. *The rdsosreport.txt file*

- The interesting part to note here is that our `/sbin/yogesh` binary will be called at the time of the `chroot`'ing to the actual root filesystem. We have not discussed `chroot` yet; you can find a detailed discussion in Chapter 10.

ro

- This is a supporting parameter to the `root` kernel command-line parameter. `ro` stands for "read-only" file system. The user's root filesystem will be mounted inside initramfs, and it will be mounted in read-only mode if the `ro` kernel command-line parameter has been passed. The `ro` is the default choice of every major Linunx distribution.

rhgb and quite

- Almost every Linux distribution shows the animation at the time of booting to make the booting procedure more exciting, but the important console messages that are required to analyze the booting sequence will be hidden behind the animation. To stop the animation and to see the verbose console messages on-screen, remove the `rhgb` and `quite` parameters.
- When `rhgb` and `quite` are passed, as you can see in Figure 6-7, the `plymouth` animation will be shown.

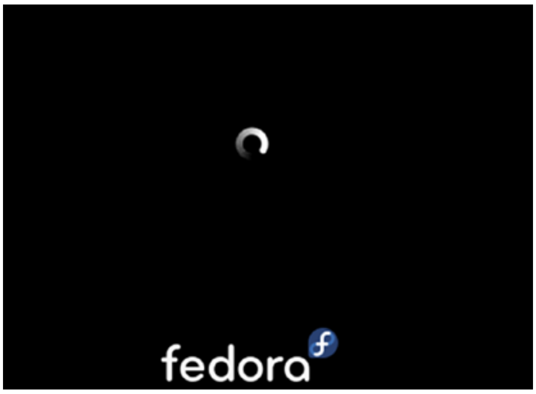
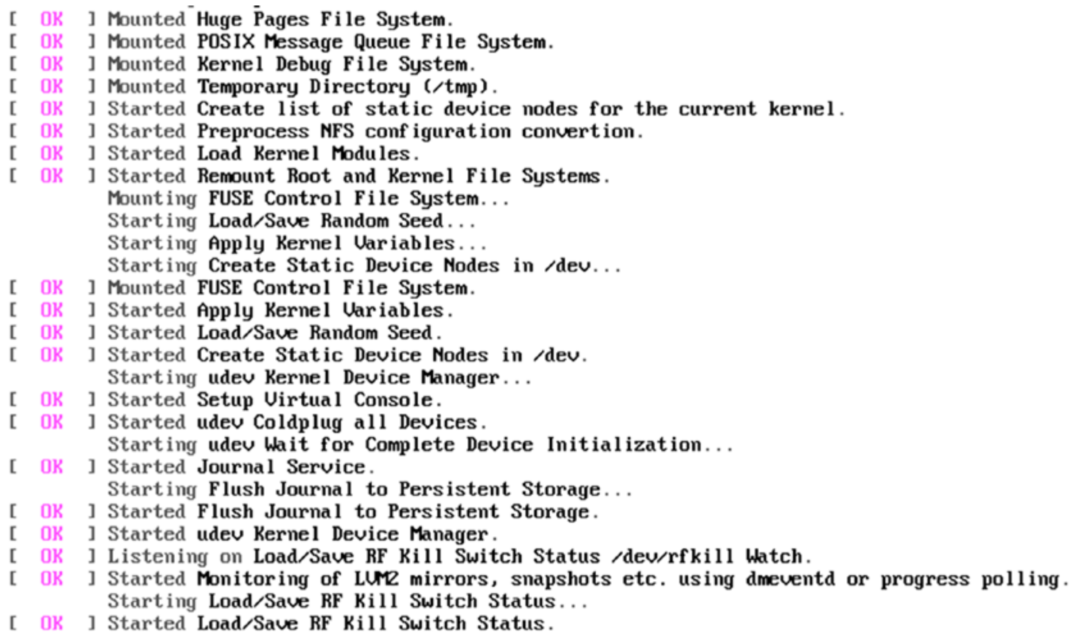


***Figure 6-7.** The plymouth screen*

- When `rhgb` and `quite` are removed, as you can see in Figure 6-8, the console messages will be exposed to the user.



```
[  OK  ] Mounted Huge Pages File System.
[  OK  ] Mounted POSIX Message Queue File System.
[  OK  ] Mounted Kernel Debug File System.
[  OK  ] Mounted Temporary Directory (/tmp).
[  OK  ] Started Create list of static device nodes for the current kernel.
[  OK  ] Started Preprocess NFS configuration convertion.
[  OK  ] Started Load Kernel Modules.
[  OK  ] Started Remount Root and Kernel File Systems.
         Mounting FUSE Control File System...
         Starting Load/Save Random Seed...
         Starting Apply Kernel Variables...
         Starting Create Static Device Nodes in /dev...
[  OK  ] Mounted FUSE Control File System.
[  OK  ] Started Apply Kernel Variables.
[  OK  ] Started Load/Save Random Seed.
[  OK  ] Started Create Static Device Nodes in /dev.
         Starting udev Kernel Device Manager...
[  OK  ] Started Setup Virtual Console.
[  OK  ] Started udev Coldplug all Devices.
         Starting udev Wait for Complete Device Initialization...
[  OK  ] Started Journal Service.
         Starting Flush Journal to Persistent Storage...
[  OK  ] Started Flush Journal to Persistent Storage.
[  OK  ] Started udev Kernel Device Manager.
[  OK  ] Listening on Load/Save RF Kill Switch Status /dev/rfkill Watch.
[  OK  ] Started Monitoring of LVM2 mirrors, snapshots etc. using dmeventd or progress polling.
         Starting Load/Save RF Kill Switch Status...
[  OK  ] Started Load/Save RF Kill Switch Status.
```

***Figure 6-8.** The console messages*

- You can also press Escape at the animation (`plymouth`) screen and can see the console messages, but for that, you have to be physically present in front of the production system, which is unlikely.

selinux

- Sometimes to resolve the "can't boot" issues, you want to completely get rid of SELinux. You can pass `selinux=0` kernel command line parameter at that time. This will disable SELinux altogether.

These were some of the kernel command-line parameters that directly affect the booting sequence. Like with the kernel command-line parameters, GRUB can accept dracut command-line parameters too, which will be accepted by initramfs or more precisely by systemd of initramfs.

dracut Command-Line Options

In layperson's terms, you can consider command-line parameters starting with `rd.` to be dracut command-line parameters that will be understood by initramfs.

rd.auto (rd.auto=1)

- According to the man page, this enables auto assembly of special devices such as cryptoLUKS, dmraid, mdraid, or lvm. The default is off.
- Consider a scenario like earlier where your system did not have `mdraid (s/w raid)` configured, but now you have recently implemented it, and you want that device to be activated at the time of the boot. In other words, the storage state of the machine is changed at the time of the initramfs creation. Now, without regenerating the new initramfs, you want the new configuration (LVM or LUKS) to be activated at the time of the boot.

rd.hostonly=0

- According to the man page, this removes all compiled in the configuration of the host system that the initramfs image was built on. This helps booting, if any disk layout has changed, especially in combination with `rd.auto` or other parameters specifying the layout.

- Say that your graphics card provider (such as Nvidia) has given you special drivers/modules that are present in your initramfs, but the modules have started creating a problem. Since the graphics driver will be loaded at an early stage of booting, you want to avoid the use of that module; instead, you want to use a generic driver (`vesa`). In that scenario, you can use `rd.hostonly=0.` With this parameter, initramfs will load the generic driver and will avoid the host-specific Nvidia driver.

rd.fstab = 0

- According to the man page, use this parameter if you do not want to honor special mount options for the root filesystem found in `/etc/fstab` of the real root.

rd.skipfsck

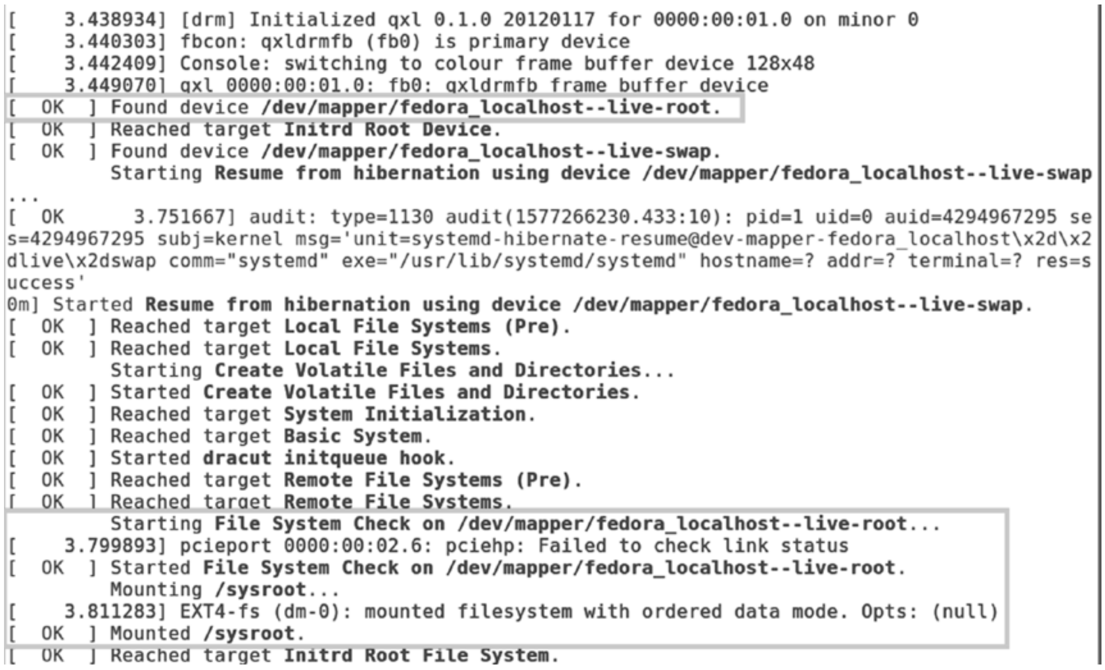
- According to the man page, this skips `fsck` for `rootfs` and `/usr`. If you're mounting `/usr` to be read-only and the `init` system performs `fsck` before the remount, you might want to use this option to avoid duplication.
- Most Linux administrators have a misconception about `fsck` and how it is combined with the `ro` kernel command-line parameter. Most of us think that the kernel first mounts the actual root filesystem in `ro` mode and then performs an `fsck` on it so that the `fsck` operation will not corrupt the root filesystem data. Once the `fsck` is successful, it will remount the root filesystem in read-write mode by referring to `/etc/fstab`.
- But this understanding has a basic flaw, which is that `fsck` cannot be performed on a mounted filesystem irrespective of `ro` or `rw` mode.

The following Fedora system's user root filesystem is on the sda5 device, and it is currently mounted in read-only mode, so `fsck` would fail since the filesystem is mounted:

```
# fsck.ext4 /dev/sda5
    e2fsck 1.45.3 (14-Jul-2019)
    /dev/sda5 is mounted.
    e2fsck: Cannot continue, aborting.
```

Hence, it is proved that the purpose of the user's root filesystem getting mounted in `ro` mode is not to perform a `fsck`. Then what is the reason to pass the `ro` command-line parameter to the kernel? Let's discuss it through the booting sequence.

- The kernel extracts initramfs and passes command-line parameters like `root` and `ro` to systemd, which will start from initramfs.
- systemd will find the actual root filesystem.
- Once the root filesystem (device) is identified, systemd will perform the `fsck` on it.
- If the `fsck` is successful, then systemd will mount the root filesystem as `ro` (as per the passed kernel command-line parameter) inside initramfs itself. It will be mounted as read-only in the `/sysroot` directory of initramfs.
- As you can see in Figure 6-9, the kernel has extracted initramfs and started systemd from it (I have removed the `rhgb` and `quite` parameters).



```
[    3.438934] [drm] Initialized qxl 0.1.0 20120117 for 0000:00:01.0 on minor 0
[    3.440303] fbcon: qxldrmfb (fb0) is primary device
[    3.442409] Console: switching to colour frame buffer device 128x48
[    3.449070] qxl 0000:00:01.0: fb0: qxldrmfb frame buffer device
[  OK  ] Found device /dev/mapper/fedora_localhost--live-root.
[  OK  ] Reached target Initrd Root Device.
[  OK  ] Found device /dev/mapper/fedora_localhost--live-swap.
         Starting Resume from hibernation using device /dev/mapper/fedora_localhost--live-swap
...
[  OK      3.751667] audit: type=1130 audit(1577266230.433:10): pid=1 uid=0 auid=4294967295 se
s=4294967295 subj=kernel msg='unit=systemd-hibernate-resume@dev-mapper-fedora_localhost\x2d\x2
dlive\x2dswap comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=s
uccess'
0m] Started Resume from hibernation using device /dev/mapper/fedora_localhost--live-swap.
[  OK  ] Reached target Local File Systems (Pre).
[  OK  ] Reached target Local File Systems.
         Starting Create Volatile Files and Directories...
[  OK  ] Started Create Volatile Files and Directories.
[  OK  ] Reached target System Initialization.
[  OK  ] Reached target Basic System.
[  OK  ] Started dracut initqueue hook.
[  OK  ] Reached target Remote File Systems (Pre).
[  OK  ] Reached target Remote File Systems.
         Starting File System Check on /dev/mapper/fedora_localhost--live-root...
[    3.799893] pcieport 0000:00:02.6: pciehp: Failed to check link status
[  OK  ] Started File System Check on /dev/mapper/fedora_localhost--live-root.
         Mounting /sysroot...
[    3.811283] EXT4-fs (dm-0): mounted filesystem with ordered data mode. Opts: (null)
[  OK  ] Mounted /sysroot.
[  OK  ] Reached target Initrd Root File System.
```

Figure 6-9. *The console messages*

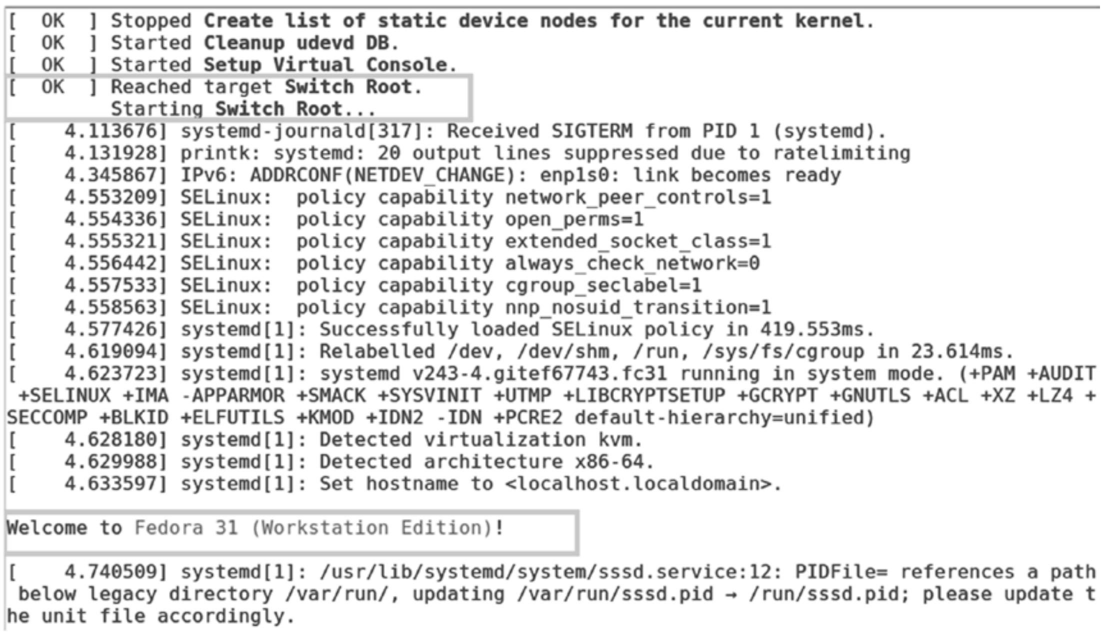
Systemd then scanned the connected storage devices for the root filesystem and found one. Before mounting the user's root filesystem, it first performed the `fsck` on it and later mounted it inside initramfs on the directory `sysroot`. The user's root filesystem will be mounted in read-only mode.

- The reason for mounting it in read-only mode is simple to understand. Suppose the system fails to boot, but it has managed to mount the user's root filesystem on `sysroot` and has provided us with a shell to fix the "can't boot" issue. Users might accidentally corrupt or even delete the user's root filesystem that is mounted under `sysroot`. So, to prevent the user's root filesystem from such accidents, it is preferred to mount it in read-only mode.

  ```
  #switch_root:/# ls -ld /sysroot/
      dr-xr-xr-x 19 root 0 4096 Sep 10  2017 /sysroot/
  ```

- How to use the debugging shells and how initramfs provides them will be discussed in Chapter 8.

- Figure 6-10 shows systemd continuing its booting sequence and leaving the initramfs environment.



```
[  OK  ] Stopped Create list of static device nodes for the current kernel.
[  OK  ] Started Cleanup udevd DB.
[  OK  ] Started Setup Virtual Console.
[  OK  ] Reached target Switch Root.
         Starting Switch Root...
[    4.113676] systemd-journald[317]: Received SIGTERM from PID 1 (systemd).
[    4.131928] printk: systemd: 20 output lines suppressed due to ratelimiting
[    4.345867] IPv6: ADDRCONF(NETDEV_CHANGE): enp1s0: link becomes ready
[    4.553209] SELinux:  policy capability network_peer_controls=1
[    4.554336] SELinux:  policy capability open_perms=1
[    4.555321] SELinux:  policy capability extended_socket_class=1
[    4.556442] SELinux:  policy capability always_check_network=0
[    4.557533] SELinux:  policy capability cgroup_seclabel=1
[    4.558563] SELinux:  policy capability nnp_nosuid_transition=1
[    4.577426] systemd[1]: Successfully loaded SELinux policy in 419.553ms.
[    4.619094] systemd[1]: Relabelled /dev, /dev/shm, /run, /sys/fs/cgroup in 23.614ms.
[    4.623723] systemd[1]: systemd v243-4.gitef67743.fc31 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=unified)
[    4.628180] systemd[1]: Detected virtualization kvm.
[    4.629988] systemd[1]: Detected architecture x86-64.
[    4.633597] systemd[1]: Set hostname to <localhost.localdomain>.

Welcome to Fedora 31 (Workstation Edition)!

[    4.740509] systemd[1]: /usr/lib/systemd/system/sssd.service:12: PIDFile= references a path
 below legacy directory /var/run/, updating /var/run/sssd.pid → /run/sssd.pid; please update t
he unit file accordingly.
```

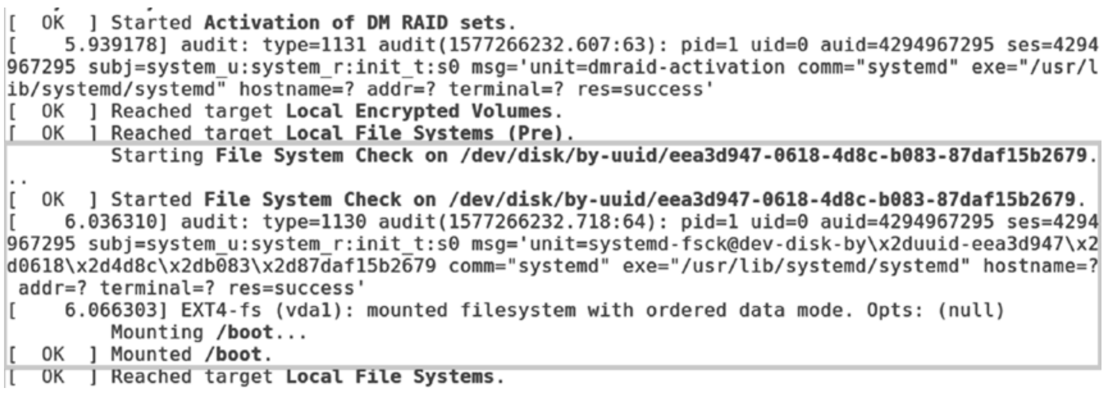
Figure 6-10. *The console messages*

- As you can see Figure 6-10, the switch root leaves the current initramfs environment and changes the root from initramfs' temporary root filesystem to `/sysroot`, which has the user's root filesystem mounted. (The switch root process will be discussed in Chapter 9.)

- Right after entering into the user's root filesystem, systemd of the user's root filesystem reads `/etc/fstab` and takes the appropriate action on mount points. For example, on this Fedora system, there is the user's root filesystem entry as well as the `/boot` entry (boot is on separate partition):

```
#cat /etc/fstab

/dev/mapper/fedora_localhost--live-root  /     ext4    defaults    1 1
UUID=eea3d947-0618-4d8c-b083-87daf15b2679 /boot  ext4    defaults  1 2
/dev/mapper/fedora_localhost--live-swap none   swap    defaults     0 0
```

- As you can see in Figure 6-11, at this stage, systemd will perform fsck only on the boot device before mounting it. Please note that it is not performing fsck on the user's root filesystem since it has already been performed inside an initramfs environment. Also the user's root filesystem is currently mounted, and we all know that it does not make sense to do an fsck on the swap device.



```
[  OK  ] Started Activation of DM RAID sets.
[    5.939178] audit: type=1131 audit(1577266232.607:63): pid=1 uid=0 auid=4294967295 ses=4294
967295 subj=system_u:system_r:init_t:s0 msg='unit=dmraid-activation comm="systemd" exe="/usr/l
ib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[  OK  ] Reached target Local Encrypted Volumes.
[  OK  ] Reached target Local File Systems (Pre).
         Starting File System Check on /dev/disk/by-uuid/eea3d947-0618-4d8c-b083-87daf15b2679.
..
[  OK  ] Started File System Check on /dev/disk/by-uuid/eea3d947-0618-4d8c-b083-87daf15b2679.
[    6.036310] audit: type=1130 audit(1577266232.718:64): pid=1 uid=0 auid=4294967295 ses=4294
967295 subj=system_u:system_r:init_t:s0 msg='unit=systemd-fsck@dev-disk-by\x2duuid-eea3d947\x2
d0618\x2d4d8c\x2db083\x2d87daf15b2679 comm="systemd" exe="/usr/lib/systemd/systemd" hostname=?
 addr=? terminal=? res=success'
[    6.066303] EXT4-fs (vda1): mounted filesystem with ordered data mode. Opts: (null)
         Mounting /boot...
[  OK  ] Mounted /boot.
[  OK  ] Reached target Local File Systems.
```

Figure 6-11. *The fsck console messages*

- If there had been any other extra mount points like /usr, it would have performed fsck on that device too.
- fsck depends on the fifth parameter of /etc/fstab. If it is 1, then fsck will be performed at the time of boot. This fstab setting is not applicable to the user's root filesystem since fsck will be compulsory performed on user's root filesystem inside initramfs, which is before reading the /etc/fstab file.
- rd.skipfsck is applicable only to root and the user's root filesystem. It is not applicable to any other filesystem like /boot.

rd.driver.blacklist, rd.driver.pre, and rd.driver.post

This is from the man page of rd.driver.blacklist:

rd.driver.blacklist=<drivername>[,<drivername>,...]

> *do not load kernel module <drivername>. This parameter can be specified multiple times.*

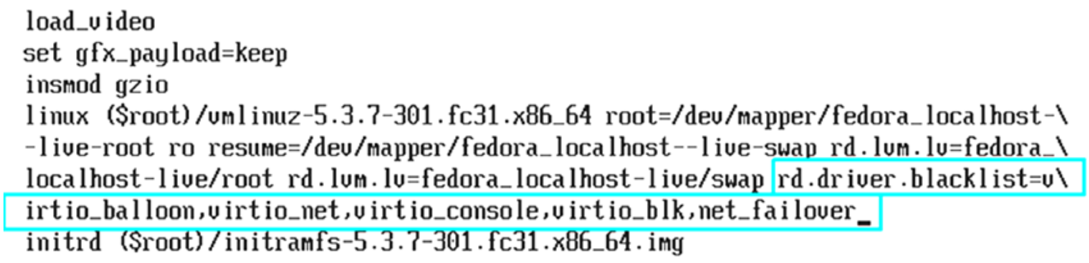
rd.driver.blacklist is one of the most important dracut command-line parameters. As the name suggests, it will blacklist the specified modules. Let's try to blacklist the virtio-related drivers that are quite important for virtual guest systems.

```
# lsmod | grep -i virt
    virtio_balloon         24576  0
    virtio_net             57344  0
    virtio_console         40960  2
    virtio_blk             20480  3
    net_failover           20480  1 virtio_net
```

It is available in initramfs as well.

```
# lsinitrd | grep -i virtio
-rw-r--r-- 1 root  root  8356 Jul 25 03:54 usr/lib/modules/5.3.7-301.fc31.
x86_64/kernel/drivers/block/virtio_blk.ko.xz
-rw-r--r--   1 root     root        14132 Jul 25 03:54 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/drivers/char/virtio_console.ko.xz
-rw-r--r--   1 root     root        25028 Jul 25 03:54 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/drivers/net/virtio_net.ko.xz
-rw-r--r--   1 root     root         7780 Jul 25 03:54 usr/lib/
modules/5.3.7-301.fc31.x86_64/kernel/drivers/scsi/virtio_scsi.ko.xz
```

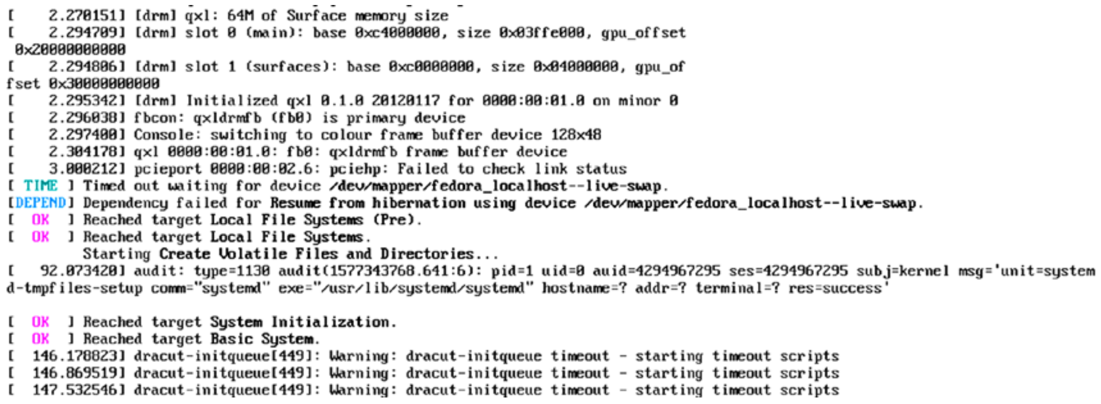
Remember, to blacklist the module, as you can see in Figure 6-12, you need to make sure that every other dependent module also has to be blacklisted; otherwise, the dependent modules would pull the blacklisted module. For example, in this case, the virtio_balloon, virtio_net, virtio_console, virtio_blk, and virtio_pci modules are dependent on each other. That means if we blacklist only virtio_blk, the other dependent modules will still load the virtio_blk module.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/fedora_localhost-\
-live-root ro resume=/dev/mapper/fedora_localhost--live-swap rd.lvm.lv=fedora_\
localhost-live/root rd.lvm.lv=fedora_localhost-live/swap rd.driver.blacklist=v\
irtio_balloon,virtio_net,virtio_console,virtio_blk,net_failover_
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 6-12. *The kernel command-line parameter*

The virtio-related drivers are important. This is the same driver through which virtual disks and networks of hypervisors get exposed to the guest operating system. Since we blacklisted them, the guest OS will stop booting. You can see the "can't boot" console messages in Figure 6-13.



```
[    2.270151] [drm] qxl: 64M of Surface memory size
[    2.294709] [drm] slot 0 (main): base 0xc4000000, size 0x03ffe000, gpu_offset
 0x20000000000
[    2.294806] [drm] slot 1 (surfaces): base 0xc0000000, size 0x04000000, gpu_of
fset 0x30000000000
[    2.295342] [drm] Initialized qxl 0.1.0 20120117 for 0000:00:01.0 on minor 0
[    2.296038] fbcon: qxldrmfb (fb0) is primary device
[    2.297400] Console: switching to colour frame buffer device 128x48
[    2.304178] qxl 0000:00:01.0: fb0: qxldrmfb frame buffer device
[    3.000212] pcieport 0000:00:02.6: pciehp: Failed to check link status
[ TIME ] Timed out waiting for device /dev/mapper/fedora_localhost--live-swap.
[DEPEND] Dependency failed for Resume from hibernation using device /dev/mapper/fedora_localhost--live-swap.
[  OK  ] Reached target Local File Systems (Pre).
[  OK  ] Reached target Local File Systems.
         Starting Create Volatile Files and Directories...
[   92.073420] audit: type=1130 audit(1577343768.641:6): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=system
d-tmpfiles-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'

[  OK  ] Reached target System Initialization.
[  OK  ] Reached target Basic System.
[  146.178823] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  146.869519] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  147.532546] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
```

Figure 6-13. *The console messages*

So, the blacklisting of the virtio modules is successful, but there are two issues in this approach.

- rd.driver.blacklist will only block the modules that are loading from initramfs.
- We need to manually provide the list of modules to rd.driver.blacklist every time.

If the module is not in initramfs, then you cannot really block it from loading. For example, the bluetooth module is not loaded from initramfs, but the kernel loads it after the initramfs environment.

```
# lsmod | grep -i bluetooth

    bluetooth              626688  37 btrtl,btintel,btbcm,bnep,btusb,rfcomm
    ecdh_generic            16384  1 bluetooth
    rfkill                  28672  5 bluetooth
```

```
# lsinitrd | grep -i bluetooth
    <no_output>
```

To block the kernel from loading the bluetooth module, we need to tell the modprobe command to block the module from loading. modprobe is a binary that loads or removes modules on behalf of the kernel.

Make a new blacklist.conf file. (You can choose any name, but it has to have a .conf suffix) and blacklist the module.

```
#cat /etc/modprobe.d/blacklist.conf
    blacklist bluetooth
```

But after reboot, you will find that bluetooth is again loaded by kernel.

```
#lsmod | grep -i bluetooth
    bluetooth              626688  37 btrtl,btintel,btbcm,bnep,btusb,rfcomm
    ecdh_generic            16384  1 bluetooth
    rfkill                  28672  5 bluetooth
```

This is because the bluetooth module is a dependency of multiple other modules such as btrtl, btintel, btbcm, bnep, btusb, rfcomm, and rfkill. Hence, modprobe has loaded bluetooth as a dependency of other modules. In such situations, we need to fool the modprobe command by adding the install bluetooth /bin/true line in the blacklist.conf file, as shown here:

```
# cat /etc/modprobe.d/blacklist.conf
    install bluetooth /bin/true
```

After rebooting, you will find the `bluetooth` module has been blocked.

```
# lsmod | grep -i bluetooth
   <no_output>
```

You can also use `/bin/false` instead of `/bin/true`.

After the explanation of `rd.driver.blacklist`, the `rd.driver.pre` and `rd.driver.post` dracut command-line parameters are easier to understand, and the man pages are self-explanatory, shown here:

`rd.driver.pre=<drivername>[,<drivername>,...]`

> *force loading kernel module <drivername>. This parameter can be specified multiple times.*

`rd.driver.post=<drivername>[,<drivername>,...]`

> *force loading kernel module <drivername> after all automatic loading modules have been loaded. This parameter can be specified multiple times.*

rd.debug

This comes from the man page:

> *set -x for the dracut shell. If systemd is active in the initramfs, all output is logged to the systemd journal, which you can inspect with "journalctl -ab". If systemd is not active, the logs are written to dmesg and /run/initramfs/init.log. If "quiet" is set, it also logs to the console.*

`rd.debug` will enable the debug logging of systemd, which will log huge messages on the console as well as in the systemd journals. The detailed messages provided by `rd.debug` will be helpful in identifying systemd-related "can't boot" issues.

rd.memdebug= [0-4]

This comes from the man page:

> *Print memory usage info at various points, set the verbose level from 0 to 4. Higher level means more debugging output:*

```
0 - no output
1 - partial /proc/meminfo
```

```
2 - /proc/meminfo
3 - /proc/meminfo + /proc/slabinfo
4 - /proc/meminfo + /proc/slabinfo + tracekomem
```

- This will print all the memory subsystem–related information on-screen, such as the `meminfo` and `slabinfo` file contents.

lvm, raid, and Multipath-Related dracut Command-Line Parameters

This comes from the man pages:

`rd.lvm=0`

disable LVM detection

`rd.lvm.vg=<volume group name>`

only activate the volume groups with the given name. rd.lvm.vg can be specified multiple times on the kernel command line.

`rd.lvm.lv=<logical volume name>`

only activate the logical volumes with the given name. rd.lvm.lv can be specified multiple times on the kernel command line.

`rd.lvm.conf=0`

remove any /etc/lvm/lvm.conf, which may exist in the initramfs

- Out of these parameters, you must have at least observed the `rd.lvm.lv` option passed by GRUB. The purpose of `rd.lvm.lv` is to activate the given LVM device at an early stage of booting. By default, the major Linux distributors activate only root and swap (if configured) LV devices. Activating only the root filesystem at the time of the boot speeds up the booting procedure. After switching the root from initramfs to the actual root filesystem, systemd can activate the remaining volume groups as per the list at `/etc/fstab`.
- Similarly, dracut provides multipath and RAID-related command-line parameters, which are again self-explanatory.

MD RAID

`rd.md=0`

disable MD RAID detection

`rd.md.imsm=0`

disable MD RAID for imsm/isw raids, use DM RAID instead

`rd.md.ddf=0`

disable MD RAID for SNIA ddf raids, use DM RAID instead

`rd.md.conf=0`

ignore mdadm.conf included in initramfs

`rd.md.waitclean=1`

wait for any resync, recovery, or reshape activity to finish before continuing

`rd.md.uuid=<md raid uuid>`

only activate the raid sets with the given UUID. This parameter can be specified multiple times.

DM RAID

`rd.dm=0`

disable DM RAID detection

`rd.dm.uuid=<dm raid uuid>`

only activate the raid sets with the given UUID. This parameter can be specified multiple times.

MULTIPATH

`rd.multipath=0`

disable multipath detection

- dracut provides *n* number of command-line parameters for networks, NFS, CIFS, iSCSI, FCoE, etc. It also means these are the various options on which you can put your root filesystem, but it is almost impossible to cover each and every dracut command-line parameter. Also, I am not in favor of booting the system from all these complex structures. I believe in keeping the user's root filesystem always on the local disk so that the booting procedure will be easy and mainly because the simpler booting sequence is quicker to fix in the case of a "can't boot" situation.

rd.break and rd.shell

`rd.shell` will provide us with the shell at the end of the booting sequence, and with `rd.break`, we can break the booting sequence. But to understand these parameters, we need to have a good understanding of systemd. Hence, before discussing `rd.break` and the dracut hooks, we will discuss systemd first in our next chapter. The following are the parameters accepted by `rd.break`:

Parameters	Purpose
`cmdline`	This hook collects the kernel command-line parameters.
`pre-udev`	This hook starts before starting the `udev` handler.
`pre-trigger`	In this hook, you can set `udev` environment variables with `'udevadm' control --property=KEY=value` or control the further execution of `udev`.
`pre-mount`	This hook starts before mounting the user's root filesystem at `/sysroot`.
`mount`	The hook will be started after mounting the root filesystem at `/sysroot`.
`pre-pivot`	The hook will be executed just before switching to actual root filesystem.

CHAPTER 7

systemd (Part I)

Here is what we know about the booting sequence so far:

1) The bootloader loads the kernel and initramfs in memory.

2) The kernel will be loaded at a specific location (an architecture-specific location), whereas initramfs will be loaded at any available location.

3) The kernel extracts itself with the help of the header of the `vmlinuz` file.

4) The kernel extracts initramfs in main memory (`init/initramfs.c`) and mounts it as a temporary root filesystem (`/`) in main memory.

5) The kernel launches (`init/main.c`) the systemd as a first process with PID-1 from a temporary root filesystem.

6) systemd will find the user's root filesystem and will `chroot` into it.

This chapter will address how systemd, which is forked from initramfs, manages to mount the user's root filesystem, and we will also see the detailed booting sequence of systemd inside initramfs. But before that, we need to understand systemd as a process.

I will let systemd's man page do the talking here:

> *"After the root file system is found and mounted, the `initrd` hands over control to the host's system manager (such as systemd(1)) stored in the root file system, which is then responsible for probing all remaining hardware, mounting all necessary file systems and spawning all configured services."*

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Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_7

Structure

systemd was first introduced in Fedora 15. We all know that systemd is a replacement for `init` scripts (quite literally, `/sbin/init` is now a symlink to `/usr/lib/systemd/systemd`), and it amazingly reduces the boot time. However, in reality, systemd is much bigger than just a replacement for `init`. This is what systemd does:

1) It maintains logs with `journalctl`.
2) It extensively uses cgroups version 1 and 2.
3) It reduces boot time.
4) It manages units. `service` is just one type of unit that systemd handles. The following are the units that systemd provides and manages:

Unit	Purpose
`systemd.service`	To manage the services
`systemd.socket`	To create and manage the sockets
`systemd.device`	To create and use devices based on `udev`'s inputs
`systemd.mount`	To mount the filesystem
`systemd.automount`	To automount the filesystem
`systemd.swap`	To make and manage swap devices
`systemd.target`	Group of services instead of runlevels
`systemd.path`	Information about a path monitored by systemd, for path-based activation
`systemd.timer`	For time-based activation
`systemd.slice`	Resource management such as CPU, memory, I/O for service units

Unit files will be stored and loaded from these three locations:

Path	Description
`/etc/systemd/system`	Local configuration
`/run/systemd/system`	Runtime units
`/usr/lib/systemd/system`	Units of installed packages

/etc/systemd/system is an admin location, whereas /usr/lib/systemd/system is an application vendor location. This means the admin's location will get precedence over the application vendor's location if the same unit file is present at both locations. Please note that in this chapter all the commands are executed from the directory in which initramfs has been extracted.

```
#  tree etc/systemd/
       etc/systemd/
       ├── journald.conf
       └── system.conf
0 directories, 2 files

#ls usr/lib/systemd/system | column

basic.target                        plymouth-switch-root.service
cryptsetup.target                   poweroff.target
ctrl-alt-del.target                 poweroff.target.wants
default.target                      reboot.target
dracut-cmdline-ask.service          reboot.target.wants
dracut-cmdline.service              remote-fs-pre.target
dracut-emergency.service            remote-fs.target
dracut-initqueue.service            rescue.service
dracut-mount.service                rescue.target
dracut-pre-mount.service            rescue.target.wants
dracut-pre-pivot.service            rpcbind.target
dracut-pre-trigger.service          shutdown.target
dracut-pre-udev.service             sigpwr.target
emergency.service                   slices.target
emergency.target                    sockets.target
emergency.target.wants              sockets.target.wants
final.target                        swap.target
halt.target                         sysinit.target
halt.target.wants                   sysinit.target.wants
initrd-cleanup.service              sys-kernel-config.mount
initrd-fs.target                    syslog.socket
initrd-parse-etc.service            systemd-ask-password-console.path
initrd-root-device.target           systemd-ask-password-console.service
```

```
initrd-root-fs.target              systemd-ask-password-console.service.wants
initrd-switch-root.service           systemd-ask-password-plymouth.path
initrd-switch-root.target            systemd-ask-password-plymouth.service
initrd-switch-root.target.wants    systemd-ask-password-plymouth.service.wants
initrd.target                        systemd-fsck@.service
initrd.target.wants                  systemd-halt.service
initrd-udevadm-cleanup-db.service    systemd-journald-audit.socket
kexec.target                         systemd-journald-dev-log.socket
kexec.target.wants                   systemd-journald.service
kmod-static-nodes.service            systemd-journald.socket
local-fs-pre.target                  systemd-kexec.service
local-fs.target                      systemd-modules-load.service
multi-user.target                    systemd-poweroff.service
multi-user.target.wants              systemd-random-seed.service
network-online.target                systemd-reboot.service
network-pre.target                   systemd-sysctl.service
network.target                       systemd-tmpfiles-setup-dev.service
nss-lookup.target                    systemd-tmpfiles-setup.service
nss-user-lookup.target               systemd-udevd-control.socket
paths.target                         systemd-udevd-kernel.socket
plymouth-halt.service                systemd-udevd.service
plymouth-kexec.service               systemd-udev-settle.service
plymouth-poweroff.service            systemd-udev-trigger.service
plymouth-quit.service                systemd-vconsole-setup.service
plymouth-quit-wait.service           timers.target
plymouth-reboot.service              umount.target
plymouth-start.service
```

The third location, `/run/systemd/system`, is a temporary location and will be used internally by systemd to manage units. For example, it will be used extensively while creating the sockets. In fact, `/run` is a separate filesystem introduced with systemd to store runtime data. As of now, the `/run` directory of initramfs is empty, which is obvious because initramfs is not in use.

```
#ls run/
    <no_output>
```

Also, it is expected that there are fewer unit files that are present in initramfs than the ones that are available on the user's root filesystem. dracut will collect only those systemd unit files that are necessary to mount the user's root filesystem. For example, it does not make sense to add the `httpd` or `mysql` related systemd unit files in initramfs. Let's try to understand one of the `service` unit files of systemd, as shown here:

```
# cat /usr/lib/systemd/system/sshd.service
[Unit]
Description=OpenSSH server daemon
Documentation=man:sshd(8) man:sshd_config(5)
After=network.target sshd-keygen.target
Wants=sshd-keygen.target

[Service]
Type=notify
EnvironmentFile=-/etc/crypto-policies/back-ends/opensshserver.config
EnvironmentFile=-/etc/sysconfig/sshd-permitrootlogin
EnvironmentFile=-/etc/sysconfig/sshd
ExecStart=/usr/sbin/sshd -D $OPTIONS $CRYPTO_POLICY $PERMITROOTLOGIN
ExecReload=/bin/kill -HUP $MAINPID
KillMode=process
Restart=on-failure
RestartSec=42s

[Install]
WantedBy=multi-user.target
```

This `sshd` service unit file will not be part of initramfs since you do not need an `ssh` service to mount the user's root filesystem. The `service` unit file is divided into three parts: `[unit]`, `[service]`, `[install]`.

- **`[unit]`**:

  `After=``network.target sshd-keygen.target`
  The `sshd` service will start only if `network.target` (listed units) and `sshd-keygen` (listed units) have successfully started. If either of them fails, then the `sshd` service will also fail.

Wants=sshd-keygen.target
This is a less severe version of Requires. If any of the units that are mentioned in wants fails, then also the sshd service (or that particular service) will start, whereas in Requires the sshd service will start only if the units mentioned under Requires have been successfully started. Before is the opposite of After The Wants, After, Before, and Requires all work independently of each other. It is a common practice to use Wants and After together.

Conflicts=
This can be used to list the units that are conflicting with the current unit. Starting this unit might stop the listed conflicting units.

OnFailure=
OnFailure units will start when any given unit reaches the failed state.

- **[Service]:**

  ExecStart=/usr/sbin/sshd
  Starting an sshd service unit just starts the binary mentioned after ExecStart.

- **[Install]:**

  The Install section of a unit file is not used by systemd. Rather, it is used by the systemctl enable, or disable command. It will be used by systemctl to create or destroy the symlinks.

How Does systemd Reduce Boot Time?

Lennart Poettering, the creator of systemd, gives a classic example of how systemd reduces the boot time in his blog at http://0pointer.de/blog/projects/systemd.html. This blog is one of the best resources if you really want to deep dive into the systemd world.

There are four daemons: syslog, dbus, avahi, and bluetooth.

syslog is necessary for every daemon to log the messages. So, syslog is a requirement for every other daemon. avahi needs syslog and dbus to run. bluetooth needs dbus and syslog but does not need avahi to be running. With the Sysv/init script model, this happens:

1) syslog will start first.
2) When it is completely ready, the dbus service will be started.
3) After dbus, avahi will be started.
4) Finally, the bluetooth service will be started. See Figure 7-1.

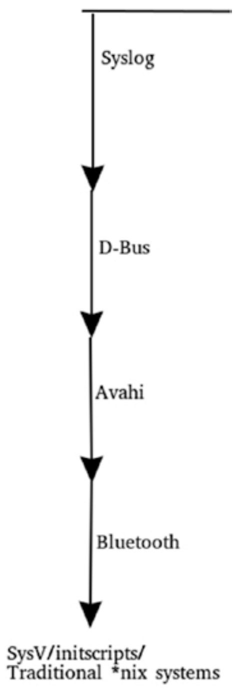


Figure 7-1. *The init model*

bluetooth and avahi are not dependent on each other, but bluetooth has to wait until avahi starts. Ubuntu-like distributions use upstart instead of init, which improves the boot time to some extent. In upstart, the services that are not dependent on each other will start in parallel, meaning avahi and bluetooth will start together. Please see Figure 7-2 for reference.

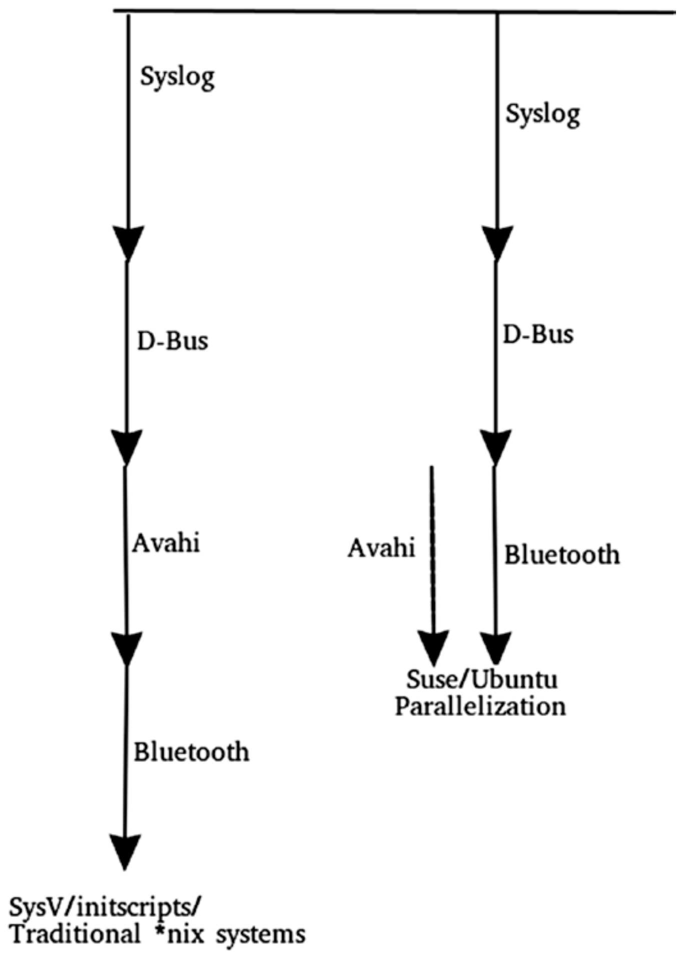


***Figure 7-2.** The upstart model*

In `systemd,` all the services are started at the same time with the help of `sockets.` Here's an example:

1) systemd will create a socket for `syslog` (which has been replaced with `journald`).

2) A socket `/dev/log` is a symlink to `/run/systemd/journal/dev-log`.

```
# file /dev/log
      /dev/log: symbolic link to /run/systemd/journal/dev-log

# file /run/systemd/journal/dev-log
      /run/systemd/journal/dev-log: socket
```

As mentioned earlier, the `run` filesystem will be used by systemd for socket file creation.

3) For dbus, the socket is created at `/run/dbus/system_bus_socket.` To run, dbus needs `journald` to be running, but since the system is still booting and `journald/syslog` is not fully started yet, dbus will log its messages to `journald`'s socket `/dev/log`, and whenever the `journald` service is fully ready, it will fetch the messages from the socket.

4) It's the same for the `bluetooth` service; it needs the `dbus` service to be running to start. So, systemd will create a `/run/dbus/system_bus_socket` socket before the `dbus` service starts. The `bluetooth` service will not wait for `dbus` to start. You can refer to Figure 7-3 for a better understanding.

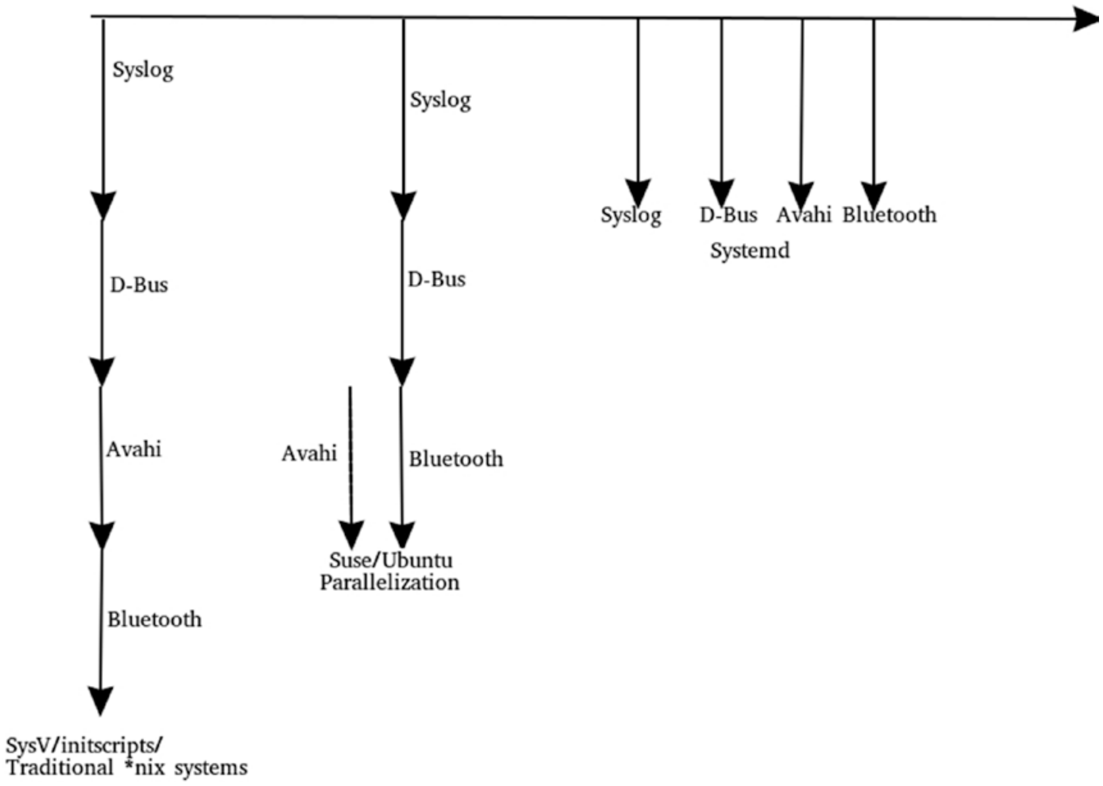


Figure 7-3. *The systemd model*

5) If the systemd created socket runs out of buffer, then the bluetooth service will be blocked until the socket is available. This socket approach will drastically reduce the boot time.

This socket-based approach was originally tried in macOS. It was called launchd at that time. Lennart Poettering took inspiration from it.

systemd-analyze

systemd provides the systemd-analyze tool to check the time taken by the system to boot.

```
# systemd-analyze
Startup finished in 1.576s (kernel) + 1.653s (initrd) + 11.574s (userspace)
= 14.805s
graphical.target reached after 11.561s in userspace
```

As you can see, my Fedora system took 1.5 seconds to initialize the kernel; then it spent 1.6 seconds inside initramfs and took almost 11 seconds to start the services or initialize the user space. The total time taken was almost 15 seconds. The total time is calculated right from the bootloader to the graphical target.

Here are some important notes:

- The total time does not include the time taken by desktop environments like GNOME, KDE, Cinnamon, etc. This also makes sense since the desktop environments are not handled by systemd, so a systemd tool cannot calculate the time taken by desktop environments.
- Also, there is a possibility that because of systemd's socket approach, services were still starting even after the total time (14.805 seconds).

So, to give more insight and clean data, systemd-analyse provides a blame tool.

```
# systemd-analyze blame
         31.202s dnf-makecache.service
         10.517s pmlogger.service
          9.264s NetworkManager-wait-online.service
          4.977s plymouth-switch-root.service
          2.994s plymouth-quit-wait.service
          1.674s systemd-udev-settle.service
```

```
1.606s lightdm.service
1.297s pmlogger_check.service
 938ms docker.service
 894ms dracut-initqueue.service
 599ms pmcd.service
 590ms lvm2-monitor.service
 568ms abrtd.service
 482ms firewalld.service
 461ms systemd-logind.service
 430ms lvm2-pvscan@259:3.service
 352ms initrd-switch-root.service
 307ms bolt.service
 290ms systemd-machined.service
 288ms registries.service
 282ms udisks2.service
 269ms libvirtd.service
 255ms sssd.service
 209ms systemd-udevd.service
 183ms systemd-journal-flush.service
 180ms docker-storage-setup.service
 169ms systemd-journald.service
 156ms polkit.service
 .
 .
 </snip>
```

The blame output could easily be misunderstood; i.e., two services might be initializing at the same time, and thus the time spent to initialize both services is much less than the sum of both individual times combined. For more precise data, you can use the plot tool of systemd-analyse, which will generate the graph and provide many more details about the boot time. You can see the generated plot image in Figure 7-4.

```
# systemd-analyze plot > plot.svg
```

```
# eog plot.svg
```

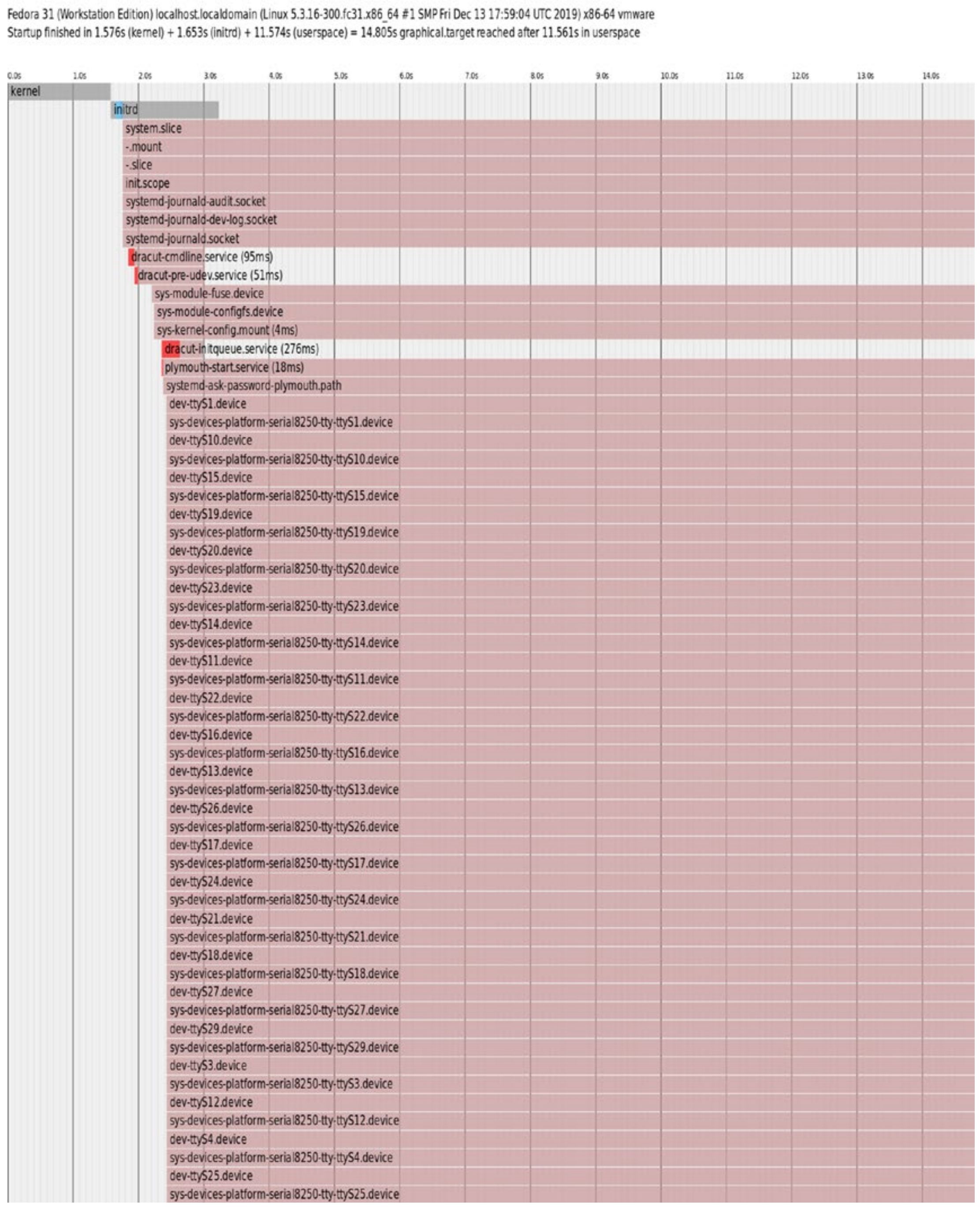


Figure 7-4. *The generated plot image*

The following are some of the other tools that `systemd-analyse` provides that can be used to identify the boot time.

systemd-analyze <tool>	Description
`time`	Prints time spent in the kernel
`blame`	Prints list of running units ordered by time to `init`
`critical-chain [UNIT...]`	Prints a tree of the time-critical chain of units
`plot`	Outputs SVG graphic showing service initialization
`dot [UNIT...]`	Outputs dependency graph in `dot(1)` format
`log-level [LEVEL]`	Gets/sets logging threshold for manager
`log-target [TARGET]`	Gets/sets logging target for manager
`dump`	Output state serialization of service manager
`cat-config`	Shows configuration file and drop-ins
`unit-files`	Lists files and symlinks for units
`units-paths`	Lists load directories for units
`exit-status [STATUS...]`	Lists exit status definitions
`syscall-filter [NAME...]`	Prints list of syscalls in seccomp filter
`condition...`	Evaluates conditions and asserts
`verify FILE...`	Checks unit files for correctness

(*continued*)

systemd-analyze <tool>	Description
service-watchdogs [BOOL]	Gets/sets service watchdog state
calendar SPEC...	Validates repetitive calendar time events
timestamp...	Validates a timestamp
timespan SPAN...	Validates a time span
security [UNIT...]	Analyzes security of unit

"Can't Boot" Issue 6 (systemd)

Issue: The system successfully boots, but the nagios service fails to start at the time of the boot.

Here are the steps to resolve this issue:

1) We need to isolate the issue first. Remove the rhgb quiet kernel command-line parameters when GRUB appears on the screen.

2) The verbose logs show that the system is able to boot, but the nagios service fails to start while booting. As you can see, the NetworkManager service of systemd which is responsible for the network has successfully started. This means it is not a network communication issue.

```
13:23:52   systemd: Starting Network Manager...
13:23:52   systemd: Started Kernel Samepage Merging (KSM)
           Tuning Daemon.
13:23:52   systemd: Started Install ABRT coredump hook.
13:23:52   abrtd: Init complete, entering main loop
13:23:52   systemd: Started Load CPU microcode update.
13:23:52   systemd: Started Authorization Manager.
13:23:53   NetworkManager[1356]: <info>  [1534389833.1078]
           NetworkManager is starting... (for the first time)
```

```
13:23:53   NetworkManager[1356]: <info>  [1534389833.1079] Read
           config: /etc/NetworkManager/NetworkManager.conf (lib:
           00-server.conf, 10-slaves-order.conf)
13:23:53   NetworkManager[1356]: <info>  [1534389833.1924]
           manager[0x558b0496a0c0]: monitoring kernel firmware
           directory '/lib/firmware'.
13:23:53   NetworkManager[1356]: <info>  [1534389833.2051] dns-
           mgr[0x558b04971150]: init: dns=default, rc-manager=file
13:23:53   systemd: Started Network Manager.
```

3) The nagios service tries to execute right after the NetworkManager service. This means nagios must have mentioned after=Network.target in its service unit file. But the nagios service fails to start.

```
13:24:03   nagios: Nagios 4.2.4 starting... (PID=5006)
13:24:03   nagios: Local time is Thu  13:24:03 AEST 2018
13:24:03   nagios: LOG VERSION: 2.0
13:24:03   nagios: qh: Socket '/usr/local/nagios/var/rw/nagios.qh'
           successfully initialized
13:24:03   nagios: qh: core query handler registered
13:24:03   nagios: nerd: Channel hostchecks registered
           successfully
13:24:03   nagios: nerd: Channel servicechecks registered
           successfully
13:24:03   nagios: nerd: Channel opathchecks registered
           successfully
13:24:03   nagios: nerd: Fully initialized and ready to
           rock!  Nagios Can't ping devices (not 100% packet loss
           at the end of each line)
13:24:04   nagios: HOST ALERT:  X ;DOWN;SOFT;1;CRITICAL -  X: Host
           unreachable @  X. rta nan, lost 100%
```

Resolution: The strange thing is that the nagios error message says it failed to start because it is not able to connect to the network, but as per NetworkManager, it has successfully started, and the system has already been placed in network.

The issue is clearly created by systemd's "speeding up the booting procedure" approach. To place the system in the network, systemd has to do a lot of work: initialize the network cards, activate the link, put the IP on the NIC card, check if any duplicate IPs are already available, start communicating on the network, etc. Obviously, to finish every bit of this, systemd will take some time. On my test system, it took almost 20 seconds to fully populate the network. Of course, systemd cannot pause the booting sequence for that whole time. If systemd waits until the network fully populates, then one of the main aspects of systemd's innovation to speed up the booting process will be ruined.

systemd with the help of `NetworkManager` will give its best shot to make sure we are on the network, but it will not wait for the user-specified network spawning and will not wait until every rule of topology is achieved.

In some situations like this "can't boot" issue, it is possible that `NetworkManager` has told systemd to initialize `nagios`, which was dependent on `network.target`, but the network is not yet fully up, so `nagios` might not be able to contact its servers.

1) To solve such issues, systemd suggests enabling `NetworkManager-wait-online.service.` This service will make `NetworkManager` wait until the network fully comes up. Once the network is fully populated, `NetworkManager` will signal to systemd to start the services that are dependent on `network.target`.

```
# cat /usr/lib/systemd/system/NetworkManager-wait-online.service
[Unit]
Description=Network Manager Wait Online
Documentation=man:nm-online(1)
Requires=NetworkManager.service
After=NetworkManager.service
Before=network-online.target

[Service]
Type=oneshot
ExecStart=/usr/bin/nm-online -s -q --timeout=30
RemainAfterExit=yes

[Install]
WantedBy=network-online.target
```

This simply calls the `nm-online` binary and passes the `-s` switch to it. The service will hold `NetworkManager` for a maximum of 30 seconds.

This is what the man page has to say about the nm-online:

"Wait for NetworkManager startup to complete, rather than waiting for network connectivity specifically. Startup is considered complete once NetworkManager has activated (or attempted to activate) every auto-activate connection which is available given the current network state. (This is generally only useful at boot time; after startup has completed, nm-online -s will just return immediately, regardless of the current network state.)"

2) After enabling `NetworkManager-wait-online-service`, the issue has been resolved, but the boot time has been reduced slightly. As you can see in Figure 7-5, most of the boot time has been eaten up by `NetworkManager-wait-online-service`, which is expected.

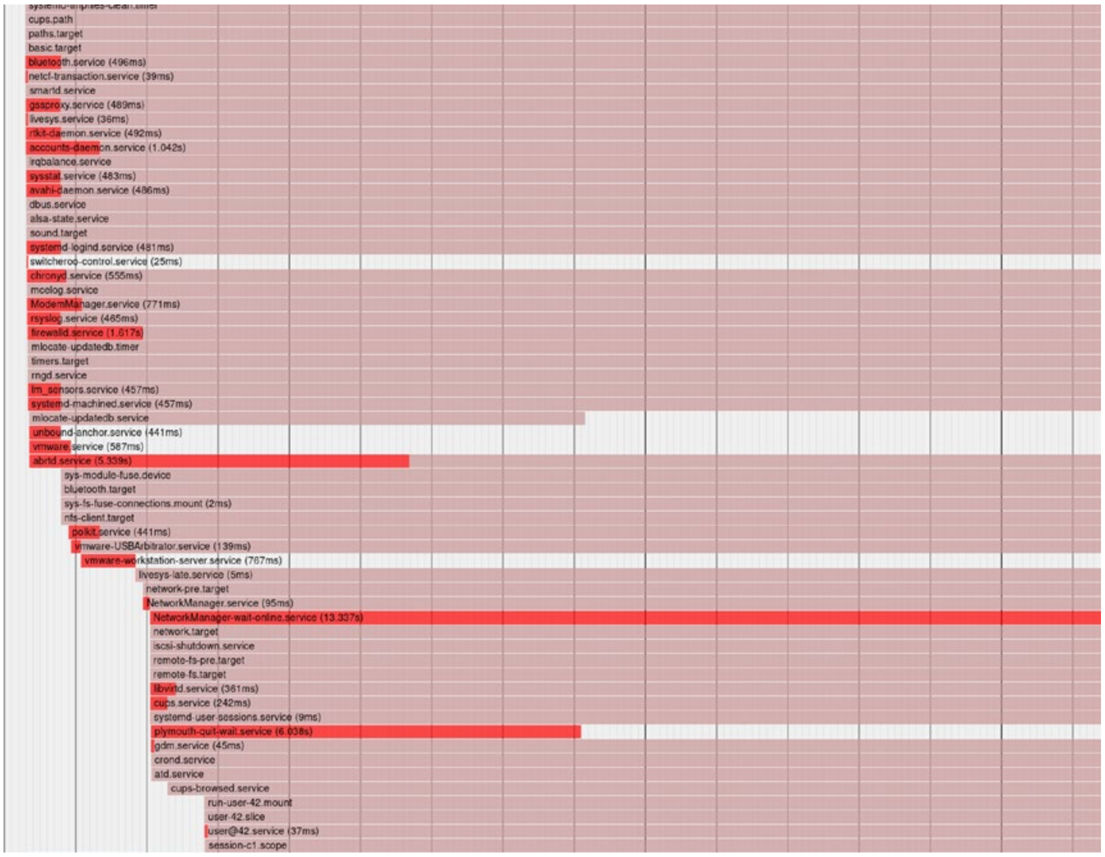
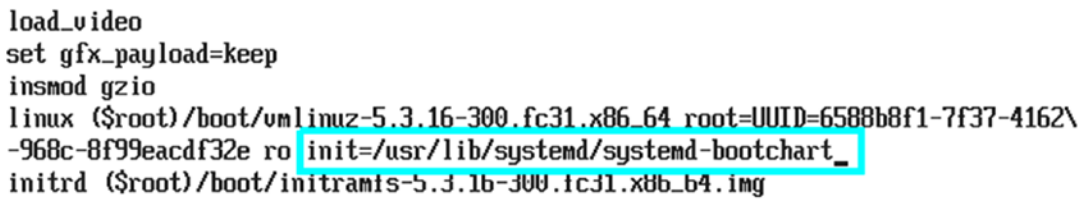


***Figure 7-5.** The plot after enabling NetworkManager-wait-online-service*

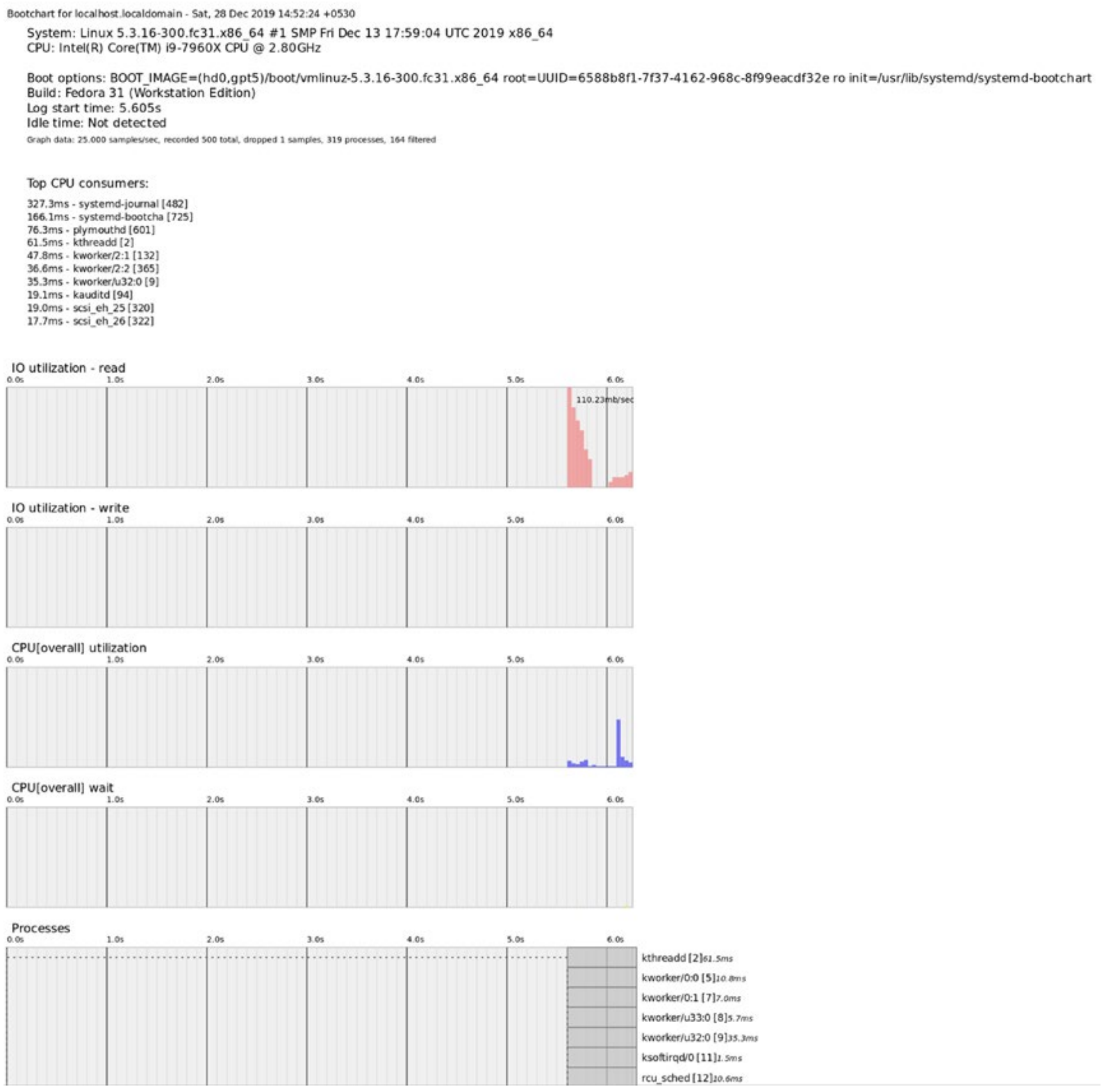
systemd provides one more tool, `bootchart`, which is basically a daemon through which you can conduct a performance analysis of the Linux boot process. It will collect the data at boot time and make a graph out of it. You can consider `bootchart` to be an advanced version of a `systemd-analyze` plot. To use this tool, as shown in Figure 7-6, you need to pass the full path of the `systemd-bootchart` binary to the `init` kernel command-line parameter.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro init=/usr/lib/systemd/systemd-bootchart_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 7-6. *The kernel command-line parameters*

After the successful boot process, as you can see in Figure 7-7, the tool will create a detailed graph image at `/run/log/bootchart*.` Once the image is generated, `systemd-bootchart` will hand over control to the systemd, and systemd will continue the booting procedure.



```
Bootchart for localhost.localdomain - Sat, 28 Dec 2019 14:52:24 +0530
    System: Linux 5.3.16-300.fc31.x86_64 #1 SMP Fri Dec 13 17:59:04 UTC 2019 x86_64
    CPU: Intel(R) Core(TM) i9-7960X CPU @ 2.80GHz

    Boot options: BOOT_IMAGE=(hd0,gpt5)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162-968c-8f99eacdf32e ro init=/usr/lib/systemd/systemd-bootchart
    Build: Fedora 31 (Workstation Edition)
    Log start time: 5.605s
    Idle time: Not detected
    Graph data: 25.000 samples/sec, recorded 500 total, dropped 1 samples, 319 processes, 164 filtered

    Top CPU consumers:
    327.3ms - systemd-journal [482]
    166.1ms - systemd-bootcha [725]
    76.3ms - plymouthd [601]
    61.5ms - kthreadd [2]
    47.8ms - kworker/2:1 [132]
    36.6ms - kworker/2:2 [365]
    35.3ms - kworker/u32:0 [9]
    19.1ms - kauditd [94]
    19.0ms - scsi_eh_25 [320]
    17.7ms - scsi_eh_26 [322]
```

Figure 7-7. *The bootchart graph*

Since we now understand the basics of systemd, we can continue our paused booting sequence. So far, we have reached the stage where the kernel has extracted initramfs in RAM and started the systemd binary from it. Once the systemd process starts, it will follow the regular booting sequence.

Flow of systemd Inside initramfs

systemd will be launched from initramfs and will follow the booting sequence shown in Figure 7-8. Harald Hoyer (who created dracut initramfs and is the lead systemd developer) created this flowchart, which is also available in the systemd man pages.

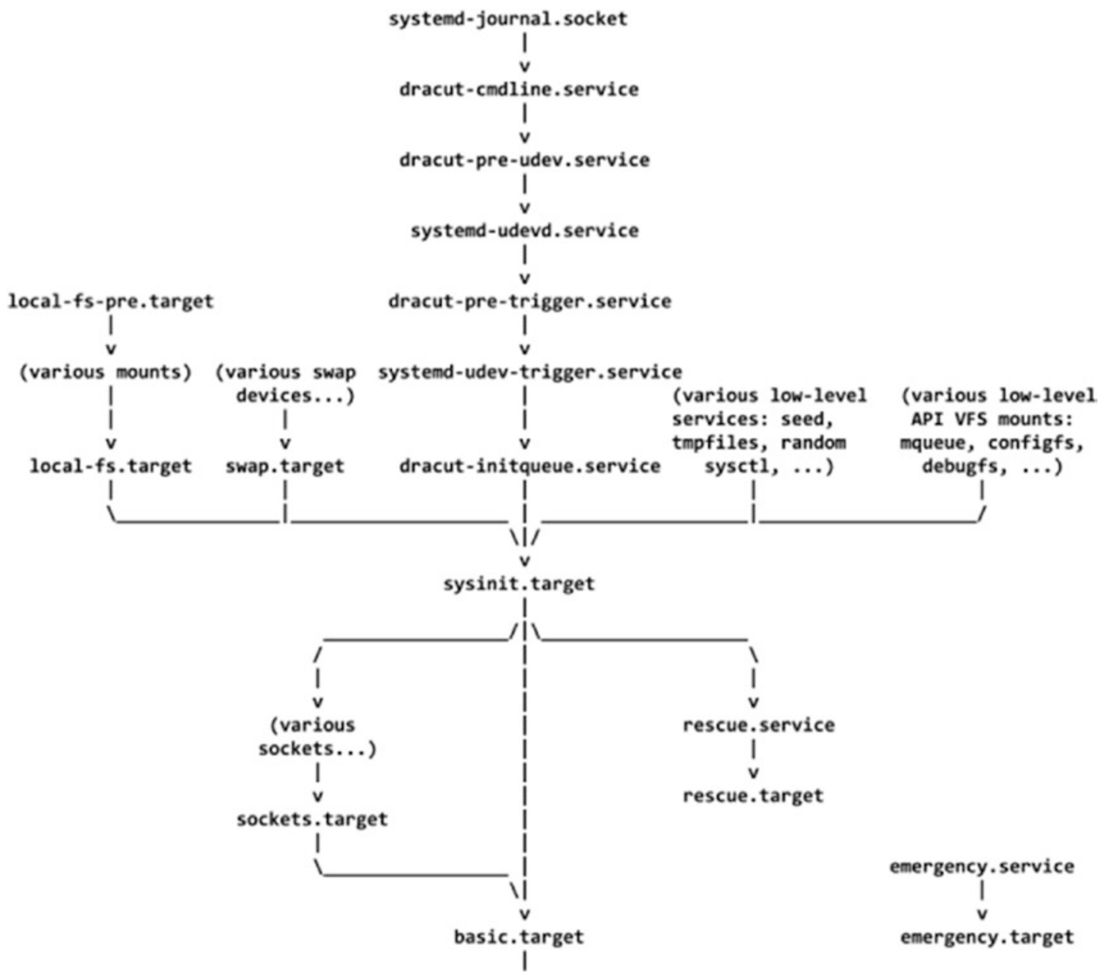


Figure 7-8. *The booting flowchart*

```
             ______________________/|
            /                       |
            |                       v
            |            dracut-pre-mount.service
            |                       |
            |                       v
            |                  sysroot.mount
            |                       |
            |                       v
            |             initrd-root-fs.target
(custom initrd services)            |
            |                       v
            |              dracut-mount.service
            |                       |
            |                       v
            |            initrd-parse-etc.service
            |                       |
            |                       v
            |            (sysroot-usr.mount and
            |             various mounts marked
            |               with fstab option
            |                x-initrd.mount)
            |                       |
            |                       v
            |                initrd-fs.target
            \______________________ |
                                   \|
                                    v
                               initrd.target
                                    |
                                    v
                         dracut-pre-pivot.service
                                    |
                                    v
                          initrd-cleanup.service
                               isolates to
                         initrd-switch-root.target
                                    |
                                    v
             ______________________/|
            /                       |
            |        initrd-udevadm-cleanup-db.service
            |                       |
(custom initrd services)            |
            |                       |
            \______________________ |
                                   \|
                                    v
                        initrd-switch-root.target
                                    |
                                    v
                        initrd-switch-root.service
                                    |
                                    v
                                switch-root
```

Figure 7-8. *(continued)*

This flowchart comes from the man page of dracut. The ultimate aim of systemd in the booting procedure is to mount the user's root filesystem inside initramfs (`sysroot`) and then switch into it. Once systemd has `switch_rooted` into the new (user's) root filesystem, it will leave the initramfs environment and continue the booting procedure by starting the userspace services such as `httpd`, `mysql`, etc. It will also draw a desktop/GUI if the user is booting the system in graphical mode. This book's scope is to cover the booting sequence until systemd mounts the user's root filesystem and then switches into it. There are a few reasons for not covering the booting sequence after `switch_root`. I will mention the reasons here, which are very important:

- The ultimate goal of booting is to mount the user's root filesystem and present it to the user, which this book is covering in detail.
- The activities performed by systemd after initramfs are easy to understand since systemd performs similar activities but under the new root filesystem environment.
- Production systems generally do not run in graphical mode.
- Linux has a couple of desktops such as GNOME, KDE, Cinnamon, Unity, etc. Every user has their own favorite desktop, and it is almost impossible to document every step taken by every desktop while booting.

So, with this understanding, in this chapter we will cover the booting sequence up to `basic.target.` Please refer to Figure 7-9.

```
                                 systemd-journal.socket
                                           |
                                           v
                                 dracut-cmdline.service
                                           |
                                           v
                                 dracut-pre-udev.service
                                           |
                                           v
                                  systemd-udevd.service
                                           |
                                           v
 local-fs-pre.target            dracut-pre-trigger.service
          |                                |
          v                                v
  (various mounts)  (various swap  systemd-udev-trigger.service
          |          devices...)           |             (various low-level   (various low-level
          |               |                |             services: seed,       API VFS mounts:
          v               v                v             tmpfiles, random      mqueue, configfs,
   local-fs.target   swap.target   dracut-initqueue.service    sysctl, ...)      debugfs, ...)
          |               |                |                    |                    |
          \_______________|________________ | ___________________|____________________/
                                          \|/
                                           v
                                     sysinit.target
                                           |
                      _________________/|\___________________
                     /                     |                 \
                     |                     |                 |
                     v                     |                 v
                 (various                  |           rescue.service
                 sockets...)               |                 |
                     |                     |                 v
                     v                     |           rescue.target
               sockets.target              |
                     |                     |
                     \_________________    |                          emergency.service
                                          \|                                  |
                                           v                                  v
                                      basic.target                     emergency.target
```

__Figure 7-9.__ The boot sequence up to basic.target

systemd-journal.socket

Every process has to log its messages. In fact, a process, service, or daemon will start only if it is able to log its messages in the OS logging mechanism. These days, the OS logging mechanism is `journald`. So, it is obvious that the `journald` service has to be started first, but as we know, systemd won't wait until the services fully start. To speed up the procedure, it uses the socket approach. Hence, systemd has to start the `journald` sockets first. The `journald` service creates the following four sockets and listens for messages:

- `systemd-journald.socket`
- `systemd-journald-dev-log.socket`

- `systemd-journald-audit.socket`
- `syslog.socket`

These sockets will be used by daemons, applications, and every process to log their messages.

```
 # vim usr/lib/systemd/system/systemd-journald.socket

#  SPDX-License-Identifier: LGPL-2.1+
#
#  This file is part of systemd.
#
#  systemd is free software; you can redistribute it and/or modify it
#  under the terms of the GNU Lesser General Public License as published by
#  the Free Software Foundation; either version 2.1 of the License, or
#  (at your option) any later version.

[Unit]
Description=Journal Socket
Documentation=man:systemd-journald.service(8) man:journald.conf(5)
DefaultDependencies=no
Before=sockets.target

# Mount and swap units need this. If this socket unit is removed by an
# isolate request the mount and swap units would be removed too,
# hence let's exclude this from isolate requests.
IgnoreOnIsolate=yes

[Socket]
ListenStream=/run/systemd/journal/stdout
ListenDatagram=/run/systemd/journal/socket
SocketMode=0666
PassCredentials=yes
PassSecurity=yes
ReceiveBuffer=8M
Service=systemd-journald.service

# cat usr/lib/systemd/system/systemd-journald-dev-log.socket | grep -v '#'
```

```
[Unit]
Description=Journal Socket (/dev/log)
Documentation=man:systemd-journald.service(8) man:journald.conf(5)
DefaultDependencies=no
Before=sockets.target

IgnoreOnIsolate=yes

[Socket]
Service=systemd-journald.service
ListenDatagram=/run/systemd/journal/dev-log
Symlinks=/dev/log
SocketMode=0666
PassCredentials=yes
PassSecurity=yes

ReceiveBuffer=8M
SendBuffer=8M
```

We have already discussed the way sockets work, especially the `/dev/log` socket. The next step in the booting sequence is `dracut-cmdline.service.`

dracut-cmdline.service

After initializing `journald` sockets, systemd collects the kernel command-line parameters such as the `root`, `rflags`, and `fstype` variables through `usr/lib/systemd/system/dracut-cmdline.service`. This is also called a *cmdline hook* of initramfs, which we mentioned at the end of Chapter 6. The hook can be called by passing the `cmdline` value to `rd.break` (a dracut command-line parameter). We will explore this stage of the booting process by using the `cmdline` hook. We need to pass the `rd.break=cmdline` dracut command-line parameter to the kernel at the time of the boot.

Inside initramfs, systemd calls this hook from `usr/lib/systemd/system/dracut-cmdline.service`.

```
# cat usr/lib/systemd/system/dracut-cmdline.service

#  This file is part of dracut.
#
# See dracut.bootup(7) for details

[Unit]
Description=dracut cmdline hook
Documentation=man:dracut-cmdline.service(8)
DefaultDependencies=no
Before=dracut-pre-udev.service
After=systemd-journald.socket
Wants=systemd-journald.socket
ConditionPathExists=/usr/lib/initrd-release
ConditionPathExistsGlob=|/etc/cmdline.d/*.conf
ConditionDirectoryNotEmpty=|/lib/dracut/hooks/cmdline
ConditionKernelCommandLine=|rd.break=cmdline
ConditionKernelCommandLine=|resume
ConditionKernelCommandLine=|noresume
Conflicts=shutdown.target emergency.target
[Service]
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
Type=oneshot
ExecStart=-/bin/dracut-cmdline
StandardInput=null
StandardOutput=syslog
StandardError=syslog+console
KillMode=process
RemainAfterExit=yes

# Bash ignores SIGTERM, so we send SIGHUP instead, to ensure that bash
# terminates cleanly.
KillSignal=SIGHUP
```

As you can see, systemd has called a `dracut-cmdline` script. The script is available in initramfs itself, which will collect the kernel command-line parameters.

```
# vim bin/dracut-cmdline
# Get the "root=" parameter from the kernel command line, but differentiate
# between the case where it was set to the empty string and the case where it
# wasn't specified at all.
if ! root="$(getarg root=)"; then
    root_unset='UNSET'
fi

rflags="$(getarg rootflags=)"
getargbool 0 ro && rflags="${rflags},ro"
getargbool 0 rw && rflags="${rflags},rw"
rflags="${rflags#,}"

fstype="$(getarg rootfstype=)"
if [ -z "$fstype" ]; then
    fstype="auto"
fi

export root
export rflags
export fstype

make_trace_mem "hook cmdline" '1+:mem' '1+:iomem' '3+:slab' '4+:komem'
# run scriptlets to parse the command line
getarg 'rd.break=cmdline' -d 'rdbreak=cmdline' && emergency_shell -n cmdline "Break before cmdline"
source_hook cmdline

[ -f /lib/dracut/parse-resume.sh ] && . /lib/dracut/parse-resume.sh

case "${root}${root_unset}" in
    block:LABEL=*|LABEL=*)
        root="${root#block:}"
```

```
            root="$(echo $root | sed 's,/,\\x2f,g')"
            root="block:/dev/disk/by-label/${root#LABEL=}"
            rootok=1 ;;
        block:UUID=*|UUID=*)
            root="${root#block:}"
            root="block:/dev/disk/by-uuid/${root#UUID=}"
            rootok=1 ;;
        block:PARTUUID=*|PARTUUID=*)
            root="${root#block:}"
            root="block:/dev/disk/by-partuuid/${root#PARTUUID=}"
            rootok=1 ;;
        block:PARTLABEL=*|PARTLABEL=*)
            root="${root#block:}"
            root="block:/dev/disk/by-partlabel/${root#PARTLABEL=}"
            rootok=1 ;;
        /dev/*)
            root="block:${root}"
            rootok=1 ;;
        UNSET|gpt-auto)
            # systemd's gpt-auto-generator handles this case.
            rootok=1 ;;
esac

[ -z "${root}${root_unset}" ] && die "Empty root= argument"
[ -z "$rootok" ] && die "Don't know how to handle 'root=$root'"

export root rflags fstype netroot NEWROOT

export -p > /dracut-state.sh

exit 0
```

Basically, there are three parameters (kernel command-line parameters) that will be exported in this hook:

- **root** = User's root file system name

- **rflags** = User's root filesystem flags (`ro` or `rw`)
- **fstype** = Auto (auto mounting or not)

Let's see how these parameters are discovered by initramfs (or in the cmdline hook of initramfs). The `getarg` named function will be used to get these three kernel command-line parameters.

```
root="$(getarg root=)
rflags="$(getarg rootflags=)
fstype="$(getarg rootfstype=)"
.
.
export root
export rflags
export fstype
```

The `getarg` function is defined in the `usr/lib/dracut-lib.sh` file of initramfs.

```
#vim usr/lib/dracut-lib.sh
getarg() {
    debug_off
    local _deprecated _newoption
    while [ $# -gt 0 ]; do
        case $1 in
            -d) _deprecated=1; shift;;
            -y) if _dogetarg $2 >/dev/null; then
                    if [ "$_deprecated" = "1" ]; then
                        [ -n "$_newoption" ] && warn "Kernel command line option '$2' is deprecated, use '$_newoption' instead." || warn "Option '$2' is deprecated."
                    fi
                    echo 1
                    debug_on
                    return 0
                fi
                _deprecated=0
        shift 2;;
      -n) if _dogetarg $2 >/dev/null; then
          echo 0;
          if [ "$_deprecated" = "1" ]; then
            [ -n "$_newoption" ] && warn "Kernel command line option '$2' is deprecated, use '$_newoption=0' instead." || warn "Option '$2' is deprecated."
          fi
          debug_on
          return 1
        fi
        _deprecated=0
        shift 2;;
      *)  if [ -z "$_newoption" ]; then
          _newoption="$1"
        fi
        if _dogetarg $1; then
          if [ "$_deprecated" = "1" ]; then
            [ -n "$_newoption" ] && warn "Kernel command line option '$1' is deprecated, use '$_newoption' instead." || warn "Option '$1' is deprecated."
          fi
          debug_on
          return 0;
        fi
        _deprecated=0
        shift;;
    esac
  done
  debug_on
  return 1
}
```

The getarg function is calling the _dogetarg function from the same file.

```
_dogetarg() {
    local _o _val _doecho
    unset _val
    unset _o
    unset _doecho
    CMDLINE=$(getcmdline)

    for _o in $CMDLINE; do
        if [ "${_o%%=*}" = "${1%%=*}" ]; then
            if [ -n "${1#*=}" -a "${1#*=*}" != "${1}" ]; then
                # if $1 has a "=<value>", we want the exact match
                if [ "$_o" = "$1" ]; then
                    _val="1";
                    unset _doecho
                fi
                continue
            fi

            if [ "${_o#*=}" = "$_o" ]; then
                # if cmdline argument has no "=<value>", we assume "=1"
                _val="1";
                unset _doecho
                continue
            fi

            _val="${_o#*=}"
            _doecho=1
        fi
    done
    if [ -n "$_val" ]; then
        [ "x$_doecho" != "x" ] && echo "$_val";
        return 0;
    fi
    return 1;
}
```

Then the `_dogetarg()` function calls the `getcmdline` named function, which collects the actual kernel command-line parameters from `/proc/cmdline`.

```
getcmdline() {
    local _line
    local _i
    local CMDLINE_ETC_D
    local CMDLINE_ETC
    local CMDLINE_PROC
    unset _line

    if [ -e /etc/cmdline ]; then
        while read -r _line || [ -n "$_line" ]; do
            CMDLINE_ETC="$CMDLINE_ETC $_line";
        done </etc/cmdline;
    fi
    for _i in /etc/cmdline.d/*.conf; do
        [ -e "$_i" ] || continue
        while read -r _line || [ -n "$_line" ]; do
            CMDLINE_ETC_D="$CMDLINE_ETC_D $_line";
        done <"$_i";
    done
    if [ -e /proc/cmdline ]; then
        while read -r _line || [ -n "$_line" ]; do
            CMDLINE_PROC="$CMDLINE_PROC $_line"
        done </proc/cmdline;
    fi
    CMDLINE="$CMDLINE_ETC_D $CMDLINE_ETC $CMDLINE_PROC"
    printf "%s" "$CMDLINE"
}
```

Here is the booting sequence so far:

1. The bootloader collects the kernel command-line parameters from the user and stores them in its own configuration file (`grub.cfg`).
2. It passes those command-line parameters to the kernel by filling the kernel header.
3. The kernel extracts itself and copies the kernel command-line parameters found in the kernel header.
4. The kernel extracts initramfs in memory and uses it as a temporary root filesystem.
5. In the same procedure, the kernel prepares the virtual filesystems such as `proc`, `sys`, `dev`, `devpts`, `shm`, etc.
6. The kernel stores the command-line parameters in the `/proc/cmdline` file.
7. systemd collects the kernel command-line parameters by reading the `/proc/cmdline` file and stores them in the `root`, `rootfs`, and `fstype` variables.

We can verify this procedure by using the `cmdline` hook.

Getting back to the `/bin/dracut-cmdline` script, let's take a look:

```
export root
export rflags
export fstype

make_trace_mem "hook cmdline" '1+:mem' '1+:iomem' '3+:slab' '4+:komem'
# run scriptlets to parse the command line
getarg 'rd.break=cmdline' -d 'rdbreak=cmdline' && emergency_shell -n cmdline "Break before cmdline"
source_hook cmdline

[ -f /lib/dracut/parse-resume.sh ] && . /lib/dracut/parse-resume.sh
```

The condition says if the user has passed the `rd.break=cmdline` parameter on the kernel stanza of GRUB, then execute the `emergency_shell` function. Figure 7-10 shows the condition.

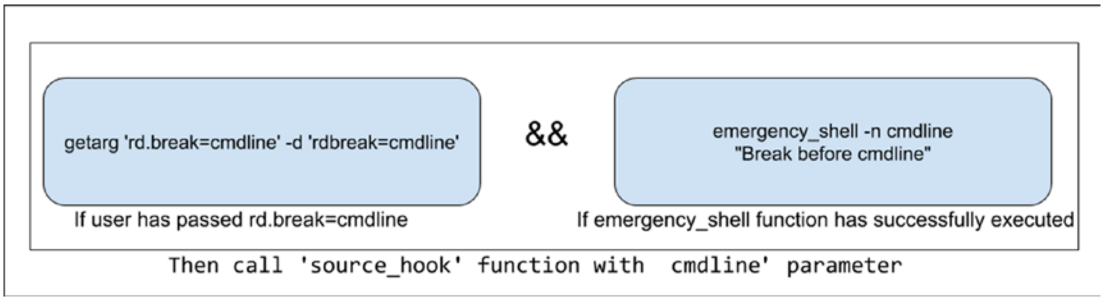

getarg 'rd.break=cmdline' -d 'rdbreak=cmdline'
&&
emergency_shell -n cmdline "Break before cmdline"
If user has passed rd.break=cmdline
If emergency_shell function has successfully executed
Then call 'source_hook' function with cmdline' parameter

Figure 7-10. *The condition*

If the user has passed `rd.break=cmdline`, then the script calls the function named `emergency_shell`. As the name suggests, it will provide the debugging shell, and if the debugging shell has successfully launched, then it calls another function named `source_hook` and passes the `cmdline` parameter to it. Whoever wrote this code to provide users with a debugging shell is a genius programmer!

We will not discuss the emergency shell function at this stage since we need to understand systemd more first. Hence, we will discuss it in much more detail in Chapter 8.

Figure 7-11 shows the flowchart of the `dracut-cmdline.service` units working.

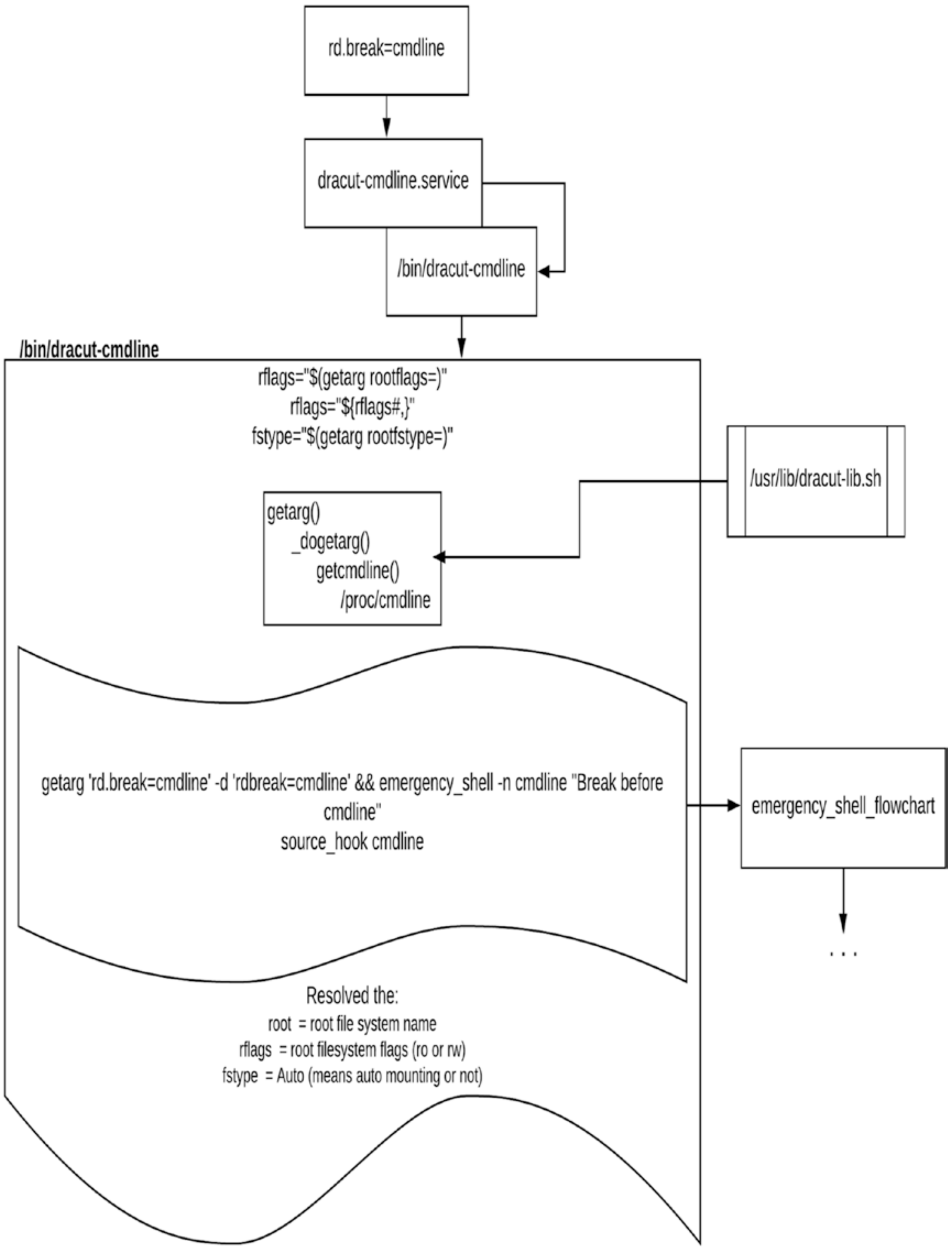
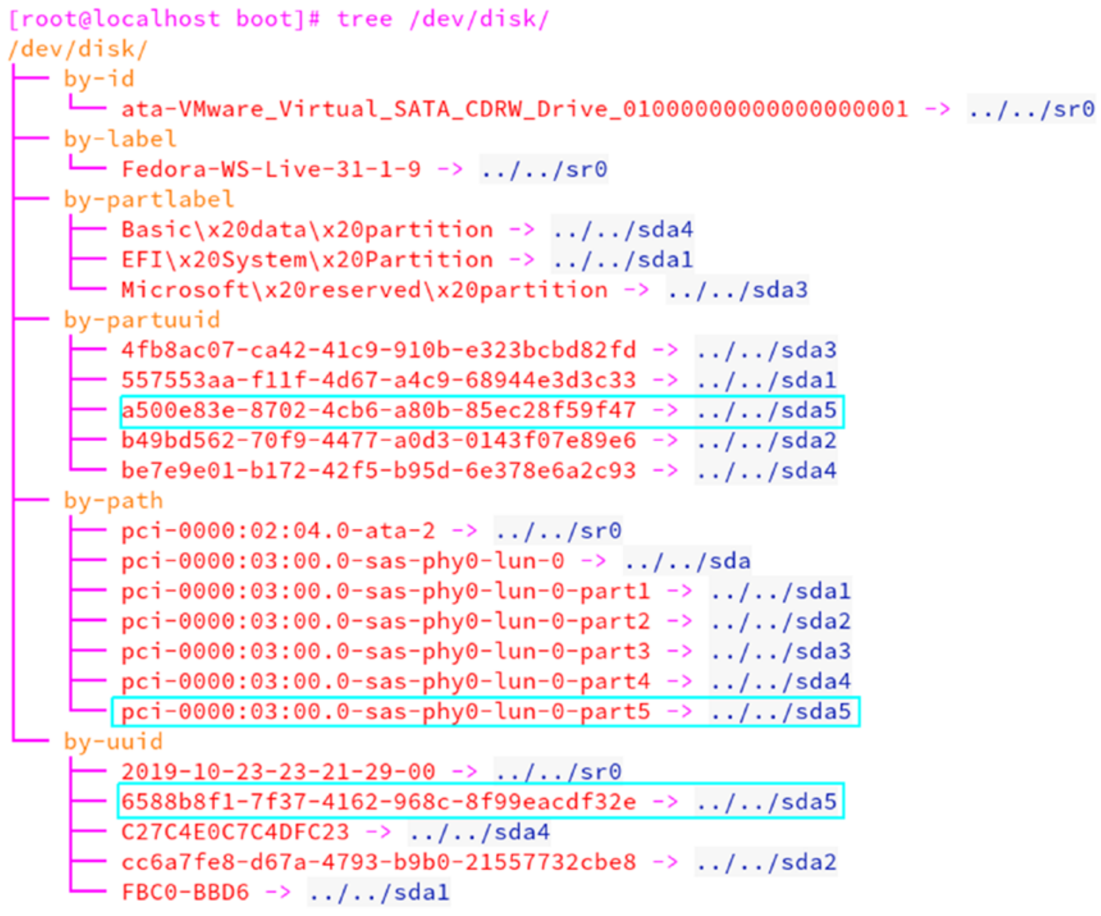

rd.break=cmdline
dracut-cmdline.service
/bin/dracut-cmdline
/bin/dracut-cmdline
rflags="$(getarg rootflags=)"
rflags="${rflags#,}"
fstype="$(getarg rootfstype=)"
/usr/lib/dracut-lib.sh
getarg()
_dogetarg()
getcmdline()
/proc/cmdline
getarg 'rd.break=cmdline' -d 'rdbreak=cmdline' && emergency_shell -n cmdline "Break before cmdline"
source_hook cmdline
emergency_shell_flowchart
. . .
Resolved the:
root = root file system name
rflags = root filesystem flags (ro or rw)
fstype = Auto (means auto mounting or not)

Figure 7-11. *The flowchart of dracut-cmdline.service*

Going further, a user's root filesystem name could just be `/dev/sda5`, but the same sda5 device might be referred via `uuid`, `partuuid`, or `label`. At the end, every other reference of sda5 has to reach `/dev/sda5`; hence, the kernel prepares symlinks files for all of these different device names under `/dev/disk/`. Please refer to Figure 7-12.



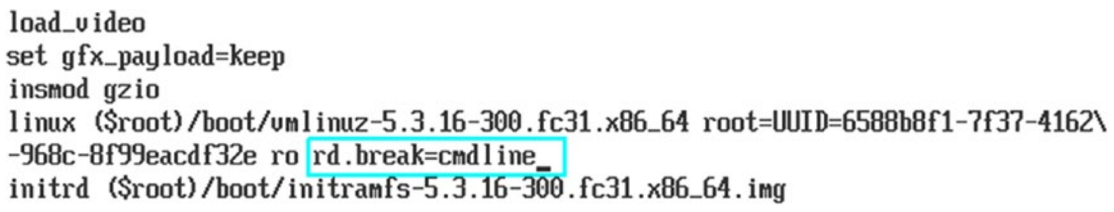
```
[root@localhost boot]# tree /dev/disk/
/dev/disk/
├── by-id
│   └── ata-VMware_Virtual_SATA_CDRW_Drive_01000000000000000001 -> ../../sr0
├── by-label
│   └── Fedora-WS-Live-31-1-9 -> ../../sr0
├── by-partlabel
│   ├── Basic\x20data\x20partition -> ../../sda4
│   ├── EFI\x20System\x20Partition -> ../../sda1
│   └── Microsoft\x20reserved\x20partition -> ../../sda3
├── by-partuuid
│   ├── 4fb8ac07-ca42-41c9-910b-e323bcbd82fd -> ../../sda3
│   ├── 557553aa-f11f-4d67-a4c9-68944e3d3c33 -> ../../sda1
│   ├── a500e83e-8702-4cb6-a80b-85ec28f59f47 -> ../../sda5
│   ├── b49bd562-70f9-4477-a0d3-0143f07e89e6 -> ../../sda2
│   └── be7e9e01-b172-42f5-b95d-6e378e6a2c93 -> ../../sda4
├── by-path
│   ├── pci-0000:02:04.0-ata-2 -> ../../sr0
│   ├── pci-0000:03:00.0-sas-phy0-lun-0 -> ../../sda
│   ├── pci-0000:03:00.0-sas-phy0-lun-0-part1 -> ../../sda1
│   ├── pci-0000:03:00.0-sas-phy0-lun-0-part2 -> ../../sda2
│   ├── pci-0000:03:00.0-sas-phy0-lun-0-part3 -> ../../sda3
│   ├── pci-0000:03:00.0-sas-phy0-lun-0-part4 -> ../../sda4
│   └── pci-0000:03:00.0-sas-phy0-lun-0-part5 -> ../../sda5
└── by-uuid
    ├── 2019-10-23-23-21-29-00 -> ../../sr0
    ├── 6588b8f1-7f37-4162-968c-8f99eacdf32e -> ../../sda5
    ├── C27C4E0C7C4DFC23 -> ../../sda4
    ├── cc6a7fe8-d67a-4793-b9b0-21557732cbe8 -> ../../sda2
    └── FBC0-BBD6 -> ../../sda1
```

Figure 7-12. *The /dev/disk directory contents*

The same `/bin/dracut-cmdline` script converts the mear sda5 root filesystem name to `/dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e`.

```
case "${root}${root_unset}" in
    block:LABEL=*|LABEL=*)
        root="${root#block:}"
        root="$(echo $root | sed 's,/,\\x2f,g')"
        root="block:/dev/disk/by-label/${root#LABEL=}"
        rootok=1 ;;
    block:UUID=*|UUID=*)
        root="${root#block:}"
        root="block:/dev/disk/by-uuid/${root#UUID=}"
        rootok=1 ;;
    block:PARTUUID=*|PARTUUID=*)
        root="${root#block:}"
        root="block:/dev/disk/by-partuuid/${root#PARTUUID=}"
        rootok=1 ;;
    block:PARTLABEL=*|PARTLABEL=*)
        root="${root#block:}"
        root="block:/dev/disk/by-partlabel/${root#PARTLABEL=}"
        rootok=1 ;;
    /dev/*)
        root="block:${root}"
        rootok=1 ;;
    UNSET|gpt-auto)
        # systemd's gpt-auto-generator handles this case.
        rootok=1 ;;
esac

[ -z "${root}${root_unset}" ] && die "Empty root= argument"
[ -z "$rootok" ] && die "Don't know how to handle 'root=$root'"

export root rflags fstype netroot NEWROOT

export -p > /dracut-state.sh

exit 0
```

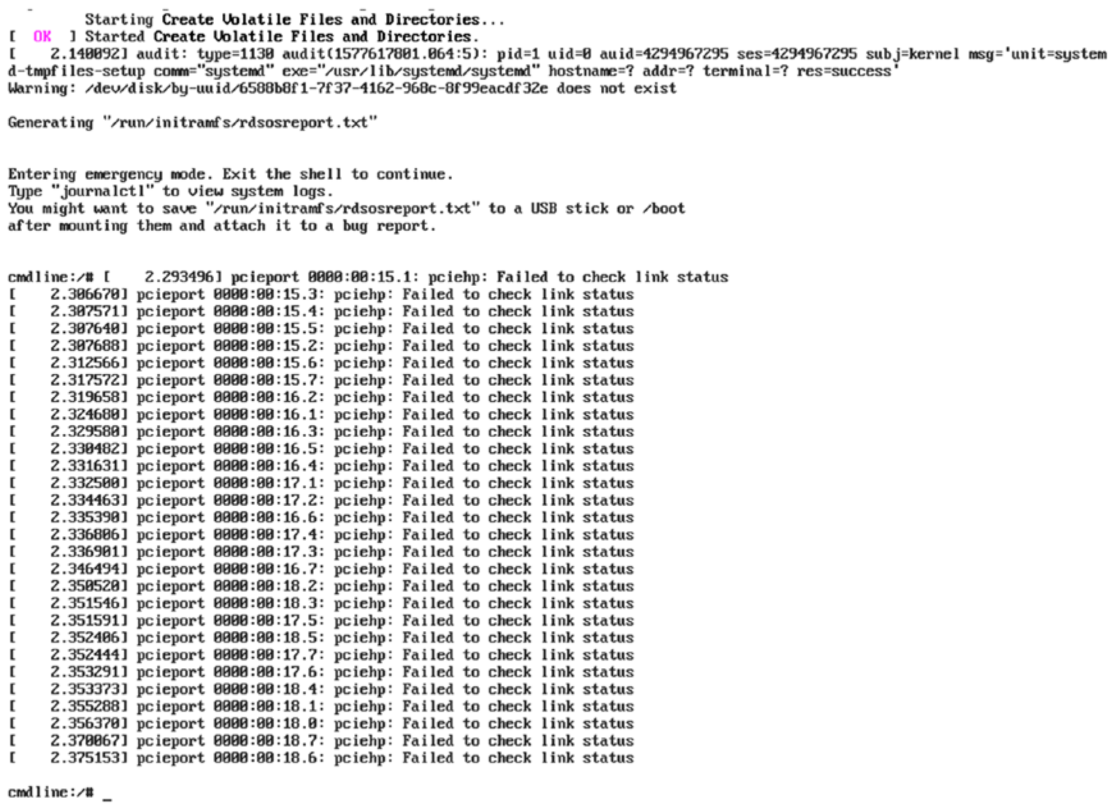
Let’s see the `cmdline` hook in action. As shown in Figure 7-13, pass `rd.break=cmdline` on the kernel stanza of GRUB.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro rd.break=cmdline_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 7-13. *The kernel command-line parameter*

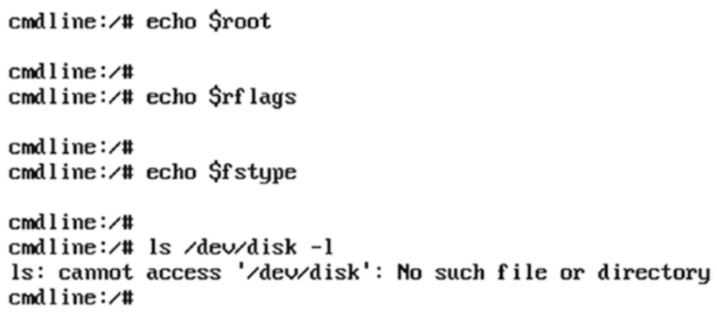
The kernel will extract initramfs, the systemd process will launch, systemd will initialize the `journald` sockets, and as you can see in Figure 7-14, systemd will drop us on a cmdline shell since we told systemd to break (hook) the booting sequence before executing the `dracut-cmdline` hook.



```
         Starting Create Volatile Files and Directories...
[  OK  ] Started Create Volatile Files and Directories.
[    2.140092] audit: type=1130 audit(1577617801.064:5): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=system
d-tmpfiles-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
Warning: /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e does not exist

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


cmdline:/# [    2.293496] pcieport 0000:00:15.1: pciehp: Failed to check link status
[    2.306670] pcieport 0000:00:15.3: pciehp: Failed to check link status
[    2.307571] pcieport 0000:00:15.4: pciehp: Failed to check link status
[    2.307640] pcieport 0000:00:15.5: pciehp: Failed to check link status
[    2.307688] pcieport 0000:00:15.2: pciehp: Failed to check link status
[    2.312566] pcieport 0000:00:15.6: pciehp: Failed to check link status
[    2.317572] pcieport 0000:00:15.7: pciehp: Failed to check link status
[    2.319658] pcieport 0000:00:16.2: pciehp: Failed to check link status
[    2.324680] pcieport 0000:00:16.1: pciehp: Failed to check link status
[    2.329580] pcieport 0000:00:16.3: pciehp: Failed to check link status
[    2.330482] pcieport 0000:00:16.5: pciehp: Failed to check link status
[    2.331631] pcieport 0000:00:16.4: pciehp: Failed to check link status
[    2.332500] pcieport 0000:00:17.1: pciehp: Failed to check link status
[    2.334463] pcieport 0000:00:17.2: pciehp: Failed to check link status
[    2.335390] pcieport 0000:00:16.6: pciehp: Failed to check link status
[    2.336806] pcieport 0000:00:17.4: pciehp: Failed to check link status
[    2.336901] pcieport 0000:00:17.3: pciehp: Failed to check link status
[    2.346494] pcieport 0000:00:16.7: pciehp: Failed to check link status
[    2.350520] pcieport 0000:00:18.2: pciehp: Failed to check link status
[    2.351546] pcieport 0000:00:18.3: pciehp: Failed to check link status
[    2.351591] pcieport 0000:00:17.5: pciehp: Failed to check link status
[    2.352406] pcieport 0000:00:18.5: pciehp: Failed to check link status
[    2.352444] pcieport 0000:00:17.7: pciehp: Failed to check link status
[    2.353291] pcieport 0000:00:17.6: pciehp: Failed to check link status
[    2.353373] pcieport 0000:00:18.4: pciehp: Failed to check link status
[    2.355288] pcieport 0000:00:18.1: pciehp: Failed to check link status
[    2.356370] pcieport 0000:00:18.0: pciehp: Failed to check link status
[    2.370067] pcieport 0000:00:18.7: pciehp: Failed to check link status
[    2.375153] pcieport 0000:00:18.6: pciehp: Failed to check link status

cmdline:/# _
```

Figure 7-14. *The command-line hook*

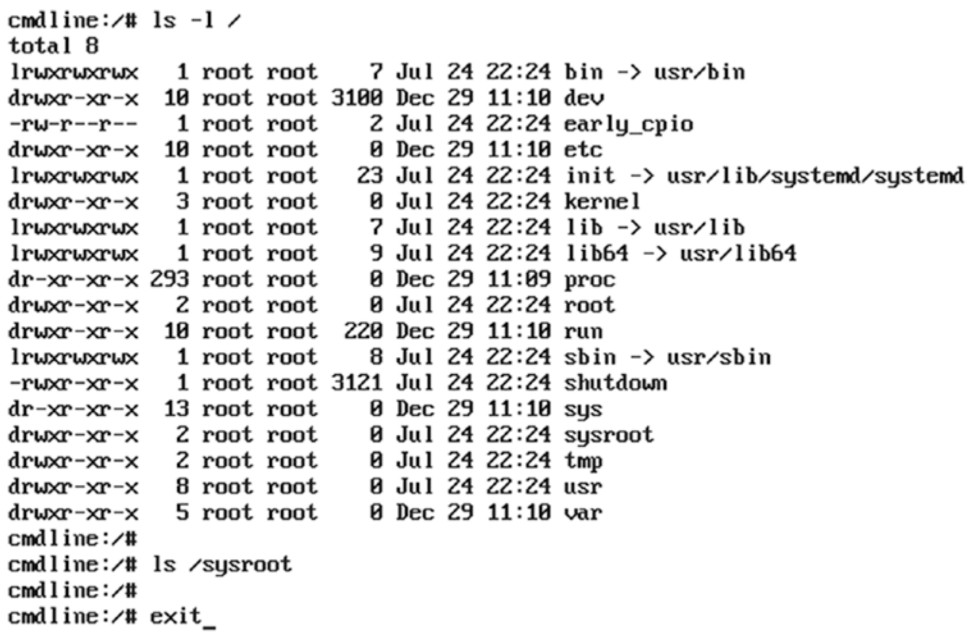
Currently, we are inside initramfs, and we have paused (dracut hooked) systemd's booting sequence after `systemd-journal.socket.` Since `dracut-cmdline.service` has not yet started, systemd has not yet collected the kernel command-line parameters such as `root`, `rsflags`, and `fstype` from `/proc/cmdline`. Please see Figure 7-15 for a better understanding. Also, the symlinks under `/dev/disk` have not yet been created by dracut.



```
cmdline:/# echo $root

cmdline:/#
cmdline:/# echo $rflags

cmdline:/#
cmdline:/# echo $fstype

cmdline:/#
cmdline:/# ls /dev/disk -l
ls: cannot access '/dev/disk': No such file or directory
cmdline:/#
```

Figure 7-15. *The command-line hook*

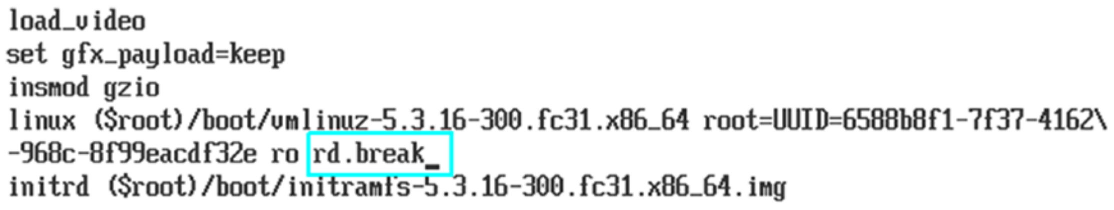
Since systemd has not yet collected the name of the user's root filesystem, there is no question that you will not find user's root filesystem mounted inside initramfs. `sysroot` is a directory inside initramfs where systemd mounts the user's root filesystem. Refer to Figure 7-16.



```
cmdline:/# ls -l /
total 8
lrwxrwxrwx   1 root root    7 Jul 24 22:24 bin -> usr/bin
drwxr-xr-x  10 root root 3100 Dec 29 11:10 dev
-rw-r--r--   1 root root    2 Jul 24 22:24 early_cpio
drwxr-xr-x  10 root root    0 Dec 29 11:10 etc
lrwxrwxrwx   1 root root   23 Jul 24 22:24 init -> usr/lib/systemd/systemd
drwxr-xr-x   3 root root    0 Jul 24 22:24 kernel
lrwxrwxrwx   1 root root    7 Jul 24 22:24 lib -> usr/lib
lrwxrwxrwx   1 root root    9 Jul 24 22:24 lib64 -> usr/lib64
dr-xr-xr-x 293 root root    0 Dec 29 11:09 proc
drwxr-xr-x   2 root root    0 Jul 24 22:24 root
drwxr-xr-x  10 root root  220 Dec 29 11:10 run
lrwxrwxrwx   1 root root    8 Jul 24 22:24 sbin -> usr/sbin
-rwxr-xr-x   1 root root 3121 Jul 24 22:24 shutdown
dr-xr-xr-x  13 root root    0 Dec 29 11:10 sys
drwxr-xr-x   2 root root    0 Jul 24 22:24 sysroot
drwxr-xr-x   2 root root    0 Jul 24 22:24 tmp
drwxr-xr-x   8 root root    0 Jul 24 22:24 usr
drwxr-xr-x   5 root root    0 Dec 29 11:10 var
cmdline:/#
cmdline:/# ls /sysroot
cmdline:/#
cmdline:/# exit_
```

Figure 7-16. *The sysroot directory*

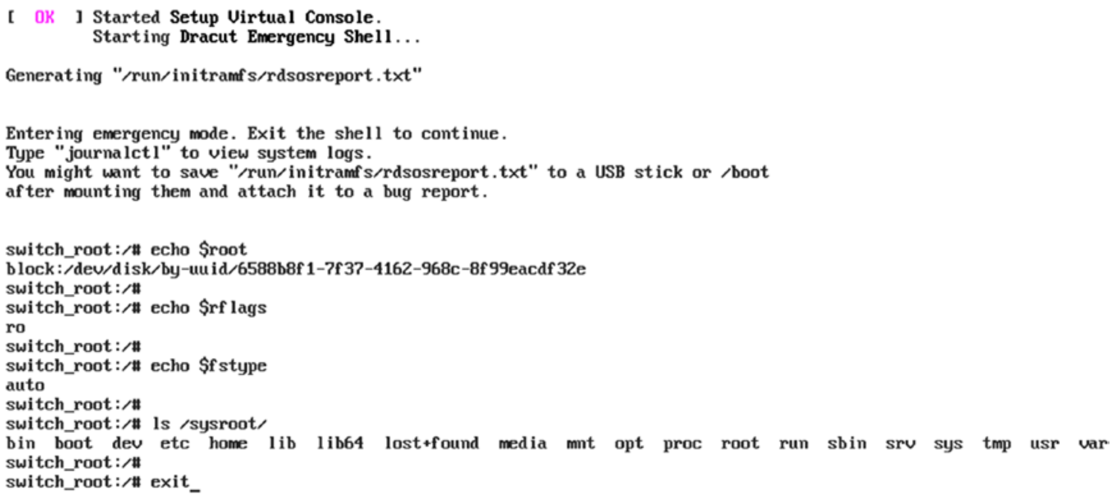
But if we do not pass any argument to `rd.break` or simply exit from the current cmdline shell, we will be dropped at the `switch_root` shell. The `switch_root` shell is the final stage of systemd's boot sequence inside initramfs. In Figure 7-17, you can see that we are passing `rd.break` without any arguments.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro rd.break_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 7-17. *The rd.break kernel command-line parameter*

As you can see in Figure 7-18, in the `switch_root` shell since the `dracut-cmdline.service` has been executed, you will find the kernel command-line parameters have been collected by systemd. Also, the user's root filesystem has been mounted inside initramfs under `sysroot`.



```
[  OK  ] Started Setup Virtual Console.
         Starting Dracut Emergency Shell...

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


switch_root:/# echo $root
block:/dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e
switch_root:/#
switch_root:/# echo $rflags
ro
switch_root:/#
switch_root:/# echo $fstype
auto
switch_root:/#
switch_root:/# ls /sysroot/
bin  boot  dev  etc  home  lib  lib64  lost+found  media  mnt  opt  proc  root  run  sbin  srv  sys  tmp  usr  var
switch_root:/#
switch_root:/# exit_
```

Figure 7-18. *The switch_root hook*

If we exit from this stage, `switch_root` (`pivot_root`) will be performed by systemd, and it will leave the initramfs environment. Later systemd will carry the remaining booting procedure, and as shown in Figure 7-19, eventually we will get the desktop.

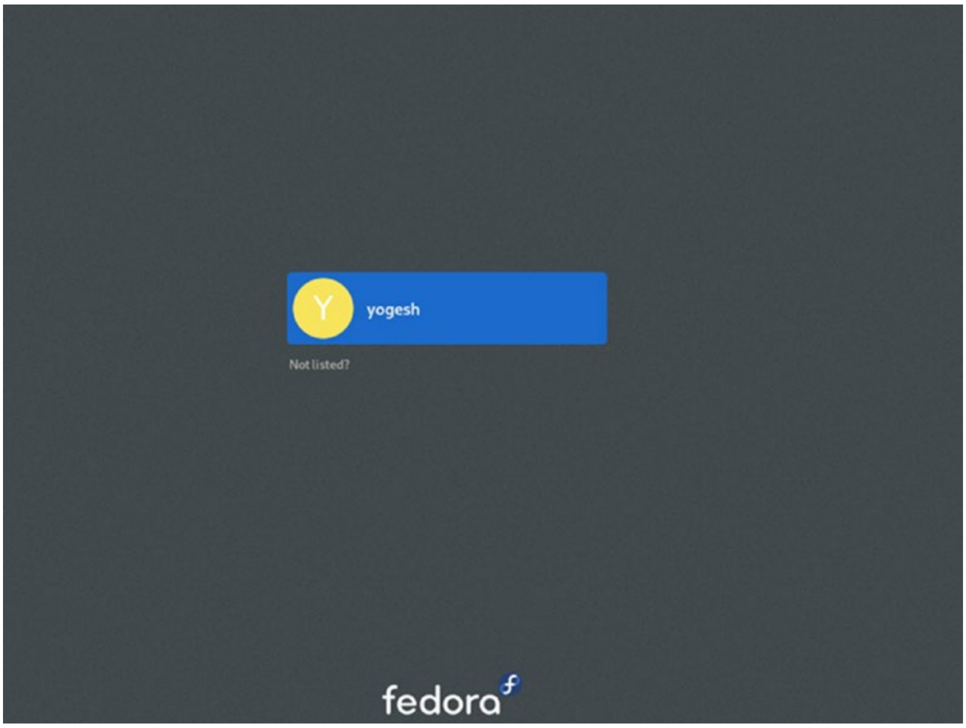


Figure 7-19. *The login screen of Fedora*

Coming back to our booting sequence so far, we have reached the pre-udev stage. You can refer to Figure 7-20 for this.

```
systemd-journal.socket
          |
          v
dracut-cmdline.service
          |
          v
dracut-pre-udev.service
```

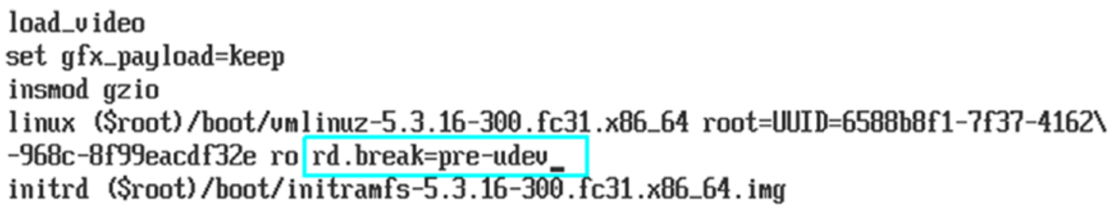
Figure 7-20. *The booting sequence covered so far*

dracut-pre-udev.service

Next systemd will deal with the attached devices. For that, systemd has to start the udev daemon, but before starting the udev service, it checks whether users want to stop the booting procedure before udev kicks in. If a user has passed the `rd.break=pre-udev` `dracut` command-line parameter, systemd will stop the booting sequence just before executing the udev daemon.

```
# cat usr/lib/systemd/system/dracut-pre-udev.service | grep -v '#'

[Unit]
Description=dracut pre-udev hook
Documentation=man:dracut-pre-udev.service(8)
DefaultDependencies=no
Before=systemd-udevd.service dracut-pre-trigger.service
After=dracut-cmdline.service
Wants=dracut-cmdline.service
ConditionPathExists=/usr/lib/initrd-release
ConditionDirectoryNotEmpty=|/lib/dracut/hooks/pre-udev
ConditionKernelCommandLine=|rd.break=pre-udev
ConditionKernelCommandLine=|rd.driver.blacklist
ConditionKernelCommandLine=|rd.driver.pre
ConditionKernelCommandLine=|rd.driver.post
ConditionPathExistsGlob=|/etc/cmdline.d/*.conf
Conflicts=shutdown.target emergency.target

[Service]
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
Type=oneshot
ExecStart=-/bin/dracut-pre-udev
StandardInput=null
StandardOutput=syslog
StandardError=syslog+console
KillMode=process
RemainAfterExit=yes

KillSignal=SIGHUP
```

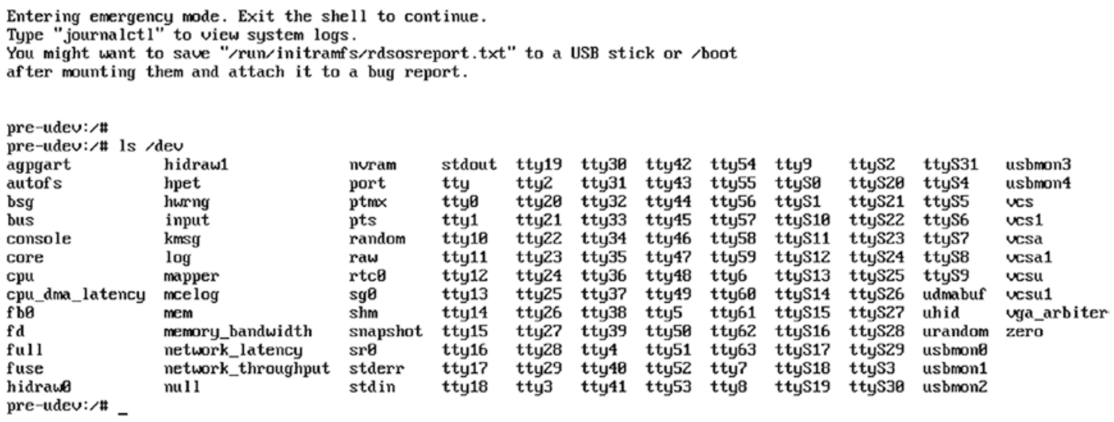
It will drop us on a pre-udev shell. Notice the `after`, `before`, and `wants` variables. Executing `dracut-pre-udev.service` just starts a `/bin/dracut-pre-udev` binary from initramfs. In Figure 7-21, we have passed `rd.break=pre-udev` as a kernel command-line parameter.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro rd.break=pre-udev_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 7-21. *Passing the pre-udev kernel command-line parameter*

To understand the `pre-udev` hook, you can simply list the contents of `/dev`, and in Figure 7-22 you will notice there is no device file named sda. sda is our HDD where we have our root filesystem.



```
Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


pre-udev:/#
pre-udev:/# ls /dev
agpgart          hidraw1              nvram     stdout  tty19  tty30  tty42  tty54  tty9    ttyS2   ttyS31   usbmon3
autofs           hpet                 port      tty     tty2   tty31  tty43  tty55  ttyS0   ttyS20  ttyS4    usbmon4
bsg              hwrng                ptmx      tty0    tty20  tty32  tty44  tty56  ttyS1   ttyS21  ttyS5    vcs
bus              input                pts       tty1    tty21  tty33  tty45  tty57  ttyS10  ttyS22  ttyS6    vcs1
console          kmsg                 random    tty10   tty22  tty34  tty46  tty58  ttyS11  ttyS23  ttyS7    vcsa
core             log                  raw       tty11   tty23  tty35  tty47  tty59  ttyS12  ttyS24  ttyS8    vcsa1
cpu              mapper               rtc0      tty12   tty24  tty36  tty48  tty6   ttyS13  ttyS25  ttyS9    vcsu
cpu_dma_latency  mcelog               sg0       tty13   tty25  tty37  tty49  tty60  ttyS14  ttyS26  udmabuf  vcsu1
fb0              mem                  shm       tty14   tty26  tty38  tty5   tty61  ttyS15  ttyS27  uhid     vga_arbiter
fd               memory_bandwidth     snapshot  tty15   tty27  tty39  tty50  tty62  ttyS16  ttyS28  urandom  zero
full             network_latency      sr0       tty16   tty28  tty4   tty51  tty63  ttyS17  ttyS29  usbmon0
fuse             network_throughput   stderr    tty17   tty29  tty40  tty52  tty7   ttyS18  ttyS3   usbmon1
hidraw0          null                 stdin     tty18   tty3   tty41  tty53  tty8   ttyS19  ttyS30  usbmon2
pre-udev:/# _
```

Figure 7-22. *The pre-udev hook*

The reason for the absence of `sda` device files is because the `udev` daemon has not started yet. The daemon will be started by the `/usr/lib/systemd/system/systemd-udevd.service` unit file, which will start after the `pre-udev` hook.

```
# cat usr/lib/systemd/system/systemd-udevd.service | grep -v '#'
```

```
[Unit]
Description=udev Kernel Device Manager
Documentation=man:systemd-udevd.service(8) man:udev(7)
DefaultDependencies=no
After=systemd-sysusers.service systemd-hwdb-update.service
Before=sysinit.target
ConditionPathIsReadWrite=/sys

[Service]
Type=notify
OOMScoreAdjust=-1000
Sockets=systemd-udevd-control.socket systemd-udevd-kernel.socket
Restart=always
RestartSec=0
ExecStart=/usr/lib/systemd/systemd-udevd
KillMode=mixed
WatchdogSec=3min
TasksMax=infinity
PrivateMounts=yes
ProtectHostname=yes
MemoryDenyWriteExecute=yes
RestrictAddressFamilies=AF_UNIX AF_NETLINK AF_INET AF_INET6
RestrictRealtime=yes
RestrictSUIDSGID=yes
SystemCallFilter=@system-service @module @raw-io
SystemCallErrorNumber=EPERM
SystemCallArchitectures=native
LockPersonality=yes
IPAddressDeny=any
```

Let’s try to understand how udev works and how it creates device files under /dev.

It’s the kernel that detects the connected hardware to the system; more precisely, it’s the drivers that are compiled inside kernels or the modules inserted later that will detect the hardware and will register their objects with sysfs (/sys mount point). Because of the /sys mount point, this data becomes available to userspace and to tools like udev. So, it’s the kernel that detects the hardware through drivers and creates a device file in /dev, which is a devfs filesystem. After this, the kernel sends a uevent to udevd, and udevd changes the device file’s name, owner, or group, or it sets the proper permissions according to the rules defined here:

```
     /etc/udev/rules.d,
     /lib/udev/rules.d, and
     /run/udev/rules.d

# ls etc/udev/rules.d/
     59-persistent-storage.rules  61-persistent-storage.rules

# ls lib/udev/rules.d/
     50-udev-default.rules        70-uaccess.rules    75-net-description.
     rules  85-nm-unmanaged.rules
     60-block.rules               71-seat.rules       80-drivers.rules
     90-vconsole.rules
     60-persistent-storage.rules  73-seat-late.rules  80-net-setup-link.
     rules   99-systemd.rules
```

initramfs has few udev rules files compared to the available udev rules present on the user's root filesystem. Basically, it has only those rules that are necessary to manage the user's root filesystem devices. Once udevd is in control, it will call the respective systemd units based on lib/udev/rules.d/99-systemd.rules. Here's an example:

```
# cat lib/udev/rules.d/99-systemd.rules
SUBSYSTEM=="net", KERNEL!="lo", TAG+="systemd", ENV{SYSTEMD_ALIAS}+="/sys/
subsystem/net/devices/$name"
SUBSYSTEM=="bluetooth", TAG+="systemd", ENV{SYSTEMD_ALIAS}+="/sys/
subsystem/bluetooth/devices/%k"

SUBSYSTEM=="bluetooth", TAG+="systemd", ENV{SYSTEMD_WANTS}+="bluetooth.
target", ENV{SYSTEMD_USER_WANTS}+="bluetooth.target"
ENV{ID_SMARTCARD_READER}=="?*", TAG+="systemd", ENV{SYSTEMD_
WANTS}+="smartcard.target", ENV{SYSTEMD_USER_WANTS}+="smartcard.target"
SUBSYSTEM=="sound", KERNEL=="card*", TAG+="systemd", ENV{SYSTEMD_
WANTS}+="sound.target", ENV{SYSTEMD_USER_WANTS}+="sound.target"

SUBSYSTEM=="printer", TAG+="systemd", ENV{SYSTEMD_WANTS}+="printer.target",
ENV{SYSTEMD_USER_WANTS}+="printer.target"
SUBSYSTEM=="usb", KERNEL=="lp*", TAG+="systemd", ENV{SYSTEMD_
WANTS}+="printer.target", ENV{SYSTEMD_USER_WANTS}+="printer.target"
```

```
SUBSYSTEM=="usb", ENV{DEVTYPE}=="usb_device", ENV{ID_USB_
INTERFACES}=="*:0701??:*", TAG+="systemd", ENV{SYSTEMD_WANTS}+="printer.
target", ENV{SYSTEMD_USER_WANTS}+="printer.target"

SUBSYSTEM=="udc", ACTION=="add", TAG+="systemd", ENV{SYSTEMD_WANTS}+="usb-
gadget.target"
```

The rule is tagged with the `systemd` tag. That means whenever a `bluetooth` device is detected, `udevd` will call systemd's `bluetooth.target.` The `bluetooth.target` will execute the `/usr/libexec/bluetooth/bluetoothd` binary, which will take care of the rest of the `bluetooth` device handling. So, the complete sequence of `udevd` handling the `bluetooth` device is as follows:

1) If a user has a bluetooth device connected to the system while booting, it's the kernel or drivers compiled in the kernel or modules inserted later that will detect the bluetooth device and register its object with `/sys`.

2) Later the kernel will create a device file in the `/dev` mount point. After the device file creation, the kernel will send a `uevent` to `udevd`.

3) `udevd` will refer to `lib/udev/rules.d/99-systemd.rules` from initramfs and will call systemd. As per the tag, systemd is supposed to handle the rest of it.

4) systemd will execute the `bluetooth.target`, which will execute the `bluetoothd` binary, and the bluetooth hardware will be ready to be used.

Of course, bluetooth is not the kind of hardware that is necessary at the time of the boot. I have taken this example just for the ease of understanding.

So, we have reached up to `systemd-udev.service.` systemd will continue its booting sequence and will execute `dracut-pre-trigger.service.` You can see the booting sequence in Figure 7-23.

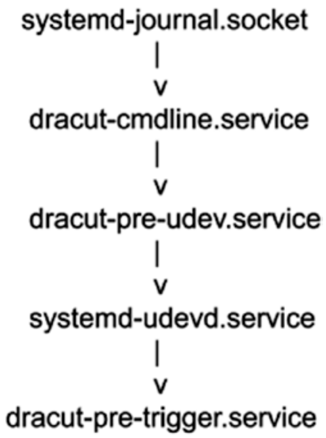
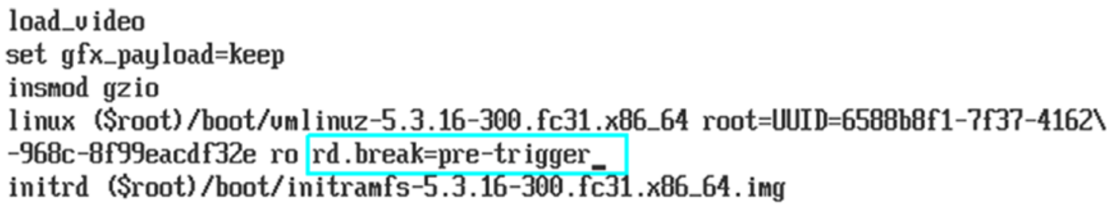


Figure 7-23. *The boot sequence covered so far*

dracut-pre-trigger.service

systemd's initramfs boot sequence will be broken (hooked) if the user has passed the `rd.break=pre-trigger` dracut command-line parameter. You can see in Figure 7-24 that we have passed `pre-trigger` as an argument to the `rd.break` kernel command-line parameter.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro rd.break=pre-trigger_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 7-24. *The rd.break=pre-trigger kernel command-line parameter*

It will drop us on a `pre-trigger` shell, which is just after starting the udevd service. First let's see how it drops on a `pre-trigger` shell.

```
# cat usr/lib/systemd/system/dracut-pre-trigger.service | grep -v '#'
[Unit]
Description=dracut pre-trigger hook
Documentation=man:dracut-pre-trigger.service(8)
DefaultDependencies=no
Before=systemd-udev-trigger.service dracut-initqueue.service
```

```
After=dracut-pre-udev.service systemd-udevd.service systemd-tmpfiles-setup-
dev.service
Wants=dracut-pre-udev.service systemd-udevd.service
ConditionPathExists=/usr/lib/initrd-release
ConditionDirectoryNotEmpty=|/lib/dracut/hooks/pre-trigger
ConditionKernelCommandLine=|rd.break=pre-trigger
Conflicts=shutdown.target emergency.target

[Service]
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
Type=oneshot
ExecStart=-/bin/dracut-pre-trigger
StandardInput=null
StandardOutput=syslog
StandardError=syslog+console
KillMode=process
RemainAfterExit=yes

KillSignal=SIGHUP
```

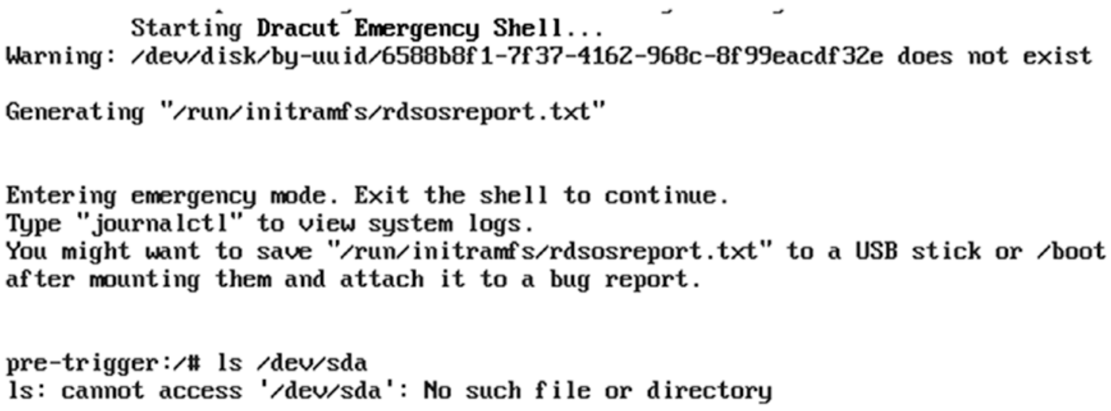
Please note the `After`, `Before`, and `wants` sections of the service unit file. This service file will execute `/bin/dracut-pre-trigger` from initramfs if this `ConditionDirectoryNotEmpty=|/lib/dracut/hooks/pre-trigger` directory exists and if the user has passed `rd.break=pre-trigger` as a command-line parameter.

```
[root@fedorab boot]# cat bin/dracut-pre-trigger
#!/usr/bin/sh

export DRACUT_SYSTEMD=1
if [ -f /dracut-state.sh ]; then
    . /dracut-state.sh 2>/dev/null
fi
type getarg >/dev/null 2>&1 || . /lib/dracut-lib.sh
source_conf /etc/conf.d
make_trace_mem "hook pre-trigger" '1:shortmem' '2+:mem' '3+:slab'
'4+:komem'
source_hook pre-trigger
```

```
getarg 'rd.break=pre-trigger' 'rdbreak=pre-trigger' && emergency_shell -n
pre-trigger "Break pre-trigger"
udevadm control --reload >/dev/null 2>&1 || :
export -p > /dracut-state.sh
exit 0
```

As you can see, it is checking the passed dracut command-line parameters (`rd.break=pre-trigger`) through the `getarg` function. We saw how `getarg` works earlier in this chapter. If the user has passed `rd.break=pre-trigger`, then it will call the `emergency_shell` function with `pre-trigger` as a parameter passed to it. The `emergency_shell` function is written in the `dracut-lib.sh` file. This function will provide us with the `pre-trigger` shell. Chapter 8 covers the procedure behind providing an emergency shell.

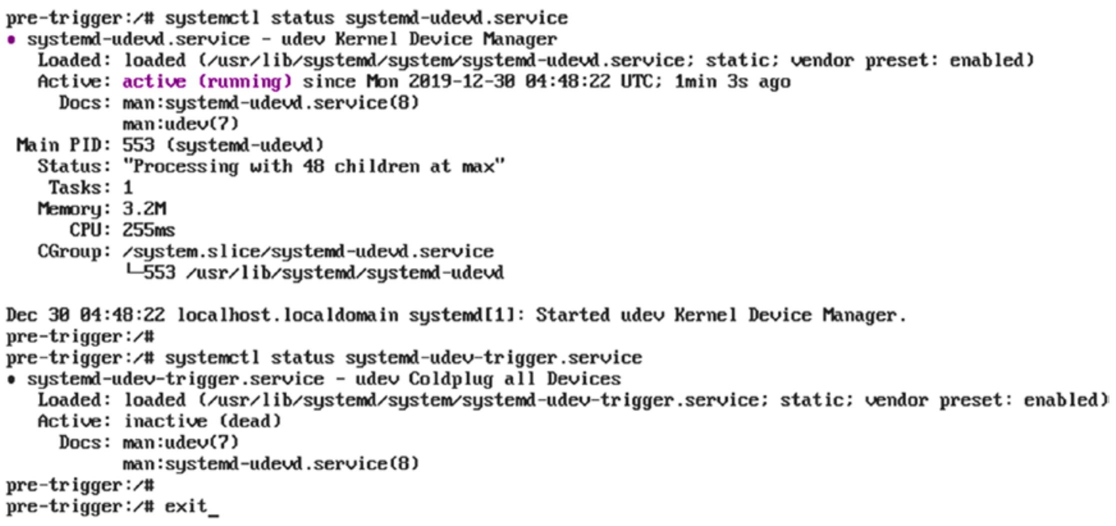
As the `pre-trigger` name suggests, and as you can see in Figure 7-25, we have stopped the booting sequence just before the udev triggers. Hence, the sda disk is not yet available under dev.



```
         Starting Dracut Emergency Shell...
Warning: /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e does not exist

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


pre-trigger:/# ls /dev/sda
ls: cannot access '/dev/sda': No such file or directory
```

Figure 7-25. *The pre-trigger hook*

This is because the `udevadm` trigger has not been executed yet. The service `dracut-pre-trigger.service` executes only `udevadm control --reload`, which reloads the udev rules. As shown in Figure 7-26, the service `systemd-udev.service` has been started, but the `systemd-udev-trigger` service has not yet started.



```
pre-trigger:/# systemctl status systemd-udevd.service
● systemd-udevd.service - udev Kernel Device Manager
   Loaded: loaded (/usr/lib/systemd/system/systemd-udevd.service; static; vendor preset: enabled)
   Active: active (running) since Mon 2019-12-30 04:48:22 UTC; 1min 3s ago
     Docs: man:systemd-udevd.service(8)
           man:udev(7)
 Main PID: 553 (systemd-udevd)
   Status: "Processing with 48 children at max"
    Tasks: 1
   Memory: 3.2M
      CPU: 255ms
   CGroup: /system.slice/systemd-udevd.service
           └─553 /usr/lib/systemd/systemd-udevd

Dec 30 04:48:22 localhost.localdomain systemd[1]: Started udev Kernel Device Manager.
pre-trigger:/#
pre-trigger:/# systemctl status systemd-udev-trigger.service
● systemd-udev-trigger.service - udev Coldplug all Devices
   Loaded: loaded (/usr/lib/systemd/system/systemd-udev-trigger.service; static; vendor preset: enabled)
   Active: inactive (dead)
     Docs: man:udev(7)
           man:systemd-udevd.service(8)
pre-trigger:/#
pre-trigger:/# exit_
```

Figure 7-26. *The pre-trigger hook*

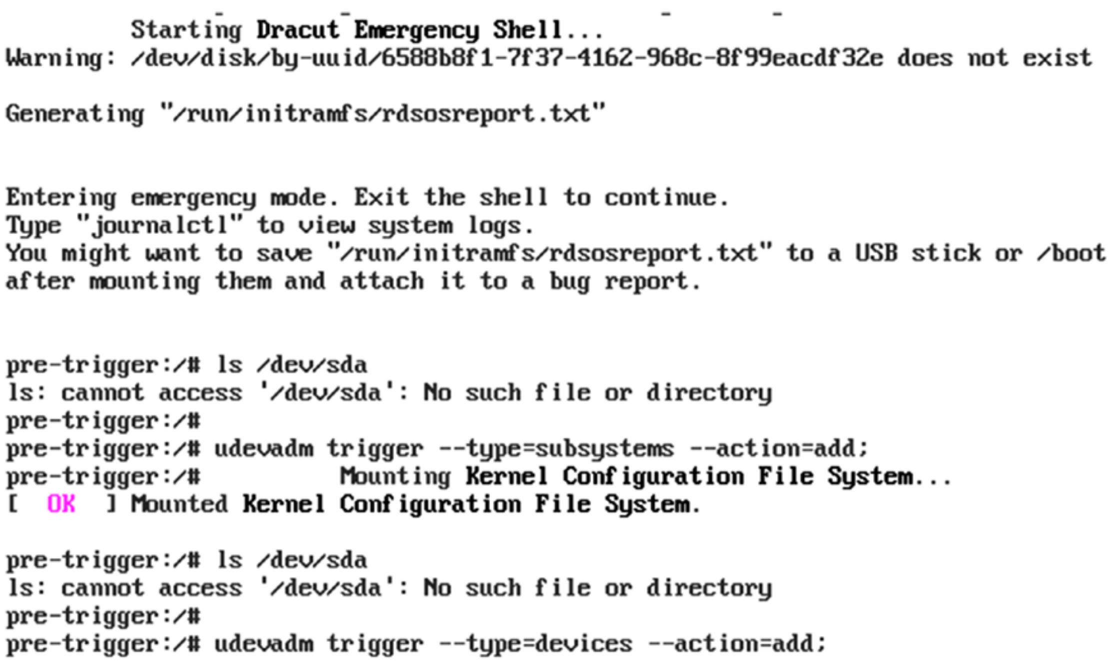
systemd-udev-trigger.service

Figure 7-27 shows the stage of booting we have reached.

```
systemd-journal.socket
          |
          v
dracut-cmdline.service
          |
          v
dracut-pre-udev.service
          |
          v
 systemd-udevd.service
          |
          v
dracut-pre-trigger.service
          |
          v
systemd-udev-trigger.service
```

Figure 7-27. *The booting sequence so far*

As we have seen, with pre-udev the /dev was not populated since the systemd-udevd.service itself was not started. With pre-trigger, it's the same: /dev is not populated, but the udevd service has started. The udevd service will create an environment to start/run the various udev tools like udevadm. By using the environment provided by the udevd daemon, as you can see in Figure 7-28, inside pre-trigger we will be able to execute the udevadm, which we were not able to use at the pre-udev shell.



```
         Starting Dracut Emergency Shell...
Warning: /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e does not exist

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


pre-trigger:/# ls /dev/sda
ls: cannot access '/dev/sda': No such file or directory
pre-trigger:/#
pre-trigger:/# udevadm trigger --type=subsystems --action=add;
pre-trigger:/#          Mounting Kernel Configuration File System...
[  OK  ] Mounted Kernel Configuration File System.

pre-trigger:/# ls /dev/sda
ls: cannot access '/dev/sda': No such file or directory
pre-trigger:/#
pre-trigger:/# udevadm trigger --type=devices --action=add;
```

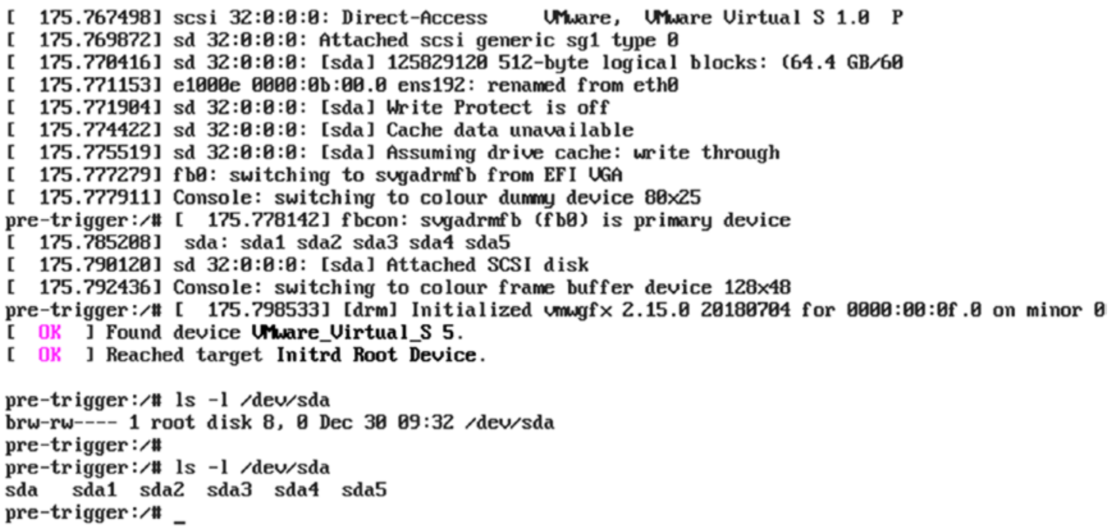
Figure 7-28. *The pre-trigger hook*

As you can see inside the pre-trigger switch, the sda device has not been created yet. But since we have a udevadm environment ready, we can discover the devices through it. As shown in Figure 7-29, we will first mount the kernel configuration filesystem.

```
pre-trigger:/ # udevadm trigger --type=subsystems --action=add
```

Then we will trigger udevadm to add the devices.

```
pre-trigger:/ # udevadm trigger --type=devices --action=add
```



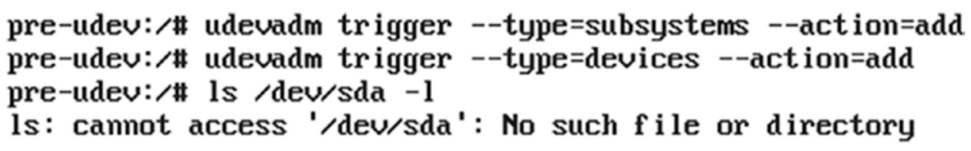
```
[  175.767498] scsi 32:0:0:0: Direct-Access     VMware,  VMware Virtual S 1.0  P
[  175.769872] sd 32:0:0:0: Attached scsi generic sg1 type 0
[  175.770416] sd 32:0:0:0: [sda] 125829120 512-byte logical blocks: (64.4 GB/60
[  175.771153] e1000e 0000:0b:00.0 ens192: renamed from eth0
[  175.771904] sd 32:0:0:0: [sda] Write Protect is off
[  175.774422] sd 32:0:0:0: [sda] Cache data unavailable
[  175.775519] sd 32:0:0:0: [sda] Assuming drive cache: write through
[  175.777279] fb0: switching to svgadrmfb from EFI VGA
[  175.777911] Console: switching to colour dummy device 80x25
pre-trigger:/# [  175.778142] fbcon: svgadrmfb (fb0) is primary device
[  175.785208]  sda: sda1 sda2 sda3 sda4 sda5
[  175.790120] sd 32:0:0:0: [sda] Attached SCSI disk
[  175.792436] Console: switching to colour frame buffer device 128x48
pre-trigger:/# [  175.798533] [drm] Initialized vmwgfx 2.15.0 20180704 for 0000:00:0f.0 on minor 0
[  OK  ] Found device VMware_Virtual_S 5.
[  OK  ] Reached target Initrd Root Device.

pre-trigger:/# ls -l /dev/sda
brw-rw---- 1 root disk 8, 0 Dec 30 09:32 /dev/sda
pre-trigger:/#
pre-trigger:/# ls -l /dev/sda
sda   sda1  sda2  sda3  sda4  sda5
pre-trigger:/# _
```

Figure 7-29. *The pre-trigger hook*

As you can see in Figure 7-29, the sda devices have been created. The same commands will be fired by systemd through `systemd-udev-trigger.service`, which will discover and create the storage device files under `/dev`.

```
# cat usr/lib/systemd/system/systemd-udev-trigger.service  | grep -v '#'

[Unit]
Description=udev Coldplug all Devices
Documentation=man:udev(7) man:systemd-udevd.service(8)
DefaultDependencies=no
Wants=systemd-udevd.service
After=systemd-udevd-kernel.socket systemd-udevd-control.socket
Before=sysinit.target
ConditionPathIsReadWrite=/sys

[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/bin/udevadm trigger -type=subsystems -action=add
ExecStart=/usr/bin/udevadm trigger -type=devices -action=add
```

But as you can see in Figure 7-30, the same `udevadm` command will not be successful in the `pre-udev` hook since the udev environment is missing.



```
pre-udev:/# udevadm trigger --type=subsystems --action=add
pre-udev:/# udevadm trigger --type=devices --action=add
pre-udev:/# ls /dev/sda -l
ls: cannot access '/dev/sda': No such file or directory
```

Figure 7-30. *The udevadm in pre-udev hook*

This is the importance of `dracut-pre-trigger.service` or of the `pre-trigger` hook.

The flowchart given in Figure 7-31 will help you understand the steps so far taken by systemd inside initramfs. The flowchart will be even more understandable after reading Chapter 8. I highly recommend revisiting this chapter after finishing Chapter 8.

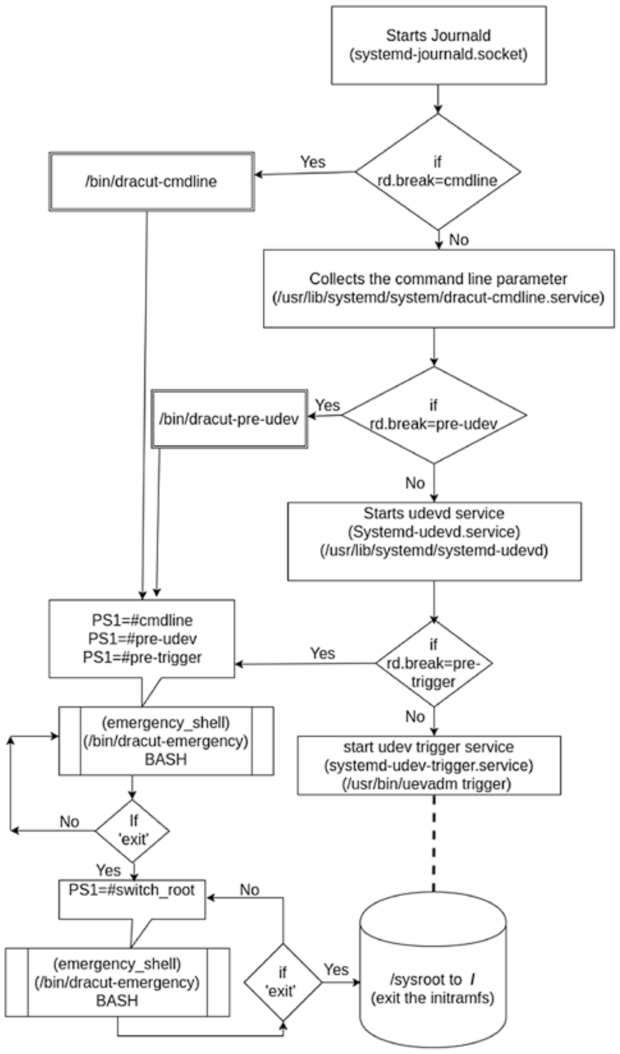


Figure 7-31. *The flowchart*

local-fs.target

As you can see in Figure 7-32, we have reached the `local-fs-target` stage of booting.

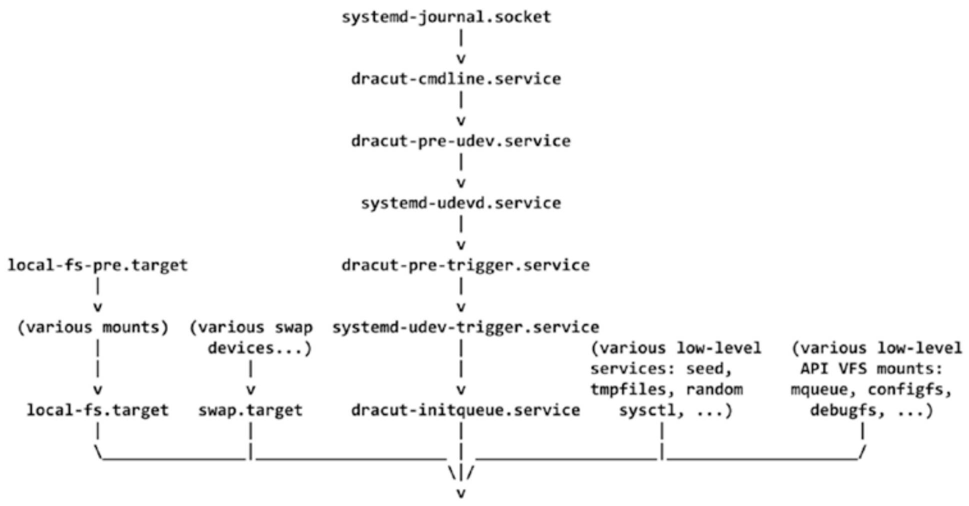

systemd-journal.socket
dracut-cmdline.service
dracut-pre-udev.service
systemd-udevd.service
local-fs-pre.target
dracut-pre-trigger.service
(various mounts)
(various swap devices...)
systemd-udev-trigger.service
(various low-level services: seed, tmpfiles, random sysctl, ...)
(various low-level API VFS mounts: mqueue, configfs, debugfs, ...)
local-fs.target
swap.target
dracut-initqueue.service

Figure 7-32. *The booting sequence covered so far*

So, systemd has reached up to `local-fs.target.` So far, systemd has been executing services one after another only because storage devices were not ready. Since the `udevadm` trigger was successful and storage devices have been populated, it's time to prepare the mount points, which will be achieved by `local-fs.target`. Before entering into `local-fs.target`, it will make sure to run the `local-fs.pre.target`.

```
# cat usr/lib/systemd/system/local-fs-pre.target

[Unit]
Description=Local File Systems (Pre)
Documentation=man:systemd.special(7)
RefuseManualStart=yes

#cat usr/lib/systemd/system/local-fs.target

[Unit]
Description=Local File Systems
Documentation=man:systemd.special(7)
DefaultDependencies=no
```

```
Conflicts=shutdown.target
After=local-fs-pre.target
OnFailure=emergency.target
OnFailureJobMode=replace-irreversibly
```

The `systemd-fstab-generator` will be navigated by `local-fs.target`.

man page - systemd.special

> *`systemd-fstab-generator(3)` automatically adds dependencies of type `Before=` to all mount units that refer to local mount points for this target unit. In addition, it adds dependencies of type `Wants=` to this target unit for those mounts listed in `/etc/fstab` that have the auto mount option set.*

The `systemd-fstab-generator` binary will be called from initramfs.

```
# file usr/lib/systemd/system-generators/systemd-fstab-generator

usr/lib/systemd/system-generators/systemd-fstab-generator: ELF 64-bit LSB
pie executable, x86-64, version 1 (SYSV), dynamically linked, interpreter /
lib64/ld-linux-x86-64.so.2, BuildID[sha1]=e16e9d4188e2cab491f551b5f703a5caa
645764b, for GNU/Linux 3.2.0, stripped
```

In fact, systemd runs all the generators at an early stage of the booting sequence.

```
# ls -l usr/lib/systemd/system-generators
    total 92
    -rwxr-xr-x. 1 root root  3750 Dec 21 12:19 dracut-rootfs-generator
    -rwxr-xr-x. 1 root root 45640 Dec 21 12:19 systemd-fstab-generator
    -rwxr-xr-x. 1 root root 37032 Dec 21 12:19 systemd-gpt-auto-generator
```

`systemd-fstab-generator` is one of them. The main task of `systemd-fstab-generator` is to read the kernel command line and create systemd mount unit files under the `/tmp` directory or under `/run/systemd/generator/` (keep reading, and this all will make sense). As you can see, it's a binary, which means we need to check the C source code of systemd to understand what it does. The `systemd-fstab-generator` takes either no input or three inputs.

```
# usr/lib/systemd/system-generators/systemd-fstab-generator /dev/sda5
This program takes zero or three arguments.
```

Of course, the three inputs are the root filesystem name, filesystem type, and root filesystem flag. While writing this book, the latest version of systemd is version 244, so we have used this for the explanation here. The previously shown error message comes from `src/shared/generator.h`.

```
# vim systemd-244/src/shared/generator.h
/* Similar to DEFINE_MAIN_FUNCTION, but initializes logging and assigns positional arguments. */
#define DEFINE_MAIN_GENERATOR_FUNCTION(impl)                            \
        _DEFINE_MAIN_FUNCTION(                                          \
                ({                                                      \
                        log_setup_generator();                          \
                        if (argc > 1 && argc != 4)                      \
                                return log_error_errno(SYNTHETIC_ERRNO(EINVAL), \
                                                "This program takes zero or three arguments."); \
                }),                                                     \
                impl(argc > 1 ? argv[1] : "/tmp",                       \
                     argc > 1 ? argv[2] : "/tmp",                       \
```

The systemd-fstab-generator binary is made from `src/fstab-generator/fstab-generator.c`.

```
# vim systemd-244/src/fstab-generator/fstab-generator.c

static int run(const char *dest, const char *dest_early, const char *dest_late) {
        int r, r2 = 0, r3 = 0;

        assert_se(arg_dest = dest);
        assert_se(arg_dest_late = dest_late);

        r = proc_cmdline_parse(parse_proc_cmdline_item, NULL, 0);
        if (r < 0)
```

```
                log_warning_errno(r, "Failed to parse kernel command
                line, ignoring: %m");

        (void) determine_root();

        /* Always honour root= and usr= in the kernel command line if
        we are in an initrd */
        if (in_initrd()) {
                r = add_sysroot_mount();

                r2 = add_sysroot_usr_mount();

                r3 = add_volatile_root();
        } else
                r = add_volatile_var();

        /* Honour /etc/fstab only when that's enabled */
        if (arg_fstab_enabled) {
                /* Parse the local /etc/fstab, possibly from the initrd */
                r2 = parse_fstab(false);

                /* If running in the initrd also parse the /etc/fstab
                from the host */
                if (in_initrd())
                        r3 = parse_fstab(true);
                else
                        r3 = generator_enable_remount_fs_service(arg_dest);
        }

        return r < 0 ? r : r2 < 0 ? r2 : r3;
}

DEFINE_MAIN_GENERATOR_FUNCTION(run);
```

As you can see, first it parses the command-line parameters through the function `proc_cmdline_parse`.

```
root        = root filesystem name
rootfstype  = root filesystem type
rootflags   = ro, rw or auto etc.
```

`systemd-fstab-generator` runs twice: when it is inside of initramfs and when it is outside of initramfs. Once systemd comes out of initramfs (after mounting the user's root filesystem in `sysroot`), `systemd-fstab-generator` will collect the command-line parameters for the usr filesystem (if it is a separate partition and if its entry is available in `etc/fstab`).

```
'usr' filesystem name
'usr' filesystem type
'usr' filesystem flags
```

For ease of understanding, we will consider the following:

```
Inside of initramfs:   Before mounting the user's root filesystem in /sysroot
Outside of initramfs:   After mounting the user's root filesystem in /sysroot
```

So, the `systemd-fstab-generator` binary will collect the user's root filesystem-related command-line parameters when systemd is running inside initramfs, and it will collect the usr filesystem-related command-line parameters when systemd is running outside of initramfs. systemd is running inside or outside of initramfs will be checked through the `in_initrd` function. The function is written in the file `src/basic/util.c.` It's interesting to check how it verifies whether it is inside or outside the initramfs environment.

```
# vim systemd-244/src/basic/util.c
bool in_initrd(void) {
        struct statfs s;
        int r;

        if (saved_in_initrd >= 0)
                return saved_in_initrd;

        /* We make two checks here:
         *
         * 1. the flag file /etc/initrd-release must exist
         * 2. the root file system must be a memory file system
         *
         * The second check is extra paranoia, since misdetecting an
         * initrd can have bad consequences due the initrd
         * emptying when transititioning to the main systemd.
         */

        r = getenv_bool_secure("SYSTEMD_IN_INITRD");
        if (r < 0 && r != -ENXIO)
                log_debug_errno(r, "Failed to parse $SYSTEMD_IN_INITRD, ignoring: %m");

        if (r >= 0)
                saved_in_initrd = r > 0;
        else
                saved_in_initrd = access("/etc/initrd-release", F_OK) >= 0 &&
                                  statfs("/", &s) >= 0 &&
                                  is_temporary_fs(&s);

        return saved_in_initrd;
}
```

It checks whether the `/etc/initrd-release` file is available. If this file is not present, it means we are outside of initramfs. This function then calls the `statfs` function, which will provide the filesystem details, as shown here:

```
struct statfs {
               __fsword_t f_type;    /* Type of filesystem (see below) */
               __fsword_t f_bsize;   /* Optimal transfer block size */
               fsblkcnt_t f_blocks;  /* Total data blocks in filesystem */
               fsblkcnt_t f_bfree;   /* Free blocks in filesystem */
               fsblkcnt_t f_bavail;  /* Free blocks available to
                                        unprivileged user */
```

```
            fsfilcnt_t f_files;   /* Total file nodes in filesystem */
            fsfilcnt_t f_ffree;   /* Free file nodes in filesystem */
            fsid_t     f_fsid;    /* Filesystem ID */
            __fsword_t f_namelen; /* Maximum length of filenames */
            __fsword_t f_frsize;  /* Fragment size (since Linux 2.6) */
            __fsword_t f_flags;   /* Mount flags of filesystem
                                     (since Linux 2.6.36) */
            __fsword_t f_spare[xxx];
                               /* Padding bytes reserved for future use */
        };
```

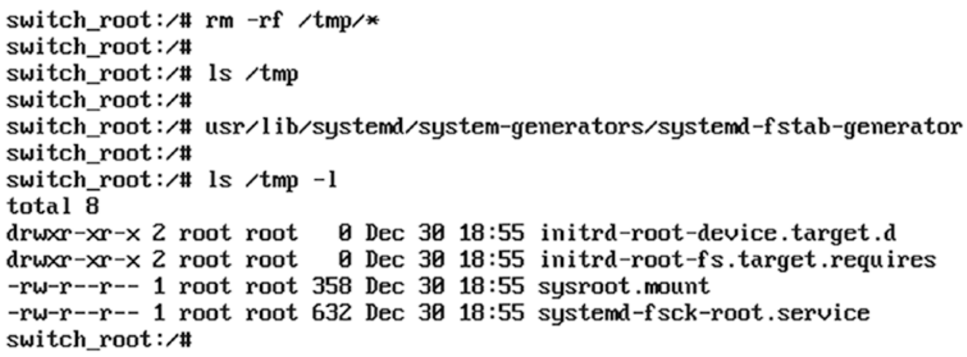
Then it calls the `is_temporary_fs()` function, which is written inside `/src/basic/stat-util.c`.

```
bool is_temporary_fs(const struct statfs *s) {
        return is_fs_type(s, TMPFS_MAGIC) ||
                is_fs_type(s, RAMFS_MAGIC);
}
```

As you can see, it checks whether the root filesystem has a ramfs magic number assigned to it. If yes, then we are inside initramfs. In our case, we are inside the initramfs environment, so this function will return `true` and will proceed further from `src/fstab-generator/fstab-generator.c` to create only the root filesystem's `-.mount` (`sysroot.mount`) unit files. If we had been outside of initramfs (after mounting `sysroot` with the user's root filesystem), it would have created a `-.mount` unit file for the usr filesystem. In short, first it checks if we are inside initramfs. If we are, then it creates the mount unit file for the root filesystem, and if we're outside, then it creates it for the usr (if it is a separate filesystem) filesystem. To see this in action, we will drop ourselves in the `switch_root` (hook) stage so that we are able to run the `systemd-fstab-generator` binary manually.

1) First I have deleted the `/tmp` directory contents. This is because the `fstab` generator makes the mount unit files inside `/tmp`.

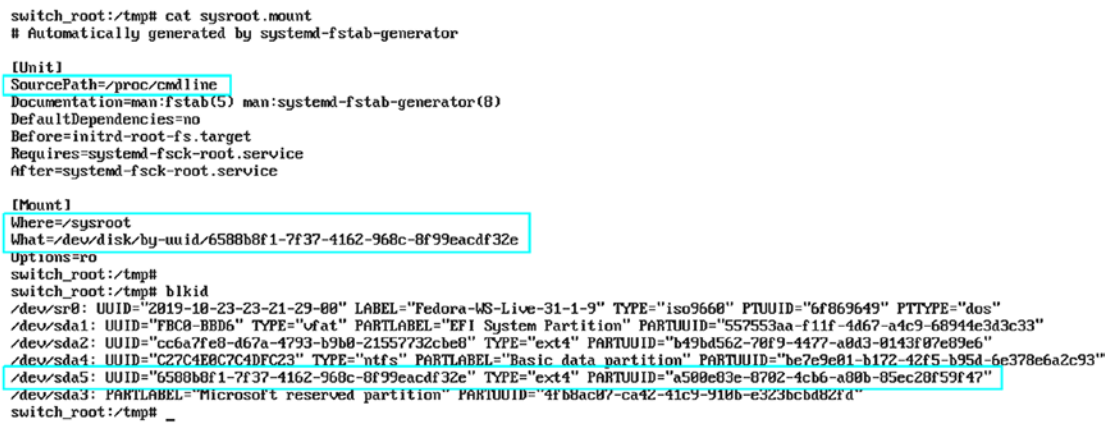
2) Run the `systemd-fstab-generator` binary, and as you can see in Figure 7-33, it has created a couple of files in `/tmp`.



```
switch_root:/# rm -rf /tmp/*
switch_root:/#
switch_root:/# ls /tmp
switch_root:/#
switch_root:/# usr/lib/systemd/system-generators/systemd-fstab-generator
switch_root:/#
switch_root:/# ls /tmp -l
total 8
drwxr-xr-x 2 root root   0 Dec 30 18:55 initrd-root-device.target.d
drwxr-xr-x 2 root root   0 Dec 30 18:55 initrd-root-fs.target.requires
-rw-r--r-- 1 root root 358 Dec 30 18:55 sysroot.mount
-rw-r--r-- 1 root root 632 Dec 30 18:55 systemd-fsck-root.service
switch_root:/#
```

Figure 7-33. *The systemd-fstab-generato0072*

3) It has created a `sysroot.mount` unit file. As the name suggests, it has been created to mount the user's root filesystem. The unit file has been created by reading `/proc/cmdline.` Please refer to Figure 7-34 to see the contents of `sysroot.mount` file.

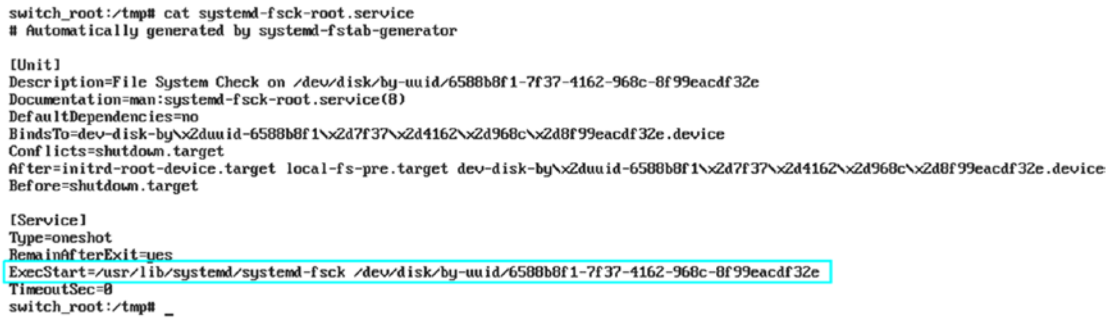


```
switch_root:/tmp# cat sysroot.mount
# Automatically generated by systemd-fstab-generator

[Unit]
SourcePath=/proc/cmdline
Documentation=man:fstab(5) man:systemd-fstab-generator(8)
DefaultDependencies=no
Before=initrd-root-fs.target
Requires=systemd-fsck-root.service
After=systemd-fsck-root.service

[Mount]
Where=/sysroot
What=/dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e
Options=ro
switch_root:/tmp#
switch_root:/tmp# blkid
/dev/sr0: UUID="2019-10-23-23-21-29-00" LABEL="Fedora-WS-Live-31-1-9" TYPE="iso9660" PTUUID="6f869649" PTTYPE="dos"
/dev/sda1: UUID="FBC0-BBD6" TYPE="vfat" PARTLABEL="EFI System Partition" PARTUUID="557553aa-f11f-4d67-a4c9-68944e3d3c33"
/dev/sda2: UUID="cc6a7fe8-d67a-4793-b9b0-21557732cbe8" TYPE="ext4" PARTUUID="b49bd562-70f9-4477-a0d3-0143f07e89e6"
/dev/sda4: UUID="C27C4E0C7C4DFC23" TYPE="ntfs" PARTLABEL="Basic data partition" PARTUUID="be7e9e01-b172-42f5-b95d-6e378e6a2c93"
/dev/sda5: UUID="6588b8f1-7f37-4162-968c-8f99eacdf32e" TYPE="ext4" PARTUUID="a500e83e-8702-4cb6-a80b-85ec28f59f47"
/dev/sda3: PARTLABEL="Microsoft reserved partition" PARTUUID="4fb8ac07-ca42-41c9-910b-e323bcbd82fd"
switch_root:/tmp# _
```

Figure 7-34. *The sysroot.mount file*

The root filesystem will be mounted from sda5 (by using the UUID) to the `sysroot` directory.

4) Check the `requires` section of the `sysroot.mount` unit file. It says `systemd-fsck-root.service` has to be executed first, before mounting the root filesystem. Figure 7-35 shows the `systemd-fsck-root.service` file.



```
switch_root:/tmp# cat systemd-fsck-root.service
# Automatically generated by systemd-fstab-generator

[Unit]
Description=File System Check on /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e
Documentation=man:systemd-fsck-root.service(8)
DefaultDependencies=no
BindsTo=dev-disk-by\x2duuid-6588b8f1\x2d7f37\x2d4162\x2d968c\x2d8f99eacdf32e.device
Conflicts=shutdown.target
After=initrd-root-device.target local-fs-pre.target dev-disk-by\x2duuid-6588b8f1\x2d7f37\x2d4162\x2d968c\x2d8f99eacdf32e.device
Before=shutdown.target

[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/lib/systemd/systemd-fsck /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e
TimeoutSec=0
switch_root:/tmp# _
```

Figure 7-35. *The systemd-fsck-root.service file contents*

So while booting, if you are inside initramfs, then `systemd-fstab-generator` will generate the mount unit files for the user's root filesystem, and the respective `fsck` service file will also be generated.

At the end of the initramfs booting sequence, systemd will refer to these files from the `/tmp` directory, will perform the `fsck` first on a root device, and will mount the root filesystem on sysroot (inside initramfs); eventually `switch_root` will be performed.

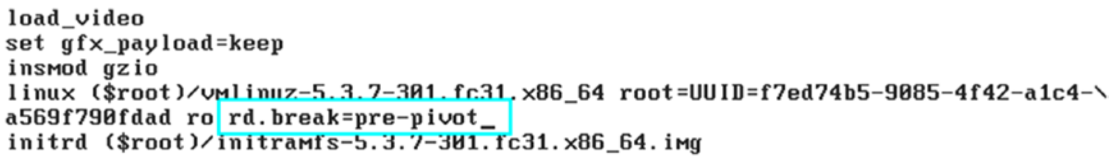
Now you must understand that though the binary name is `systemd-fstab-generator`, it does not really create the `/etc/fstab` file. Rather, its job is to create the systemd mount units for `root` (when inside initramfs) and `usr` (when outside of initramfs) at `/tmp` or inside the `run/systemd/generator/` directories. This system has only the `root` mount point, so it created the systemd unit files only for root filesystem. Inside initramfs, it calls `add_sysroot_mount` for mounting the user's root filesystem. Once it is mounted, the root filesystem systemd calls the `add_sysroot_usr_mount` function. These functions call the `add_mount` named function, which in turn makes the systemd mount unit files. The following is a snippet of the `add_mount` function from `src/fstab-generator/fstab-generator.c`:

```
# vim systemd-244/src/fstab-generator/fstab-generator.c
        r = unit_name_from_path(where, ".mount", &name);
           if (r < 0)
                   return log_error_errno(r, "Failed to generate unit
                   name: %m");

           r = generator_open_unit_file(dest, fstab_path(), name, &f);
           if (r < 0)
                   return r;

           fprintf(f,
                "[Unit]\n"
                "SourcePath=%s\n"
                "Documentation=man:fstab(5) man:systemd-fstab-generator(8)\n",
                source);

        /* All mounts under /sysroot need to happen later, at initrd-fs.target time. IOW, it's not
         * technically part of the basic initrd filesystem itself, and so shouldn't inherit the default
         * Before=local-fs.target dependency. */
        if (in_initrd() && path_startswith(where, "/sysroot"))
                fprintf(f, "DefaultDependencies=no\n");
```

The current system has only a root partition. To help you understand this even better, here I have prepared a test system that has `root`, `boot`, `usr`, `var`, and `opt` as separate filesystems:

```
UUID = f7ed74b5-9085-4f42-a1c4-a569f790fdad    /       ext4   defaults    1  1
UUID = 06609f65-5818-4aee-a9c5-710b76b36c68    /boot   ext4   defaults    1  2
UUID = 68fa7990-edf9-4a03-9011-21903a676322    /opt    ext4   defaults    1  2
UUID = 6fa78ab3-6c05-4a2f-9907-31be6d2a1071    /usr    ext4   defaults    1  2
UUID = 9c721a59-b62d-4d60-9988-adc8ed9e8770    /var    ext4   defaults    1  2
```

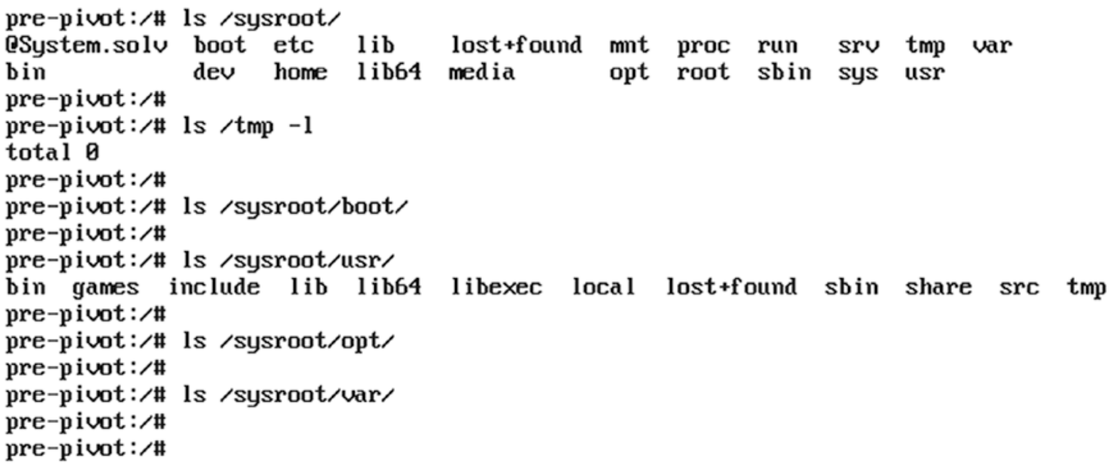
We will drop ourselves in the `pre-pivot` shell (which we have not discussed yet) of initramfs. Figure 7-36 shows that we have passed the `rd.break=pre-pivot` command-line parameter to the kernel.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=UUID=f7ed74b5-9085-4f42-a1c4-\
a569f790fdad ro rd.break=pre-pivot_
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 7-36. *The kernel command-line parameter*

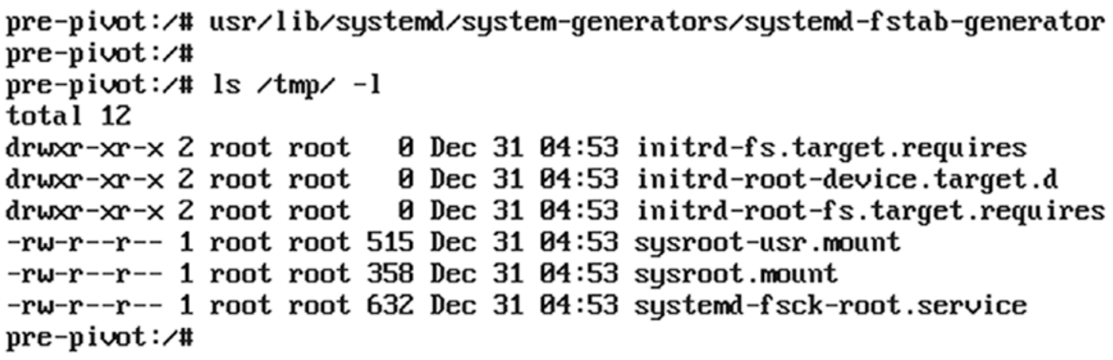
As you can see in Figure 7-37, in the `pre-pivot` hook, the `root` filesystem will be mounted along with the `usr` filesystem since the `pre-pivot` hook stops the booting sequence after mounting the user's root filesystem on `sysroot`. But `opt`, `var`, and `boot` will not be mounted.



```
pre-pivot:/# ls /sysroot/
@System.solv  boot  etc   lib    lost+found  mnt  proc  run   srv  tmp  var
bin           dev   home  lib64  media       opt  root  sbin  sys  usr
pre-pivot:/#
pre-pivot:/# ls /tmp -l
total 0
pre-pivot:/#
pre-pivot:/# ls /sysroot/boot/
pre-pivot:/#
pre-pivot:/# ls /sysroot/usr/
bin  games  include  lib  lib64  libexec  local  lost+found  sbin  share  src  tmp
pre-pivot:/#
pre-pivot:/# ls /sysroot/opt/
pre-pivot:/#
pre-pivot:/# ls /sysroot/var/
pre-pivot:/#
pre-pivot:/#
```

Figure 7-37. *The pre-pivot hook*

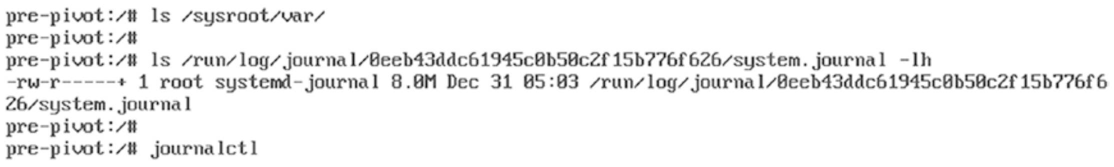
Even if you run `systemd-fstab-generator`, you will find that only the `usr` and `root` mount unit files will be created. You can see the `systemd-fstab-generator` output in Figure 7-38.



```
pre-pivot:/# usr/lib/systemd/system-generators/systemd-fstab-generator
pre-pivot:/#
pre-pivot:/# ls /tmp/ -l
total 12
drwxr-xr-x 2 root root   0 Dec 31 04:53 initrd-fs.target.requires
drwxr-xr-x 2 root root   0 Dec 31 04:53 initrd-root-device.target.d
drwxr-xr-x 2 root root   0 Dec 31 04:53 initrd-root-fs.target.requires
-rw-r--r-- 1 root root 515 Dec 31 04:53 sysroot-usr.mount
-rw-r--r-- 1 root root 358 Dec 31 04:53 sysroot.mount
-rw-r--r-- 1 root root 632 Dec 31 04:53 systemd-fsck-root.service
pre-pivot:/#
```

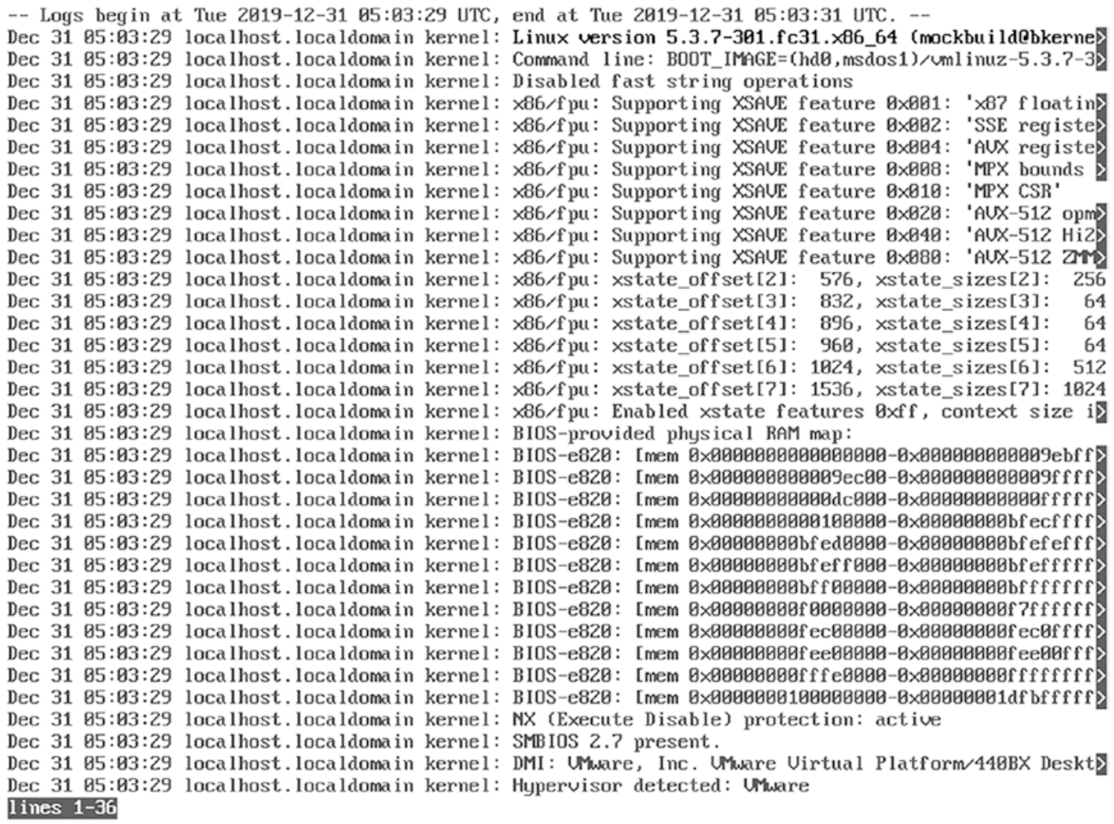
Figure 7-38. *The systemd-fstab-generator in pre-pivot hook*

This proves that in an initramfs environment, only `root` and `usr` will be mounted. The rest of the mount points will be mounted after initramfs or after switching to root. Since the `var` filesystem is not mounted yet, the `journalctl` logs will be maintained from the `/run` filesystem, and as we know, this is a temporary filesystem. This clearly says that inside the initramfs environment, you cannot access the permanent logs of journald, which are at `/var/log`. Please refer to Figures 7-39, 7-40, and 7-41 to understand this better.



```
pre-pivot:/# ls /sysroot/var/
pre-pivot:/#
pre-pivot:/# ls /run/log/journal/0eeb43ddc61945c0b50c2f15b776f626/system.journal -lh
-rw-r-----+ 1 root systemd-journal 8.0M Dec 31 05:03 /run/log/journal/0eeb43ddc61945c0b50c2f15b776f6
26/system.journal
pre-pivot:/#
pre-pivot:/# journalctl
```

Figure 7-39. *The journalctl command in pre-pivot hook*



```
-- Logs begin at Tue 2019-12-31 05:03:29 UTC, end at Tue 2019-12-31 05:03:31 UTC. --
Dec 31 05:03:29 localhost.localdomain kernel: Linux version 5.3.7-301.fc31.x86_64 (mockbuild@bkerne>
Dec 31 05:03:29 localhost.localdomain kernel: Command line: BOOT_IMAGE=(hd0,msdos1)/vmlinuz-5.3.7-3>
Dec 31 05:03:29 localhost.localdomain kernel: Disabled fast string operations
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x001: 'x87 floatin>
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x002: 'SSE registe>
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x004: 'AVX registe>
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x008: 'MPX bounds >
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x010: 'MPX CSR'
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x020: 'AVX-512 opm>
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x040: 'AVX-512 Hi2>
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Supporting XSAVE feature 0x080: 'AVX-512 ZMM>
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: xstate_offset[2]:  576, xstate_sizes[2]:  256
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: xstate_offset[3]:  832, xstate_sizes[3]:   64
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: xstate_offset[4]:  896, xstate_sizes[4]:   64
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: xstate_offset[5]:  960, xstate_sizes[5]:   64
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: xstate_offset[6]: 1024, xstate_sizes[6]:  512
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: xstate_offset[7]: 1536, xstate_sizes[7]: 1024
Dec 31 05:03:29 localhost.localdomain kernel: x86/fpu: Enabled xstate features 0xff, context size i>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-provided physical RAM map:
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x0000000000000000-0x000000000009ebff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x000000000009ec00-0x000000000009ffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000000dc000-0x00000000000fffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x0000000000100000-0x00000000bfecffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000bfed0000-0x00000000bfefefff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000bfeff000-0x00000000bfefffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000bff00000-0x00000000bfffffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000f0000000-0x00000000f7ffffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000fec00000-0x00000000fec0ffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000fee00000-0x00000000fee00fff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x00000000fffe0000-0x00000000ffffffff>
Dec 31 05:03:29 localhost.localdomain kernel: BIOS-e820: [mem 0x0000000100000000-0x00000001dfbfffff>
Dec 31 05:03:29 localhost.localdomain kernel: NX (Execute Disable) protection: active
Dec 31 05:03:29 localhost.localdomain kernel: SMBIOS 2.7 present.
Dec 31 05:03:29 localhost.localdomain kernel: DMI: VMware, Inc. VMware Virtual Platform/440BX Deskt>
Dec 31 05:03:29 localhost.localdomain kernel: Hypervisor detected: VMware
lines 1-36
```

Figure 7-40. *The logs provided by journalctl from /run*

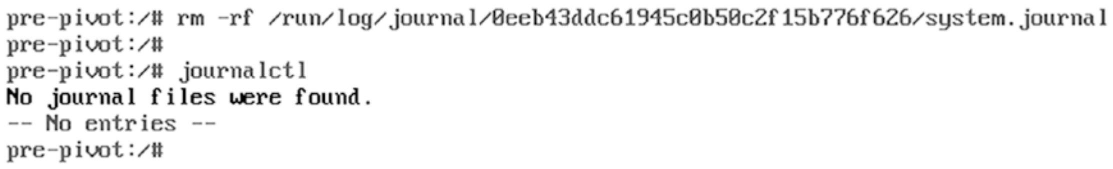

```
pre-pivot:/# rm -rf /run/log/journal/0eeb43ddc61945c0b50c2f15b776f626/system.journal
pre-pivot:/#
pre-pivot:/# journalctl
No journal files were found.
-- No entries --
pre-pivot:/#
```

Figure 7-41. *The journalctl behavior in pre-pivot hook*

Did you notice one thing? The `dracut-cmdline` service is reading the kernel command-line parameters, and the `usr`-related command-line parameters are not available in `/proc/cmdline`. So, how does systemd manage to mount the `usr` filesystem? Also, at the time of initramfs generation, dracut does not copy the `etc/fstab` file in it.

```
# lsinitrd | grep -i fstab
-rw-r--r--  1 root root       0 Jul 25 03:54 etc/fstab.empty
-rwxr-xr-x  1 root root   45640 Jul 25 03:54 usr/lib/systemd/system-
generators/systemd-fstab-generator
```

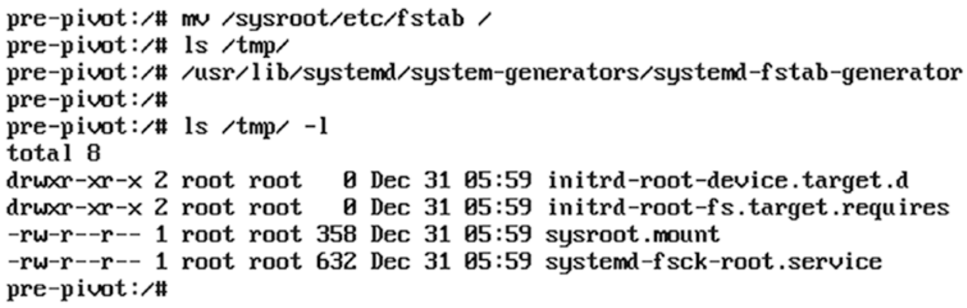
```
# lsinitrd -f etc/fstab.empty
      <no_output>
```

Then how does systemd manage to mount the `usr` filesystem inside initramfs when it does not have an entry of it?

When `systemd-fstab-generator` runs during `local-fs.target`, it makes the mount unit files only for root; then it continues the booting sequence and mounts the root file system on `sysroot`. Once the root filesystem is mounted, it reads the `usr` entry from `/etc/sysroot/etc/fstab` and makes a `usr.mount` unit file and at the end mounts it. Let's cross-verify this understanding:

1) Drop in the `pre-pivot` hook.
2) Delete the `/etc/fstab` from the mounted `/sysroot.`
3) Run the `systemd-fstab-generator.`
4) Refer to Figure 7-42.

Since the `root` filesystem name will be fetched by `dracut-cmdline` from `proc/cmdline, systemd-fstab-generator` will make the `sysroot.mount`. But since the `fstab` file is missing inside `sysroot`, it will consider the `usr` as an separate partition that is not available, and it will skip creating the `usr.mount` unit file even though `usr` is a separate mount point.



```
pre-pivot:/# mv /sysroot/etc/fstab /
pre-pivot:/# ls /tmp/
pre-pivot:/# /usr/lib/systemd/system-generators/systemd-fstab-generator
pre-pivot:/#
pre-pivot:/# ls /tmp/ -l
total 8
drwxr-xr-x 2 root root   0 Dec 31 05:59 initrd-root-device.target.d
drwxr-xr-x 2 root root   0 Dec 31 05:59 initrd-root-fs.target.requires
-rw-r--r-- 1 root root 358 Dec 31 05:59 sysroot.mount
-rw-r--r-- 1 root root 632 Dec 31 05:59 systemd-fsck-root.service
pre-pivot:/#
```

Figure 7-42. *The systemd-fstab-generator behavior*

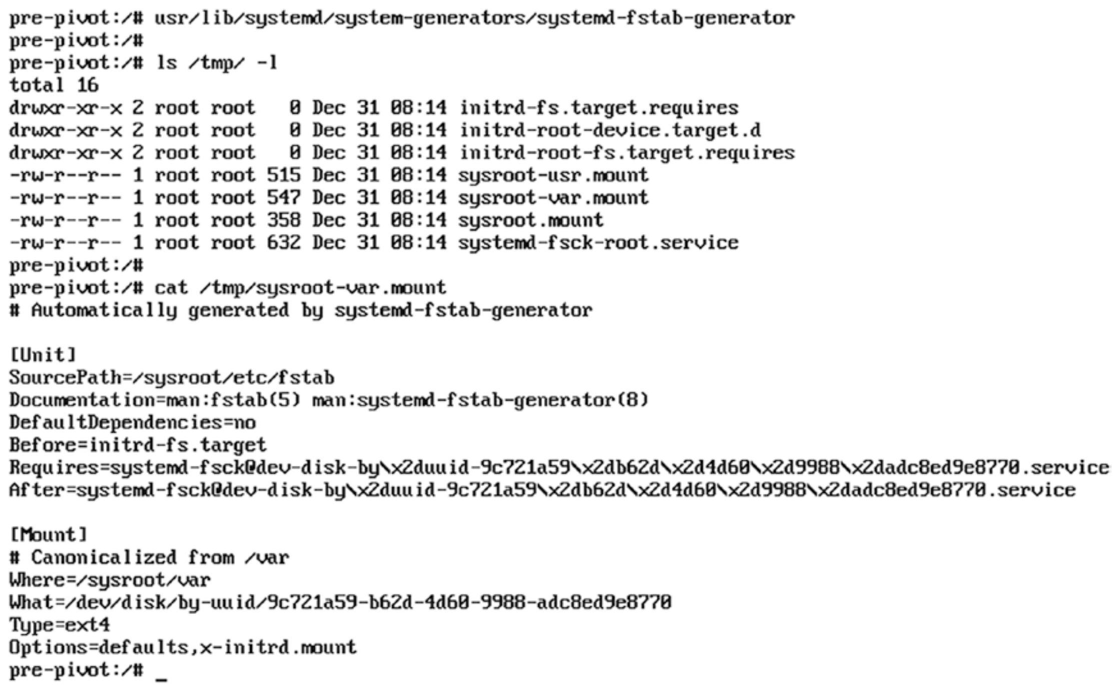
What if you want to have `opt`- and `var`-like separate mount points available inside `/sysroot` or you want them in an initramfs environment? systemd's man page has an answer for this, shown here:

> *x-initrd.mount*
>
> *An additional filesystem to be mounted in the initramfs. See the `initrd-fs.target` description in `systemd.special(7)`.*
>
> *initrd-fs.target*
>
> *`systemd-fstab-generator(3)` automatically adds dependencies of type `Before=` to `sysroot-usr.mount` and all mount points found in `/etc/fstab` that have `x-initrd.mount` and not have the `noauto` mount options set.*

So, we need to use the `x-initrd.mount [systemd.mount]` option in `/etc/fstab`. For example, here I have enabled the `var` mount point inside initramfs through the same `pre-pivot` environment:

```
pre-pivot:/# vi /sysroot/etc/fstab

UUID=f7ed74b5-9085-4f42-a1c4-a569f790fdad  /      ext4  defaults    1  1
UUID=06609f65-5818-4aee-a9c5-710b76b36c68  /boot  ext4  defaults    1  2
UUID=68fa7990-edf9-4a03-9011-21903a676322  /opt   ext4  defaults    1  2
UUID=6fa78ab3-6c05-4a2f-9907-31be6d2a1071  /usr   ext4  defaults    1  2
UUID=9c721a59-b62d-4d60-9988-adc8ed9e8770  /var   ext4  defaults,x-initrd.
mount   1  2
```

As you can see in Figure 7-43, the `var` mount unit file has been created, but `fsck` is available only for the `root` filesystem. Please refer to the flowchart in Figure 7-44 to help you understand this better.



```
pre-pivot:/# usr/lib/systemd/system-generators/systemd-fstab-generator
pre-pivot:/#
pre-pivot:/# ls /tmp/ -l
total 16
drwxr-xr-x 2 root root   0 Dec 31 08:14 initrd-fs.target.requires
drwxr-xr-x 2 root root   0 Dec 31 08:14 initrd-root-device.target.d
drwxr-xr-x 2 root root   0 Dec 31 08:14 initrd-root-fs.target.requires
-rw-r--r-- 1 root root 515 Dec 31 08:14 sysroot-usr.mount
-rw-r--r-- 1 root root 547 Dec 31 08:14 sysroot-var.mount
-rw-r--r-- 1 root root 358 Dec 31 08:14 sysroot.mount
-rw-r--r-- 1 root root 632 Dec 31 08:14 systemd-fsck-root.service
pre-pivot:/#
pre-pivot:/# cat /tmp/sysroot-var.mount
# Automatically generated by systemd-fstab-generator

[Unit]
SourcePath=/sysroot/etc/fstab
Documentation=man:fstab(5) man:systemd-fstab-generator(8)
DefaultDependencies=no
Before=initrd-fs.target
Requires=systemd-fsck@dev-disk-by\x2duuid-9c721a59\x2db62d\x2d4d60\x2d9988\x2dadc8ed9e8770.service
After=systemd-fsck@dev-disk-by\x2duuid-9c721a59\x2db62d\x2d4d60\x2d9988\x2dadc8ed9e8770.service

[Mount]
# Canonicalized from /var
Where=/sysroot/var
What=/dev/disk/by-uuid/9c721a59-b62d-4d60-9988-adc8ed9e8770
Type=ext4
Options=defaults,x-initrd.mount
pre-pivot:/# _
```

Figure 7-43. *The working of systemd-fstab-generator*

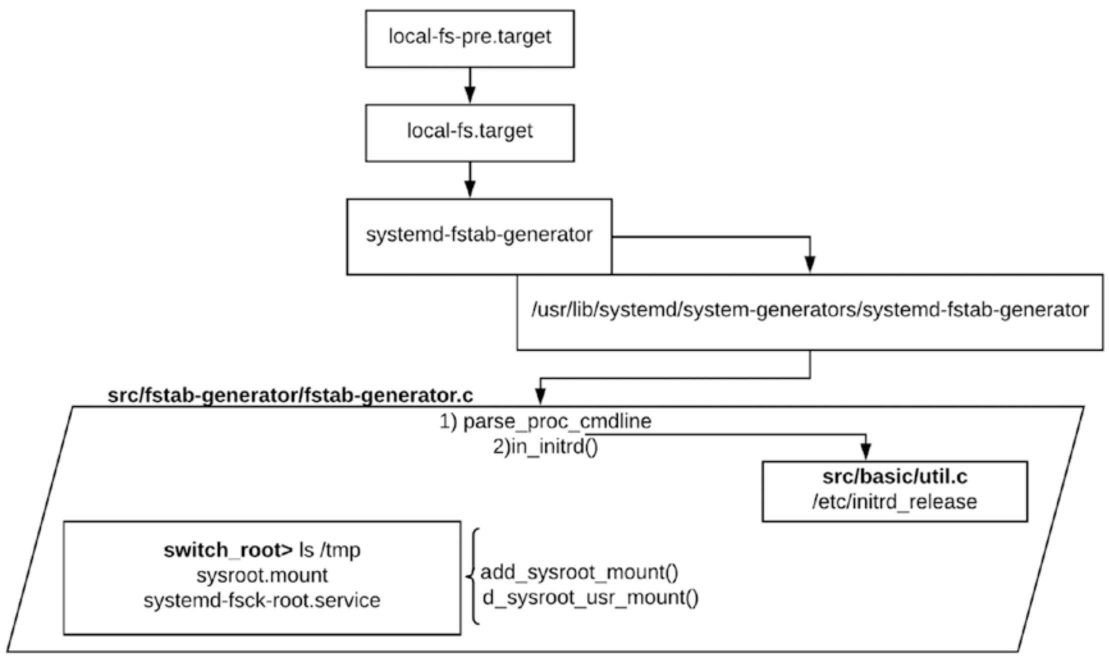
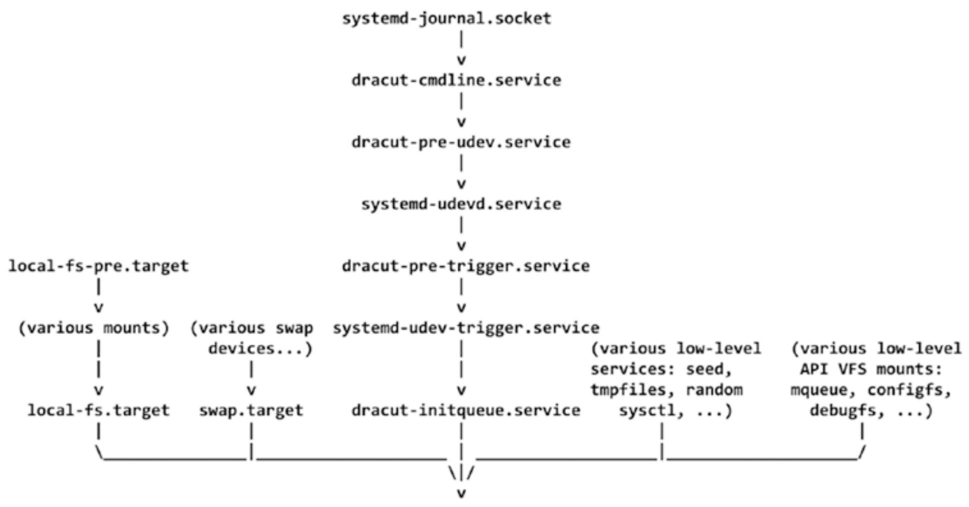


Figure 7-44. *The flowchart*

swap.target

As you can see in Figure 7-45, we have reached the `swap.target` stage of booting.



```
                                 systemd-journal.socket
                                          |
                                          v
                                  dracut-cmdline.service
                                          |
                                          v
                                  dracut-pre-udev.service
                                          |
                                          v
                                   systemd-udevd.service
                                          |
                                          v
local-fs-pre.target              dracut-pre-trigger.service
         |                                |
         v                                v
 (various mounts)  (various swap  systemd-udev-trigger.service
         |           devices...)          |             (various low-level   (various low-level
         |               |                |             services: seed,       API VFS mounts:
         v               v                v             tmpfiles, random     mqueue, configfs,
  local-fs.target   swap.target     dracut-initqueue.service    sysctl, ...)      debugfs, ...)
         |               |                |                    |                    |
         \_______________|________________ | ___________________|____________________/
                                         \|/
                                          v
```

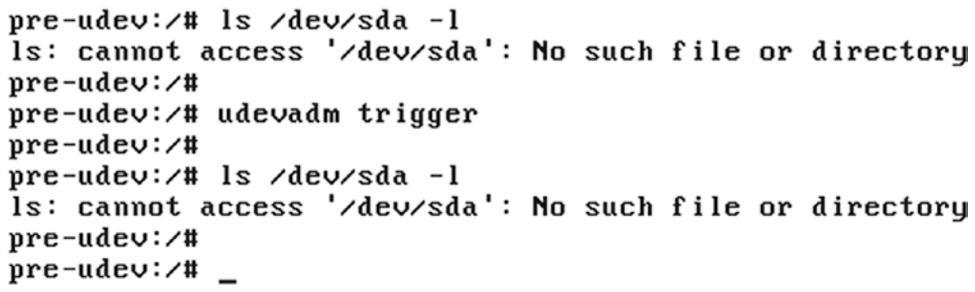
__Figure 7-45.__ The booting sequence so far

This will execute parallel to `local-fs.target`. `local-fs-.target` makes the mount points for `root` and `usr`, whereas `swap.target` makes the mount unit files for the swap device. Once the root filesystem mount file is ready, `sysroot` is mounted according to it. `systemd-fstab-generator` will read the `fstab`, and if the swap device entry is present, it will make the `swap.mount` unit file. That means the `swap.mount` file will be created only after switching into the user's root filesystem (`switch_root` into `sysroot`). The `swap.mount` will not be created at this stage.

dracut-initqueue.service

This service creates the actual `root`, `swap`, and `usr` devices. Let's understand this with an example.

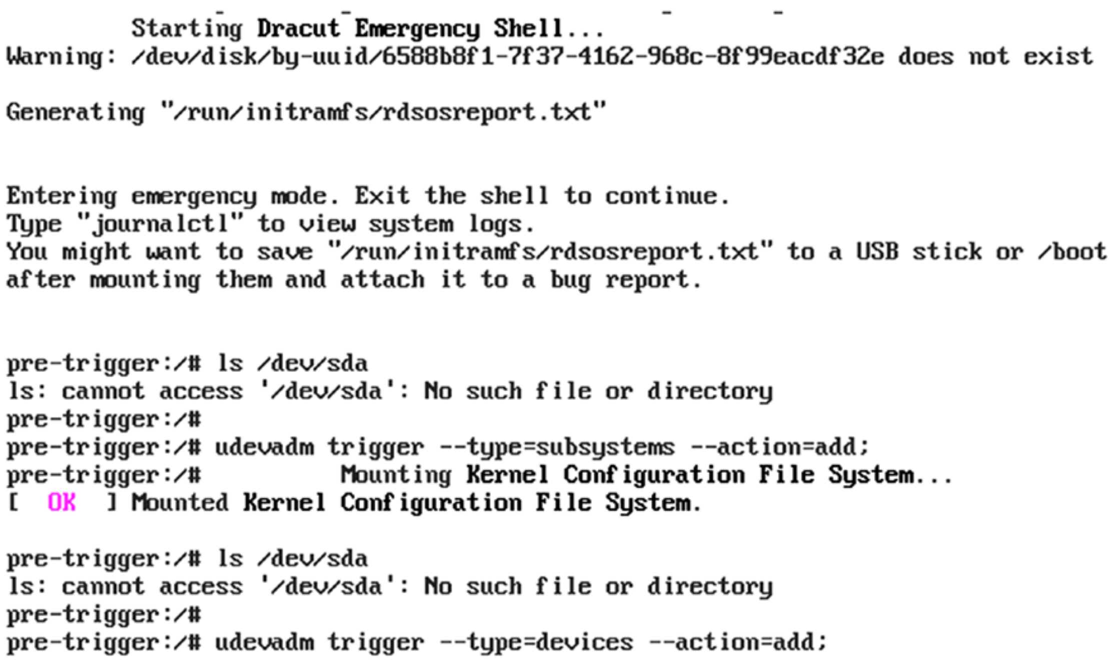
With the `pre-udev` hook, we have seen that sda-like devices are not available. Neither `udevadm` command will work as the `udevd` service itself is not started yet. Refer to Figure 7-46.



```
pre-udev:/# ls /dev/sda -l
ls: cannot access '/dev/sda': No such file or directory
pre-udev:/#
pre-udev:/# udevadm trigger
pre-udev:/#
pre-udev:/# ls /dev/sda -l
ls: cannot access '/dev/sda': No such file or directory
pre-udev:/#
pre-udev:/# _
```

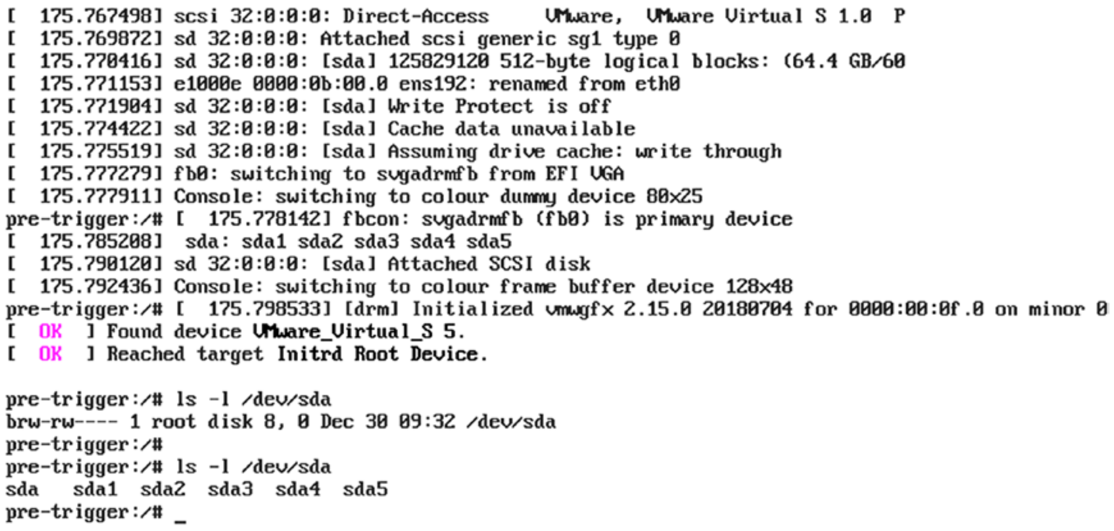
Figure 7-46. *The working of the pre-udev hook*

With the `pre-trigger` hook, the sda device is not created, but the `udevd` service has been started; hence, as you can see in Figure 7-47 and Figure 7-48, you can use a `udevadm`-like tool, which will create the `sda` device under `/dev`, but it will not create `lvm` or `raid`-like devices on it. Such devices are also called `dm` (device mapper) devices. So, the `pre-trigger` service will not be able to make the device files for the root if it is on `lvm`, and therefore the devices like `/dev/fedora_localhost-live/` will not be created.



```
         Starting Dracut Emergency Shell...
Warning: /dev/disk/by-uuid/6588b8f1-7f37-4162-968c-8f99eacdf32e does not exist

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


pre-trigger:/# ls /dev/sda
ls: cannot access '/dev/sda': No such file or directory
pre-trigger:/#
pre-trigger:/# udevadm trigger --type=subsystems --action=add;
pre-trigger:/#          Mounting Kernel Configuration File System...
[  OK  ] Mounted Kernel Configuration File System.

pre-trigger:/# ls /dev/sda
ls: cannot access '/dev/sda': No such file or directory
pre-trigger:/#
pre-trigger:/# udevadm trigger --type=devices --action=add;
```

Figure 7-47. *The pre-trigger hook*



```
[  175.767498] scsi 32:0:0:0: Direct-Access     VMware,  VMware Virtual S 1.0  P
[  175.769872] sd 32:0:0:0: Attached scsi generic sg1 type 0
[  175.770416] sd 32:0:0:0: [sda] 125829120 512-byte logical blocks: (64.4 GB/60
[  175.771153] e1000e 0000:0b:00.0 ens192: renamed from eth0
[  175.771904] sd 32:0:0:0: [sda] Write Protect is off
[  175.774422] sd 32:0:0:0: [sda] Cache data unavailable
[  175.775519] sd 32:0:0:0: [sda] Assuming drive cache: write through
[  175.777279] fb0: switching to svgadrmfb from EFI VGA
[  175.777911] Console: switching to colour dummy device 80x25
pre-trigger:/# [  175.778142] fbcon: svgadrmfb (fb0) is primary device
[  175.785208]  sda: sda1 sda2 sda3 sda4 sda5
[  175.790120] sd 32:0:0:0: [sda] Attached SCSI disk
[  175.792436] Console: switching to colour frame buffer device 128x48
pre-trigger:/# [  175.798533] [drm] Initialized vmwgfx 2.15.0 20180704 for 0000:00:0f.0 on minor 0
[  OK  ] Found device VMware_Virtual_S 5.
[  OK  ] Reached target Initrd Root Device.

pre-trigger:/# ls -l /dev/sda
brw-rw---- 1 root disk 8, 0 Dec 30 09:32 /dev/sda
pre-trigger:/#
pre-trigger:/# ls -l /dev/sda
sda   sda1  sda2  sda3  sda4  sda5
pre-trigger:/# _
```

Figure 7-48. *The sda devices have been created under the pre-trigger hook*

The service `dracut-initqueue.service` has not started yet. Let's see first what exactly the unit file says.

```
# cat usr/lib/systemd/system/dracut-initqueue.service | grep -v '#'

[Unit]
Description=dracut initqueue hook
Documentation=man:dracut-initqueue.service(8)
DefaultDependencies=no
Before=remote-fs-pre.target
Wants=remote-fs-pre.target
After=systemd-udev-trigger.service
Wants=systemd-udev-trigger.service
ConditionPathExists=/usr/lib/initrd-release
ConditionPathExists=|/lib/dracut/need-initqueue
ConditionKernelCommandLine=|rd.break=initqueue
Conflicts=shutdown.target emergency.target

[Service]
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
Type=oneshot
```

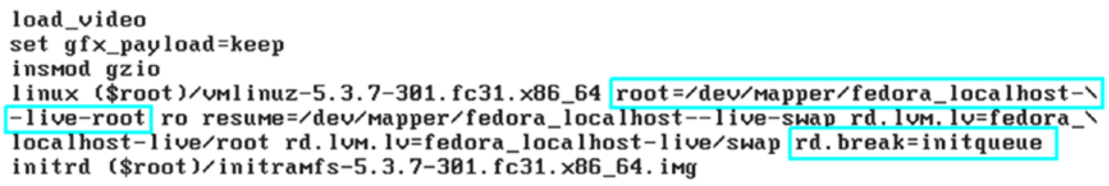
```
ExecStart=-/bin/dracut-initqueue
StandardInput=null
StandardOutput=syslog
StandardError=syslog+console
KillMode=process
RemainAfterExit=yes
KillSignal=SIGHUP
```

As you can see, this service is simply starting the `/bin/dracut-initqueue` script, and if we open this script, you will find it is actually executing the `udevadm settle` command with a `timeout` value of 0.

```
# vim bin/dracut-initqueue
while :; do

    check_finished && break

    udevadm settle --exit-if-exists=$hookdir/initqueue/work

    check_finished && break

    if [ -f $hookdir/initqueue/work ]; then
        rm -f -- "$hookdir/initqueue/work"
    fi

    for job in $hookdir/initqueue/*.sh; do
        [ -e "$job" ] || break
        job=$job . $job
        check_finished && break 2
    done

    udevadm settle --timeout=0 >/dev/null 2>&1 || continue

    for job in $hookdir/initqueue/settled/*.sh; do
        [ -e "$job" ] || break
        job=$job . $job
```

```
            check_finished && break 2
        done

        udevadm settle --timeout=0 >/dev/null 2>&1 || continue

        # no more udev jobs and queues empty.
        sleep 0.5
```

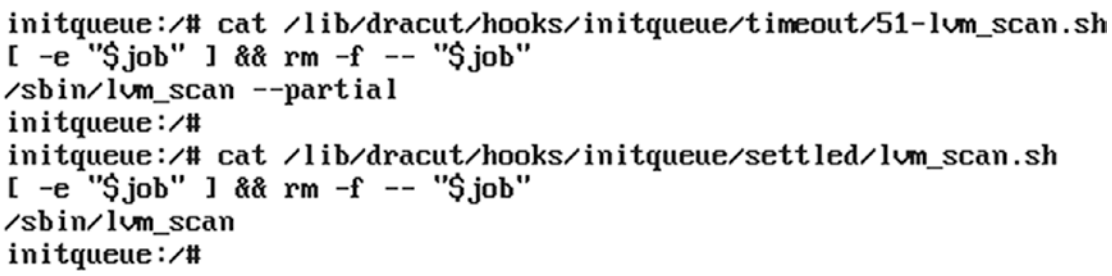
This will eventually run the `lvm_scan` command from `lib/dracut/hooks/initqueue/timeout/`. Note the `root` and `rd.break` kernel command-line parameters that are passed in Figure 7-49.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/fedora_localhost-\
-live-root ro resume=/dev/mapper/fedora_localhost--live-swap rd.lvm.lv=fedora_\
localhost-live/root rd.lvm.lv=fedora_localhost-live/swap rd.break=initqueue
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 7-49. *The kernel command-line parameters*

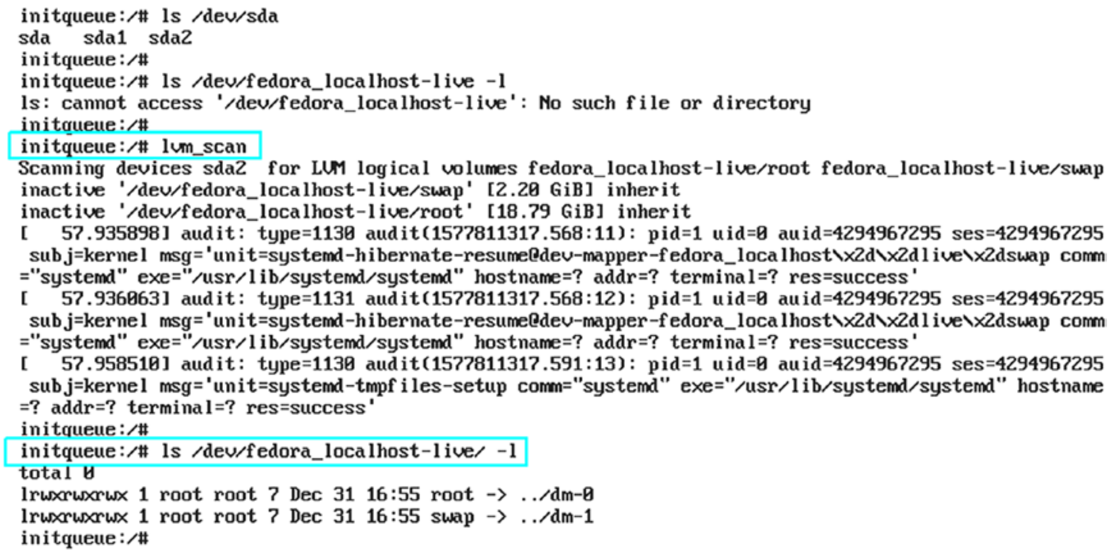
As you can see in Figure 7-50, the `lvm_scan` command is written in one of the files.



```
initqueue:/# cat /lib/dracut/hooks/initqueue/timeout/51-lvm_scan.sh
[ -e "$job" ] && rm -f -- "$job"
/sbin/lvm_scan --partial
initqueue:/#
initqueue:/# cat /lib/dracut/hooks/initqueue/settled/lvm_scan.sh
[ -e "$job" ] && rm -f -- "$job"
/sbin/lvm_scan
initqueue:/#
```

Figure 7-50. *The initqueue hook*

So, here we have two options: either we can just execute `/bin/dracut-initqueue` or, as shown in Figure 7-51, we can execute the `lvm_scan` command either from the `pre-trigger` hook or from the `initqueue` hook.



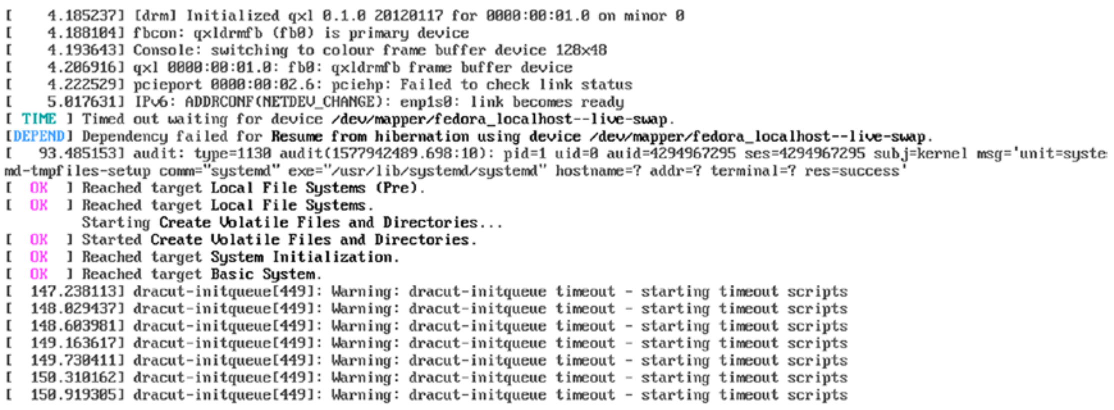
```
initqueue:/# ls /dev/sda
sda   sda1  sda2
initqueue:/#
initqueue:/# ls /dev/fedora_localhost-live -l
ls: cannot access '/dev/fedora_localhost-live': No such file or directory
initqueue:/#
initqueue:/# lvm_scan
Scanning devices sda2  for LVM logical volumes fedora_localhost-live/root fedora_localhost-live/swap
inactive '/dev/fedora_localhost-live/swap' [2.20 GiB] inherit
inactive '/dev/fedora_localhost-live/root' [18.79 GiB] inherit
[   57.935898] audit: type=1130 audit(1577811317.568:11): pid=1 uid=0 auid=4294967295 ses=4294967295
 subj=kernel msg='unit=systemd-hibernate-resume@dev-mapper-fedora_localhost\x2d\x2dlive\x2dswap comm
="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[   57.936063] audit: type=1131 audit(1577811317.568:12): pid=1 uid=0 auid=4294967295 ses=4294967295
 subj=kernel msg='unit=systemd-hibernate-resume@dev-mapper-fedora_localhost\x2d\x2dlive\x2dswap comm
="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[   57.958510] audit: type=1130 audit(1577811317.591:13): pid=1 uid=0 auid=4294967295 ses=4294967295
 subj=kernel msg='unit=systemd-tmpfiles-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname
=? addr=? terminal=? res=success'
initqueue:/#
initqueue:/# ls /dev/fedora_localhost-live/ -l
total 0
lrwxrwxrwx 1 root root 7 Dec 31 16:55 root -> ../dm-0
lrwxrwxrwx 1 root root 7 Dec 31 16:55 swap -> ../dm-1
initqueue:/#
```

Figure 7-51. *The lvm_scan command in the initqueue hook*

Since we have discussed up to the LVM part of initramfs, it is the right time to see one of the most common and crucial "can't boot" issue.

"Can't Boot" Issue 7 (systemd + Root LVM)

Issue: We changed the standard root device name from `/dev/mapper/fedora_localhost--live-root` to `/dev/mapper/root_vg-root`. We made the appropriate entry in `/etc/fstab`, but after rebooting, the system is not able to boot. Figure 7-52 shows what is visible on the screen.



```
[    4.185237] [drm] Initialized qxl 0.1.0 20120117 for 0000:00:01.0 on minor 0
[    4.188104] fbcon: qxldrmfb (fb0) is primary device
[    4.193643] Console: switching to colour frame buffer device 128x48
[    4.206916] qxl 0000:00:01.0: fb0: qxldrmfb frame buffer device
[    4.222529] pcieport 0000:00:02.6: pciehp: Failed to check link status
[    5.017631] IPv6: ADDRCONF(NETDEV_CHANGE): enp1s0: link becomes ready
[ TIME ] Timed out waiting for device /dev/mapper/fedora_localhost--live-swap.
[DEPEND] Dependency failed for Resume from hibernation using device /dev/mapper/fedora_localhost--live-swap.
[   93.485153] audit: type=1130 audit(1577942489.698:10): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=syste
md-tmpfiles-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[  OK  ] Reached target Local File Systems (Pre).
[  OK  ] Reached target Local File Systems.
         Starting Create Volatile Files and Directories...
[  OK  ] Started Create Volatile Files and Directories.
[  OK  ] Reached target System Initialization.
[  OK  ] Reached target Basic System.
[  147.238113] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  148.029437] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  148.603981] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  149.163617] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  149.730411] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  150.310162] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
[  150.919305] dracut-initqueue[449]: Warning: dracut-initqueue timeout - starting timeout scripts
```

Figure 7-52. *The console messages*

Since we have a better understanding of `dracut-initqueue` now, we can see that the error messages clearly mean systemd is not able to assemble the `root lvm` device.

1. Let's isolate the issue first by recalling the performed steps. The original `root lv` name is as follows:

    ```
    #cat /etc/fstab

    /dev/mapper/fedora_localhost--live-root     /
    ext4  defaults 1  1
    UUID=eea3d947-0618-4d8c-b083-87daf15b2679  /boot  ext4  defaults 1  2
    /dev/mapper/fedora_localhost--live-
    swap        none   ext4  defaults 0  0
    ```

2. The `root volume group` name has been changed.

    ```
    # vgrename  fedora_localhost-live  root_vg

    The volume group Fedora_localhost-live was successfully renamed to
    root_vg.
    ```

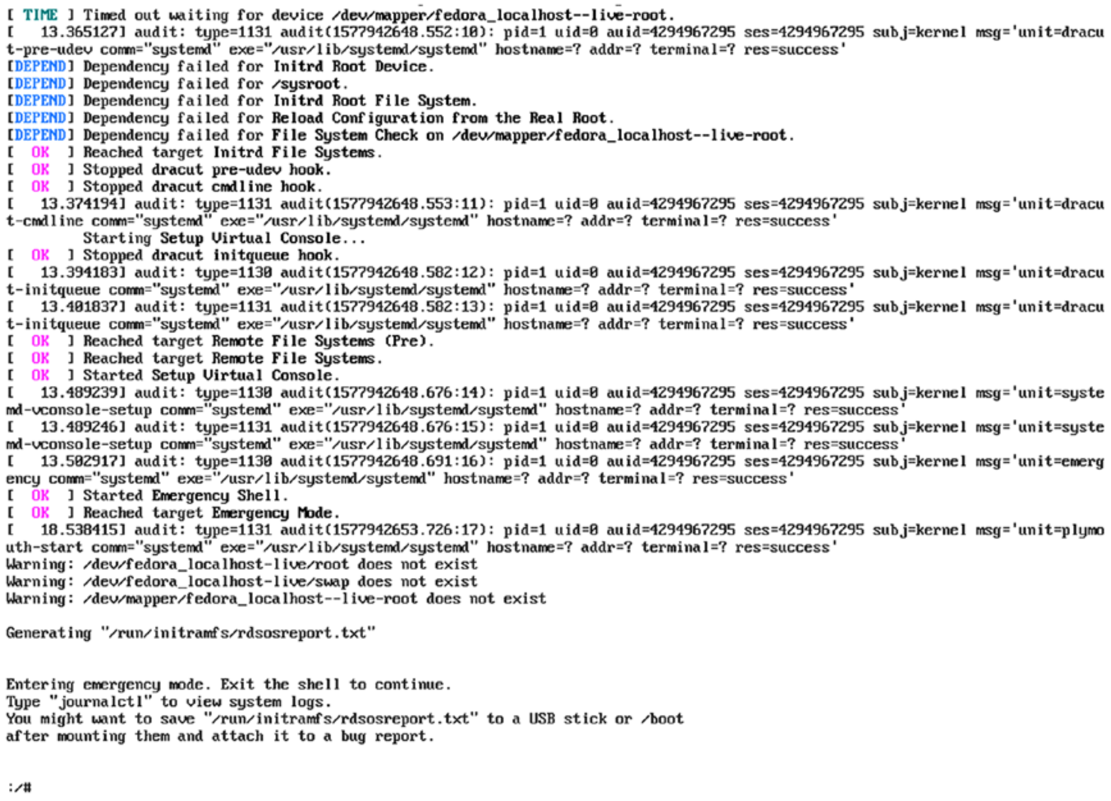
3. The `/etc/fstab` entry of `root lvm` has been appropriately changed.

    ```
    /dev/mapper/root_vg-root /            ext4    defaults   1 1
    UUID=eea3d947-0618-4d8c-b083-87daf15b2679 /boot ext4  defaults  1 2
    /dev/mapper/root_vg-swap none         swap    defaults     0 0
    ```

But after rebooting, systemd starts throwing `dracut-initqueue timeout` error messages.

The steps look like they were properly followed, but we need to investigate further to understand why `dracut-initqueue` is not able to assemble LVMs.

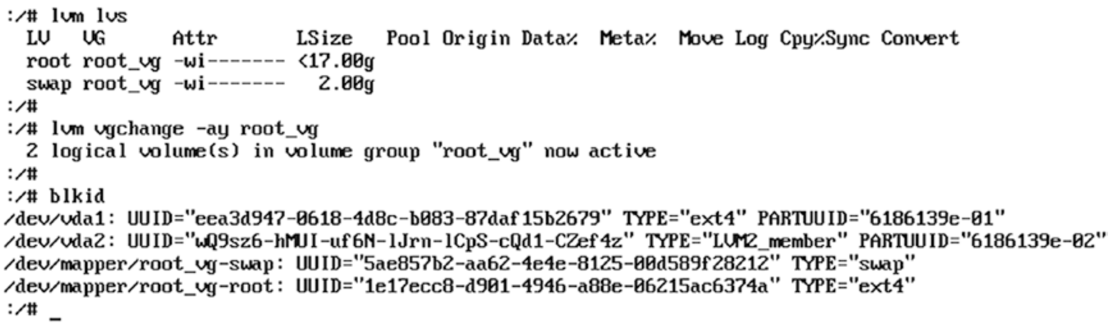
If we wait for some time on the error screen, as shown in Figure 7-53, systemd will automatically drop us on an emergency shell. We will see in detail how systemd drops us in an emergency shell in Chapter 8.



```
[ TIME ] Timed out waiting for device /dev/mapper/fedora_localhost--live-root.
[   13.365127] audit: type=1131 audit(1577942648.552:10): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=dracu
t-pre-udev comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[DEPEND] Dependency failed for Initrd Root Device.
[DEPEND] Dependency failed for /sysroot.
[DEPEND] Dependency failed for Initrd Root File System.
[DEPEND] Dependency failed for Reload Configuration from the Real Root.
[DEPEND] Dependency failed for File System Check on /dev/mapper/fedora_localhost--live-root.
[  OK  ] Reached target Initrd File Systems.
[  OK  ] Stopped dracut pre-udev hook.
[  OK  ] Stopped dracut cmdline hook.
[   13.374194] audit: type=1131 audit(1577942648.553:11): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=dracu
t-cmdline comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
         Starting Setup Virtual Console...
[  OK  ] Stopped dracut initqueue hook.
[   13.394183] audit: type=1130 audit(1577942648.582:12): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=dracu
t-initqueue comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[   13.401837] audit: type=1131 audit(1577942648.582:13): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=dracu
t-initqueue comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[  OK  ] Reached target Remote File Systems (Pre).
[  OK  ] Reached target Remote File Systems.
[  OK  ] Started Setup Virtual Console.
[   13.489239] audit: type=1130 audit(1577942648.676:14): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=syste
md-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[   13.489246] audit: type=1131 audit(1577942648.676:15): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=syste
md-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[   13.502917] audit: type=1130 audit(1577942648.691:16): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=emerg
ency comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[  OK  ] Started Emergency Shell.
[  OK  ] Reached target Emergency Mode.
[   18.538415] audit: type=1131 audit(1577942653.726:17): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=plymo
uth-start comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
Warning: /dev/fedora_localhost-live/root does not exist
Warning: /dev/fedora_localhost-live/swap does not exist
Warning: /dev/mapper/fedora_localhost--live-root does not exist

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


:/#
```

Figure 7-53. *The emergency shell*

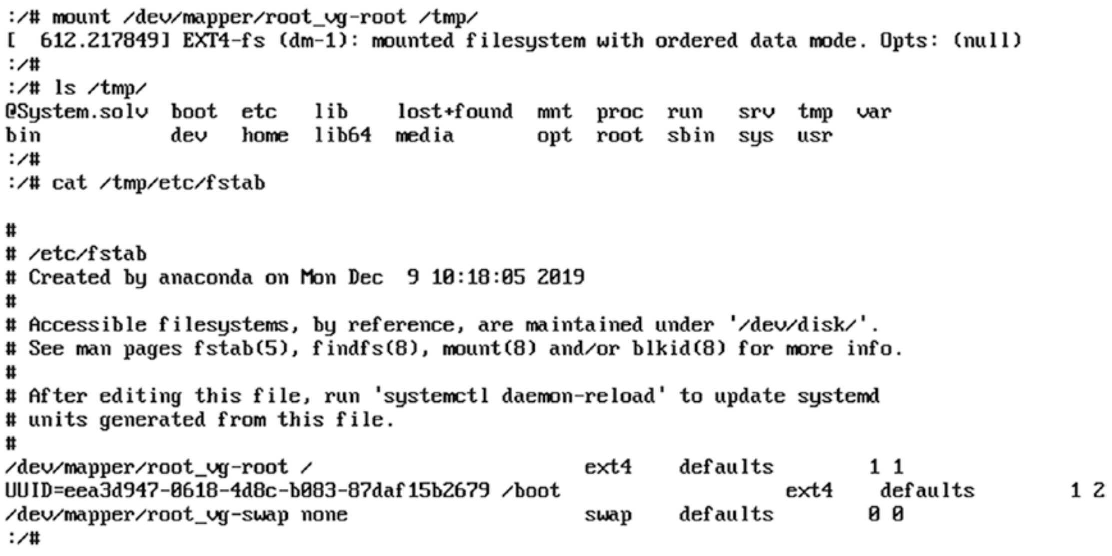
As shown in Figure 7-54, we will scan the currently available LVs and will mount `root vg` to verify its contents.



```
:/# lvm lvs
  LV   VG      Attr       LSize   Pool Origin Data%  Meta%  Move Log Cpy%Sync Convert
  root root_vg -wi------- <17.00g
  swap root_vg -wi-------   2.00g
:/#
:/# lvm vgchange -ay root_vg
  2 logical volume(s) in volume group "root_vg" now active
:/#
:/# blkid
/dev/vda1: UUID="eea3d947-0618-4d8c-b083-87daf15b2679" TYPE="ext4" PARTUUID="6186139e-01"
/dev/vda2: UUID="wQ9sz6-hMUI-uf6N-1Jrn-1CpS-cQd1-CZef4z" TYPE="LVM2_member" PARTUUID="6186139e-02"
/dev/mapper/root_vg-swap: UUID="5ae857b2-aa62-4e4e-8125-00d589f28212" TYPE="swap"
/dev/mapper/root_vg-root: UUID="1e17ecc8-d901-4946-a88e-06215ac6374a" TYPE="ext4"
:/# _
```

Figure 7-54. *Activating the LVs*

As you can see, `root_vg` (the renamed vg) is available, and we are able to activate it too. It clearly means that the LVM metadata is not corrupted and that the LVM device does not have any integrity issues. As shown in Figure 7-55, we will mount `root_vg` on a temporary directory and cross-verify its `fstab` entries from the emergency shell itself.

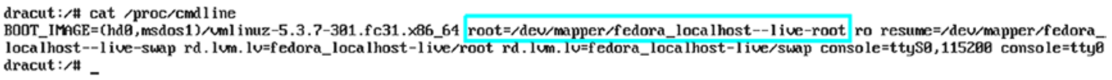


```
:/# mount /dev/mapper/root_vg-root /tmp/
[  612.217849] EXT4-fs (dm-1): mounted filesystem with ordered data mode. Opts: (null)
:/#
:/# ls /tmp/
@System.solv  boot  etc   lib    lost+found  mnt  proc  run   srv  tmp  var
bin           dev   home  lib64  media       opt  root  sbin  sys  usr
:/#
:/# cat /tmp/etc/fstab

#
# /etc/fstab
# Created by anaconda on Mon Dec  9 10:18:05 2019
#
# Accessible filesystems, by reference, are maintained under '/dev/disk/'.
# See man pages fstab(5), findfs(8), mount(8) and/or blkid(8) for more info.
#
# After editing this file, run 'systemctl daemon-reload' to update systemd
# units generated from this file.
#
/dev/mapper/root_vg-root /                       ext4    defaults        1 1
UUID=eea3d947-0618-4d8c-b083-87daf15b2679 /boot                   ext4    defaults        1 2
/dev/mapper/root_vg-swap none                    swap    defaults        0 0
:/#
```

Figure 7-55. Mounting the root filesystem

`vg` is intact, the `fstab` entries are correct, and we are able to mount the root `vg`. What is missing then?

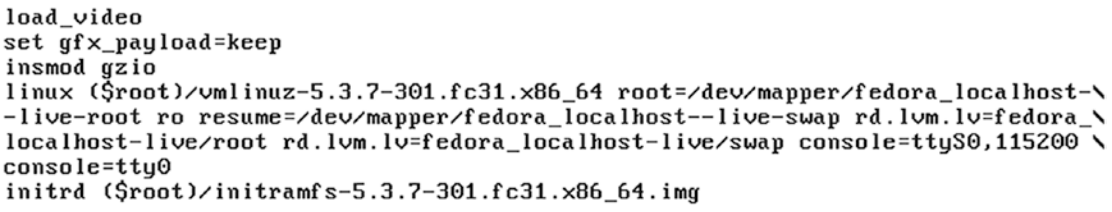
The missing part is that the kernel command-line parameters have not been adjusted in GRUB. See Figure 7-56.



```
dracut:/# cat /proc/cmdline
BOOT_IMAGE=(hd0,msdos1)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/fedora_localhost--live-root ro resume=/dev/mapper/fedora_
localhost--live-swap rd.lvm.lv=fedora_localhost-live/root rd.lvm.lv=fedora_localhost-live/swap console=ttyS0,115200 console=tty0
dracut:/# _
```

Figure 7-56. The kernel command-line parameters

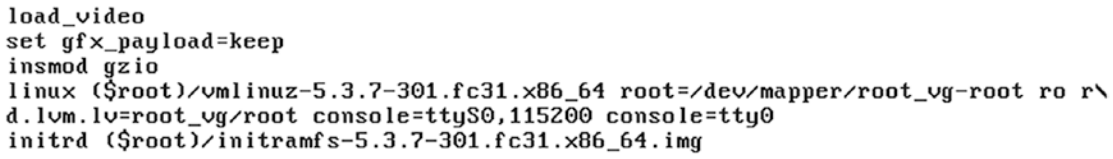
To boot, we need to interrupt the GRUB splash screen and need to change the kernel command-line parameters from what's shown in Figure 7-57.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/fedora_localhost-\
-live-root ro resume=/dev/mapper/fedora_localhost--live-swap rd.lvm.lv=fedora_\
localhost-live/root rd.lvm.lv=fedora_localhost-live/swap console=ttyS0,115200 \
console=tty0
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 7-57. The old kernel command-line parameters

See Figure 7-58 for the new ones.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/root_vg-root ro r\
d.lvm.lv=root_vg/root console=ttyS0,115200 console=tty0
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 7-58. *The new kernel command-line parameters*

Once the system is booted, change /etc/default/grub from this:

```
# cat /etc/default/grub
GRUB_TIMEOUT=10
GRUB_DISTRIBUTOR="$(sed 's, release .*$,,g' /etc/system-release)"
GRUB_DEFAULT=saved
GRUB_DISABLE_SUBMENU=true
GRUB_TERMINAL_OUTPUT="console"
GRUB_CMDLINE_LINUX="resume=/dev/mapper/fedora_localhost--live-swap rd.lvm.
lv=fedora_localhost-live/root rd.lvm.lv=fedora_localhost-live/swap
console=ttyS0,115200 console=tty0"
GRUB_DISABLE_RECOVERY="true"
GRUB_ENABLE_BLSCFG=true
```

to the following:

```
# cat /etc/default/grub
GRUB_TIMEOUT=10
GRUB_DISTRIBUTOR="$(sed 's, release .*$,,g' /etc/system-release)"
GRUB_DEFAULT=saved
GRUB_DISABLE_SUBMENU=true
GRUB_TERMINAL_OUTPUT="console"
GRUB_CMDLINE_LINUX="resume=/dev/mapper/root_vg-swap rd.lvm.lv=root_vg/root
rd.lvm.lv=root_vg/swap console=ttyS0,115200 console=tty0"
GRUB_DISABLE_RECOVERY="true"
GRUB_ENABLE_BLSCFG=true
```

It is not necessary to change the /etc/default/grub file since Fedora uses the BLS entries from /boot/loader/entries.

Change /boot/grub2/grubenv from this:

```
# cat /boot/grub2/grubenv
saved_entry=2058a9f13f9e489dba29c477a8ae2493-5.3.7-301.fc31.x86_64
menu_auto_hide=1
boot_success=0
kernelopts=root=/dev/mapper/fedora_localhost--live-root ro resume=/dev/
mapper/fedora_localhost--live-swap rd.lvm.lv=fedora_localhost-live/root
rd.lvm.lv=fedora_localhost-live/swap console=ttyS0,115200 console=tty0
boot_indeterminate=9
```

to the following:

```
# cat /boot/grub2/grubenv
saved_entry=2058a9f13f9e489dba29c477a8ae2493-5.3.7-301.fc31.x86_64
menu_auto_hide=1
boot_success=0
kernelopts=root=/dev/root_vg/root ro resume=/dev/mapper/root_vg-swap
rd.lvm.lv=root_vg/root rd.lvm.lv=root_vg/swap console=ttyS0,115200
console=tty0
boot_indeterminate=9
```

This fixes the "can't boot" issue.

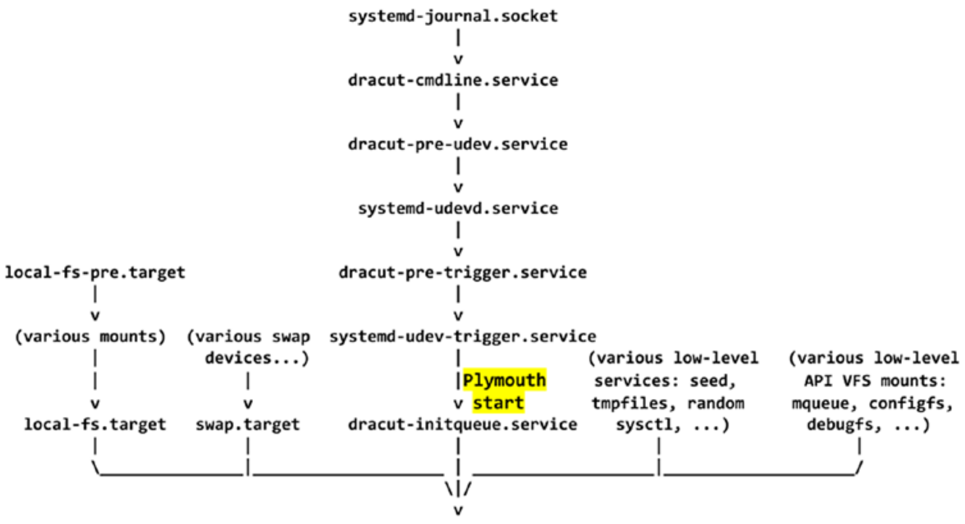
plymouth

Now it's time to talk about one interesting service called plymouth. Earlier Linux would show boot messages directly on the console, which was kind of boring for desktop users. Hence, plymouth was introduced, as shown here:

```
# cat usr/lib/systemd/system/plymouth-start.service
[Unit]
Description=Show Plymouth Boot Screen
DefaultDependencies=no
Wants=systemd-ask-password-plymouth.path systemd-vconsole-setup.service
After=systemd-vconsole-setup.service systemd-udev-trigger.service systemd-
udevd.service
Before=systemd-ask-password-plymouth.service
```

```
ConditionKernelCommandLine=!plymouth.enable=0
ConditionVirtualization=!container

[Service]
ExecStart=/usr/sbin/plymouthd --mode=boot --pid-file=/var/run/plymouth/pid
--attach-to-session
ExecStartPost=-/usr/bin/plymouth show-splash
Type=forking
KillMode=none
SendSIGKILL=no
```

As you can see, from the `/usr/lib/systemd/system/plymouth-start.service` unit file, `plymouth` starts right after `systemd-udev-trigger.service` and before `dracut-initqueue.service`, as shown in Figure 7-59.



```
                              systemd-journal.socket
                                         |
                                         v
                              dracut-cmdline.service
                                         |
                                         v
                              dracut-pre-udev.service
                                         |
                                         v
                               systemd-udevd.service
                                         |
                                         v
   local-fs-pre.target       dracut-pre-trigger.service
            |                            |
            v                            v
    (various mounts)  (various swap  systemd-udev-trigger.service
            |            devices...)     |              (various low-level   (various low-level
            |                |           |Plymouth       services: seed,       API VFS mounts:
            v                v           v start         tmpfiles, random      mqueue, configfs,
     local-fs.target    swap.target   dracut-initqueue.service  sysctl, ...)    debugfs, ...)
            |                |           |                    |                     |
            \________________|___________| __________________|_____________________/
                                        \|/
                                         v
```

Figure 7-59. The booting sequence

As shown in Figure 7-60, `plymouth` will be active throughout the booting procedure.

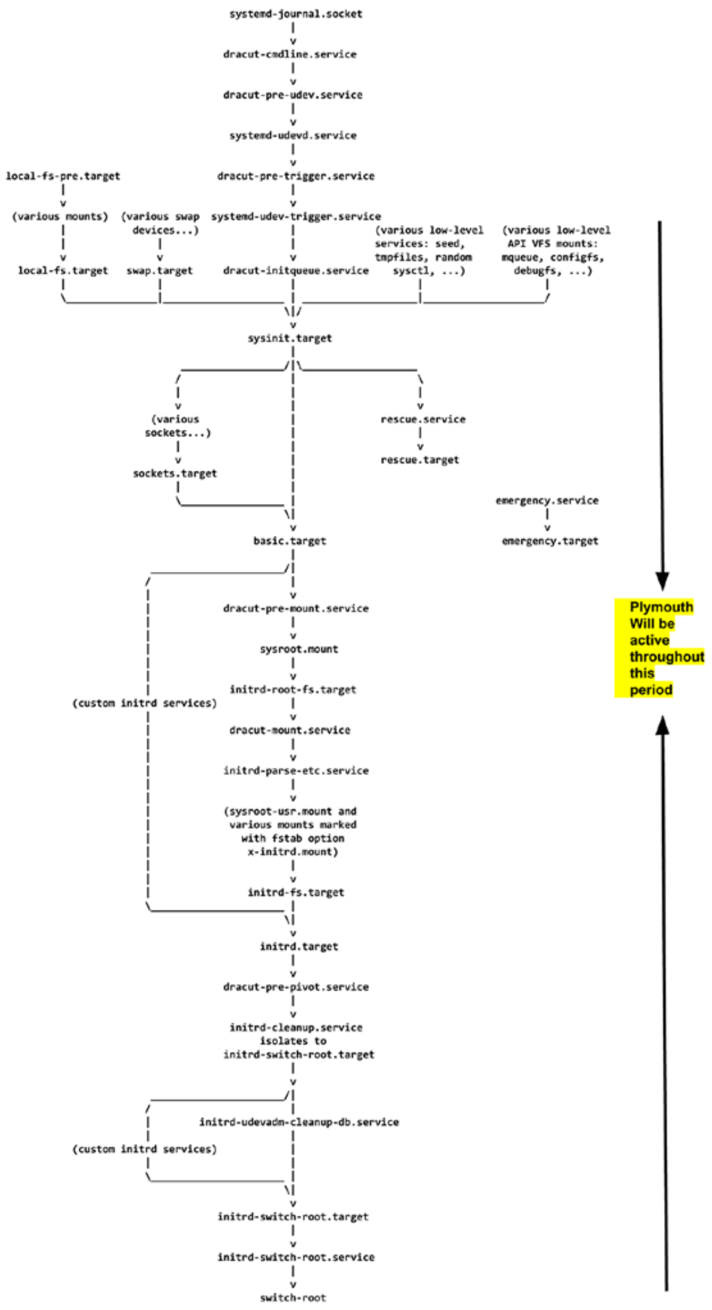
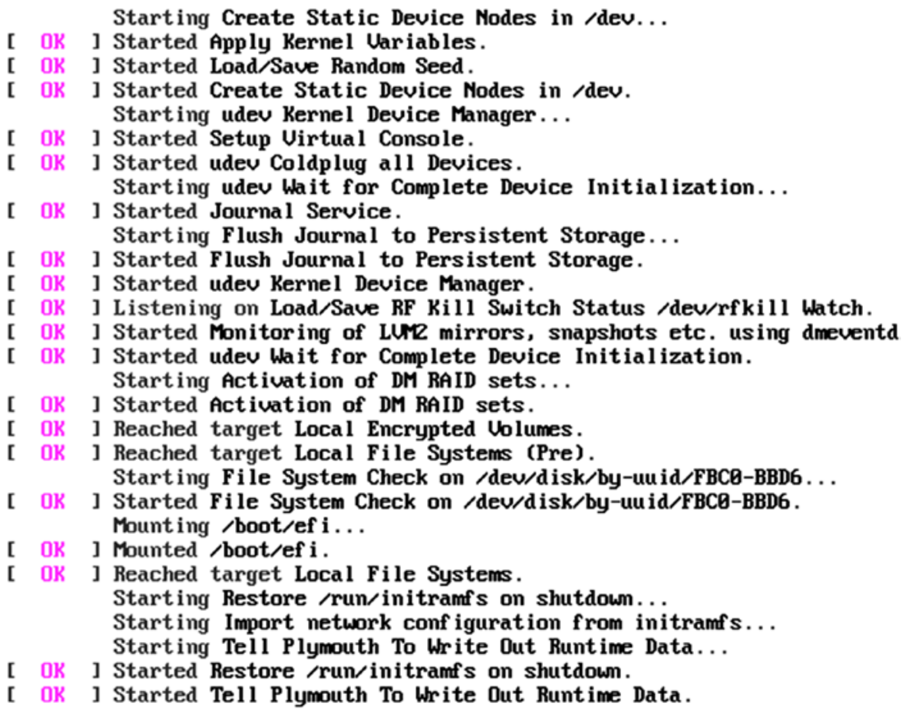


Figure 7-60. *plymouth*

`plymouth` is a tool that shows you an animation at the time of the boot. For example, in Fedora, it doesn't show the console messages shown in Figure 7-61.



```
         Starting Create Static Device Nodes in /dev...
[  OK  ] Started Apply Kernel Variables.
[  OK  ] Started Load/Save Random Seed.
[  OK  ] Started Create Static Device Nodes in /dev.
         Starting udev Kernel Device Manager...
[  OK  ] Started Setup Virtual Console.
[  OK  ] Started udev Coldplug all Devices.
         Starting udev Wait for Complete Device Initialization...
[  OK  ] Started Journal Service.
         Starting Flush Journal to Persistent Storage...
[  OK  ] Started Flush Journal to Persistent Storage.
[  OK  ] Started udev Kernel Device Manager.
[  OK  ] Listening on Load/Save RF Kill Switch Status /dev/rfkill Watch.
[  OK  ] Started Monitoring of LVM2 mirrors, snapshots etc. using dmeventd
[  OK  ] Started udev Wait for Complete Device Initialization.
         Starting Activation of DM RAID sets...
[  OK  ] Started Activation of DM RAID sets.
[  OK  ] Reached target Local Encrypted Volumes.
[  OK  ] Reached target Local File Systems (Pre).
         Starting File System Check on /dev/disk/by-uuid/FBC0-BBD6...
[  OK  ] Started File System Check on /dev/disk/by-uuid/FBC0-BBD6.
         Mounting /boot/efi...
[  OK  ] Mounted /boot/efi.
[  OK  ] Reached target Local File Systems.
         Starting Restore /run/initramfs on shutdown...
         Starting Import network configuration from initramfs...
         Starting Tell Plymouth To Write Out Runtime Data...
[  OK  ] Started Restore /run/initramfs on shutdown.
[  OK  ] Started Tell Plymouth To Write Out Runtime Data.
```

Figure 7-61. *When plymouth is not available*

`plymouth` shows you the animation shown in Figure 7-62.

Figure 7-62. *The plymouth screen*

Installing plymouth

If you want to install the different themes of `plymouth`, then this is what you can do:

1. Download `plymouth-theme` from `gnome-look.org`, or you can use the following:

   ```
   # dnf install plymouth-theme*
   ```

2. Extract the downloaded theme to the following location: `/usr/share/plymouth/themes/`

```
# ls -l /usr/share/plymouth/themes/
total 52
drwxr-xr-x. 2 root root 4096 Apr 26  2019 bgrt
drwxr-xr-x  3 root root 4096 Mar 30 09:15 breeze
drwxr-xr-x  2 root root 4096 Mar 30 09:15 breeze-text
drwxr-xr-x. 2 root root 4096 Mar 30 09:15 charge
drwxr-xr-x. 2 root root 4096 Apr 26  2019 details
drwxr-xr-x  2 root root 4096 Mar 30 09:15 fade-in
drwxr-xr-x  2 root root 4096 Mar 30 09:15 hot-dog
drwxr-xr-x  2 root root 4096 Mar 30 09:15 script
drwxr-xr-x  2 root root 4096 Mar 30 09:15 solar
drwxr-xr-x  2 root root 4096 Mar 30 09:15 spinfinity
drwxr-xr-x. 2 root root 4096 Apr 26  2019 spinner
drwxr-xr-x. 2 root root 4096 Apr 26  2019 text
drwxr-xr-x. 2 root root 4096 Apr 26  2019 tribar
```

3. You need to rebuild initramfs as `plymouth` runs from the initramfs environment. For example, its configuration file has to be updated for the new `plymouth` theme.

```
# cat /etc/plymouth/plymouthd.conf
# Administrator customizations go in this file
#[Daemon]
#Theme=fade-in
[Daemon]
Theme=hot-dog
```

After rebooting, as shown in Figure 7-63, you will see a new `plymouth` theme called `hot-dog`.

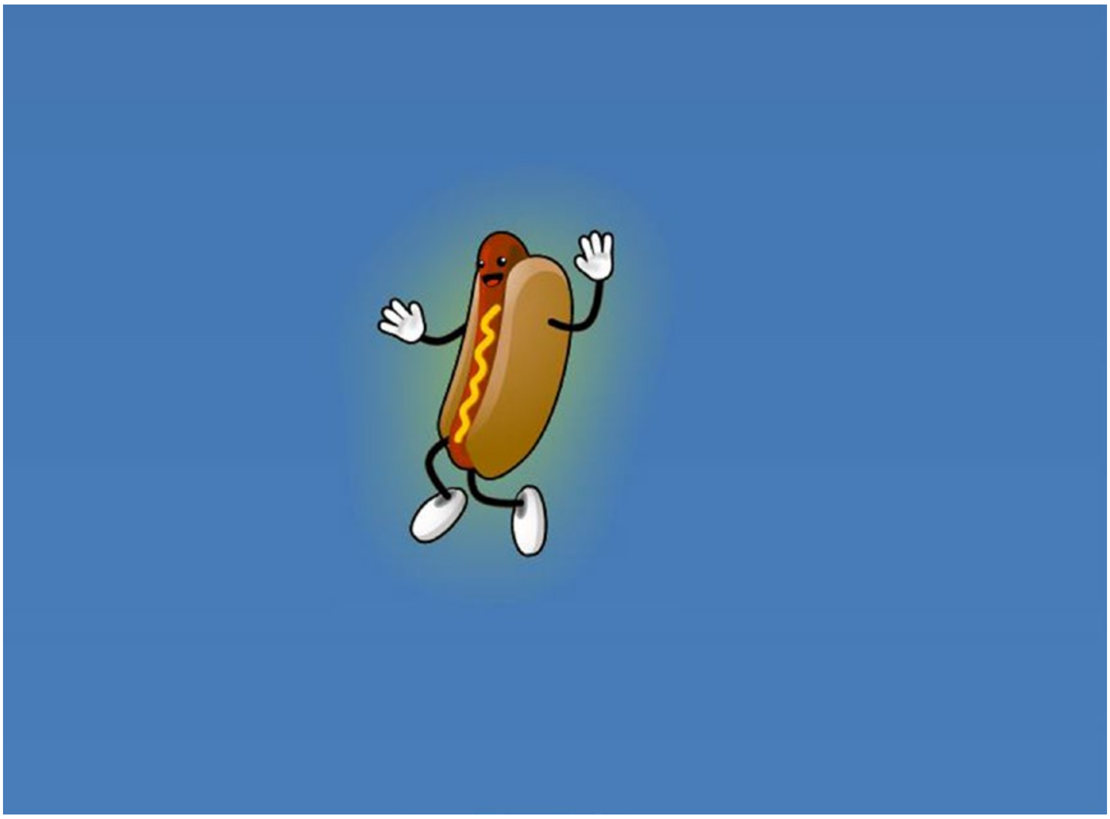


Figure 7-63. *The hot-dog plymouth theme*

Managing plymouth

Since `plymouth` starts at an early stage, dracut does provide some command-line options to manage `plymouth`'s behavior.

```
 plymouth.enable=0
      disable the plymouth bootsplash completely.

rd.plymouth=0
      disable the plymouth bootsplash only for the initramfs.
```

The hot-dog image shown earlier is called a *splash screen*. To see the installed/chosen splash screen, you can use the following:

```
#plymouth --show-splash
```

Another main motive of plymouth is to maintain all the boot-time messages in a simple text file that users can examine after the boot. The logs will be stored at /var/log/boot.log, but remember that this file is maintained by plymouth. This means you will find the booting messages only after starting plymouth. But at the same time, we need to keep in mind that plymouth does start at an early stage of initramfs (right after udevd kicks in).

```
# less /varlog/boot.log
<snip>
------------ Sat Jul 06 01:43:12 IST 2019 ------------
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mShow Plymouth Boot ScreenESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mPathsESC[0m.
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mForward Password R...s to
Plymouth Directory WatchESC[0m.
[ESC[0;32m  OK  ESC[0m] Found device ESC[0;1;39m/dev/mapper/fedora_
localhost--live-rootESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mInitrd Root DeviceESC[0m.
[ESC[0;32m  OK  ESC[0m] Found device ESC[0;1;39m/dev/mapper/fedora_
localhost--live-swapESC[0m.
         Starting ESC[0;1;39mResume from hiber...fedora_localhost--live-
         swapESC[0m...
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mResume from hibern...r/fedora_
localhost--live-swapESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mLocal File Systems (Pre)
ESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mLocal File SystemsESC[0m.
         Starting ESC[0;1;39mCreate Volatile Files and DirectoriesESC[0m...
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mCreate Volatile Files and
DirectoriesESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mSystem
InitializationESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mBasic SystemESC[0m.
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mdracut initqueue hookESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mRemote File Systems (Pre)
ESC[0m.
```

```
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mRemote File
SystemsESC[0m.
         Starting ESC[0;1;39mFile System Check...fedora_localhost--live-
         rootESC[0m...
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mFile System Check ...r/fedora_
localhost--live-rootESC[0m.
         Mounting ESC[0;1;39m/sysrootESC[0m...
[ESC[0;32m  OK  ESC[0m] Mounted ESC[0;1;39m/sysrootESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mInitrd Root File
SystemESC[0m.
         Starting ESC[0;1;39mReload Configuration from the Real
         RootESC[0m...
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mReload Configuration from the
Real RootESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mInitrd File
SystemsESC[0m.
[ESC[0;32m  OK  ESC[0m] Reached target ESC[0;1;39mInitrd Default
TargetESC[0m.
         Starting ESC[0;1;39mdracut pre-pivot and cleanup hookESC[0m...
[ESC[0;32m  OK  ESC[0m] Started ESC[0;1;39mdracut pre-pivot and cleanup
hookESC[0m.
         Starting ESC[0;1;39mCleaning Up and Shutting Down DaemonsESC[0m...
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mTimersESC[0m.
[ESC[0;32m  OK  ESC[0m] Stopped ESC[0;1;39mdracut pre-pivot and cleanup
hookESC[0m.
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mInitrd Default
TargetESC[0m.
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mRemote File
SystemsESC[0m.
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mRemote File Systems (Pre)
ESC[0m.
[ESC[0;32m  OK  ESC[0m] Stopped ESC[0;1;39mdracut initqueue hookESC[0m.
         Starting ESC[0;1;39mPlymouth switch root serviceESC[0m...
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mInitrd Root DeviceESC[0m.
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mBasic SystemESC[0m.
```

```
[ESC[0;32m  OK  ESC[0m] Stopped target ESC[0;1;39mSystem
InitializationESC[0m.
.
.
</snip>
```

Structure

`plymouth` takes inputs from initramfs/systemd to understand what stage of the booting procedure has been completed (as a percentage of the booting procedure) and accordingly shows the animation or a progress bar on the screen. There are two binaries that take care of the `plymouth` work.

```
      /bin/plymouth            (Interface to plymouthd)
   /usr/sbin/plymouthd  (main binary which shows splash and logs boot
   messages in boot.log file)
```

There are various plymouth services available inside initramfs on which systemd relies on.

```
# ls -l usr/lib/systemd/system/ -l | grep -i plymouth

-rw-r--r--. 1 root root  384 Dec 21 12:19 plymouth-halt.service
-rw-r--r--. 1 root root  398 Dec 21 12:19 plymouth-kexec.service
-rw-r--r--. 1 root root  393 Dec 21 12:19 plymouth-poweroff.service
-rw-r--r--. 1 root root  198 Dec 21 12:19 plymouth-quit.service
-rw-r--r--. 1 root root  204 Dec 21 12:19 plymouth-quit-wait.service
-rw-r--r--. 1 root root  386 Dec 21 12:19 plymouth-reboot.service
-rw-r--r--. 1 root root  547 Dec 21 12:19 plymouth-start.service
-rw-r--r--. 1 root root  295 Dec 21 12:19 plymouth-switch-root.service
-rw-r--r--. 1 root root  454 Dec 21 12:19 systemd-ask-password-plymouth.path
-rw-r--r--. 1 root root  435 Dec 21 12:19 systemd-ask-password-plymouth.service
drwxr-xr-x. 2 root root 4096 Dec 21 12:19 systemd-ask-password-plymouth.
service.wants
```

systemd, when running in initramfs, calls these services from time to time during the boot phase. As you can see, every service is calling the `plymouthd` binary and passing switches accordingly to the current stage of booting. For example, `plymouth-start.service` simply starts the `plymouthd` binary with mode `boot.` There are only two modes; one is `boot`, and another one is `shutdown.`

```
# cat usr/lib/systemd/system/plymouth*  | grep -i execstart
```

```
ExecStart=/usr/sbin/plymouthd --mode=shutdown --attach-to-session
ExecStartPost=-/usr/bin/plymouth show-splash
ExecStart=/usr/sbin/plymouthd --mode=shutdown --attach-to-session
ExecStartPost=-/usr/bin/plymouth show-splash
ExecStart=/usr/sbin/plymouthd --mode=shutdown --attach-to-session
ExecStartPost=-/usr/bin/plymouth show-splash
ExecStart=-/usr/bin/plymouth quit                                    <<---
ExecStart=-/usr/bin/plymouth --wait
ExecStart=/usr/sbin/plymouthd --mode=reboot --attach-to-session
ExecStartPost=-/usr/bin/plymouth show-splash
ExecStart=/usr/sbin/plymouthd --mode=boot --pid-file=/var/run/plymouth/pid
--attach-to-session
ExecStartPost=-/usr/bin/plymouth show-splash
ExecStart=-/usr/bin/plymouth update-root-fs --new-root-dir=/sysroot   <<---
```

Another example we can consider is that at the time of the `switch_root`, systemd simply calls `plymouth-switch-root.service`, which in turn runs the `plymouthd` binary with an updated `root` filesystem as `sysroot.` In other words, you can say along with `switch_root` that `plymouth` changes its root directory from initramfs to the actual root filesystem. Going further, you can see that systemd starts the `plymouth` service in the same way that systemd sends a `quit` message to `plymouthd` at the end of the booting sequence. At the same time, you probably noticed that systemd calls `plymouth` at the time of the reboot or shutdown too. It is not really a big deal since it just calls the same `plymouthd` with the appropriate mode.

Sysinit.target

So, we have reached the `sysinit.target` stage. Figure 7-64 shows the booting sequence we have covered so far.

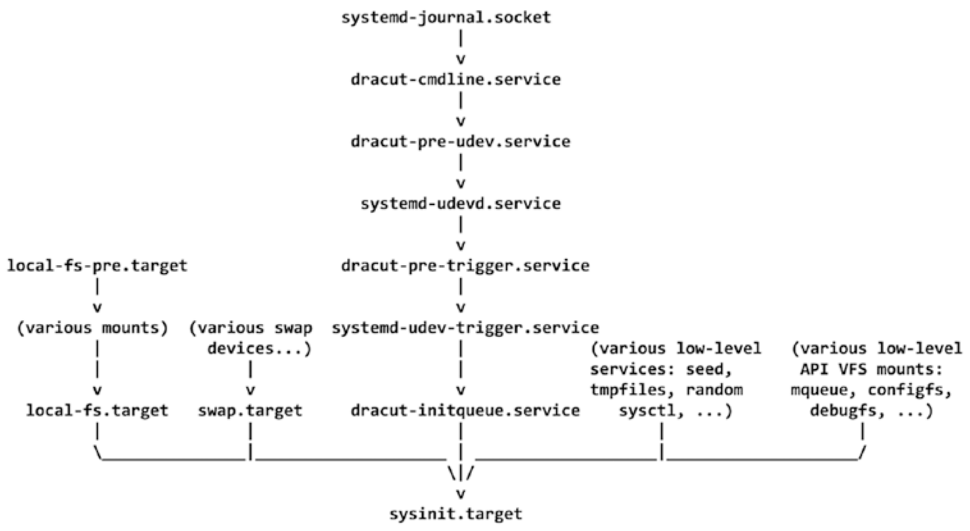

systemd-journal.socket
dracut-cmdline.service
dracut-pre-udev.service
systemd-udevd.service
local-fs-pre.target
dracut-pre-trigger.service
(various mounts)
(various swap devices...)
systemd-udev-trigger.service
(various low-level services: seed, tmpfiles, random sysctl, ...)
(various low-level API VFS mounts: mqueue, configfs, debugfs, ...)
local-fs.target
swap.target
dracut-initqueue.service
sysinit.target

Figure 7-64. *The booting sequence covered so far*

Since this is a target unit, its job is to hold or start a bunch of other units (services, sockets, etc.). The list of units will be available in its wants directory. As you can see, the available unit files are nothing but symbolic links to the original service unit files.

```
#ls -l usr/lib/systemd/system/sysinit.target.wants/

total 0
kmod-static-nodes.service -> ../kmod-static-nodes.service
plymouth-start.service -> ../plymouth-start.service
systemd-ask-password-console.path -> ../systemd-ask-password-console.path
systemd-journald.service -> ../systemd-journald.service
systemd-modules-load.service -> ../systemd-modules-load.service
systemd-sysctl.service -> ../systemd-sysctl.service
systemd-tmpfiles-setup-dev.service -> ../systemd-tmpfiles-setup-dev.service
systemd-tmpfiles-setup.service -> ../systemd-tmpfiles-setup.service
systemd-udevd.service -> ../systemd-udevd.service
systemd-udev-trigger.service -> ../systemd-udev-trigger.service
```

Most of the services have already been started before we reach sysinit.target. For example, systemd-udevd.service and systemd-udev-trigger.service (after the pre-trigger service) have already been started, and we have already seen that systemd -udevd.service will execute the /usr/lib/systemd/systemd-udevd binary, whereas the systemd-udev-trigger service will execute the udevadm binary. Then why are we starting these services again with sysinit.target? We are not. sysinit.target will start only the services that have not yet started, and it will ignore taking any action on the services that are already started. Let's see the purpose of each of these service unit files.

The kmod-static-nodes systemd unit file executes the kmod binary with the static-nodes switch. We have already seen in Chapter 5 that lsmod, insmod, modinfo, modprobe, depmod, etc., are the symlinks to the kmod binary.

```
#lsinitrd | grep -i kmod

lrwxrwxrwx   1 root  root  11 Jul 25 03:54 usr/sbin/depmod -> ../bin/kmod
lrwxrwxrwx   1 root  root  11 Jul 25 03:54 usr/sbin/insmod -> ../bin/kmod
lrwxrwxrwx   1 root  root  11 Jul 25 03:54 usr/sbin/lsmod -> ../bin/kmod
lrwxrwxrwx   1 root  root  11 Jul 25 03:54 usr/sbin/modinfo -> ../bin/kmod
lrwxrwxrwx   1 root  root  11 Jul 25 03:54 usr/sbin/modprobe -> ../bin/kmod
lrwxrwxrwx   1 root  root  11 Jul 25 03:54 usr/sbin/rmmod -> ../bin/kmod
```

```
# cat usr/lib/systemd/system/kmod-static-nodes.service | grep -v '#'
[Unit]
Description=Create list of static device nodes for the current kernel
DefaultDependencies=no
Before=sysinit.target systemd-tmpfiles-setup-dev.service
ConditionCapability=CAP_SYS_MODULE
ConditionFileNotEmpty=/lib/modules/%v/modules.devname

[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/bin/kmod static-nodes --format=tmpfiles --output=/run/
tmpfiles.d/static-nodes.conf
```

With the static-nodes switch, systemd is just collecting all of the static nodes (devices) present in the system. Why do we need static nodes in the age of dynamic node handling (udev)? There are some modules like fuse or ALSA that need some device files present in /dev, or they might create them. But it could be dangerous since the device files are made by kernel or udev. So, to avoid modules from creating device files, systemd will create static nodes like /dev/fuse or /dev/snd/seq through the kmod-static-nodes.service. The following are the static nodes created by kmod-static-nodes.service on a Fedora system:

```
# kmod static-nodes
Module: fuse
      Device node: /dev/fuse
            Type: character device
            Major: 10
            Minor: 229
Module: btrfs
      Device node: /dev/btrfs-control
            Type: character device
            Major: 10
            Minor: 234
Module: loop
      Device node: /dev/loop-control
            Type: character device
            Major: 10
            Minor: 237
Module: tun
      Device node: /dev/net/tun
            Type: character device
            Major: 10
            Minor: 200
Module: ppp_generic
      Device node: /dev/ppp
            Type: character device
            Major: 108
            Minor: 0
Module: uinput
      Device node: /dev/uinput
            Type: character device
            Major: 10
            Minor: 223
```

```
Module: uhid
      Device node: /dev/uhid
            Type: character device
            Major: 10
            Minor: 239
Module: vfio
      Device node: /dev/vfio/vfio
            Type: character device
            Major: 10
            Minor: 196
Module: hci_vhci
      Device node: /dev/vhci
            Type: character device
            Major: 10
            Minor: 137
Module: vhost_net
      Device node: /dev/vhost-net
            Type: character device
            Major: 10
            Minor: 238
Module: vhost_vsock
      Device node: /dev/vhost-vsock
            Type: character device
            Major: 10
            Minor: 241
Module: snd_timer
      Device node: /dev/snd/timer
            Type: character device
            Major: 116
            Minor: 33
Module: snd_seq
      Device node: /dev/snd/seq
            Type: character device
            Major: 116
            Minor: 1
```

```
Module: cuse
      Device node: /dev/cuse
            Type: character device
            Major: 10
            Minor: 203
```

Next, we have the plymouth service, which has already been started; then we have systemd-ask-password-console.path, which is a .path unit file.

```
# cat usr/lib/systemd/system/systemd-ask-password-console.path | grep -v '#'

[Unit]
Description=Dispatch Password Requests to Console Directory Watch
Documentation=man:systemd-ask-password-console.service(8)
DefaultDependencies=no
Conflicts=shutdown.target emergency.service
After=plymouth-start.service
Before=paths.target shutdown.target cryptsetup.target
ConditionPathExists=!/run/plymouth/pid

[Path]
DirectoryNotEmpty=/run/systemd/ask-password
MakeDirectory=yes
```

The .path unit file is for path-based activation, but since we have not encrypted our root disk with LUKS, we do not have the actual service file that will accept the password from the user. If we had configured LUKS, we would have had the /usr/lib/systemd/system/systemd-ask-password-plymouth.service service unit file, as shown here:

```
# cat usr/lib/systemd/system/systemd-ask-password-plymouth.service
[Unit]
Description=Forward Password Requests to Plymouth
Documentation=http://www.freedesktop.org/wiki/Software/systemd/
PasswordAgents
DefaultDependencies=no
Conflicts=shutdown.target
After=plymouth-start.service
Before=shutdown.target
```

```
ConditionKernelCommandLine=!plymouth.enable=0
ConditionVirtualization=!container
ConditionPathExists=/run/plymouth/pid

[Service]
ExecStart=/usr/bin/systemd-tty-ask-password-agent --watch --plymouth
```

As you can see, this is executing the `systemd-tty-ask-password-agent` binary, which will ask for a password with `plymouth` instead of a TTY. Next, the service unit file is `systemd-journald.service`, which will start the `journald` daemon for us. Until this time, all the messages are logged with the `journald` socket, which systemd started as the first service of the booting sequence. The `journald` socket is 8 MB in size. If the socket runs out of buffer, then the services will be blocked until the socket becomes available. The 8 MB of buffer space is more than enough for the production systems.

```
#vim usr/lib/systemd/system/sysinit.target.wants/systemd-journald.service
[Unit]
Description=Journal Service
Documentation=man:systemd-journald.service(8) man:journald.conf(5)
DefaultDependencies=no
Requires=systemd-journald.socket
After=systemd-journald.socket systemd-journald-dev-log.socket systemd-
journald-audit.socket syslog.socket
Before=sysinit.target

[Service]
OOMScoreAdjust=-250
CapabilityBoundingSet=CAP_SYS_ADMIN CAP_DAC_OVERRIDE CAP_SYS_PTRACE CAP_
SYSLOG CAP_AUDIT_CONTROL CAP_AUDIT_READ CAP_CHOWN CAP_DAC_READ_SEARCH CAP_
FOWNER CAP_SETUID CAP_SETGID CAP_MAC_OVERRIDE
DeviceAllow=char-* rw
ExecStart=/usr/lib/systemd/systemd-journald
FileDescriptorStoreMax=4224
IPAddressDeny=any
LockPersonality=yes
MemoryDenyWriteExecute=yes
```

```
Restart=always
RestartSec=0
RestrictAddressFamilies=AF_UNIX AF_NETLINK
RestrictNamespaces=yes
RestrictRealtime=yes
RestrictSUIDSGID=yes
Sockets=systemd-journald.socket systemd-journald-dev-log.socket systemd-
journald-audit.socket
StandardOutput=null
SystemCallArchitectures=native
SystemCallErrorNumber=EPERM
SystemCallFilter=@system-service
Type=notify
WatchdogSec=3min

LimitNOFILE=524288
```

Next, if you want systemd to load some specific module statically, then you can get some help from our next service, which is `systemd-modules-load.service`.

```
# cat usr/lib/systemd/system/systemd-modules-load.service | grep -v '#'

[Unit]
Description=Load Kernel Modules
Documentation=man:systemd-modules-load.service(8) man:modules-load.d(5)
DefaultDependencies=no
Conflicts=shutdown.target
Before=sysinit.target shutdown.target
ConditionCapability=CAP_SYS_MODULE
ConditionDirectoryNotEmpty=|/lib/modules-load.d
ConditionDirectoryNotEmpty=|/usr/lib/modules-load.d
ConditionDirectoryNotEmpty=|/usr/local/lib/modules-load.d
ConditionDirectoryNotEmpty=|/etc/modules-load.d
ConditionDirectoryNotEmpty=|/run/modules-load.d
ConditionKernelCommandLine=|modules-load
ConditionKernelCommandLine=|rd.modules-load
```

```
[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/lib/systemd/systemd-modules-load
TimeoutSec=90s
```

The service executes `/usr/lib/systemd/systemd-modules-load.` The binary understands the two command-line parameters.

- `module_load`: This is a kernel command-line parameter.
- `rd.module_load`: This is a dracut command-line parameter.

If you pass a dracut command-line parameter, then `systemd-modules-load` will statistically load the module in memory, but for that, the module has to be present in initramfs. If it is not present in initramfs, then first it has to be pulled in initramfs. While generating initramfs, dracut reads the `<module-name>.conf` files from here:

```
/etc/modules-load.d/*.conf
/run/modules-load.d/*.conf
/usr/lib/modules-load.d/*.conf
```

You need to create the `*.conf` file and need to mention the module name in it, which you want to add in initramfs.

For example, here we have created a new initramfs image that does not have the `vfio` module in it:

```
# dracut new.img
# lsinitrd | grep -i vfio
  <no_output>
```

To pull the module statistically inside initramfs, here we have created the `vfio.conf` file:

```
# cat /usr/lib/modules-load.d/vfio.conf
  vfio
```

Here we have rebuilt initramfs:

```
# dracut new.img -f
# lsinitrd new.img | grep -i vfio
```

```
Jul 25 03:54 usr/lib/modules/5.3.16-300.fc31.x86_64/kernel/drivers/vfio
Jul 25 03:54 usr/lib/modules/5.3.16-300.fc31.x86_64/kernel/drivers/vfio/
vfio.ko.xz
Jul 25 03:54 usr/lib/modules-load.d/vfio.conf
```

As you can see, the module has been pulled inside initramfs, and it will be loaded in memory as soon as the service `systemd-modules-load.service` starts.

Loading modules statistically is not really a good idea. These days, modules are loaded dynamically in memory when it is necessary or on demand, whereas static modules will always be loaded in memory irrespective of need or demand.

Don't get confused with the `/etc/modprobe.d` directory. Its use is to pass the options to modules. Here's an example:

```
#cat /etc/modprobe.d/lockd.conf
     options lockd nlm_timeout=10
```

`nlm_timeour=10` is an option passed to the `lockd` module. Remember, the `.conf` file inside `/etc/modprobe.d` has to be a module name. Through the same conf file, you can set an alias for the module name. Here's an example:

```
"alias my-mod really_long_modulename"
```

Next, systemd will set the `sysctl` kernel parameters with the help of `systemd-sysctl.service`.

```
# cat usr/lib/systemd/system/systemd-sysctl.service | grep -v '#'

[Unit]
Description=Apply Kernel Variables
Documentation=man:systemd-sysctl.service(8) man:sysctl.d(5)
DefaultDependencies=no
Conflicts=shutdown.target
After=systemd-modules-load.service
Before=sysinit.target shutdown.target
ConditionPathIsReadWrite=/proc/sys/net/
```

```
[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/lib/systemd/systemd-sysctl
TimeoutSec=90s
```

`systemd-sysctl.service` will start the `/usr/lib/systemd/systemd-sysctl` binary, which will set the kernel tuning parameters by reading the `*.conf` files from three different locations.

```
/etc/sysctl.d/*.conf
      /run/sysctl.d/*.conf
      /usr/lib/sysctl.d/*.conf
```

Here's an example:

```
# sysctl -a | grep -i swappiness
       vm.swappiness = 60
```

The default `swappiness` kernel parameter value is set to 60. If you want to change it to 10 and it has to be permanent across reboots, then add it in `/etc/sysctl.d/99-sysctl.conf`.

```
#cat /etc/sysctl.d/99-sysctl.conf


      vm.swappiness = 10
```

You can reload and set the `sysctl` parameters by using this:

```
# sysctl -p
vm.swappiness = 10
```

To make these changes in initramfs, you need to regenerate initramfs. At the time of the boot, `systemd-sysctl.service` will read the `swappiness` value from the `99-sysctl.conf` file and will set it in the initramfs environment.

systemd creates many temporary files for its smooth execution. After setting up the `sysctl` parameters, it executes the next service, called `systemd-tmpfiles-setup-dev.service`, which will execute the `/usr/bin/systemd-tmpfiles --prefix=/dev --create --boot` binary. This will create dev filesystem-related temporary files according to these rules:

```
/etc/tmpfiles.d/*.conf
/run/tmpfiles.d/*.conf
/usr/lib/tmpfiles.d/*.conf
```

After `sysinit.target`, systemd will verify if the required sockets are created or not through `sockets.target`.

```
# ls usr/lib/systemd/system/sockets.target.wants/ -l
total 0
32 Jan  3 18:05 systemd-journald-audit.socket -> ../systemd-journald-audit.
socket
34 Jan  3 18:05 systemd-journald-dev-log.socket -> ../systemd-journald-dev-
log.socket
26 Jan  3 18:05 systemd-journald.socket -> ../systemd-journald.socket
31 Jan  3 18:05 systemd-udevd-control.socket -> ../systemd-udevd-control.
socket
30 Jan  3 18:05 systemd-udevd-kernel.socket -> ../systemd-udevd-kernel.
socket
```

So, our boot process has finished the sequence up to `sysinit.target.` Refer the flowchart shown in Figure 7-65.

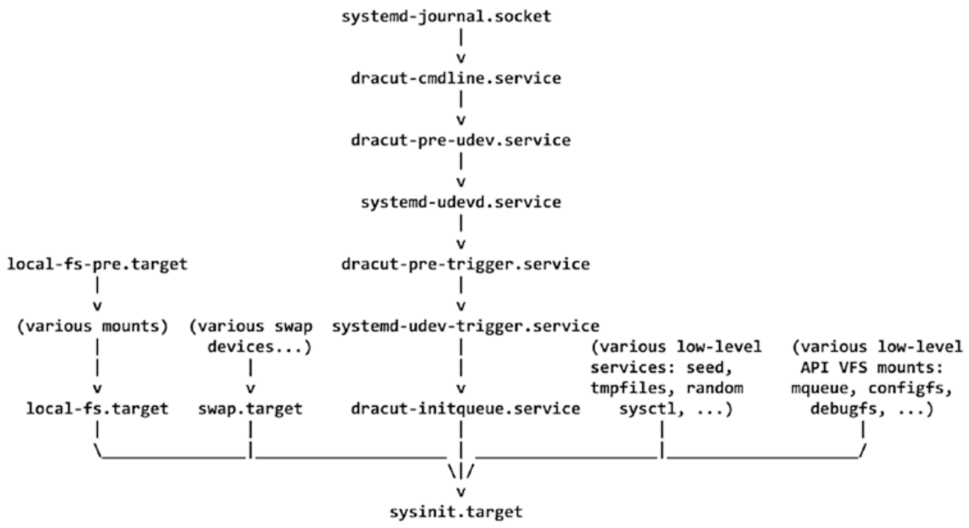

systemd-journal.socket
dracut-cmdline.service
dracut-pre-udev.service
systemd-udevd.service
local-fs-pre.target
dracut-pre-trigger.service
(various mounts)
(various swap devices...)
systemd-udev-trigger.service
(various low-level services: seed, tmpfiles, random sysctl, ...)
(various low-level API VFS mounts: mqueue, configfs, debugfs, ...)
local-fs.target
swap.target
dracut-initqueue.service
sysinit.target

Figure 7-65. *The boot sequence covered so far*

“Can’t Boot” Issue 8 (sysctl.conf)

Issue: After rebooting, the kernel is panicking, and the system is not able to boot. This is what is visible on the console:

```
[    4.596220] Mem-Info:
[    4.597455] active_anon:566 inactive_anon:1 isolated_anon:0
[    4.597455]  active_file:0 inactive_file:0 isolated_file:0
[    4.597455]  unevictable:19700 dirty:0 writeback:0 unstable:0
[    4.597455]  slab_reclaimable:2978 slab_unreclaimable:3180
[    4.597455]  mapped:2270 shmem:22 pagetables:42 bounce:0
[    4.597455]  free:23562 free_pcp:1982 free_cma:0
[    4.611930] Node 0 active_anon:2264kB inactive_anon:4kB active_file:0kB
inactive_file:0kB unevictable:78800kB isolated(anon):0kB isolated(file):0kB
mapped:9080kB dirty:0kB writeback:0kB shmem:88kB shmem_thp: 0kB
shmem_pmdmapped: 0kB anon_thp: 0kB writeback_tmp:0kB unstable:0kB all_
unreclaimable? yes
[    4.621748] Node 0 DMA free:15900kB min:216kB low:268kB high:320kB
active_anon:0kB inactive_anon:0kB active_file:0kB inactive_file:0kB
unevictable:0kB writepending:0kB present:15992kB managed:15908kB
mlocked:0kB kernel_stack:0kB pagetables:0kB bounce:0kB free_pcp:0kB local_
pcp:0kB free_cma:0kB
[    4.632561] lowmem_reserve[]: 0 1938 4764 4764 4764
[    4.634609] Node 0 DMA32 free:38516kB min:27404kB low:34252kB
high:41100kB active_anon:0kB inactive_anon:0kB active_file:0kB
inactive_file:0kB unevictable:0kB writepending:0kB present:2080628kB
managed:2015092kB mlocked:0kB kernel_stack:0kB pagetables:0kB bounce:0kB
free_pcp:2304kB local_pcp:0kB free_cma:0kB
[    4.645636] lowmem_reserve[]: 0 0 2826 2826 2826
[    4.647886] Node 0 Normal free:39832kB min:39956kB low:49944kB
high:59932kB active_anon:2264kB inactive_anon:4kB active_file:0kB
inactive_file:0kB unevictable:78800kB writepending:0kB present:3022848kB
managed:2901924kB mlocked:0kB kernel_stack:1776kB pagetables:168kB
bounce:0kB free_pcp:5624kB local_pcp:1444kB free_cma:0kB
[    4.659458] lowmem_reserve[]: 0 0 0 0 0
[    4.661319] Node 0 DMA: 1*4kB (U) 1*8kB (U) 1*16kB (U) 0*32kB 2*64kB (U)
1*128kB (U) 1*256kB (U) 0*512kB 1*1024kB (U) 1*2048kB (M) 3*4096kB (M) =
15900kB
[    4.666730] Node 0 DMA32: 1*4kB (M) 0*8kB 1*16kB (M) 1*32kB (M) 1*64kB
(M) 0*128kB 0*256kB 1*512kB (M) 3*1024kB (M) 1*2048kB (M) 8*4096kB (M) =
38516kB
[    4.673247] Node 0 Normal: 69*4kB (UME) 16*8kB (M) 10*16kB (UME) 7*32kB
(ME) 5*64kB (E) 1*128kB (E) 1*256kB (U) 9*512kB (ME) 9*1024kB (UME)
2*2048kB (ME) 5*4096kB (M) = 39892kB
[    4.680399] Node 0 hugepages_total=0 hugepages_free=0 hugepages_surp=0
hugepages_size=1048576kB
[    4.683930] Node 0 hugepages_total=2303 hugepages_free=2303 hugepages_
surp=0 hugepages_size=2048kB
[    4.687749] 19722 total pagecache pages
[    4.689841] 0 pages in swap cache
[    4.691580] Swap cache stats: add 0, delete 0, find 0/0
[    4.694275] Free swap  = 0kB
[    4.696039] Total swap = 0kB
[    4.697617] 1279867 pages RAM
[    4.699229] 0 pages HighMem/MovableOnly
[    4.700862] 46636 pages reserved
[    4.703868] 0 pages cma reserved
[    4.705589] 0 pages hwpoisoned
[    4.707435] Tasks state (memory values in pages):
[    4.709532] [  pid  ]   uid  tgid total_vm      rss pgtables_bytes
swapents oom_score_adj name
[    4.713849] [    341]     0   341     5118     1178    77824
0         -1000 (md-udevd)
[    4.717805] Out of memory and no killable processes...
[    4.719861] Kernel panic - not syncing: System is deadlocked on memory
[    4.721926] CPU: 3 PID: 1 Comm: systemd Not tainted 5.3.7-301.fc31.
x86_64 #1
[    4.724343] Hardware name: QEMU Standard PC (Q35 + ICH9, 2009), BIOS
1.12.0-2.fc30 04/01/2014
[    4.727959] Call Trace:
```

```
[    4.729204]  dump_stack+0x5c/0x80
[    4.730707]  panic+0x101/0x2d7
[    4.747357]  out_of_memory.cold+0x2f/0x88
[    4.749172]  __alloc_pages_slowpath+0xb09/0xe00
[    4.750890]  __alloc_pages_nodemask+0x2ee/0x340
[    4.752452]  alloc_slab_page+0x19f/0x320
[    4.753982]  new_slab+0x44f/0x4d0
[    4.755317]  ? alloc_slab_page+0x194/0x320
[    4.757016]  ___slab_alloc+0x507/0x6a0
[    4.758768]  ? copy_verifier_state+0x1f7/0x270
[    4.760591]  ? ___slab_alloc+0x507/0x6a0
[    4.763266]  __slab_alloc+0x1c/0x30
[    4.764846]  kmem_cache_alloc_trace+0x1ee/0x220
[    4.766418]  ? copy_verifier_state+0x1f7/0x270
[    4.768120]  copy_verifier_state+0x1f7/0x270
[    4.769604]  ? kmem_cache_alloc_trace+0x162/0x220
[    4.771098]  ? push_stack+0x35/0xe0
[    4.772367]  push_stack+0x66/0xe0
[    4.774010]  check_cond_jmp_op+0x1fe/0xe60
[    4.775644]  ? _cond_resched+0x15/0x30
[    4.777524]  ? _cond_resched+0x15/0x30
[    4.779315]  ? kmem_cache_alloc_trace+0x162/0x220
[    4.780916]  ? copy_verifier_state+0x1f7/0x270
[    4.782357]  ? copy_verifier_state+0x16f/0x270
[    4.783785]  do_check+0x1c06/0x24e0
[    4.785218]  bpf_check+0x1aec/0x24d4
[    4.786613]  ? _cond_resched+0x15/0x30
[    4.788073]  ? kmem_cache_alloc_trace+0x162/0x220
[    4.789672]  ? selinux_bpf_prog_alloc+0x1f/0x60
[    4.791564]  bpf_prog_load+0x3a3/0x670
[    4.794915]  ? seq_vprintf+0x30/0x50
[    4.797085]  ? seq_printf+0x53/0x70
[    4.799013]  __do_sys_bpf+0x7e5/0x17d0
[    4.800909]  ? __fput+0x168/0x250
[    4.802352]  do_syscall_64+0x5f/0x1a0
[    4.803826]  entry_SYSCALL_64_after_hwframe+0x44/0xa9
[    4.805587] RIP: 0033:0x7f471557915d
[    4.807638] Code: 00 c3 66 2e 0f 1f 84 00 00 00 00 00 90 f3 0f 1e fa 48
89 f8 48 89 f7 48 89 d6 48 89 ca 4d 89 c2 4d 89 c8 4c 8b 4c 24 08 0f 05
<48> 3d 01 f0 ff ff 73 01 c3 48 8b 0d fb 5c 0c 00 f7 d8 64 89 01 48
[    4.814732] RSP: 002b:00007fffd36da028 EFLAGS: 00000246 ORIG_RAX:
0000000000000141
[    4.818390] RAX: ffffffffffffffda RBX: 000055fb6ad3add0 RCX:
00007f471557915d
[    4.820448] RDX: 0000000000000070 RSI: 00007fffd36da030 RDI:
0000000000000005
[    4.822536] RBP: 0000000000000002 R08: 0070756f7267632f R09:
000001130000000f
[    4.826605] R10: 0000000000000000 R11: 0000000000000246 R12:
0000000000000000
[    4.829312] R13: 0000000000000006 R14: 000055fb6ad3add0 R15:
00007fffd36da1e0
[    4.831792] Kernel Offset: 0x26000000 from 0xffffffff81000000
(relocation range: 0xffffffff80000000-0xffffffffbfffffff)
[    4.835316] ---[ end Kernel panic - not syncing: System is deadlocked on
memory ]---
```

So, this is a “kernel panic” issue. We need to isolate the issue first since kernel panic can occur due to thousands of situations. If you look at the highlighted messages of kernel panic, it is clear that an “OOM-killer” has been invoked since the system is running out of memory. The kernel tried to free the memory from cache and even tried to use the swap space, but eventually it gave up, and the kernel panicked.

So, we have isolated the issue. We need to concentrate on who is eating the memory. The OS out-of-memory (OOM) mechanism will be invoked when the system has immense memory pressure.

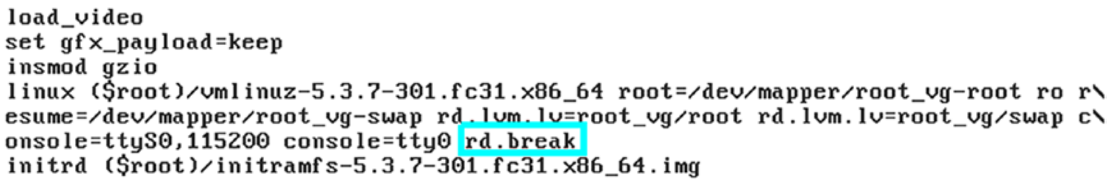
There are three situations when an OOM-killer can be invoked during the boot sequence:

- The system has really low physical memory installed.
- The wrong kernel tuning parameters have been set.
- Some modules have a memory leak.

This system has 4.9 GB of physical memory, which is not big, but it is certainly more than enough for the Linux kernel to finish the booting sequence.

Some modules might have memory leaks, but identifying that will be a difficult task. So, we will verify first whether any memory-related kernel tuning parameters have been set incorrectly.

1. To do that, we will drop ourselves inside initramfs. In Figure 7-66, we have passed `rd.break` as a kernel command-line parameter.



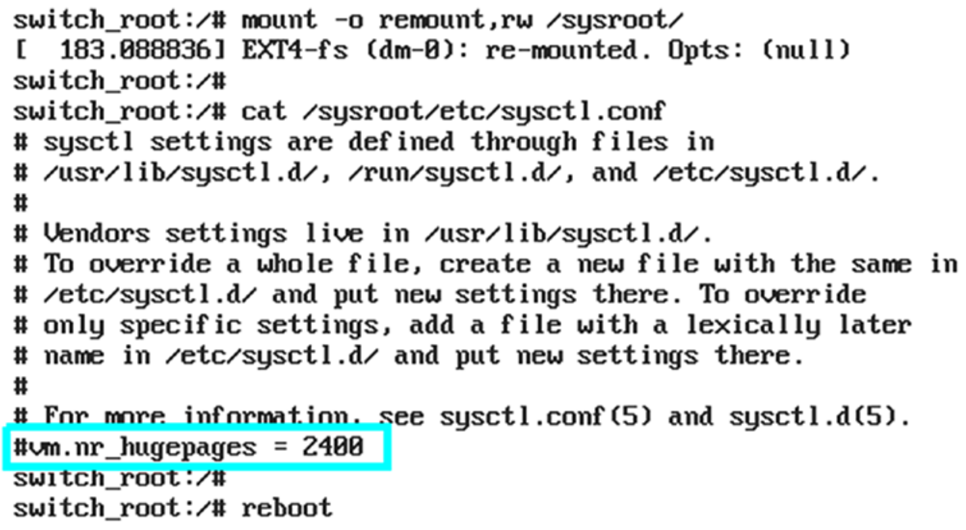
```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/root_vg-root ro r\
esume=/dev/mapper/root_vg-swap rd.lvm.lv=root_vg/root rd.lvm.lv=root_vg/swap c\
onsole=ttyS0,115200 console=tty0 rd.break
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 7-66. *The kernel command-line parameter*

2. We will remount `sysroot` in read-write mode and verify the `sysctl` parameters.

```
switch_root:/# cat /proc/sys/vm/nr_hugepages
               2400
```

3. The issue is the wrongly reserved number of hugepages. We will disable the setting as per Figure 7-67.



```
switch_root:/# mount -o remount,rw /sysroot/
[  183.088836] EXT4-fs (dm-0): re-mounted. Opts: (null)
switch_root:/#
switch_root:/# cat /sysroot/etc/sysctl.conf
# sysctl settings are defined through files in
# /usr/lib/sysctl.d/, /run/sysctl.d/, and /etc/sysctl.d/.
#
# Vendors settings live in /usr/lib/sysctl.d/.
# To override a whole file, create a new file with the same in
# /etc/sysctl.d/ and put new settings there. To override
# only specific settings, add a file with a lexically later
# name in /etc/sysctl.d/ and put new settings there.
#
# For more information, see sysctl.conf(5) and sysctl.d(5).
#vm.nr_hugepages = 2400
switch_root:/#
switch_root:/# reboot
```

Figure 7-67. *Disabling the hugepage setting*

After rebooting, the system is able to boot successfully. Let's try to understand what went wrong. This system has 4.9 GB of memory, and earlier there were no hugepages reserved.

```
# cat /proc/meminfo | grep -e MemTotal -e HugePages_Total

MemTotal:        4932916 kB
HugePages_Total:       0
```

```
# cat /proc/sys/vm/nr_hugepages
0
```

A normal page is 4 KB in size, whereas a hugepage is 2 MB in size, which is 512 times bigger than a normal page. Hugepage has its own advantages, but at the same time it has its own disadvantages too.

- A hugepage cannot be swapped out.
- The kernel don't use hugepages.
- Only the applications that are hugepage-aware can use the hugepages.

Someone wrongly set the 2,400 hugepages and rebuilt initramfs.

```
# echo "vm.nr_hugepages = 2400" >> /etc/sysctl.conf

     # sysctl -p
            vm.nr_hugepages = 2400

     # dracut /boot/new.img
     # reboot
```

So, 2,400 hugepages = 4.9 GB, which is all the installed main memory, and since the total memory got reserved in hugepages, the kernel cannot use it. So, while booting, when systemd reached the stage of `sysinit.target` and executed `systemd-sysctl.service`, the service read the `sysctl.conf` file from initramfs and reserved 4.9 GB of hugepages, which the kernel cannot use. Therefore, the kernel itself ran out of memory, and the system panicked.

basic.target

So, we have reached `basic.target`. As we know, targets are for synchronizing or grouping the units. `basic.target` is a synchronization point for late boot services.

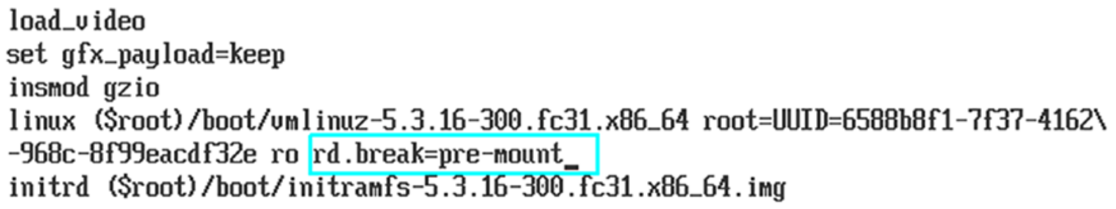
```
# cat usr/lib/systemd/system/basic.target | grep -v '#'
[Unit]
Description=Basic System
Documentation=man:systemd.special(7)
Requires=sysinit.target
Wants=sockets.target timers.target paths.target slices.target
After=sysinit.target sockets.target paths.target slices.target tmp.mount

RequiresMountsFor=/var /var/tmp
Wants=tmp.mount
```

So, `basic.target` will be successful when all the earlier services' unit files `requires`, `wants`, and `after` phases are successfully started. In fact, almost all of the services have `After=basic.target` added in their unit files.

dracut-pre-mount.service

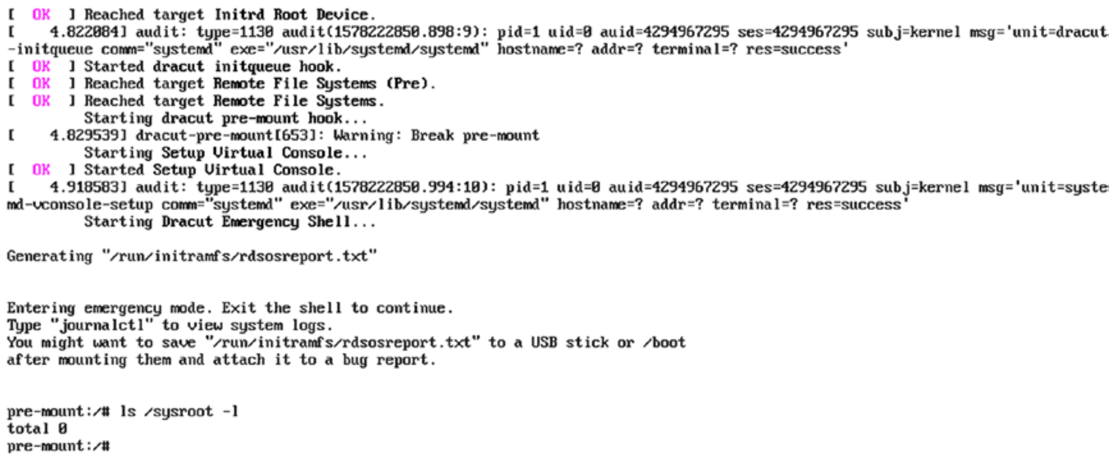
systemd will execute the `dracut-pre-mount.service` service just before mounting the user's root filesystem inside initramfs. Since it is a dracut service, it will execute only if the user has passed the `rd.break=pre-mount` dracut command-line parameter. Figure 7-68 shows that we have passed `rd.break=pre-mount` as a kernel command-line parameter.

As you can see in Figure 7-69, it has dropped us at the emergency shell, and the user's root filesystem is not mounted at `sysroot.` Yes, I said it has dropped us at the emergency shell, but you will be surprised to see that the emergency shell is nothing but a simple bash shell provided by systemd but at the time when booting is not finished yet. To understand the emergency shell better, we will pause our booting sequence for a while and discuss the debugging shells of initramfs in Chapter 8. We will resume our paused systemd's booting sequence in Chapter 9.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/boot/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=6588b8f1-7f37-4162\
-968c-8f99eacdf32e ro rd.break=pre-mount_
initrd ($root)/boot/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 7-68. *The kernel command-line parameter*



```
[  OK  ] Reached target Initrd Root Device.
[    4.822084] audit: type=1130 audit(1578222850.898:9): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=dracut
-initqueue comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[  OK  ] Started dracut initqueue hook.
[  OK  ] Reached target Remote File Systems (Pre).
[  OK  ] Reached target Remote File Systems.
         Starting dracut pre-mount hook...
[    4.829539] dracut-pre-mount[653]: Warning: Break pre-mount
         Starting Setup Virtual Console...
[  OK  ] Started Setup Virtual Console.
[    4.918583] audit: type=1130 audit(1578222850.994:10): pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=syste
md-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
         Starting Dracut Emergency Shell...

Generating "/run/initramfs/rdsosreport.txt"


Entering emergency mode. Exit the shell to continue.
Type "journalctl" to view system logs.
You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot
after mounting them and attach it to a bug report.


pre-mount:/# ls /sysroot -l
total 0
pre-mount:/#
```

Figure 7-69. *The pre-mount hook*

CHAPTER 8

Debugging Shells

As of now, we know that initramfs has bash built in, and we have used it from time to time through `rd.break` hooks. This chapter's aim is to understand how systemd provides us with a shell inside an initramfs. What are the steps that have to be followed, and how can one use it more effectively? But before that, let's recap what we have learned so far about the debugging and emergency shells of initramfs.

The Shell

```
rd.break
            drop to a shell at the end
```

`rd.break` drops us inside initramfs, and we can explore the initramfs environment through it. This initramfs environment is also called the *emergency mode*. In normal scenarios, we get dropped in emergency mode when initramfs is not able to mount the user's root filesystem. Remember, passing `rd.break` without any parameters will drop us at initramfs after mounting the user's root filesystem under `/sysroot` but before performing `switch_root` on it. You can always find the detailed logs in the `/run/initramfs/rdsosreport.txt` file. Figure 8-1 shows the logs from `rdsosreport.txt`.

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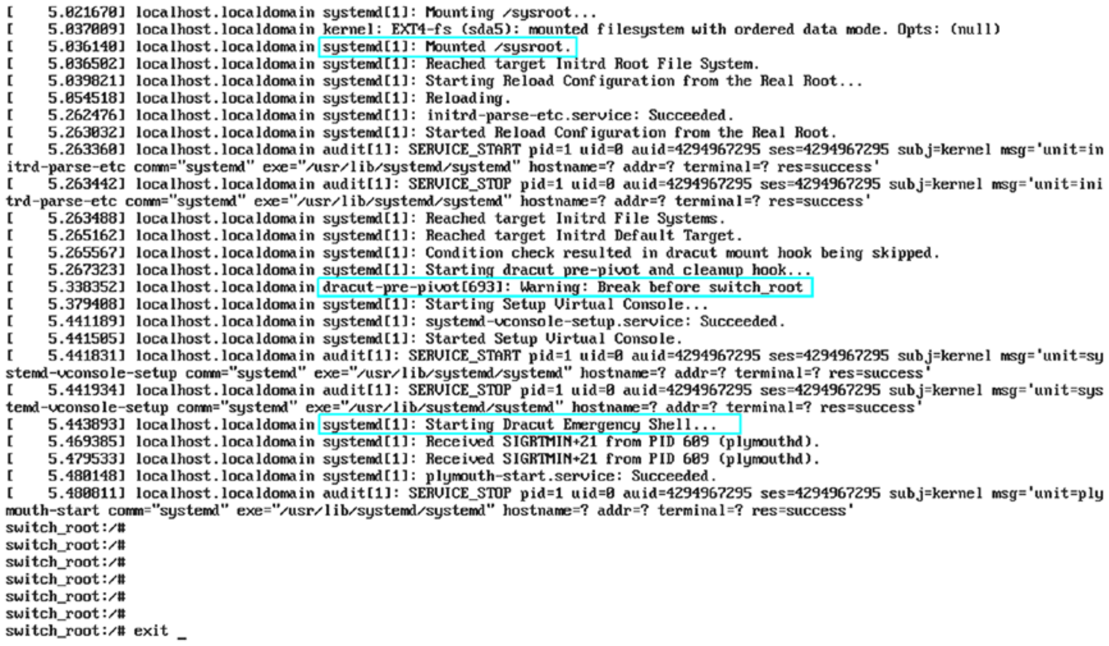
Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_8



```
[    5.021670] localhost.localdomain systemd[1]: Mounting /sysroot...
[    5.037009] localhost.localdomain kernel: EXT4-fs (sda5): mounted filesystem with ordered data mode. Opts: (null)
[    5.036140] localhost.localdomain systemd[1]: Mounted /sysroot.
[    5.036502] localhost.localdomain systemd[1]: Reached target Initrd Root File System.
[    5.039821] localhost.localdomain systemd[1]: Starting Reload Configuration from the Real Root...
[    5.054518] localhost.localdomain systemd[1]: Reloading.
[    5.262476] localhost.localdomain systemd[1]: initrd-parse-etc.service: Succeeded.
[    5.263032] localhost.localdomain systemd[1]: Started Reload Configuration from the Real Root.
[    5.263360] localhost.localdomain audit[1]: SERVICE_START pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=in
itrd-parse-etc comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[    5.263442] localhost.localdomain audit[1]: SERVICE_STOP pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=ini
trd-parse-etc comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[    5.263488] localhost.localdomain systemd[1]: Reached target Initrd File Systems.
[    5.265162] localhost.localdomain systemd[1]: Reached target Initrd Default Target.
[    5.265567] localhost.localdomain systemd[1]: Condition check resulted in dracut mount hook being skipped.
[    5.267323] localhost.localdomain systemd[1]: Starting dracut pre-pivot and cleanup hook...
[    5.338352] localhost.localdomain dracut-pre-pivot[693]: Warning: Break before switch_root
[    5.379408] localhost.localdomain systemd[1]: Starting Setup Virtual Console...
[    5.441189] localhost.localdomain systemd[1]: systemd-vconsole-setup.service: Succeeded.
[    5.441505] localhost.localdomain systemd[1]: Started Setup Virtual Console.
[    5.441831] localhost.localdomain audit[1]: SERVICE_START pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=sy
stemd-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[    5.441934] localhost.localdomain audit[1]: SERVICE_STOP pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=sys
temd-vconsole-setup comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
[    5.443893] localhost.localdomain systemd[1]: Starting Dracut Emergency Shell...
[    5.469385] localhost.localdomain systemd[1]: Received SIGRTMIN+21 from PID 609 (plymouthd).
[    5.479533] localhost.localdomain systemd[1]: Received SIGRTMIN+21 from PID 609 (plymouthd).
[    5.480148] localhost.localdomain systemd[1]: plymouth-start.service: Succeeded.
[    5.480811] localhost.localdomain audit[1]: SERVICE_STOP pid=1 uid=0 auid=4294967295 ses=4294967295 subj=kernel msg='unit=ply
mouth-start comm="systemd" exe="/usr/lib/systemd/systemd" hostname=? addr=? terminal=? res=success'
switch_root:/#
switch_root:/#
switch_root:/#
switch_root:/#
switch_root:/#
switch_root:/#
switch_root:/# exit _
```

Figure 8-1. *The rdsosreport.txt runtime logs*

In the log messages, you can clearly see that it dropped just before performing `pivot_root`. `pivot_root` and `switch_root` will be discussed in Chapter 9, whereas `chroot` will be discussed in Chapter 10. Once you exit from the emergency shell, systemd will continue the paused booting sequence and will eventually provide the login screen.

Then we discussed how we can use emergency shells to fix some of the "can't boot" issues. For example, initramfs is as good as the user's root filesystem. So, it does have `lvm`, `raid`, and filesystem-related binaries that we can use to find, assemble, diagnose, and fix the missing user's root filesystem. Then we discussed how we can mount it under `/sysroot` and explore the contents of it to fix `grub.cfg`'s wrong entries, for example.

Likewise, `rd.break` does provide us with various options to break the booting sequence at different stages.

`cmdline`: This hook gets the kernel command-line parameters.

`pre-udev`: This breaks the booting sequence before the `udev` handler.

`pre-trigger`: You can set `udev` environment variables with the `udevadm` control or can set `--property=KEY=value` like parameters or control the further execution of `udev` with `udevadm`.

`pre-mount`: This breaks the booting sequence before mounting the user's root filesystem at `/sysroot`.

`mount`: This breaks the booting sequence after mounting the root filesystem at `/sysroot`.

`pre-pivot`: This breaks the booting sequence just before switching to the actual root filesystem.

Now let's see how exactly systemd manages to provide us with the shells in these various stages.

How Does systemd Drop Us to an Emergency Shell?

Let's consider an example of a `pre-mount` hook. systemd from initramfs collects the `rd.break=pre-mount` command-line parameter from `dracut-cmdline.service`, and it runs the systemd service `dracut-pre-mount.service` from the initramfs location `/usr/lib/systemd/system`. The service will run before running `initrd-root-fs.target`, `sysroot.mount`, and `systemd-fsck-root.service`.

```
# cat usr/lib/systemd/system/dracut-pre-mount.service | grep -v #'

[Unit]
Description=dracut pre-mount hook
Documentation=man:dracut-pre-mount.service(8)
DefaultDependencies=no
Before=initrd-root-fs.target sysroot.mount systemd-fsck-root.service
After=dracut-initqueue.service cryptsetup.target
ConditionPathExists=/usr/lib/initrd-release
ConditionDirectoryNotEmpty=|/lib/dracut/hooks/pre-mount
ConditionKernelCommandLine=|rd.break=pre-mount
Conflicts=shutdown.target emergency.target

[Service]
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
Type=oneshot
ExecStart=-/bin/dracut-pre-mount
```

```
StandardInput=null
StandardOutput=syslog
StandardError=syslog+console
KillMode=process
RemainAfterExit=yes

KillSignal=SIGHUP
```

As you can see, it is simply executing the /bin/dracut-pre-mount script from initramfs.

```
# vim bin/dracut-pre-mount
#!/usr/bin/sh

export DRACUT_SYSTEMD=1
if [ -f /dracut-state.sh ]; then
    . /dracut-state.sh 2>/dev/null
fi
type getarg >/dev/null 2>&1 || . /lib/dracut-lib.sh

source_conf /etc/conf.d

make_trace_mem "hook pre-mount" '1:shortmem' '2+:mem' '3+:slab' '4+:komem'
# pre pivot scripts are sourced just before we doing cleanup and switch over
# to the new root.
getarg 'rd.break=pre-mount' 'rdbreak=pre-mount' && emergency_shell -n pre-mount "Break pre-mount"
source_hook pre-mount

export -p > /dracut-state.sh

exit 0
```

Inside the /bin/dracut-pre-mount script, the most important line is the following:

```
getarg rd.break=pre-mount' rdbreak=pre-mount
    && emergency_shell -n pre-mount "Break pre-mount"
```

We have already discussed the `getarg` function, which is used to check what parameter has been passed to `rd.break=`. If `rd.break=pre-mount` has been passed, then only the `emergency-shell()` function will be called. The function is defined in `/usr/lib/dracut-lib.sh`, and it passes `pre-mount` as a string parameter to it. `-n` stands for the following:

> `[ -n STRING ] or [ STRING ]`: True if the length of `STRING` is nonzero

The `emergency_shell` function accepts the `_rdshell_name` variable's value as `pre-mount`.

```
if [ "$1" = "-n" ]; then
      _rdshell_name=$2
```

Here, `-n` is considered as the first argument ($1), and `pre-mount` is the second argument ($2). So, the value of `_rdshell_name` becomes `pre-mount`.

```
#vim /usr/lib/dracut-lib.sh
emergency_shell()
{
    local _ctty
    set +e
    local _rdshell_name="dracut" action="Boot" hook="emergency"
    local _emergency_action

    if [ "$1" = "-n" ]; then
        _rdshell_name=$2
        shift 2
    elif [ "$1" = "--shutdown" ]; then
        _rdshell_name=$2; action="Shutdown"; hook="shutdown-emergency"
        if type plymouth >/dev/null 2>&1; then
            plymouth --hide-splash
        elif [ -x /oldroot/bin/plymouth ]; then
            /oldroot/bin/plymouth --hide-splash
        fi
        shift 2
    fi

    echo ; echo
    warn "$*"
    echo

    _emergency_action=$(getarg rd.emergency)
    [ -z "$_emergency_action" ] \
        && [ -e /run/initramfs/.die ] \
        && _emergency_action=halt

    if getargbool 1 rd.shell -d -y rdshell || getarg rd.break -d rdbreak; then
        _emergency_shell $_rdshell_name
    else
        source_hook "$hook"
        warn "$action has failed. To debug this issue add \"rd.shell rd.debug\" to the kernel command line."
        [ -z "$_emergency_action" ] && _emergency_action=halt
    fi

    case "$_emergency_action" in
        reboot)
            reboot || exit 1;;
        poweroff)
            poweroff || exit 1;;
        halt)
            halt || exit 1;;
    esac
}
```

Then, at the end, it calls another `_emergency_shell` function from the same file (note the underscore before the function name). As you can see, `_rdshell_name` is the argument to the `_emergency_shell` function.

```
_emergency_shell $_rdshell_name
```

Inside the `_emergency_shell()` function, we can see that `_name` gets the argument, which is `pre-mount`.

```
local _name="$1"
```

```
#vim usr/lib/dracut-lib.sh
```

```
_emergency_shell()
{
    local _name="$1"
    if [ -n "$DRACUT_SYSTEMD" ]; then
        > /.console_lock
        echo "PS1=\"$_name:\\\${PWD}# \"" >/etc/profile
        systemctl start dracut-emergency.service
        rm -f -- /etc/profile
        rm -f -- /.console_lock
    else
        debug_off
        source_hook "$hook"
        echo
        /sbin/rdsosreport
        echo 'You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot'
        echo 'after mounting them and attach it to a bug report.'
        if ! RD_DEBUG= getargbool 0 rd.debug -d -y rdinitdebug -d -y rdnetdebug; then
            echo
            echo 'To get more debug information in the report,'
            echo 'reboot with "rd.debug" added to the kernel command line.'
        fi
        echo
        echo 'Dropping to debug shell.'
        echo
        export PS1="$_name:\${PWD}# "
        [ -e /.profile ] || >/.profile

        _ctty="$(RD_DEBUG= getarg rd.ctty=)" && _ctty="/dev/${_ctty##*/}"
        if [ -z "$_ctty" ]; then
            _ctty=console
            while [ -f /sys/class/tty/$_ctty/active ]; do
                _ctty=$(cat /sys/class/tty/$_ctty/active)
                _ctty=${_ctty##* } # last one in the list
                done
                _ctty=/dev/$_ctty
            fi
            [ -c "$_ctty" ] || _ctty=/dev/tty1
            case "$(/usr/bin/setsid --help 2>&1)" in *--ctty*) CTTY="--
            ctty";; esac
            setsid $CTTY /bin/sh -i -l 0<>$_ctty 1<>$_ctty 2<>$_ctty
        fi
```

The same `pre-mount` string has been passed to `PS1`. Let's see first what exactly `PS1` is.

`PS1` is called a *pseudo* variable. This will be shown by bash when the user has successfully logged in. Here's an example:

```
                  [root@fedora home]#
                    |  |   |    |
             [username]@[host][CWD][# since it is a root user]
```

The ideal entries accepted by bash are `PS1='\u:\w\$'`.

u = This is the username.

w = This is the working directory.

$ = If UID is 0, then #; otherwise `$'`.

So, in our case, when we get a emergency shell, `PS1` will be printed by the shell as follows:

`'pre-mount#'`

Next in the source code, you can see that the `PS1` variable's new value is also getting added in `/etc/profile.` The reason is that bash reads this file every time before presenting the shell to the user. At the end, we are simply starting the `dracut-emergency` service.

`systemctl start dracut-emergency.service`

The following is the `dracut-emergency.service` file from `usr/lib/systemd/system/` of initramfs:

`# cat usr/lib/systemd/system/dracut-emergency.service | grep -v #'`

```
[Unit]
Description=Dracut Emergency Shell
DefaultDependencies=no
After=systemd-vconsole-setup.service
Wants=systemd-vconsole-setup.service
Conflicts=shutdown.target emergency.target

[Service]
Environment=HOME=/
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
WorkingDirectory=/
ExecStart=-/bin/dracut-emergency
ExecStopPost=-/bin/rm -f -- /.console_lock
Type=oneshot
StandardInput=tty-force
StandardOutput=inherit
StandardError=inherit
KillMode=process
IgnoreSIGPIPE=no
TasksMax=infinity

KillSignal=SIGHUP
```

The service is simply executing `/bin/dracut-emergency`. This script first stops the `plymouth` service.

```
type plymouth >/dev/null 2>&1 && plymouth quit
```

This stores the hook variable's value as `emergency` and calls the `source_hook` function with the `emergency` argument.

```
export _rdshell_name="dracut" action="Boot" hook="emergency"
source_hook "$hook"
```

```
# vim bin/dracut-emergency
#!/usr/bin/sh

export DRACUT_SYSTEMD=1
```

```
if [ -f /dracut-state.sh ]; then
    . /dracut-state.sh 2>/dev/null
fi
type getarg >/dev/null 2>&1 || . /lib/dracut-lib.sh

source_conf /etc/conf.d

type plymouth >/dev/null 2>&1 && plymouth quit

export _rdshell_name="dracut" action="Boot" hook="emergency"
_emergency_action=$(getarg rd.emergency)

if getargbool 1 rd.shell -d -y rdshell || getarg rd.break -d rdbreak; then
    FSTXT="/run/dracut/fsck/fsck_help_$fstype.txt"
    source_hook "$hook"
    echo
    rdsosreport
    echo
    echo
    echo Entering emergency mode. Exit the shell to continue.'
    echo Type "journalctl" to view system logs.'
    echo You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot'
    echo after mounting them and attach it to a bug report.'
    echo
    echo
    [ -f "$FSTXT" ] && cat "$FSTXT"
    [ -f /etc/profile ] && . /etc/profile
    [ -z "$PS1" ] && export PS1="$_name:\${PWD}# "
    exec sh -i -l
else
    export hook="shutdown-emergency"
    warn "$action has failed. To debug this issue add \"rd.shell rd.debug\" to the kernel command line."
    source_hook "$hook"
    [ -z "$_emergency_action" ] && _emergency_action=halt
fi

/bin/rm -f -- /.console_lock

case "$_emergency_action" in
    reboot)
        reboot || exit 1;;
    poweroff)
        poweroff || exit 1;;
    halt)
        halt || exit 1;;
esac

exit 0
```

The `source_hook` function is again defined in `usr/lib/dracut-lib.sh`.

```
source_hook() {
    local _dir
    _dir=$1; shift
    source_all "/lib/dracut/hooks/$_dir" "$@"
}
```

The `_dir` variable has captured the hook name, which is emergency. All the hooks are nothing but a bunch of scripts, stored and executed from the `/lib/dracut/hooks/` directory of initramfs.

```
# tree usr/lib/dracut/hooks/
usr/lib/dracut/hooks/
├── cleanup
├── cmdline
│   ├── 30-parse-lvm.sh
│   ├── 91-dhcp-root.sh
│   └── 99-nm-config.sh
├── emergency
│   └── 50-plymouth-emergency.sh
```

```
├── initqueue
│   ├── finished
│   ├── online
│   ├── settled
│   │   └── 99-nm-run.sh
│   └── timeout
│       └── 99-rootfallback.sh
├── mount
├── netroot
├── pre-mount
├── pre-pivot
│   └── 85-write-ifcfg.sh
├── pre-shutdown
├── pre-trigger
├── pre-udev
│   └── 50-ifname-genrules.sh
├── shutdown
│   └── 25-dm-shutdown.sh
└── shutdown-emergency
```

For an emergency hook, it is executing `usr/lib/dracut/hooks/emergency/50-plymouth-emergency.sh`, which is stopping the `plymouth` service.

```
#!/usr/bin/sh
plymouth --hide-splash 2>/dev/null || :
```

Once the `emergency` hook is executed and `plymouth` has been stopped, it will go back to `bin/dracut-emergency` and print the following banner:

```
echo Entering emergency mode. Exit the shell to continue.'
echo Type "journalctl" to view system logs.'
echo You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick
or /boot'
echo after mounting them and attach it to a bug report.'
```

So, it does not matter what the `rd.break=hook_name` user has passed. systemd will execute the `emergency` hook, and once the banner is printed, it will fetch the `/etc/profile` directory in which we have added `PS1=_rdshell_name/PS1=hook_name`, and then we can simply run the bash shell.

```
exec sh -i -l
```

When the shell starts running, it will read `/etc/profile`, and it will find the `PS1=hook_name` variable. In this case, `hook_name` is `pre-mount`. That is why `pre-mount` as a prompt name of bash has been printed. Refer to the flowchart shown in Figure 8-2 for a better understanding of this.

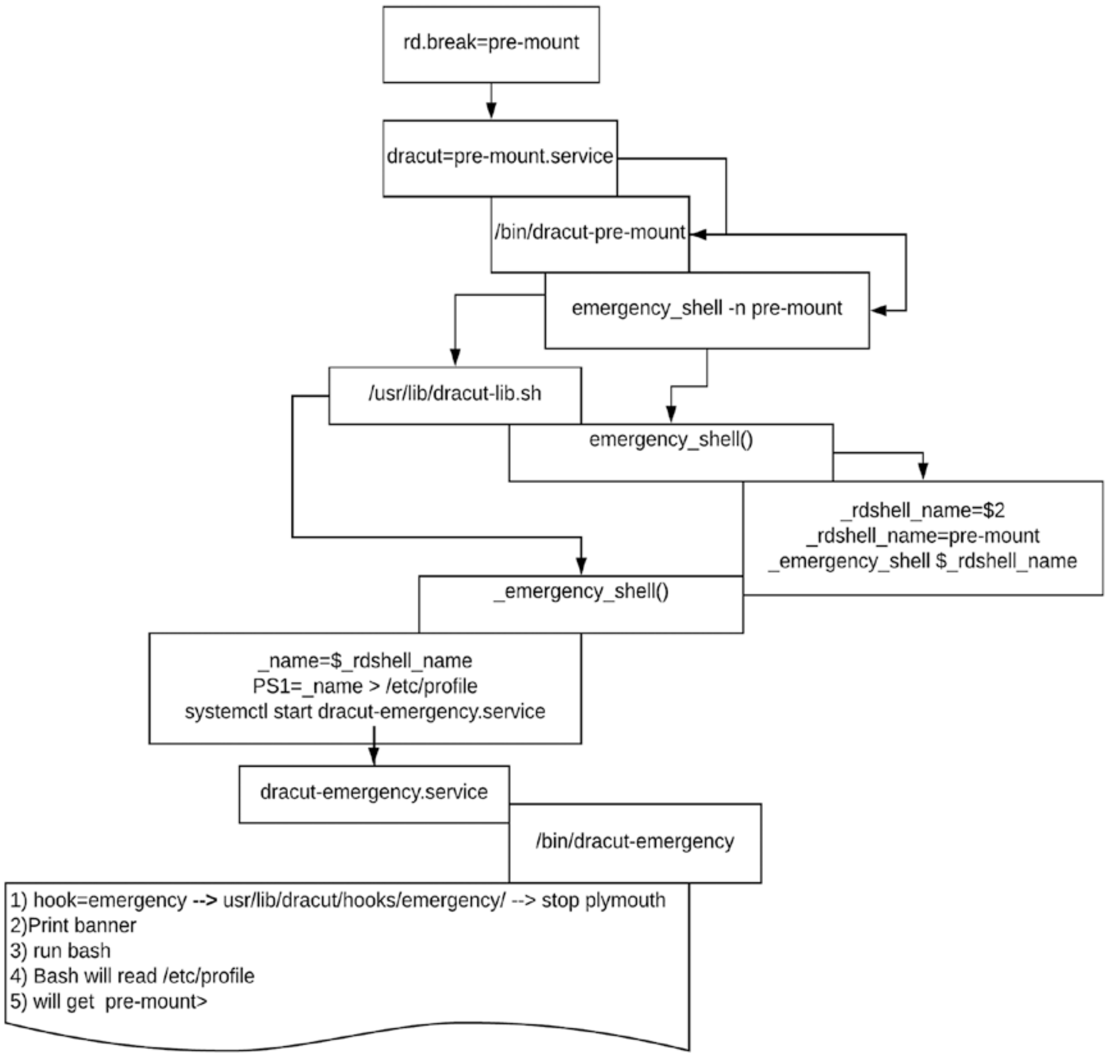


Figure 8-2. *The flowchart*

If a user passes any other parameter to `rd.break`, for example, `initqueue`, then it will be fed into `PS1`, `_rdshell_name`, and hook variables. Later, bash will be called through the emergency service. Bash will read the `PS1` value from the `/etc/profile` file and will show the `initqueue` name in the prompt.

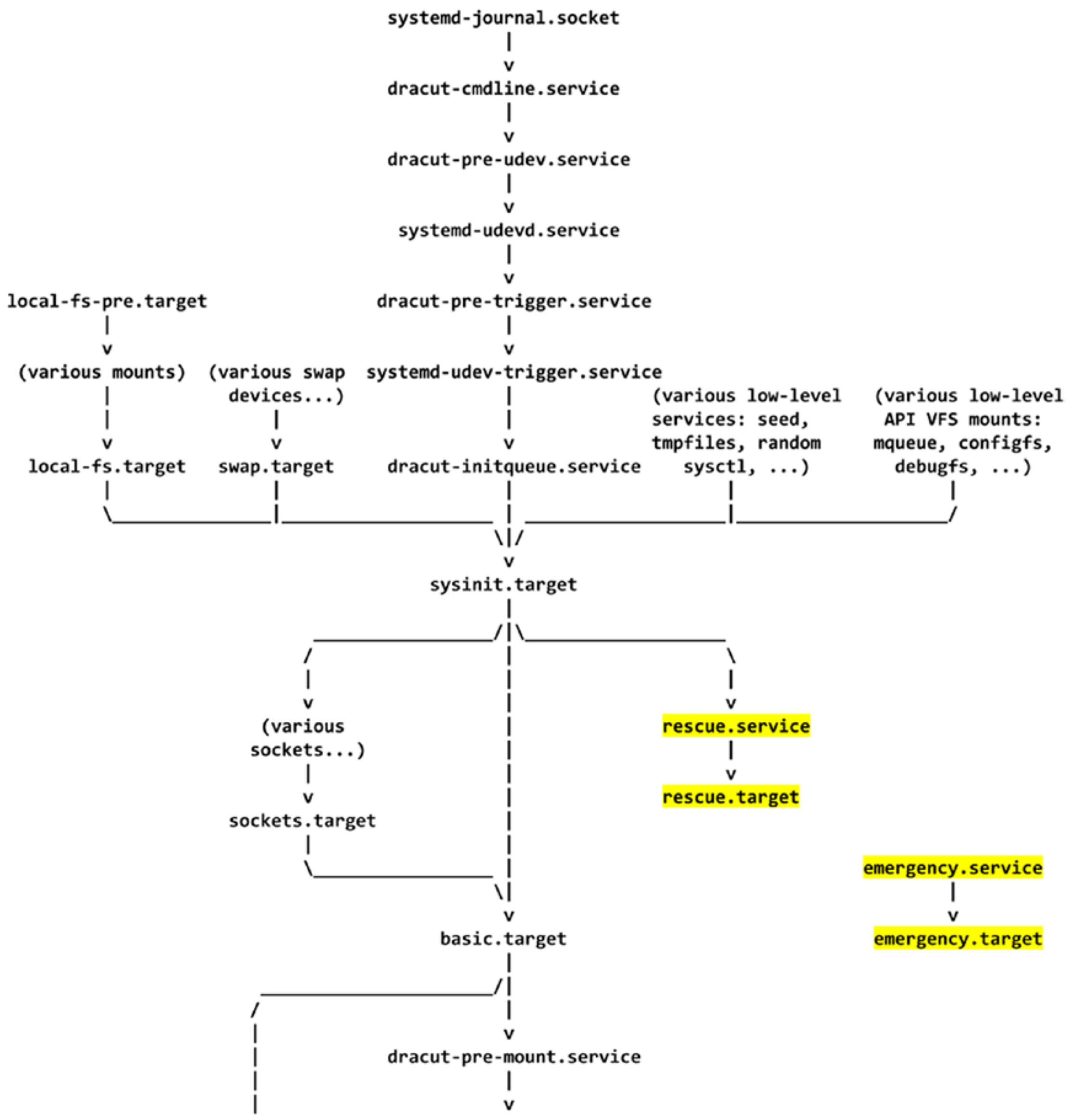
The conclusion is that the same bash shell will be provided to the user under various prompt names (`cmdline`, `pre-mount`, `switch_root`, `pre-udev`, `emergency`, etc.) but at different boot stages of initramfs.

```
cmdline:/# pre-udev:/#
pre-trigger:/# initqueue:/#
pre-mount:/# pre-pivot:/#
switch_root:/#
```

Similar to this, `rescue.target` will be executed by systemd.

rescue.service and emergency.service

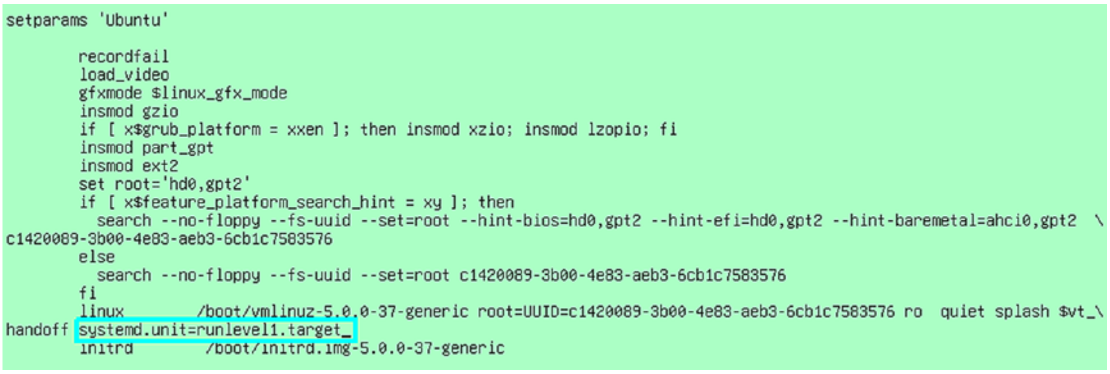
The rescue service is also called *single-user mode* in the systemd world. So if the user has requested to boot in single-user mode, then systemd actually drops the user on the emergency shell at the `rescue.service` stage. Figure 8-3 shows you the booting sequence covered so far.



```
                              systemd-journal.socket
                                        |
                                        v
                              dracut-cmdline.service
                                        |
                                        v
                              dracut-pre-udev.service
                                        |
                                        v
                               systemd-udevd.service
                                        |
                                        v
 local-fs-pre.target         dracut-pre-trigger.service
          |                             |
          v                             v
  (various mounts)  (various swap  systemd-udev-trigger.service
          |            devices...)          |          (various low-level   (various low-level
          |               |                 |          services: seed,       API VFS mounts:
          v               v                 v          tmpfiles, random     mqueue, configfs,
   local-fs.target    swap.target     dracut-initqueue.service   sysctl, ...)   debugfs, ...)
          |               |                 |                 |                    |
          \_______________|_________________ | _________________|____________________/
                                           \|/
                                            v
                                      sysinit.target
                                            |
                          _________________/|\_________________
                         /                  |                  \
                         |                  |                  |
                         v                  |                  v
                     (various               |            rescue.service
                    sockets...)             |                  |
                         |                  |                  v
                         v                  |            rescue.target
                   sockets.target           |
                         |                  |
                         \__________________|                        emergency.service
                                           \|                                |
                                            v                                v
                                       basic.target                   emergency.target
                                            |
                       ____________________/|
                      /                     |
                      |                     v
                      |           dracut-pre-mount.service
                      |                     |
                      |                     v
```

Figure 8-3. The flowchart of the booting sequence

You can either pass `rescue.target` or pass `runlevel1.target` or `emergency.service` to `systemd.unit` to boot in single-user mode. As shown in Figure 8-4, we will use Ubuntu this time to explore the booting stages.



```
setparams 'Ubuntu'

        recordfail
        load_video
        gfxmode $linux_gfx_mode
        insmod gzio
        if [ x$grub_platform = xxen ]; then insmod xzio; insmod lzopio; fi
        insmod part_gpt
        insmod ext2
        set root='hd0,gpt2'
        if [ x$feature_platform_search_hint = xy ]; then
          search --no-floppy --fs-uuid --set=root --hint-bios=hd0,gpt2 --hint-efi=hd0,gpt2 --hint-baremetal=ahci0,gpt2  \
c1420089-3b00-4e83-aeb3-6cb1c7583576
        else
          search --no-floppy --fs-uuid --set=root c1420089-3b00-4e83-aeb3-6cb1c7583576
        fi
        linux       /boot/vmlinuz-5.0.0-37-generic root=UUID=c1420089-3b00-4e83-aeb3-6cb1c7583576 ro  quiet splash $vt_\
handoff systemd.unit=runlevel1.target_
        initrd       /boot/initrd.img-5.0.0-37-generic
```

Figure 8-4. *The kernel command-line parameter*

This will drop us on an emergency shell. The single-user mode, rescue service, and emergency service all launch the `dracut-emergency` binary. This is the same binary that we launched in the emergency hook of dracut.

```
# cat usr/lib/systemd/system/emergency.service | grep -v ' #'

[Unit]
Description=Emergency Shell
DefaultDependencies=no
After=systemd-vconsole-setup.service
Wants=systemd-vconsole-setup.service
Conflicts=shutdown.target
Before=shutdown.target

[Service]
Environment=HOME=/
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
WorkingDirectory=/
ExecStart=/bin/dracut-emergency
ExecStopPost=-/usr/bin/systemctl --fail --no-block default
Type=idle
StandardInput=tty-force
StandardOutput=inherit
```

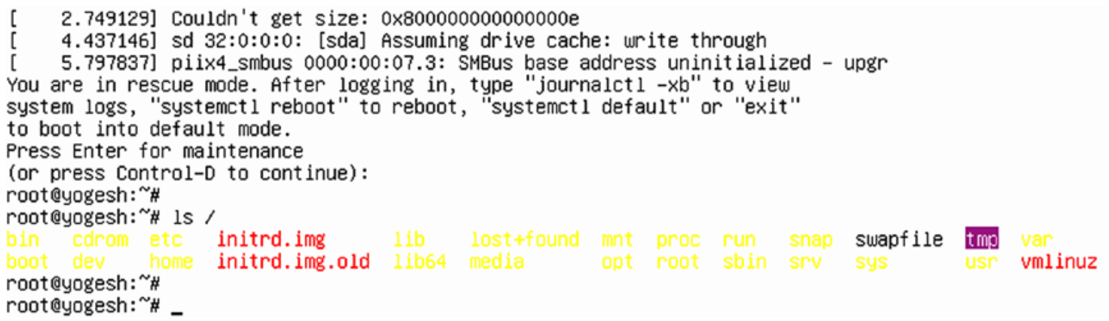
```
StandardError=inherit
KillMode=process
IgnoreSIGPIPE=no
TasksMax=infinity

KillSignal=SIGHUP
```

```
# cat usr/lib/systemd/system/rescue.service | grep -v ' #'

[Unit]
Description=Emergency Shell
DefaultDependencies=no
After=systemd-vconsole-setup.service
Wants=systemd-vconsole-setup.service
Conflicts=shutdown.target
Before=shutdown.target

[Service]
Environment=HOME=/
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
WorkingDirectory=/
ExecStart=/bin/dracut-emergency
ExecStopPost=-/usr/bin/systemctl --fail --no-block default
Type=idle
StandardInput=tty-force
StandardOutput=inherit
StandardError=inherit
KillMode=process
IgnoreSIGPIPE=no
TasksMax=infinity

KillSignal=SIGHUP
```

And as we all know, the `dracut-emergency` script executes a bash shell.

```
# vim bin/dracut-emergency
#!/usr/bin/sh

export DRACUT_SYSTEMD=1
if [ -f /dracut-state.sh ]; then
    . /dracut-state.sh 2>/dev/null
fi
type getarg >/dev/null 2>&1 || . /lib/dracut-lib.sh

source_conf /etc/conf.d

type plymouth >/dev/null 2>&1 && plymouth quit

export _rdshell_name="dracut" action="Boot" hook="emergency"
_emergency_action=$(getarg rd.emergency)

if getargbool 1 rd.shell -d -y rdshell || getarg rd.break -d rdbreak; then
    FSTXT="/run/dracut/fsck/fsck_help_$fstype.txt"
    source_hook "$hook"
    echo
    rdsosreport
    echo
    echo
    echo 'Entering emergency mode. Exit the shell to continue.'
    echo 'Type "journalctl" to view system logs.'
    echo 'You might want to save "/run/initramfs/rdsosreport.txt" to a USB stick or /boot'
    echo 'after mounting them and attach it to a bug report.'
    echo
    echo
    [ -f "$FSTXT" ] && cat "$FSTXT"
    [ -f /etc/profile ] && . /etc/profile
    [ -z "$PS1" ] && export PS1="$_name:\${PWD}# "
    exec sh -i -l
else
```

```
    export hook="shutdown-emergency"
    warn "$action has failed. To debug this issue add \"rd.shell
    rd.debug\" to the kernel command line."
    source_hook "$hook"
    [ -z "$_emergency_action" ] && _emergency_action=halt
fi

/bin/rm -f -- /.console_lock

case "$_emergency_action" in
    reboot)
        reboot || exit 1;;
    poweroff)
        poweroff || exit 1;;
    halt)
        halt || exit 1;;
esac

exit 0
```



```
[    2.749129] Couldn't get size: 0x800000000000000e
[    4.437146] sd 32:0:0:0: [sda] Assuming drive cache: write through
[    5.797837] piix4_smbus 0000:00:07.3: SMBus base address uninitialized - upgr
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.
Press Enter for maintenance
(or press Control-D to continue):
root@yogesh:~#
root@yogesh:~# ls /
bin   cdrom  etc   initrd.img      lib    lost+found  mnt  proc  run   snap  swapfile  tmp  var
boot  dev    home  initrd.img.old  lib64  media       opt  root  sbin  srv   sys       usr  vmlinuz
root@yogesh:~#
root@yogesh:~# _
```

Figure 8-5. *The emergency shell*

As you can see in Figure 8-5, sysroot is not mounted yet since we have not reached the mounting stage of booting.

I hope you now understand how systemd presents the emergency shell to users at various booting stages. In the next chapter, we will resume our paused systemd's booting sequence.

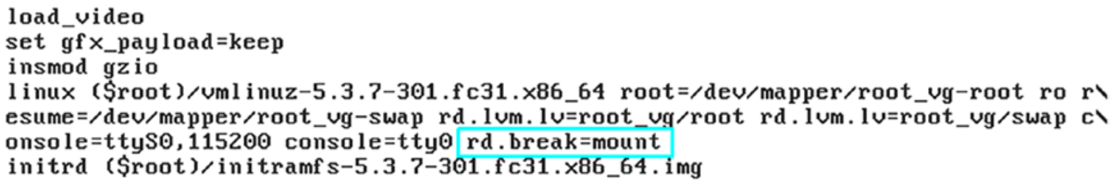
CHAPTER 9

systemd (Part II)

So far, we have reached the service `dracut.pre-mount.service` where the user's root filesystem is not yet mounted inside initramfs. systemd's next stage of booting will mount the root filesystem on `sysroot`.

sysroot.mount

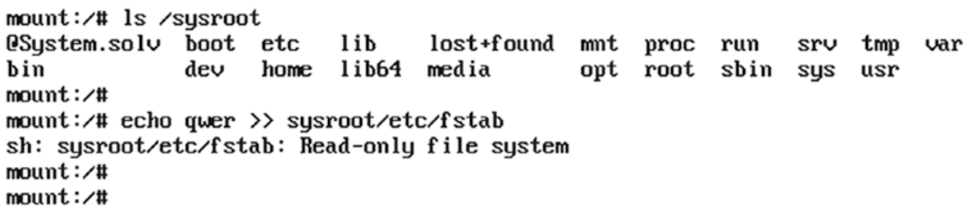
systemd accepts the `mount` dracut command-line parameter, which will drop us on a `mount` emergency shell. As you can see in Figure 9-1, we have passed the `rd.break=mount` kernel command-line parameter.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.7-301.fc31.x86_64 root=/dev/mapper/root_vg-root ro r\
esume=/dev/mapper/root_vg-swap rd.lvm.lv=root_vg/root rd.lvm.lv=root_vg/swap c\
onsole=ttyS0,115200 console=tty0 rd.break=mount
initrd ($root)/initramfs-5.3.7-301.fc31.x86_64.img
```

Figure 9-1. *The kernel command-line parameter*

As you can see in Figure 9-2, `sysroot` has been mounted with a user's root filesystem in read-only mode.



```
mount:/# ls /sysroot
@System.solv  boot  etc   lib    lost+found  mmt  proc  run   srv  tmp  var
bin           dev   home  lib64  media       opt  root  sbin  sys  usr
mount:/#
mount:/# echo qwer >> sysroot/etc/fstab
sh: sysroot/etc/fstab: Read-only file system
mount:/#
mount:/#
```

Figure 9-2. *The mount hook*

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Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_9

The `dracut.mount` hook (`usr/lib/systemd/system/dracut-mount.service`) will run the `/bin/dracut-mount` script from initramfs, which will do the mounting part.

```
#vim usr/lib/systemd/system/dracut-mount.service
```

As you can see, this is executing the `dracut-mount` script from initramfs and also exporting the `NEWROOT` variable with the `sysroot` value.

```
Environment=NEWROOT=/sysroot
ExecStart=-/bin/dracut-mount
```

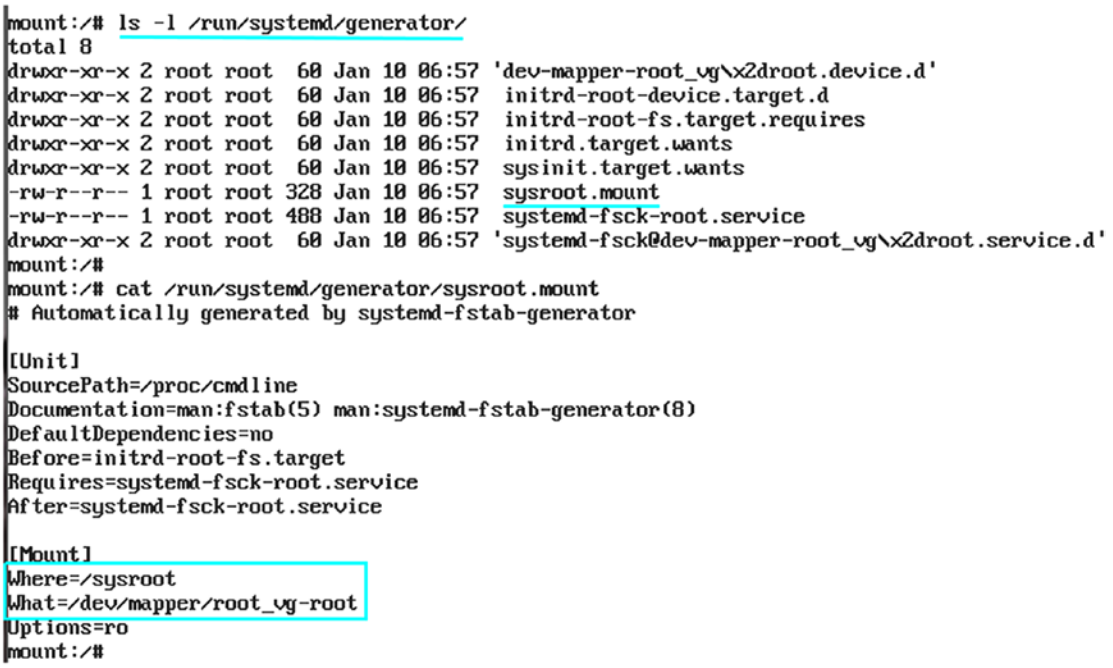
```
[Unit]
Description=dracut mount hook
Documentation=man:dracut-mount.service(8)
After=initrd-root-fs.target initrd-parse-etc.service
After=dracut-initqueue.service dracut-pre-mount.service
ConditionPathExists=/usr/lib/initrd-release
ConditionDirectoryNotEmpty=|/lib/dracut/hooks/mount
ConditionKernelCommandLine=|rd.break=mount
DefaultDependencies=no
Conflicts=shutdown.target emergency.target

[Service]
Environment=DRACUT_SYSTEMD=1
Environment=NEWROOT=/sysroot
Type=oneshot
ExecStart=-/bin/dracut-mount
StandardInput=null
StandardOutput=syslog
StandardError=syslog+console
KillMode=process
RemainAfterExit=yes

KillSignal=SIGHUP
```

```
#vim bin/dracut-mount
#!/usr/bin/sh
export DRACUT_SYSTEMD=1
if [ -f /dracut-state.sh ]; then
```

```
    . /dracut-state.sh 2>/dev/null
fi
type getarg >/dev/null 2>&1 || . /lib/dracut-lib.sh

source_conf /etc/conf.d

make_trace_mem "hook mount" '1:shortmem' '2+:mem' '3+:slab'

getarg 'rd.break=mount' -d 'rdbreak=mount' && emergency_shell -n mount "Break mount"
# mount scripts actually try to mount the root filesystem, and may
# be sourced any number of times. As soon as one suceeds, no more are sourced.
i=0
while :; do
    if ismounted "$NEWROOT"; then
        usable_root "$NEWROOT" && break;
        umount "$NEWROOT"
    fi
    for f in $hookdir/mount/*.sh; do
        [ -f "$f" ] && . "$f"
        if ismounted "$NEWROOT"; then
            usable_root "$NEWROOT" && break;
            warn "$NEWROOT has no proper rootfs layout, ignoring and removing offending mount hook"
            umount "$NEWROOT"
            rm -f -- "$f"
        fi
    done

    i=$(($i+1))
    [ $i -gt 20 ] && emergency_shell "Can't mount root filesystem"
done

```

```
export -p > /dracut-state.sh

exit 0
```

We saw in Chapter 8 how exactly it drops us on an emergency shell and the associated functions of this. Since we stopped the booting sequence after mounting the user's root filesystem inside initramfs, as you can see in Figure 9-3, the `systemd-fstab-generator` has already been executed, and the `-mount` unit files have already been created.



```
mount:/# ls -l /run/systemd/generator/
total 8
drwxr-xr-x 2 root root  60 Jan 10 06:57 'dev-mapper-root_vg\x2droot.device.d'
drwxr-xr-x 2 root root  60 Jan 10 06:57  initrd-root-device.target.d
drwxr-xr-x 2 root root  60 Jan 10 06:57  initrd-root-fs.target.requires
drwxr-xr-x 2 root root  60 Jan 10 06:57  initrd.target.wants
drwxr-xr-x 2 root root  60 Jan 10 06:57  sysinit.target.wants
-rw-r--r-- 1 root root 328 Jan 10 06:57  sysroot.mount
-rw-r--r-- 1 root root 488 Jan 10 06:57  systemd-fsck-root.service
drwxr-xr-x 2 root root  60 Jan 10 06:57 'systemd-fsck@dev-mapper-root_vg\x2droot.service.d'
mount:/#
mount:/# cat /run/systemd/generator/sysroot.mount
# Automatically generated by systemd-fstab-generator

[Unit]
SourcePath=/proc/cmdline
Documentation=man:fstab(5) man:systemd-fstab-generator(8)
DefaultDependencies=no
Before=initrd-root-fs.target
Requires=systemd-fsck-root.service
After=systemd-fsck-root.service

[Mount]
Where=/sysroot
What=/dev/mapper/root_vg-root
Options=ro
mount:/#
```

Figure 9-3. *The systemd-fstab-generator behavior*

Remember, the user's root filesystem name added in `sysroot.mount` has been taken from the `/proc/cmdline` file. The `sysroot.mount` clearly mentions what has to be mounted and where it has to be mounted.

initrd.target

As we have said multiple times, the ultimate aim of the booting sequence is to provide the user's root filesystem to the user, and while doing that, the major stages that systemd achieves are as follows:

1) Find the user's root filesystem.

2) Mount the user's root filesystem (we have reached this stage of booting).

3) Find the other necessary filesystems and mount them (`usr`, `var`, `nfs`, `cifs`, etc.).

4) Switch into the mounted user's root filesystem.

5) Start the user space daemons.

6) Start either `multi-user.target` or `graphical.target` (which is outside the scope of this book).

As you can see, as of now, we have reached step 2, which is mounting the user's root filesystem inside initramfs. We all know that systemd has `.targets`, and `target` is nothing but a bunch of unit files. The `.target` can be successfully started only when all of its unit files have been successfully started.

There are many targets in the systemd world, such as `basic.target`, `multi-user.target`, `graphical.target`, `default.target`, and `sysinit.target` to name a few. The ultimate aim of `initramfs` is to achieve the `initrd.target`. Once the `initrd.target` is successfully started, then systemd will `switch_root` into it. So, first, let's look at `initrd.target` and where it stands in terms of the booting sequence. Please refer to the flowchart shown in Figure 9-4.

```
                               systemd-journal.socket
                                          |
                                          v
                               dracut-cmdline.service
                                          |
                                          v
                               dracut-pre-udev.service
                                          |
                                          v
                                systemd-udevd.service
                                          |
                                          v
    local-fs-pre.target       dracut-pre-trigger.service
             |                            |
             v                            v
     (various mounts)  (various swap  systemd-udev-trigger.service
             |           devices...)      |             (various low-level   (various low-level
             |               |            |             services: seed,       API VFS mounts:
             v               v            v             tmpfiles, random      mqueue, configfs,
      local-fs.target   swap.target  dracut-initqueue.service  sysctl, ...)     debugfs, ...)
             |               |            |                    |                    |
             \_______________|___________ | ___________________|____________________/
                                         \|/
                                          v
                                   sysinit.target
                                          |
                        _________________/|\___________________
                       /                  |                    \
                       |                  |                    |
                       v                  |                    v
                   (various               |              rescue.service
                  sockets...)             |                    |
                       |                  |                    v
                       v                  |              rescue.target
                 sockets.target           |
                       |                  |
                       \_________________ |                         emergency.service
                                         \|                                 |
                                          v                                 v
                                     basic.target                   emergency.target
                                          |
                   ______________________/|
                  /                       |
                  |                       v
                  |            dracut-pre-mount.service
                  |                       |
                  |                       v
                  |                  sysroot.mount
                  |                       |
                  |                       v
                  |             initrd-root-fs.target
       (custom initrd services)           |
                  |                       v
                  |             dracut-mount.service
                  |                       |
                  |                       v
                  |            initrd-parse-etc.service
                  |                       |
                  |                       v
                  |            (sysroot-usr.mount and
                  |             various mounts marked
                  |               with fstab option
                  |                x-initrd.mount)
                  |                       |
                  |                       v
                  |                initrd-fs.target
                  \______________________ |
                                         \|
                                          v
                                     initrd.target
```

Figure 9-4. *The booting sequence*

When you are outside of initramfs (that means after `switch_root`), systemd's `default.target` will be either `multi-user.target` or `graphical.target`, whereas inside initramfs (that means before `switch_root`) after `basic.target`, systemd's `default.target` will be `initrd.target`. So, after successfully completing the `sysinit.target` and `basic.target`, systemd's main task is to achieve the `initrd.target`. To reach there, systemd will use the `sysroot.mount` stage to read the mount unit files created by `systemd-fstab-generator`. The service `dracut-mount.service` will mount the user's root filesystem to `/sysroot`, and then systemd will execute the service `initrd-parse-etc.service.` It will parse the `/sysroot/etc/fstab` file and will make the mount unit files for `usr` or any other mount points that have the `x-initrd.mount` option set. This is how the `initrd-parse-etc.service` works:

```
# cat usr/lib/systemd/system/initrd-parse-etc.service | grep -v '#'

[Unit]
Description=Reload Configuration from the Real Root
DefaultDependencies=no
Requires=initrd-root-fs.target
After=initrd-root-fs.target
OnFailure=emergency.target
OnFailureJobMode=replace-irreversibly
ConditionPathExists=/etc/initrd-release

[Service]
Type=oneshot
ExecStartPre=-/usr/bin/systemctl daemon-reload
ExecStart=-/usr/bin/systemctl --no-block start initrd-fs.target
ExecStart=/usr/bin/systemctl --no-block start initrd-cleanup.service
```

Basically, the service is executing `systemctl` with a `daemon-reload` switch. This will reload the systemd manager configuration. This will rerun all generators, reload all unit files, and re-create the entire dependency tree. While the daemon is being reloaded, all sockets that systemd listens to on behalf of the user configuration will stay accessible. The systemd generators, which will be re-executed, are as follows:

```
# ls usr/lib/systemd/system-generators/ -l
     total 92
     -rwxr-xr-x. 1 root root  3750 Jan 10 19:18 dracut-rootfs-generator
     -rwxr-xr-x. 1 root root 45640 Dec 21 12:19 systemd-fstab-generator
     -rwxr-xr-x. 1 root root 37032 Dec 21 12:19 systemd-gpt-auto-generator
```

As you can see, it will execute `systemd-fstab-generator`, which will read the `/sysroot/etc/fstab` entries and create the mount unit files for `usr` and for devices that have the `x-initrd.mount` option set. In short, `systemd-fstab-generator` has executed twice.

So, when you drop yourself to the mount shell (`rd.break=mount`), you are actually interrupting the booting sequence after the target `initrd.target`. This target just runs the following services:

```
# ls usr/lib/systemd/system/initrd.target.wants/
    dracut-cmdline-ask.service  dracut-mount.service      dracut-pre-
                                                          trigger.service
    dracut-cmdline.service      dracut-pre-mount.service  dracut-pre-udev.
                                                          service
    dracut-initqueue.service    dracut-pre-pivot.service
```

Please refer to Figure 9-5 for a better understanding of this.

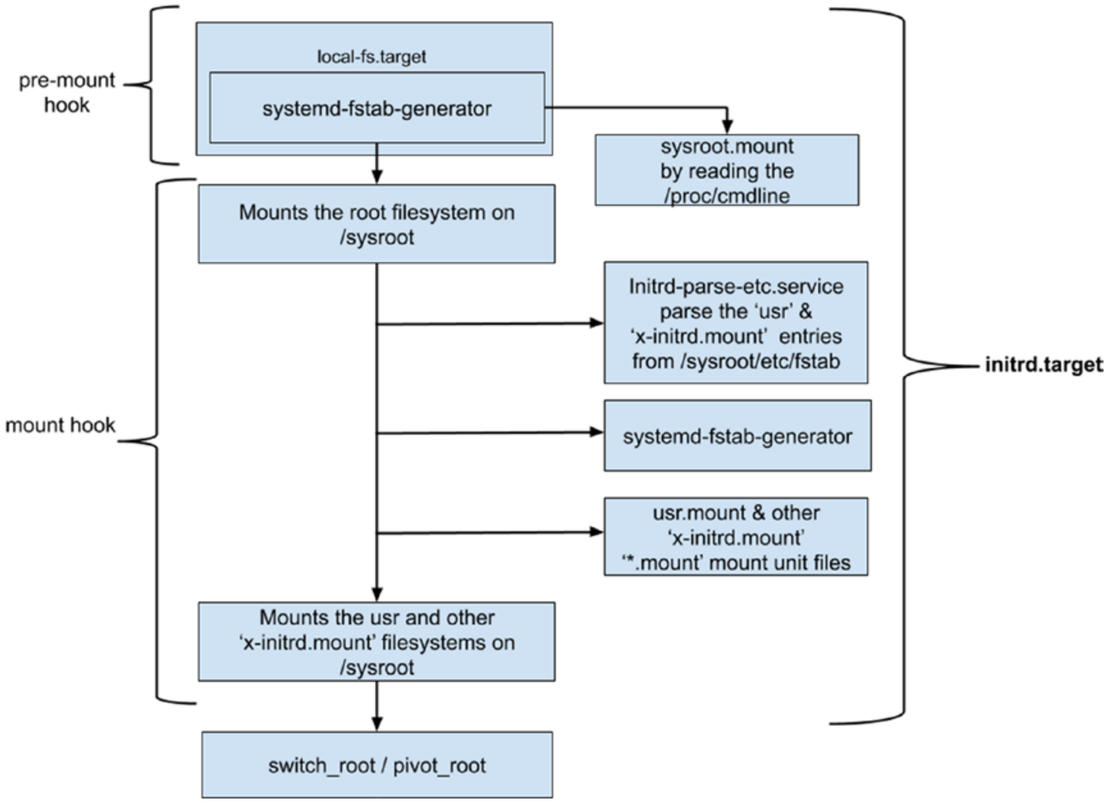

pre-mount hook
local-fs.target
systemd-fstab-generator
sysroot.mount by reading the /proc/cmdline
Mounts the root filesystem on /sysroot
Initrd-parse-etc.service parse the 'usr' & 'x-initrd.mount' entries from /sysroot/etc/fstab
mount hook
systemd-fstab-generator
usr.mount & other 'x-initrd.mount' '*.mount' mount unit files
initrd.target
Mounts the usr and other 'x-initrd.mount' filesystems on /sysroot
switch_root / pivot_root

Figure 9-5. *The overall execution of initrd.target*

switch_root/pivot_root

Now we have reached the final stage of systemd's booting, which is `switch_root`. systemd switches the root filesystem from initramfs (`/`) to the user's root filesystem (`/sysroot`). systemd achieves this by taking the following steps:

1. Mounting the new root filesystem (`/sysroot`)
2. Turning it into the root filesystem (`/`)
3. Removing all accesses to the old (initramfs) root filesystem
4. Unmounting the initramfs filesystem and de-allocating the ramfs filesystem

There are three major points that will be discussed in this chapter.

- `switch_root`: We will explain this the old `init` way.
- `pivot_root`: We will explain this the `systemd` way.
- `chroot`: We will explain this in Chapter 10.

Switching to the New Root Filesystem on an init-Based System

An `init`-based system uses `switch_root` to switch to a new root filesystem (`sysroot`). The purpose of `switch_root` is explained well on its man page, as shown here:

```
#man switch_root
NAME
       switch_root - switch to another filesystem as the root of the mount tree

SYNOPSIS
       switch_root [-hV]

       switch_root newroot init [arg...]

DESCRIPTION
       switch_root moves already mounted /proc, /dev, /sys and /run to
       newroot and makes newroot the new root filesystem and starts init
       process.
       WARNING: switch_root removes recursively all files and directories
       on the current root filesystem.

OPTIONS
       -h, --help
              Display help text and exit.

       -V, --version
              Display version information and exit.

RETURN VALUE
       switch_root returns 0 on success and 1 on failure.

NOTES
       switch_root will fail to function if newroot is not the root of a
       mount. If you want to switch root into a directory that does not
       meet this requirement then you can first use a bind-mounting trick
       to turn any directory into a mount point:

              mount --bind $DIR $DIR
```

So, it switches to a new root filesystem (sysroot), and along with the root, it moves the old root filesystem's virtual file systems (proc, dev, sys, etc.) to the new root. The best feature of switch_root is that after mounting the new root filesystem, it starts the init process on its own. Switching to a new root filesystem takes place in dracut's source code. The latest version of dracut while writing this book was 049. The switch_root function is defined in the dracut-049/modules.d/99base/init.sh file.

```
unset PS4

CAPSH=$(command -v capsh)
SWITCH_ROOT=$(command -v switch_root)
PATH=$OLDPATH
export PATH

if [ -f /etc/capsdrop ]; then
    . /etc/capsdrop
    info "Calling $INIT with capabilities $CAPS_INIT_DROP dropped."
    unset RD_DEBUG
    exec $CAPSH --drop="$CAPS_INIT_DROP" -- \
        -c "exec switch_root \"$NEWROOT\" \"$INIT\" $initargs" || \
    {
        warn "Command:"
        warn capsh --drop=$CAPS_INIT_DROP -- -c exec switch_root
        "$NEWROOT" "$INIT" $initargs
        warn "failed."
        emergency_shell
    }
else
    unset RD_DEBUG
    exec $SWITCH_ROOT "$NEWROOT" "$INIT" $initargs || {
        warn "Something went very badly wrong in the initramfs.  Please "
        warn "file a bug against dracut."
        emergency_shell
    }
fi
```

In the previous code, you can see that exec switch_root has been called just like it was described on the man page of switch_root. The defined variable values of NEWROOT and INIT are as follows:

```
NEWROOT = "/sysroot"
INIT   = 'init' or  'sbin/init'
```

Just for your information, these days the init file is a symlink to systemd.

```
# ls -l sbin/init
lrwxrwxrwx. 1 root root 22 Dec 21 12:19 sbin/init -> ../lib/systemd/systemd
```

To successfully switch_root the virtual filesystems, they have to be mounted first. This will be achieved through dracut-049/modules.d/99base/init.sh. These are the steps that will be followed:

1. Mount the proc filesystem.
2. Mount the sys filesystem.
3. Mount the /dev directory with devtmpfs.

4. Create the `stdin`, `stdout`, `stderr`, `pts`, and `shm` device files manually.

5. Make the `/run` mount point with tmpfs in it. (The `/run` mount point is not available on `init`-based systems.)

#vim dracut-049/modules.d/99base/init.sh

```
NEWROOT="/sysroot"
[ -d $NEWROOT ] || mkdir -p -m 0755 $NEWROOT

OLDPATH=$PATH
PATH=/usr/sbin:/usr/bin:/sbin:/bin
export PATH

# mount some important things
[ ! -d /proc/self ] && \
    mount -t proc -o nosuid,noexec,nodev proc /proc >/dev/null

if [ "$?" != "0" ]; then
    echo "Cannot mount proc on /proc! Compile the kernel with CONFIG_PROC_FS!"
    exit 1
fi

[ ! -d /sys/kernel ] && \
    mount -t sysfs -o nosuid,noexec,nodev sysfs /sys >/dev/null

if [ "$?" != "0" ]; then
    echo "Cannot mount sysfs on /sys! Compile the kernel with CONFIG_SYSFS!"
    exit 1
fi

RD_DEBUG=""
. /lib/dracut-lib.sh

```

```
setdebug

if ! ismounted /dev; then
    mount -t devtmpfs -o mode=0755,noexec,nosuid,strictatime devtmpfs /dev >/dev/null
fi

if ! ismounted /dev; then
    echo "Cannot mount devtmpfs on /dev! Compile the kernel with CONFIG_DEVTMPFS!"
    exit 1
fi

# prepare the /dev directory
[ ! -h /dev/fd ] && ln -s /proc/self/fd /dev/fd >/dev/null 2>&1
[ ! -h /dev/stdin ] && ln -s /proc/self/fd/0 /dev/stdin >/dev/null 2>&1
[ ! -h /dev/stdout ] && ln -s /proc/self/fd/1 /dev/stdout >/dev/null 2>&1
[ ! -h /dev/stderr ] && ln -s /proc/self/fd/2 /dev/stderr >/dev/null 2>&1

if ! ismounted /dev/pts; then
    mkdir -m 0755 /dev/pts
    mount -t devpts -o gid=5,mode=620,noexec,nosuid devpts /dev/pts >/dev/null
fi

if ! ismounted /dev/shm; then
    mkdir -m 0755 /dev/shm
    mount -t tmpfs -o mode=1777,noexec,nosuid,nodev,strictatime tmpfs /dev/shm >/dev/null
fi

if ! ismounted /run; then
    mkdir -m 0755 /newrun
    if ! str_starts "$(readlink -f /bin/sh)" "/run/"; then
```

```
        mount -t tmpfs -o mode=0755,noexec,nosuid,nodev,strictatime tmpfs /newrun >/dev/null
    else
        # the initramfs binaries are located in /run, so don't mount it with noexec
        mount -t tmpfs -o mode=0755,nosuid,nodev,strictatime tmpfs /newrun >/dev/null
    fi
    cp -a /run/* /newrun >/dev/null 2>&1
    mount --move /newrun /run
    rm -fr -- /newrun
fi
```

Switching to a New Root Filesystem on a systemd-Based System

The steps are almost similar to what we discussed for an `init`-based system. The only difference for `systemd` is a binary made from C code. So, obviously, switching the root will take place in systemd's C source code, as shown here:

`src/shared/switch-root.c:`

First, consider the following:

```
new_root = sysroot
old_root = /
```

This will move the virtual filesystems that are already populated in initramfs' root filesystem; then the `path_equal` function checks whether the `new_root` path is available.

```
if (path_equal(new_root, "/"))
      return 0;
```

Later it calls a `pivot_root` syscall (`init` uses `switch_root`) and changes the root from / (the initramfs root filesystem) to `sysroot` (the user's root filesystem).

```
pivot_root(new_root, resolved_old_root_after) >= 0)
```

Before we go further, we need to understand what `pivot_root` is and what it does.

```
# man pivot_root
NAME
       pivot_root - change the root filesystem

SYNOPSIS
       pivot_root new_root put_old

DESCRIPTION
       pivot_root moves the root file system of the current process to
       the directory put_old and makes new_root the new root file system.
       Since pivot_root(8) simply calls pivot_root(2), we refer to the man
       page of the latter for further details:
```

Note that, depending on the implementation of pivot_root, root and cwd of the caller may or may not change. The following is a sequence for invoking pivot_root that works in either case, assuming that pivot_root and chroot are in the current PATH:

cd new_root

pivot_root . put_old

exec chroot . command

Note that chroot must be available under the old root and under the new root, because pivot_root may or may not have implicitly changed the root directory of the shell.

Note that exec chroot changes the running executable, which is necessary if the old root directory should be unmounted afterwards. Also note that standard input, output, and error may still point to a device on the old root file system, keeping it busy. They can easily be changed when invoking chroot (see below; note the absence of leading slashes to make it work whether pivot_root has changed the shell's root or not).

`pivot_root` changes the root filesystem (the initramfs root filesystem) of the current process (systemd) to the new root filesystem (`sysroot`), and it also changes the running executable (systemd from initramfs) to a new one (systemd from the user's root filesystem).

After pivot_root, it detaches the old root device of initramfs (src/shared/switch-root.c).

# vim src/shared/switch-root.c

```
        /* We first try a pivot_root() so that we can umount the old
           root dir. In many cases (i.e. where rootfs is /),
         * that's not possible however, and hence we simply overmount
           root */
        if (pivot_root(new_root, resolved_old_root_after) >= 0) {

                /* Immediately get rid of the old root, if detach_
                   oldroot is set.
                 * Since we are running off it we need to do this
                   lazily. */
                if (unmount_old_root) {
                        r = umount_recursive(old_root_after,
                            MNT_DETACH);
                        if (r < 0)
                                log_warning_errno(r, "Failed to unmount
                                old root directory tree, ignoring: %m");
                }

        } else if (mount(new_root, "/", NULL, MS_MOVE, NULL) < 0)
                return log_error_errno(errno, "Failed to move %s
                to /: %m", new_root);

```

After a successful pivot_root, this is the current state:

- sysroot has become root (/).
- The current working directory has become root (/).
- chroot will be executed so that bash changes its root directory from the old root (initramfs) to the new (user's) root filesystem. chroot will be discussed in the next chapter.

Finally, delete the old_root device (rm -rf).

```

        if (chroot(".") < 0)
                return log_error_errno(errno, "Failed to change root: %m");

        if (chdir("/") < 0)
                return log_error_errno(errno, "Failed to change directory: %m");

        if (old_root_fd >= 0) {
                struct stat rb;

                if (fstat(old_root_fd, &rb) < 0)
                        log_warning_errno(errno, "Failed to stat old root directory, leaving: %m");
                else
                        (void) rm_rf_children(TAKE_FD(old_root_fd), 0, &rb); /* takes possession of the dir fd, even on failure */
        }
```

For a better understanding, I highly recommend reading the entire `src/shared/switch-root.c` source code shown here:

```
/* SPDX-License-Identifier: LGPL-2.1+ */

#include <errno.h>
#include <fcntl.h>
#include <limits.h>
#include <stdbool.h>
#include <sys/mount.h>
#include <sys/stat.h>
#include <unistd.h>

#include "base-filesystem.h"
#include "fd-util.h"
#include "fs-util.h"
```

```
#include "log.h"
#include "missing_syscall.h"
#include "mkdir.h"
#include "mount-util.h"
#include "mountpoint-util.h"
#include "path-util.h"
#include "rm-rf.h"
#include "stdio-util.h"
#include "string-util.h"
#include "strv.h"
#include "switch-root.h"
#include "user-util.h"
#include "util.h"

int switch_root(const char *new_root,
                const char *old_root_after, /* path below the new root, where to place the old root after the transition */
                bool unmount_old_root,
                unsigned long mount_flags) {  /* MS_MOVE or MS_BIND */

        _cleanup_free_ char *resolved_old_root_after = NULL;
        _cleanup_close_ int old_root_fd = -1;
        bool old_root_remove;
        const char *i;
        int r;

        assert(new_root);
        assert(old_root_after);

        if (path_equal(new_root, "/"))
                return 0;

        /* Check if we shall remove the contents of the old root */
        old_root_remove = in_initrd();
        if (old_root_remove) {
                old_root_fd = open("/", O_RDONLY|O_NONBLOCK|
                O_CLOEXEC|O_NOCTTY|O_DIRECTORY);
                if (old_root_fd < 0)
                        return log_error_errno(errno, "Failed to open
                        root directory: %m");
        }

        /* Determine where we shall place the old root after the
           transition */
        r = chase_symlinks(old_root_after, new_root, CHASE_PREFIX_
            ROOT|CHASE_NONEXISTENT, &resolved_old_root_after, NULL);
        if (r < 0)
                return log_error_errno(r, "Failed to resolve %s/%s:
                %m", new_root, old_root_after);
        if (r == 0) /* Doesn't exist yet. Let's create it */
                (void) mkdir_p_label(resolved_old_root_after, 0755);

        /* Work-around for kernel design: the kernel refuses MS_MOVE if
           any file systems are mounted MS_SHARED. Hence
         * remount them MS_PRIVATE here as a work-around.
         *
         * https://bugzilla.redhat.com/show_bug.cgi?id=847418 */
        if (mount(NULL, "/", NULL, MS_REC|MS_PRIVATE, NULL) < 0)
                return log_error_errno(errno, "Failed to set \"/\"
                mount propagation to private: %m");

        FOREACH_STRING(i, "/sys", "/dev", "/run", "/proc") {
                _cleanup_free_ char *chased = NULL;

                r = chase_symlinks(i, new_root, CHASE_PREFIX_
                    ROOT|CHASE_NONEXISTENT, &chased, NULL);
                if (r < 0)
                        return log_error_errno(r, "Failed to resolve
                        %s/%s: %m", new_root, i);
                if (r > 0) {
```

```
                /* Already exists. Let's see if it is a mount
                   point already. */
                r = path_is_mount_point(chased, NULL, 0);
                if (r < 0)
                    return log_error_errno(r, "Failed to
                    determine whether %s is a mount
                    point: %m", chased);
                if (r > 0) /* If it is already mounted, then do
                nothing */
                    continue;
            } else
                 /* Doesn't exist yet? */
                (void) mkdir_p_label(chased, 0755);

            if (mount(i, chased, NULL, mount_flags, NULL) < 0)
                return log_error_errno(errno, "Failed to
                mount %s to %s: %m", i, chased);
    }

    /* Do not fail if base_filesystem_create() fails. Not all
       switch roots are like base_filesystem_create() wants
     * them to look like. They might even boot, if they are RO and
       don't have the FS layout. Just ignore the error
     * and switch_root() nevertheless. */
    (void) base_filesystem_create(new_root, UID_INVALID,
    GID_INVALID);

    if (chdir(new_root) < 0)
            return log_error_errno(errno, "Failed to change
            directory to %s: %m", new_root);

    /* We first try a pivot_root() so that we can umount the old
       root dir. In many cases (i.e. where rootfs is /),
     * that's not possible however, and hence we simply overmount
       root */
```

```
        if (pivot_root(new_root, resolved_old_root_after) >= 0) {

                /* Immediately get rid of the old root, if detach_oldroot is set.
                 * Since we are running off it we need to do this lazily. */
                if (unmount_old_root) {
                        r = umount_recursive(old_root_after, MNT_DETACH);
                        if (r < 0)
                                log_warning_errno(r, "Failed to unmount old root directory tree, ignoring: %m");
                }

        } else if (mount(new_root, "/", NULL, MS_MOVE, NULL) < 0)
                return log_error_errno(errno, "Failed to move %s to /: %m", new_root);

        if (chroot(".") < 0)
                return log_error_errno(errno, "Failed to change root: %m");

        if (chdir("/") < 0)
                return log_error_errno(errno, "Failed to change directory: %m");

        if (old_root_fd >= 0) {
                struct stat rb;

                if (fstat(old_root_fd, &rb) < 0)
                        log_warning_errno(errno, "Failed to stat old root directory, leaving: %m");
                else
                        (void) rm_rf_children(TAKE_FD(old_root_fd), 0, &rb); /* takes possession of the dir fd, even on failure */
        }

        return 0;
}
```

Here we have successfully switched to the user's root filesystem and left the initramfs environment. Now systemd from the user's root filesystem with PID 1 will start running and take care of the rest of the booting procedure, which is as follows:

– systemd will start the user space services such as `httpd`, `mysql`, `postfix`, `network services`, etc.

– Ultimately, the goal will be to reach `default.target`. As we discussed earlier, before `switch_root`, the target called `default.target` of systemd will be `initrd.target`, and after `switch_root`, it will be either `multi-user.target` or `graphical.target`.

But what happens to the existing `systemd` process, which started from initramfs (the root filesystem)? Is it getting killed after `switch_root` or `pivot_root`? Is the new `systemd` process starting from the user's root filesystem?

The answer is simple.

1) systemd of initramfs creates a pipe.

2) systemd forks.

3) The original PID 1 `chroots` into `/systemd` and executes `/sysroot/usr/lib/systemd/systemd`.

4) The forked systemd serializes its state over the pipe to PID 1 and exits.

5) PID 1 deserializes the data from the pipe and continues with the fresh configuration in `/` (formerly `/sysroot`).

I hope you have enjoyed the journey of systemd inside initramfs. As we mentioned earlier, the rest of the systemd booting sequence, which will take place outside of initramfs, will be more or less similar to what we have discussed so far.

How GUI is started is beyond the scope of this book. In our next chapter, we will discuss the live ISO images and about the rescue mode.

CHAPTER 10

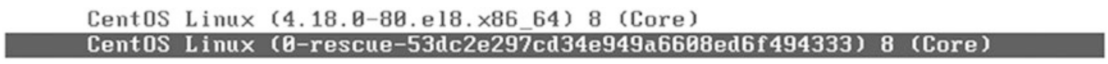
Rescue Mode and Live Images

In this final chapter, we'll cover rescue mode and live images. During our rescue mode discussion, we'll cover the rescue initramfs, as well as some "can't boot" issues. The live images discussion covers Squashfs, `rootfs.img`, and the booting sequence of live images.

Rescue Mode

There are two ways to boot in rescue mode.

- Through the built-in GRUB menuentry. Refer to Figure 10-1.



```
CentOS Linux (4.18.0-80.el8.x86_64) 8 (Core)
CentOS Linux (0-rescue-53dc2e297cd34e949a6608ed6f494333) 8 (Core)
```

Figure 10-1. *The rescue mode entry from GRUB*

- Through a live ISO image. Refer to Figure 10-2.

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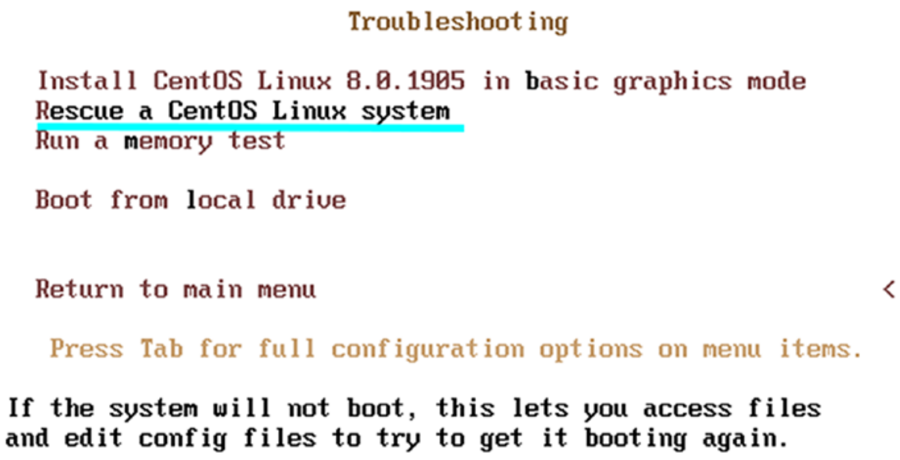
Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3_10



```
                    Troubleshooting

  Install CentOS Linux 8.0.1905 in basic graphics mode
  Rescue a CentOS Linux system
  Run a memory test

  Boot from local drive


  Return to main menu                                <

   Press Tab for full configuration options on menu items.

 If the system will not boot, this lets you access files
 and edit config files to try to get it booting again.
```

Figure 10-2. *The rescue mode entry from a live image*

As the name suggests, this mode is designed to rescue the systems that are stuck in “can’t boot” issues. Imagine a situation where the system is not able to mount the root filesystem and you are getting this never-ending generic message:

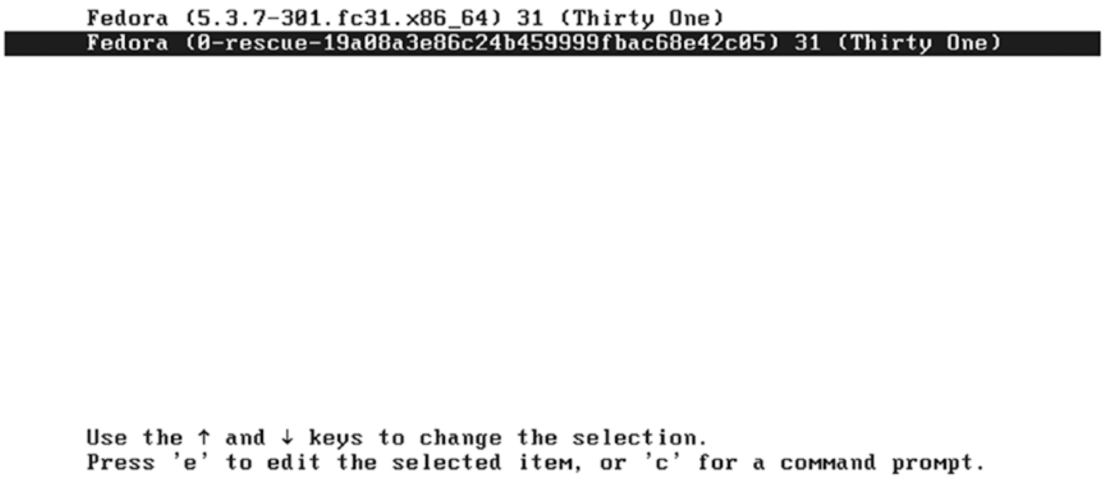
‘**`dracut-initqueue: warning dracut-initqueue timeout - starting timeout scripts`**’.

And say you have only one kernel installed, as shown here:

```
<snip>
.
.
[  OK  ] Started Show Plymouth Boot Screen.
[  OK  ] Started Forward Password R...s to Plymouth Directory Watch.
[  OK  ] Reached target Paths.
[  OK  ] Reached target Basic System.
[  145.832487] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
[  146.541525] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
[  147.130873] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
[  147.703069] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
```

```
[  148.267123] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
[  148.852865] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
[  149.430171] dracut-initqueue[437]: Warning: dracut-initqueue timeout -
starting timeout scripts
.
.
</snip>
```

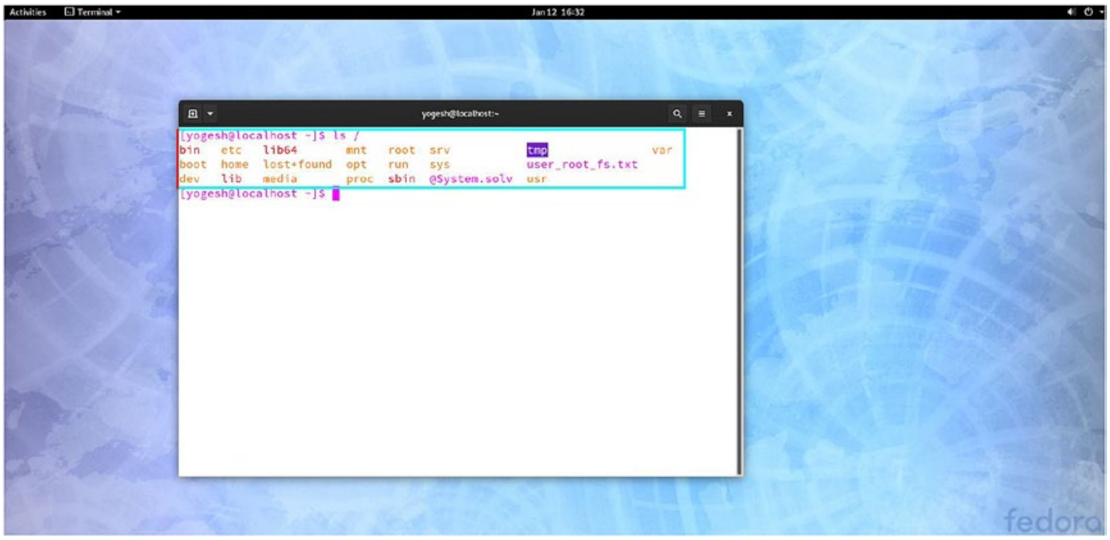
Since this system has only one kernel (which can’t boot), how would you fix the “can’t boot” issue without an environment? Rescue mode was created for this sole purpose. Let’s first choose the default rescue mode, which comes pre-installed with Linux and can be chosen from the GRUB menu. Please see Figure 10-3.



```
      Fedora (5.3.7-301.fc31.x86_64) 31 (Thirty One)
      Fedora (0-rescue-19a08a3e86c24b459999fbac68e42c05) 31 (Thirty One)

      Use the ↑ and ↓ keys to change the selection.
      Press 'e' to edit the selected item, or 'c' for a command prompt.
```

Figure 10-3. *The GRUB screen*

The rescue mode will boot normally, and as you can see in Figure 10-4, if everything is good, it will present the user with its root filesystem.



```
[yogesh@localhost ~]$ ls /
bin   etc   lib64        mnt   root  srv            tmp                var
boot  home  lost+found   opt   run   sys            user_root_fs.txt
dev   lib   media        proc  sbin  @System.solv   usr
[yogesh@localhost ~]$
```

***Figure 10-4.** The root filesystem mounted under rescue mode*

But a question comes to mind: when the normal kernel is not able to boot, then how come the same system is able to boot in rescue mode?

This is because when you install Fedora or any Linux distribution, the installer of Linux, called Anaconda, installs two kernels inside /boot.

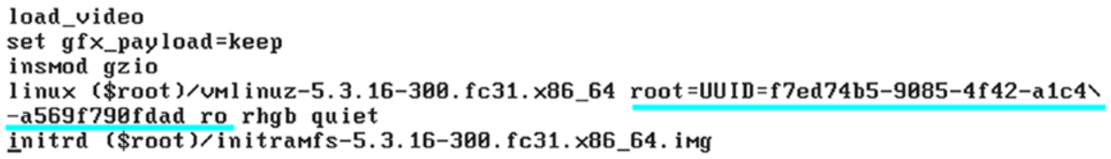
```
# ls -lh /boot/
total 164M
-rw-r--r--. 1 root root 209K Oct 22 01:03 config-5.3.7-301.fc31.x86_64
drwx------. 4 root root 4.0K Oct 24 04:44 efi
-rw-r--r--. 1 root root 181K Aug  2  2019 elf-memtest86+-5.01
drwxr-xr-x. 2 root root 4.0K Oct 24 04:42 extlinux
drwx------. 5 root root 4.0K Mar 28 13:37 grub2
-rw-------. 1 root root  80M Dec  9 10:18 initramfs-0-rescue-2058a9f13f9e48
                                          9dba29c477a8ae2493.img
-rw-------. 1 root root  32M Dec  9 10:19 initramfs-5.3.7-301.fc31.x86_64.img
drwxr-xr-x. 3 root root 4.0K Dec  9 10:18 loader
drwx------. 2 root root  16K Dec  9 10:12 lost+found
-rw-r--r--. 1 root root 179K Aug  2  2019 memtest86+-5.01
-rw-------. 1 root root  30M Jan  6 09:37 new.img
-rw-------. 1 root root 4.3M Oct 22 01:03 System.map-5.3.7-301.fc31.x86_64
```

```
-rwxr-xr-x. 1 root root 8.9M Dec  9 10:18 vmlinuz-0-rescue-2058a9f13f9e489d
                                          ba29c477a8ae2493
-rwxr-xr-x. 1 root root 8.9M Oct 22 01:04 vmlinuz-5.3.7-301.fc31.x86_64
```

As you can see, `vmlinuz-5.3.7-301.fc31.x86_64` is a normal kernel, whereas `vmlinuz-0-rescue-19a08a3e86c24b459999fbac68e42c05` is the rescue kernel, which is a separate kernel with its own initramfs file, called `initramfs-0-rescue-19a08a3e86c24b459999fbac68e42c05.img`.

Let's say you installed a new package (`.rpm` or `.deb`) provided by `nvidia`, which has new graphics drivers in it. Since the graphics drivers have to be added in initramfs, the `nvidia` package rebuilt the original kernel initramfs (`initramfs-5.3.7-301.fc31.x86_64.img`). So, the original kernel has the newly added graphics driver, but the rescue initramfs does not have that driver added. When the user tries to boot, the system fails to boot with the original kernel (`vmlinuz-5.3.7-301.fc31.x86_64`) since the installed graphics driver is not compatible with the attached graphics card, but at the same time the system will successfully boot with the rescue mode because the noncompatible drivers are not present in the rescue initramfs. The rescue mode kernel will have the same command-line parameters as the normal kernel has, and therefore the installed rescue kernel knows the name of the user's root filesystem.

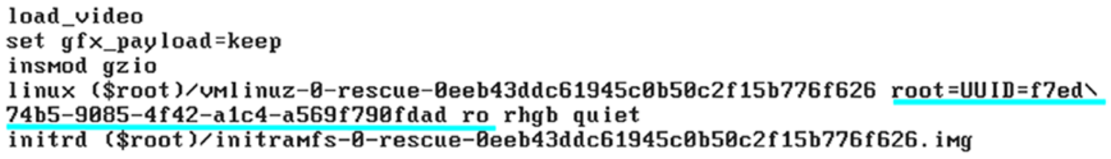
Figure 10-5 shows the normal kernel's command-line parameters.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-5.3.16-300.fc31.x86_64 root=UUID=f7ed74b5-9085-4f42-a1c4\
-a569f790fdad ro rhgb quiet
initrd ($root)/initramfs-5.3.16-300.fc31.x86_64.img
```

Figure 10-5. *The normal kernel's command-line parameters*

Figure 10-6 shows the rescue kernel's command-line parameters.



```
load_video
set gfx_payload=keep
insmod gzio
linux ($root)/vmlinuz-0-rescue-0eeb43ddc61945c0b50c2f15b776f626 root=UUID=f7ed\
74b5-9085-4f42-a1c4-a569f790fdad ro rhgb quiet
initrd ($root)/initramfs-0-rescue-0eeb43ddc61945c0b50c2f15b776f626.img
```

Figure 10-6. *The rescue kernel's command-line parameters*

Rescue Mode initramfs

The rescue mode initramfs (`initramfs-0-rescue-2058a9f13f9e489dba29c477a8ae2493.img`) is much bigger in size than the original kernel's initramfs (`initramfs-5.3.7-301.fc31.x86_64.img`).

```
# ls -lh /boot/
total 164M
-rw-r--r--. 1 root root 209K Oct 22 01:03 config-5.3.7-301.fc31.x86_64
drwx------. 4 root root 4.0K Oct 24 04:44 efi
-rw-r--r--. 1 root root 181K Aug  2  2019 elf-memtest86+-5.01
drwxr-xr-x. 2 root root 4.0K Oct 24 04:42 extlinux
drwx------. 5 root root 4.0K Mar 28 13:37 grub2
-rw-------. 1 root root  80M Dec  9 10:18 initramfs-0-rescue-2058a9f13f9e48
                                          9dba29c477a8ae2493.img
-rw-------. 1 root root  32M Dec  9 10:19 initramfs-5.3.7-301.fc31.x86_64.img
drwxr-xr-x. 3 root root 4.0K Dec  9 10:18 loader
drwx------. 2 root root  16K Dec  9 10:12 lost+found
-rw-r--r--. 1 root root 179K Aug  2  2019 memtest86+-5.01
-rw-------. 1 root root  30M Jan  6 09:37 new.img
-rw-------. 1 root root 4.3M Oct 22 01:03 System.map-5.3.7-301.fc31.x86_64
-rwxr-xr-x. 1 root root 8.9M Dec  9 10:18 vmlinuz-0-rescue-2058a9f13f9e489d
ba29c477a8ae2493
-rwxr-xr-x. 1 root root 8.9M Oct 22 01:04 vmlinuz-5.3.7-301.fc31.x86_64
```

Why is this? It's because the rescue initramfs is not host-specific the way a normal kernel's initramfs is. The rescue initramfs is a generic initramfs that is prepared by considering all the possible devices on which a user can create a root filesystem. Let's compare both the initramfs systems.

```
# tree
.
├── normal_kernel
│   └── initramfs-5.3.7-301.fc31.x86_64.img
└── rescue_kernel
    └── initramfs-0-rescue-2058a9f13f9e489dba29c477a8ae2493.img

2 directories, 2 files
```

We will extract them in their respective directories.

```
#/usr/lib/dracut/skipcpio
    initramfs-5.3.7-301.fc31.x86_64.img | gunzip -c | cpio -idv

#/usr/lib/dracut/skipcpio
    initramfs-0-rescue-2058a9f13f9e489dba29c477a8ae2493.img | gunzip -c |
    cpio -idv
```

We will make the list of files from the extracted initramfs.

```
# tree normal_kernel/ > normal.txt
# tree rescue_kernel/ > rescue.txt
```

The following are the differences among both the initramfs systems. The rescue initramfs system has almost 2,189 extra files compared to the normal initramfs. Also, almost 719 extra modules have been added in the rescue initramfs.

```
# diff -yt rescue.txt normal.txt  | grep '<' | wc -l
    2186
# diff -yt rescue.txt normal.txt  | grep '<' | grep -i '.ko'  | wc -l
    719

<skip>
.
.
│   │   ├── lspci                                               <
│   │   ├── mdadm                                               <
│   │   ├── mdmon                                               <
│   │   ├── mdraid-cleanup                                      <
│   │   ├── mdraid_start                                        <
│   │   ├── mount.cifs                                          <
│   │   ├── mount.nfs                                           <
│   │   ├── mount.nfs4 -> mount.nfs                             <
│   │   ├── mpathpersist                                        <
│   │   ├── multipath                                           <
│   │   ├── multipathd                                          <
│   │   ├── nfsroot                                             <
│   │   ├── partx                                               <
│   │   ├── pdata_tools                                    <
│   │   ├── ping -> ../bin/ping                            <
│   │   ├── ping6 -> ../bin/ping                           <
│   │   ├── rpcbind -> ../bin/rpcbind                      <
│   │   ├── rpc.idmapd                                     <
│   │   ├── rpcinfo -> ../bin/rpcinfo                      <
│   │   ├── rpc.statd                                      <
│   │   ├── setpci                                         <
│   │   ├── showmount                                      <
│   │   ├── thin_check -> pdata_tools                      <
│   │   ├── thin_dump -> pdata_tools                       <
│   │   ├── thin_repair -> pdata_tools                     <
│   │   ├── thin_restore -> pdata_tools                    <
│   │   ├── xfs_db                                         <
│   │   ├── xfs_metadump                                   <
│   │   └── xfs_repair                                     <
    ├── lib                                               <
    │   ├── iscsi                                          <
    │   ├── lldpad                                         <
    │   ├── nfs                                            <
    │   │   ├── rpc_pipefs                                 <
    │   │   └── statd                                      <
    │   │       └── sm                                     <
</skip>
```

The rescue initramfs will have almost all the modules and supported files for the device on which the user can make a root filesystem, whereas the normal initramfs will be host-specific. It will have only those modules and supported files of the device on which the user has made the root filesystem. If you want to make a rescue initramfs on your own, then you can install a `dracut-config-generic` package on Fedora-based systems. The package provides only one file, and it has the configuration to turn off the host-specific initramfs generation.

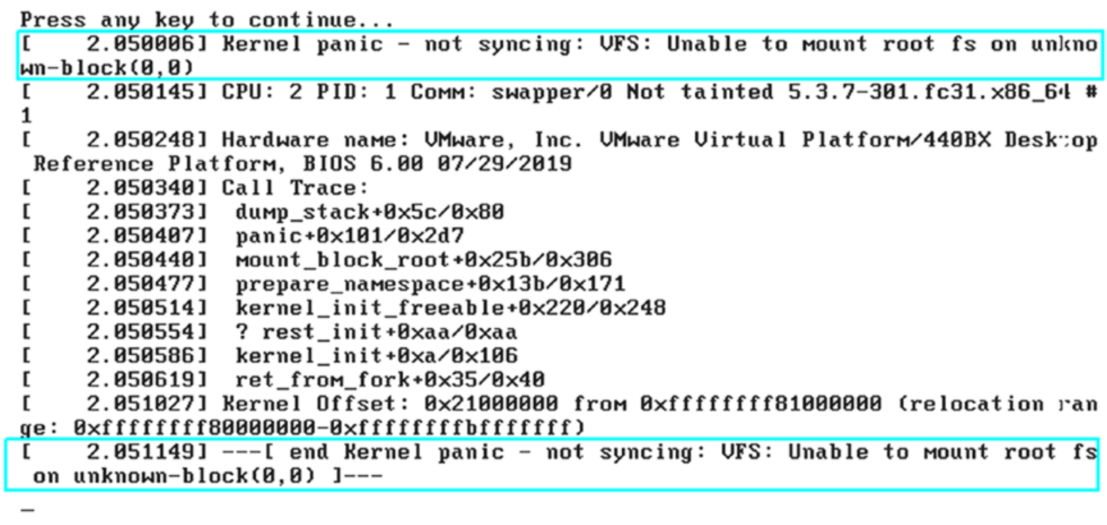
```
# rpm -ql dracut-config-generic
     /usr/lib/dracut/dracut.conf.d/02-generic-image.conf
```

```
# cat /usr/lib/dracut/dracut.conf.d/02-generic-image.conf
      hostonly="no"
```

As you can see, the file will restrict dracut from creating a host-specific initramfs.

“Can’t Boot” Issue 9 (chroot)

Issue: Both the normal and rescue kernels are failing to boot. Figure 10-7 shows the normal kernel panic messages.



```
Press any key to continue...
[    2.050006] Kernel panic - not syncing: VFS: Unable to mount root fs on unkno
wn-block(0,0)
[    2.050145] CPU: 2 PID: 1 Comm: swapper/0 Not tainted 5.3.7-301.fc31.x86_64 #
1
[    2.050248] Hardware name: VMware, Inc. VMware Virtual Platform/440BX Desktop
 Reference Platform, BIOS 6.00 07/29/2019
[    2.050340] Call Trace:
[    2.050373]  dump_stack+0x5c/0x80
[    2.050407]  panic+0x101/0x2d7
[    2.050440]  mount_block_root+0x25b/0x306
[    2.050477]  prepare_namespace+0x13b/0x171
[    2.050514]  kernel_init_freeable+0x220/0x248
[    2.050554]  ? rest_init+0xaa/0xaa
[    2.050586]  kernel_init+0xa/0x106
[    2.050619]  ret_from_fork+0x35/0x40
[    2.051027] Kernel Offset: 0x21000000 from 0xffffffff81000000 (relocation ran
ge: 0xffffffff80000000-0xffffffffbfffffff)
[    2.051149] ---[ end Kernel panic - not syncing: VFS: Unable to mount root fs
 on unknown-block(0,0) ]---
_
```

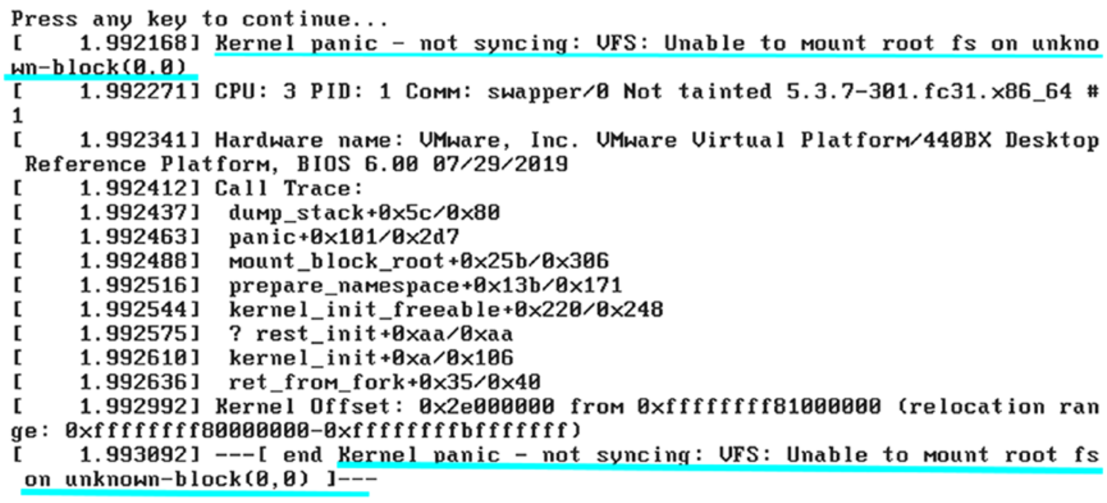
***Figure 10-7.** The kernel panic messages*

The thrown kernel panic messages are complaining that the kernel is not able to mount the root filesystem. We saw earlier that whenever the kernel is not able to mount the user’s root filesystem, it throws the `dracut-initqueue` timeout messages.

```
'dracut-initqueue: warning dracut-initqueue timeout - starting timeout
scripts'
```

However, this time, the panic messages are different. So, it looks like the issue is not related to the user’s root filesystem. One more clue is that it mentions the VFS filesystem; VFS stands for “virtual file system,” so this indicates that the panic messages are not able to mount the root filesystem from initramfs. Based on these clues, I guess we have isolated the issue, and we should concentrate on initramfs of both the kernels.

As you can see in Figure 10-8, the rescue mode kernel panic messages are also similar.

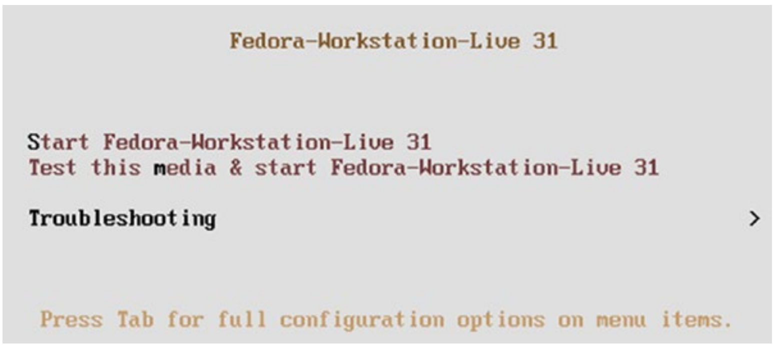


```
Press any key to continue...
[    1.992168] Kernel panic - not syncing: VFS: Unable to mount root fs on unkno
wn-block(0,0)
[    1.992271] CPU: 3 PID: 1 Comm: swapper/0 Not tainted 5.3.7-301.fc31.x86_64 #
1
[    1.992341] Hardware name: VMware, Inc. VMware Virtual Platform/440BX Desktop
 Reference Platform, BIOS 6.00 07/29/2019
[    1.992412] Call Trace:
[    1.992437]  dump_stack+0x5c/0x80
[    1.992463]  panic+0x101/0x2d7
[    1.992488]  mount_block_root+0x25b/0x306
[    1.992516]  prepare_namespace+0x13b/0x171
[    1.992544]  kernel_init_freeable+0x220/0x248
[    1.992575]  ? rest_init+0xaa/0xaa
[    1.992610]  kernel_init+0xa/0x106
[    1.992636]  ret_from_fork+0x35/0x40
[    1.992992] Kernel Offset: 0x2e000000 from 0xffffffff81000000 (relocation ran
ge: 0xffffffff80000000-0xffffffffbfffffff)
[    1.993092] ---[ end Kernel panic - not syncing: VFS: Unable to mount root fs
 on unknown-block(0,0) ]---
```

Figure 10-8. *The rescue mode kernel panic messages*

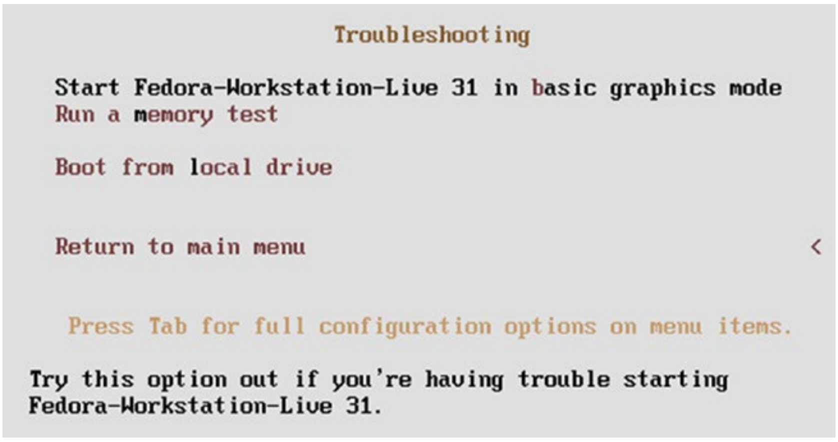
Resolution: Here are the steps to resolve the issue:

1) Since the installed rescue kernel is also panicking, we need to use the live image of Fedora or of any Linux distribution to boot. As shown in Figure 10-9 and Figure 10-10, we are using a live image of Fedora.



Fedora-Workstation-Live 31
Start Fedora-Workstation-Live 31
Test this media & start Fedora-Workstation-Live 31
Troubleshooting >
Press Tab for full configuration options on menu items.

Figure 10-9. *The live image welcome screen*



```
                    Troubleshooting

  Start Fedora-Workstation-Live 31 in basic graphics mode
  Run a memory test

  Boot from local drive


  Return to main menu                                      <


   Press Tab for full configuration options on menu items.

Try this option out if you're having trouble starting
Fedora-Workstation-Live 31.
```

Figure 10-10. *Booting with a live image*

2) The system has booted in rescue mode. The live image booting sequence will be discussed in the "Live Images" section of this chapter. Let's become a sudo user first.

```
$ sudo su

We trust you have received the usual lecture from your local
system administrator. It usually boils down to these three things:

#1) Respect the privacy of others.
#2) Think before you type.
#3) With great power comes great responsibility.

[root@localhost-live liveuser] #
```

3) The root directory that we are seeing here is from a live image. Since the live image kernel does not know the name of the user's root filesystem, it cannot mount it like a rescue kernel.

```
[root@localhost-live liveuser]# ls /
     bin boot dev etc home lib lib64 lost+found media mnt
     opt proc root run sbin srv sys tmp usr var
```

4) Let's find out what is wrong with the initramfs of the normal and rescue kernels. To do that, we need to mount the user's root filesystem first.

```
# vgscan -v
  Found volume group "fedora_localhost-live" using metadata type lvm2

# lvscan -v
  ACTIVE      '/dev/fedora_localhost-live/swap' [2.20 GiB] inherit
  ACTIVE      '/dev/fedora_localhost-live/root' [18.79 GiB]
inherit

# pvscan -v
  PV /dev/sda2  VG fedora_localhost-live  lvm2 [<21.00 GiB / 0  free]
  Total: 1 [<21.00 GiB] / in use: 1 [<21.00 GiB] / in no VG: 0 [0 ]
```

As you can see, this system has a user's root filesystem based on LVM. The physical volume is on the sda device. Next we will mount the user's root filesystem on a temporary directory.

```
# mkdir temp_root
# mount /dev/fedora_localhost-live/root temp_root/
# ls temp_root/
     bin   dev  home  lib64  media  opt   root  sbin  sys
     tmp usr boot  etc  lib   lost+found  mnt    proc  run
     srv   @System.solv user_root_fs.txt  var
```

5) Let's check the initramfs file's status.

```
# ls temp_root/boot/ -l
     total 0
```

The boot directory of the user's root filesystem is empty. That is because on this system, the boot is a separate partition.

```
# mount /dev/sda1 temp_root/boot/
#ls temp_root/boot/
Config-5.3.7-301.fc31.x86_64  efi elf-memtest86+-5.01
extlinux grub2 loader lost+found
Memtest86+-5.01 System.map-5.3.7-301.fc31.x86_64
vmlinuz-0-rescue-19a08a3e86c24b459999fbac68e42c05
vmlinuz-5.3.7-301.fc31.x86_64
```

Surprisingly, as you can see, there are no initramfs files available on the user's root filesystem, and this is the reason why both the kernels were panicking.

So, the issue has been identified, and we need to regenerate the initramfs. To make the new initramfs, we need to use the `dracut` command, but there are some problems.

- Whichever binary or command we execute, that binary will be from the live image root filesystem. For example, the `dracut` command will run from `/usr/bin/dracut`, whereas the user's root filesystem's binary is in `temp_root/usr/bin/dracut`.
- To run any binary, it needs supporting libraries like `libc.so`, which will again be used from the root filesystem of a live image. This means the entire environment that we are using now is from the live image, and it can create serious issues. For example, we can install any package, and it will be installed in the live image root filesystem, not in the user's root filesystem.

In short, we need to change our current root (`/`) from the live image root filesystem to the user's root filesystem (`temp_root`). `chroot` is the command that we need to use for this.

6) The name itself suggests it will change the root of bash from the current root to the new root. `chroot` will be successful only if the virtual filesystems are already mounted on the new root.

```
root@localhost-live liveuser]# ls /
     bin  boot  dev  etc  home  lib  lib64  lost+found  media  mnt
     opt  proc  root  run  sbin  srv  sys  tmp  usr  var
```

Our current root is the live image root filesystem. Before `chroot`, we will mount the `proc`, `dev`, `devpts`, `sys`, and `run` virtual filesystems.

```
# mount -v --bind /dev/ temp_root/dev
mount: /dev bound on /home/liveuser/temp_root/dev.

# mount -vt devpts devpts temp_root/dev/pts -o gid=5,mode=620
mount: devpts mounted on /home/liveuser/temp_root/dev/pts.

# mount -vt proc proc temp_root/proc
mount: proc mounted on /home/liveuser/temp_root/proc.

# mount -vt sysfs sysfs temp_root/sys
mount: sysfs mounted on /home/liveuser/temp_root/sys.
```

```
# mount -vt tmpfs tmpfs temp_root/run
mount: tmpfs mounted on /home/liveuser/temp_root/run.
```

7) We are all set to `chroot` into a user's root filesystem.

```
# chroot temp_root/
# ls
     bin   dev  home  lib64
media  opt   root  sbin  sys   tmp
     usr boot  etc  lib   lost+found  mnt    proc  run   srv
     @System.solv  user_root_fs.txt  var
```

So, `temp_root` became the root filesystem of bash now. If you exit from this shell, bash will change its root directory from the user's root filesystem to a live image root filesystem. So, as long as we are in the same shell instance, our root directory is `temp_root`. Now, no matter what command or binary we execute, it will run inside the user's root filesystem environment. Hence, it is completely safe to execute the processes in this environment now.

8) To fix this "can't boot" issue, we need to regenerate initramfs.

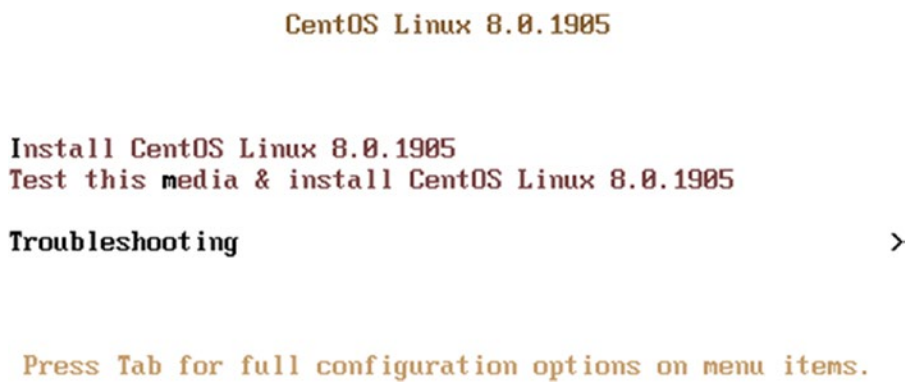
```
root@localhost-live /]# ls /lib/modules
5.3.7-301.fc31.x86_64

[root@localhost-live /]# cd /boot/

[root@localhost-live boot]# rpm -qa | grep -i 'kernel-5'
kernel-5.3.7-301.fc31.x86_64

[root@localhost-live boot]# dracut initramfs-5.3.7-301.fc31.
x86_64.img  5.3.7-301.fc31.x86_64
```

9) If you want to regenerate the rescue kernel initramfs, then you need to install a `dracut-config-generic` package.

10) After rebooting, the system is able to boot, and the "can't boot" issue has been fixed.

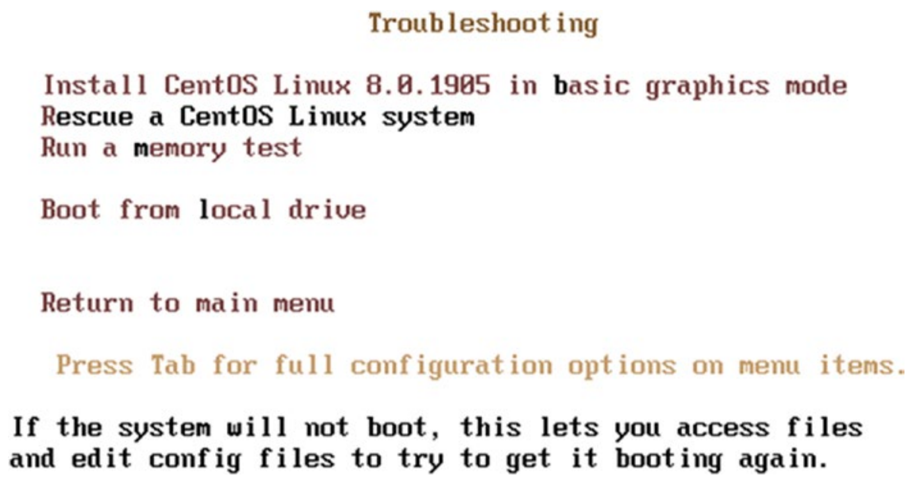
Rescue Mode of Enterprise Linux Distributions

In some of the Linux distributions such as CentOS, the rescue image approach is a bit different. The enterprise edition of Linux will try to find the user's root filesystem on its own. Let's see this in action. Figure 10-11 and Figure 10-12 show the rescue mode selection procedure of CentOS.



```
                    CentOS Linux 8.0.1905


Install CentOS Linux 8.0.1905
Test this media & install CentOS Linux 8.0.1905

Troubleshooting                                            >


 Press Tab for full configuration options on menu items.
```

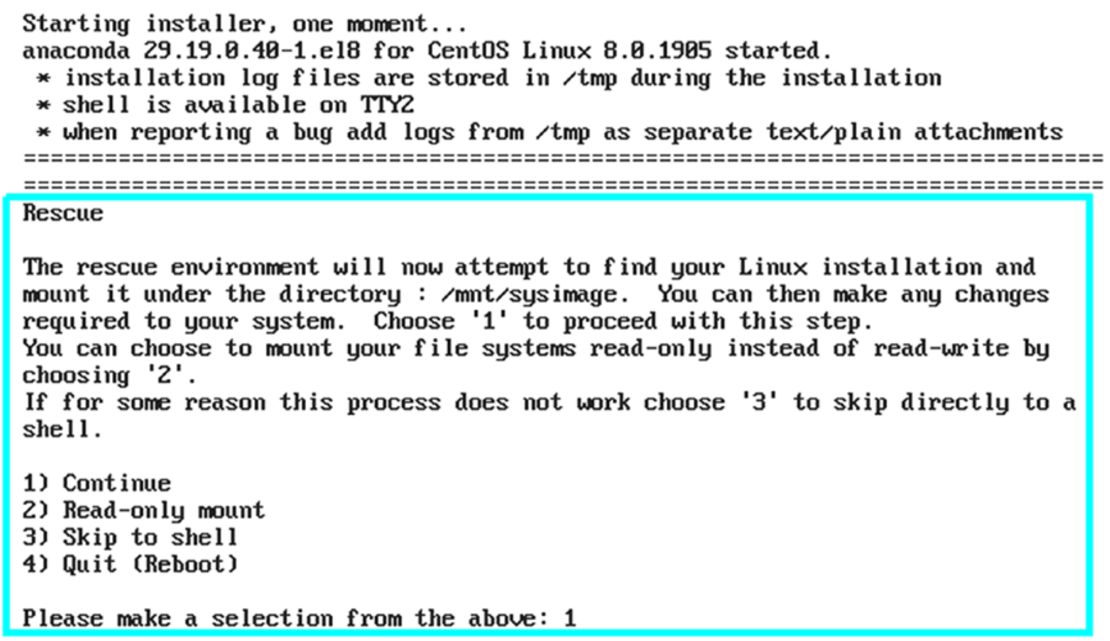
Figure 10-11. *The CentOS welcome screen*



```
                      Troubleshooting

  Install CentOS Linux 8.0.1905 in basic graphics mode
  Rescue a CentOS Linux system
  Run a memory test

  Boot from local drive


  Return to main menu

   Press Tab for full configuration options on menu items.

If the system will not boot, this lets you access files
and edit config files to try to get it booting again.
```

Figure 10-12. *The rescue mode selection*

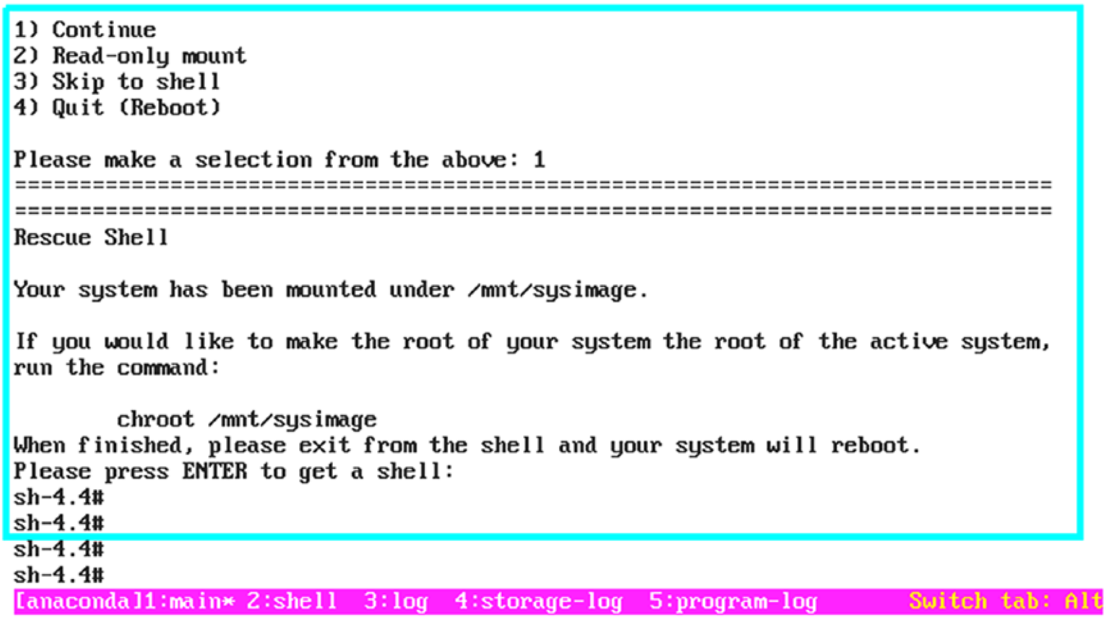
It will boot, and as you can see in Figure 10-13, it will display some messages on the screen.



```
Starting installer, one moment...
anaconda 29.19.0.40-1.el8 for CentOS Linux 8.0.1905 started.
 * installation log files are stored in /tmp during the installation
 * shell is available on TTY2
 * when reporting a bug add logs from /tmp as separate text/plain attachments
================================================================================
================================================================================
Rescue

The rescue environment will now attempt to find your Linux installation and
mount it under the directory : /mnt/sysimage.  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
```

Figure 10-13. *The informative message*

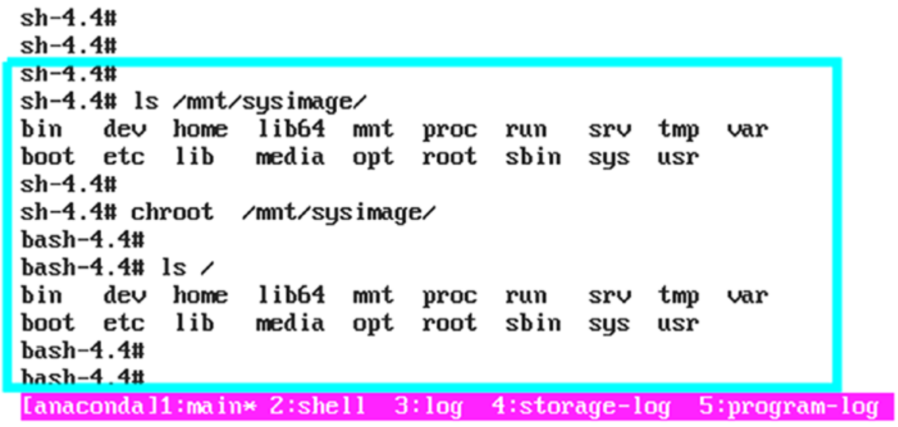
If we choose option 1, `continue`, then the rescue mode will search the disk and will find the root filesystem on its own. Once the user's root filesystem has been identified, it will mount it under the `/mnt/sysimage` directory. Please refer to Figure 10-14.



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

Please make a selection from the above: 1
================================================================================
================================================================================
Rescue Shell

Your system has been mounted under /mnt/sysimage.

If you would like to make the root of your system the root of the active system,
run the command:

        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#
sh-4.4#
sh-4.4#
sh-4.4#
[anaconda]1:main* 2:shell  3:log  4:storage-log  5:program-log        Switch tab: Alt
```

Figure 10-14. *The root filesystem is mounted under /mnt/sysimage*

As you can see, it has mounted the user's root filesystem in `/mnt/sysimage`; we just need to `chroot` into it. But the beauty is we don't need to mount the virtual filesystems beforehand. This is because, as you can see in Figure 10-15, the `chroot` binary used in CentOS has been customized, and it will mount the virtual filesystems on its own.



```
sh-4.4#
sh-4.4#
sh-4.4#
sh-4.4# ls /mnt/sysimage/
bin   dev  home  lib64  mnt  proc  run   srv  tmp  var
boot  etc  lib   media  opt  root  sbin  sys  usr
sh-4.4#
sh-4.4# chroot  /mnt/sysimage/
bash-4.4#
bash-4.4# ls /
bin   dev  home  lib64  mnt  proc  run   srv  tmp  var
boot  etc  lib   media  opt  root  sbin  sys  usr
bash-4.4#
bash-4.4#
[anaconda]1:main* 2:shell  3:log  4:storage-log  5:program-log
```

Figure 10-15. *chroot*

If we had chosen option 2, `Read-Only Mount`, then the rescue scripts would have mounted the user's root filesystem in read-only mode but in `/mnt/sysimage`. If we had chosen the third option of `Skip`, the rescue system would not have attempted to find and mount the user's root filesystem on its own; it would have simply provided us with a shell.

But how does it manage to find out the root filesystem when the rescue kernel of the CentOS ISO does not have a user's root filesystem name with it?

There is no trick here that Anaconda can do to find out the user's root filesystem name. Anaconda will mount each and every disk connected to the system and check whether `/etc/fstab` is present on it or not. If `/etc/fstab` is found, then it will fetch the user's root filesystem name from it. If your system has a huge number of disks attached, then there is a high chance that Anaconda might take a long time to mount the user's root filesystem. It is better to manually mount the user's root filesystem in such a scenario. The source code to find the user's root filesystem is present in Anaconda's source tarball, as shown here:

```
#vim pyanaconda/storage/root.py
```

```
def _find_existing_installations(devicetree):
    """Find existing GNU/Linux installations on devices from the
       device tree.

    :param devicetree: a device tree to find existing installations in
    :return: roots of all found installations
    """
    if not os.path.exists(conf.target.physical_root):
        blivet_util.makedirs(conf.target.physical_root)

    sysroot = conf.target.physical_root
    roots = []
    direct_devices = (dev for dev in devicetree.devices if dev.direct)
    for device in direct_devices:
        if not device.format.linux_native or not device.format.
        mountable or \
           not device.controllable or not device.format.exists:
            continue

        try:
            device.setup()
        except Exception:  # pylint: disable=broad-except
            log_exception_info(log.warning, "setup of %s failed",
            [device.name])
            continue

        options = device.format.options + ",ro"
        try:
            device.format.mount(options=options, mountpoint=sysroot)
        except Exception:  # pylint: disable=broad-except
            log_exception_info(log.warning, "mount of %s as %s failed",
            [device.name, device.format.type])
            blivet_util.umount(mountpoint=sysroot)
            continue

        if not os.access(sysroot + "/etc/fstab", os.R_OK):
            blivet_util.umount(mountpoint=sysroot)
            device.teardown()
            continue

        try:
            (architecture, product, version) = get_release_
            string(chroot=sysroot)
        except ValueError:
            name = _("Linux on %s") % device.name
        else:
            # I'd like to make this finer grained, but it'd be very
            difficult
            # to translate.
            if not product or not version or not architecture:
                name = _("Unknown Linux")
            elif "linux" in product.lower():
                name = _("%(product)s %(version)s for %(arch)s") % \
            {"product": product, "version": version, "arch": architecture}
    else:
       name = _("%(product)s Linux %(version)s for %(arch)s") % \
            {"product": product, "version": version, "arch": architecture}

(mounts, swaps) = _parse_fstab(devicetree, chroot=sysroot)
blivet_util.umount(mountpoint=sysroot)
if not mounts and not swaps:
    # empty /etc/fstab. weird, but I've seen it happen.
    continue
roots.append(Root(mounts=mounts, swaps=swaps, name=name))

```

Live Images

Live images are one of the best features of Linux systems. This book wouldn't be complete if we just stuck to the normal hard disk booting part. Let's see how a live image of Linux boots. First let's mount the ISO image and see what it holds.

```
# mkdir live_image
# mount /dev/cdrom live_image/
mount: /home/yogesh/live_image: WARNING: device write-protected, mounted
read-only.
```

```
# tree live_image/
live_image/
├── EFI
│   └── BOOT
│       ├── BOOT.conf
│       ├── BOOTIA32.EFI
│       ├── BOOTX64.EFI
│       ├── fonts
│       │   └── unicode.pf2
│       ├── grub.cfg
│       ├── grubia32.efi
│       ├── grubx64.efi
│       ├── mmia32.efi
│       └── mmx64.efi
├── images
│   ├── efiboot.img
│   ├── macboot.img
│   └── pxeboot
│       ├── initrd.img
│       └── vmlinuz
├── isolinux
│   ├── boot.cat
│   ├── boot.msg
│   ├── grub.conf
│   ├── initrd.img
│   ├── isolinux.bin
│   ├── isolinux.cfg
│   ├── ldlinux.c32
│   ├── libcom32.c32
│   ├── libutil.c32
│   ├── memtest
│   ├── splash.png
│   ├── vesamenu.c32
│   └── vmlinuz
└── LiveOS
    └── squashfs.img
```

The live image is divided into four directories: `EFI`, `images`, `isolinux`, and `LiveOS`.

- **EFI:**

  We have already discussed this directory when talking about the bootloader. The UEFI firmware will jump into this directory and will run the `grubx64.efi` file. The `grubx64.efi` file will read the `grub.cfg` file and will pull the `initrd.img` and `vmlinuz` files from the `isolinux` directory.

- **images:**

  This will be used mainly if we are booting through PXE. A network boot is out of the scope of this book.

- **isolinux:**
  If UEFI is booting the BIOS way, then it will read the `grub.conf` file from here. This directory is mainly for storing the `initrd` and `vmlinuz` files. In other words, this directory is `/boot` for a normal root filesystem.

- **liveOS:**

  This is where the magic happens. This directory has a file named `squashfs.img`. Once you mount that, you will find `rootfs.img` in it.

```
# mkdir live_image_extract_1
# mount live_image/LiveOS/squashfs.img  live_image_extract_1/

# ls live_image_extract_1/
    LiveOS
# ls live_image_extract_1/LiveOS/
    rootfs.img

# mkdir live_image_extract_2
# mount live_image_extract_1/LiveOS/rootfs.img live_image_extract_2/

# ls live_image_extract_2/
    bin  boot  dev  etc  home  lib  lib64  lost+found  media
    mnt  opt  proc  root  run  sbin  srv  sys  tmp  usr  var
```

SquashFS

Squashfs is a small, compressed, read-only filesystem. This filesystem is generally used for embedded systems where every byte of storage is precious. Squashfs gives us more flexibility and performance over tarball archives. Squashfs stores a live Fedora's root filesystem (`rootfs.img`) in it, and it will be mounted as read-only.

```
# mount | grep -i rootfs
/home/yogesh/live_image_extract_1/LiveOS/rootfs.img on /home/yogesh/
live_image_extract_2 type ext4 (ro,relatime,seclabel)
```

You can use the `mksquashfs` command provided by `squashfs-tool` to make the Squashfs image/archive.

rootfs.img

`rootfs.img` is an ext4 filesystem with a typical root filesystem in it. Some distros create a guest user or a user named `live` for a live image, but in Fedora it's the root user who does everything.

```
# file live_image_extract_1/LiveOS/rootfs.img
live_image_extract_1/LiveOS/rootfs.img: Linux rev 1.0 ext4 filesystem data,
UUID=849bdfdc-c8a9-4fed-a727-de52e24d981f, volume name "Anaconda" (extents)
(64bit) (large files) (huge files)
```

Booting Sequence of a Live Image

Here is the sequence:

1) The firmware will call the bootloader (`grubx64.efi`). It will read the `grub.cfg` file and copy the `vmlinuz` and `initrd` files from the `isolinux` directory.

2) The kernel will extract itself at a specific location and will extract initramfs at any available location.

3) systemd, started from initramfs, will extract the `rootfs.img` file to the device-mapper target device at `/dev/mapper/live-rw`, mount it on the root (`/`) filesystem, and `switch_root` into it.

4) Once the root filesystem is available, you can consider it as a normal operating that is installed in a CD, DVD, or `.iso` file.

Also, it is obvious that the live-image initramfs will be much bigger in size compared to the host-specific initramfs.

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Y. Babar, *Hands-on Booting*, https://doi.org/10.1007/978-1-4842-5890-3