Lecture 10: User Space

Kernel to Userspace Transition

- The Kernel code is tightly controlled by Linus Torvolds. He decides* what is included in new releases.
- The Kernel code has to be efficient and stable. Kernel code runs as a single monolithic process.
- All the other code in the world that executes on Linux is in ”User Space” under the control of the Kernel.

Linus Torvolds
Finnish Computer Scientist

*This is why he wrote git. Probably named that because he has to be a “ruthless git” when deciding what kernel changes to include.

The init program (system for example)

- Systemd is a collection of programs.
- These programs often run as daemons* (increasingly called services, that's what the "d" stands for)
- Daemons run in the background performing system tasks usually without administrator intervention.
- Systemd daemon programs are in `/sbin` (system binaries)
- Programs that admins and users run to interface with systemd are in `/bin` (general binaries).
- The majority of the systemd code is in `/lib/systemd`. (`/lib` is for library files)

Lennart Poettering†
German/Brazilian Computer Scientist

*In Greek mythology a daemon was a spirit that served the gods. They were below the gods but above mere mortals. They often served has helpers and guardians of humans.

†Debate between Linus Torvolds and Lennart Poettering regarding the User Space/Kernel interface https://www.youtube.com/watch?v=Nn-SGblUhi4

SystemD paradigm

- Systemd handles the boot process after the Kernel has identified devices and filesytems.
- Systemd is relatively recent and aims to replace a lot of standard Linux tools (such as cron)*
- Systemd is “goal oriented” where each goal is defined as a *unit.*
- Most *units* run as daemons, they start on boot and run as long as the system is up.
- Each *unit* has a configuration file that defines how it works. These config files are in `/usr/lib/systemd/system/`

SystemD paradigm

- Each *unit* has a configuration file that defines how it works. These config files are in `/usr/lib/systemd/system/`

```
[matthew@moonshine ~]$ ls /usr/lib/systemd/system | head -n 10
arp-ethers.service
auditd.service
auth-rpcgss-module.service
autovt@.service
basic.target
basic.target.wants
blk-availability.service
blockdev@.target
bluetooth.target
boot-complete.target
```

```
[matthew@moonshine ~]$ cat /usr/lib/systemd/system/systemd-udevd.service
#  SPDX-License-Identifier: LGPL-2.1-or-later
#
#  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=Rule-based Manager for Device Events and Files
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]
CapabilityBoundingSet=~CAP_SYS_TIME CAP_WAKE_ALARM
Delegate=pids
Type=notify
# Note that udev will reset the value internally for its workers
OOMScoreAdjust=-1000
Sockets=systemd-udevd-control.socket systemd-udevd-kernel.socket
Restart=always
```

Recall from the devices lecture that the udev deamon handles device events reported by the Kernel.

```
[matthew@moonshine ~]$ cat /usr/lib/systemd/system/systemd-udevd.service
#  SPDX-License-Identifier: LGPL-2.1-or-later
#
#  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=Rule-based Manager for Device Events and Files
Documentation=man:systemd-udevd.service(8) man:udev(7)
DefaultDependencies=no
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Delegate=pids
Type=notify
# Note that udev will reset the value internally for its workers
OOMScoreAdjust=-1000
Sockets=systemd-udevd-control.socket systemd-udevd-kernel.socket
Restart=always
```

Systemd units start as soon as they are ready, the order is constrained by the “before” and “after” keywords.

Unit Types

- Services

  Manage Linux daemons

- Targets

  Manage other units (starting groups of units for example)

- Sockets

  Handles socket communications (see devices lecture)

- Mounts

  For accessing filesystems

Systemd Daemon Example

- This example has three parts.
  1. A little python program that prints to *standard out* whatever it receives on *standard in* (recall *standard out* and *standard in* from the devices lecture)
  2. A *systemd* socket unit that opens a TCP network *port* (4444) and listens for data (recall TCP *ports* from the networking lecture)
  3. A *systemd* service unit that creates a new daemon process to handle connections to *port* 4444. A new daemon is created for each new connection so it can hold multiple conversations at once.

- We will also need to install a little program to easily write data to port 4444.

- SELinux is a security daemon. We will have to temporarily make it not care about port 4444.

Git Clone the Files

```
[matthew@moonshine ~]$ git clone https://github.com/gmfricke/echo_daemon.git
Cloning into 'echo_daemon'...
remote: Enumerating objects: 6, done.
remote: Counting objects: 100% (6/6), done.
remote: Compressing objects: 100% (5/5), done.
remote: Total 6 (delta 0), reused 6 (delta 0), pack-reused 0
Receiving objects: 100% (6/6), done.
```

Install socat (socket concatenator – it's like the "cat" command you have been using, but for network sockets)

```
[matthew@moonshine ~]$ sudo yum install socat
Last metadata expiration check: 1:45:44 ago on Sat 17 Feb 2024 09:56:45 PM CST.
Dependencies resolved.
================================================================================
 Package     Architecture Version                 Repository       Size
================================================================================
Installing:
 socat       x86_64       1.7.4.1-5.el9          appstream       300 k

Transaction Summary
================================================================================
Install  1 Package

Total download size: 300 k
Installed size: 1.1 M
Is this ok [y/N]: y
Downloading Packages:
socat-1.7.4.1-5.el9.x86_64.rpm      695 kB/s | 300 kB     00:00
--------------------------------------------------------------------------------
Total                               347 kB/s | 300 kB     00:00
```

Only one person per server team needs to do this

Make SELinux “Permissive” so we can use the port

```
[matthew@moonshine ~]$ sestatus
SELinux status:                 enabled
SELinuxfs mount:                /sys/fs/selinux
SELinux root directory:         /etc/selinux
Loaded policy name:             targeted
Current mode:                   enforcing
Mode from config file:          enforcing
Policy MLS status:              enabled
Policy deny_unknown status:     allowed
Memory protection checking:     actual (secure)
Max kernel policy version:      33
```

Make SELinux “Permissive” so we can use the port

```
[matthew@moonshine ~]$ sudo setenforce Permissive
[matthew@moonshine ~]$ sestatus
SELinux status:                 enabled
SELinuxfs mount:                /sys/fs/selinux
SELinux root directory:         /etc/selinux
Loaded policy name:             targeted
Current mode:                   permissive
Mode from config file:          enforcing
Policy MLS status:              enabled
Policy deny_unknown status:     allowed
Memory protection checking:     actual (secure)
Max kernel policy version:      33
```

Read through the systemd and python code.

```
[matthew@moonshine echo_daemon]$ cd echo_daemon/
[matthew@moonshine echo_daemon]$ ls
echod@.service  echod.socket  echo.py  README.md
```

Read through the systemd and python code.

```
[matthew@moonshine echo_daemon]$ cat echod.socket

# Create a Socket to Listen to
[Unit]
Description = Echo server


[Socket]
ListenStream = 4444
Accept = yes


[Install]
WantedBy = sockets.target
```

Socket units automatically look for a service unit with the same name + @ and activate that service. In this case echod@.service.

Read through the systemd and python code.

```
[matthew@moonshine echo_daemon]$ cat echod@.service
# echo@.service
[Unit]
Description=Echo server service

[Service]
User=root
ExecStart=/sbin/echo.py
StandardInput=socket
```

The @ means this is a “template service”. Template services take an argument – in this case it will be an identifier to uniquely label the conversation this service will handle. (More than one program might connect to port 4444 at a time).

Read through the systemd and python code.

```
[matthew@moonshine echo_daemon]$ cat echod@.service
# echo@.service
[Unit]
Description=Echo server service

[Service]
User=root
ExecStart=/sbin/echo.py
StandardInput=socket
```

Read through the systemd and python code.

```
[matthew@moonshine echo_daemon]$ cat echod@.service
# echo@.service
[Unit]
Description=Echo server service

[Service]
User=root
ExecStart=/sbin/echo.py
StandardInput=socket
```

This the path to our program that will handle the data and write a reply.

Python Program to Read from Standard in and write to standard out.

```
[matthew@moonshine echo_daemon]$ cat echo.py
#!/usr/bin/python

# Program that reads
import sys

# Incoming Message
message = sys.stdin.readline().strip()

# Print the message
sys.stdout.write( "Echo Server Received: " + message + "\n")
```

Python is a scripting language.

The first line tells the system what program to use to execute the script.

Guido van Rossen

Dutch Computer Scientist and “benevolent dictator for life" (BDFL)

- Guido wrote Python to be a system scripting language. It’s designed to make automating Linux tasks easy.
- It became so popular that now it is used for all sorts of tasks and has become a general purpose language.

Let’s move these files into place (coordinate with your team mate)

```
[matthew@moonshine echo_daemon]$ sudo cp echo.py /sbin/
[matthew@moonshine echo_daemon]$ sudo cp echod@.service /usr/lib/systemd/system/
[matthew@moonshine echo_daemon]$ sudo cp echod.socket /usr/lib/systemd/system/
```

Now activate the echod.socket systemd unit

We are going to start the daemon that listens for data on socket 4444. It sits between the “Kernel god” and the “mortal user” programs.

```
[matthew@moonshine echo_daemon]$ sudo systemctl start echod.socket
```

We use the systemctl program to control system units.

Now check the status of the echod socket handler daemon.

```
[matthew@moonshine echo_daemon]$ sudo systemctl start echod.socket
[matthew@moonshine echo_daemon]$ systemctl status echod.socket
● echod.socket - Echo server
     Loaded: loaded (/usr/lib/systemd/system/echod.socket; disabled; preset: disabled)
     Active: active (listening) since Sun 2024-02-18 00:28:46 CST; 11s ago
      Until: Sun 2024-02-18 00:28:46 CST; 11s ago
     Listen: [::]:4444 (Stream)
   Accepted: 0; Connected: 0;
      Tasks: 0 (limit: 407887)
     Memory: 8.0K
        CPU: 595us
     CGroup: /system.slice/echod.socket
[matthew@moonshine echo_daemon]$
```

Journalctl -u {unit name} displays the system unit log

```
[matthew@moonshine echo_daemon]$ sudo journalctl -u echod.socket
Feb 18 00:28:46 moonshine systemd[1]: Listening on Echo server.
```

Any error messages will show up here

Journalctl -xe will show all messages from systemd

```
[matthew@moonshine echo_daemon]$ sudo journalctl -xe
Feb 18 00:37:58 moonshine sshd[191411]: Received disconnect from 111.230.20.37 port 48942:11: Bye Bye [preauth]
Feb 18 00:37:58 moonshine sshd[191411]: Disconnected from invalid user xmj 111.230.20.37 port 48942 [preauth]
Feb 18 00:38:22 moonshine sshd[191480]: Invalid user nichengzhuo from 186.117.143.206 port 35074
Feb 18 00:38:22 moonshine sshd[191480]: pam_unix(sshd:auth): check pass; user unknown
Feb 18 00:38:22 moonshine sshd[191480]: pam_unix(sshd:auth): authentication failure; logname= uid=0 euid=0 tty=ssh
ruser= rhost=186.117.143.206
Feb 18 00:38:24 moonshine sshd[191480]: Failed password for invalid user nichengzhuo from 186.117.143.206 port 35074
ssh2
Feb 18 00:38:25 moonshine sshd[191480]: Received disconnect from 186.117.143.206 port 35074:11: Bye Bye [preauth]
Feb 18 00:38:25 moonshine sshd[191480]: Disconnected from invalid user nichengzhuo 186.117.143.206 port 35074 [preauth]
Feb 18 00:37:22 moonshine sshd[191341]: Failed password for invalid user yaowz from 186.117.143.206
Feb 18 00:37:23 moonshine sshd[191341]: Received disconnect from 186.117.143.206 port 44992:11: Bye
Feb 18 00:37:23 moonshine sshd[191341]: Disconnected from invalid user yaowz 186.117.143.206 port 44
Feb 18 00:37:35 moonshine sudo[191137]: pam_unix(sudo:session): session closed for user root
Feb 18 00:37
```

Journalctl -f will display the log “live”

```
[matthew@moonshine echo_daemon]$ sudo journalctl -f
Feb 18 00:41:38 moonshine sshd[191876]: Failed password for root from 103.124.191.67 port 51242 ssh2
Feb 18 00:41:40 moonshine sshd[191876]: Connection closed by authenticating user root 103.124.191.67 port 51242 [preauth]
Feb 18 00:41:59 moonshine sshd[191941]: Invalid user forest from 111.230.20.37 port 53846
Feb 18 00:41:59 moonshine sshd[191941]: pam_unix(sshd:auth): check pass; user unknown
Feb 18 00:41:59 moonshine sshd[191941]: pam_unix(sshd:auth): authentication failure; logname= uid=0 euid=0 tty=ssh ruser= rhost=111.230.20.37
Feb 18 00:42:01 moonshine sshd[191941]: Failed password for invalid user forest from 111.230.20.37 port 53846 ssh2
Feb 18 00:42:01 moonshine sshd[191941]: Received disconnect from 111.230.20.37 port 53846:11: Bye Bye [preauth]
Feb 18 00:42:01 moonshine sshd[191941]: Disconnected from invalid user forest 111.230.20.37 port 53846 [preauth]
Feb 18 00:42:15 moonshine sudo[191980]:  matthew : TTY=pts/1 ; PWD=/home/matthew/echo_daemon ; USER=root ; COMMAND=/bin/journalctl -f
Feb 18 00:42:15 moonshine sudo[191980]: pam_unix(sudo:session): session opened for user root(uid=0) by matthew(uid=1000)
Feb 18 00:42:20 moonshine sshd[191736]: fatal: Timeout before authentication for 140.246.225.169 port 47158
```

Journalctl -f will display the log “live”

```
[matthew@moonshine echo_daemon]$ sudo journalctl -f
Feb 18 00:41:38 moonshine sshd[191876]: Failed password for root from 103.124.191.67 port 51242 ssh2
Feb 18 00:41:40 moonshine sshd[191876]: Connection closed by authenticating user root 103.124.191.67 port 51242 [preauth]
Feb 18 00:41:59 moonshine sshd[191941]: Invalid user forest from 111.230.20.37 port 53846
Feb 18 00:41:59 moonshine sshd[191941]: pam_unix(sshd:auth): check pass; user unknown
Feb 18 00:41:59 moonshine sshd[191941]: pam_unix(sshd:auth): authentication failure; logname= uid=0 euid=0 tty=ssh ruser= rhost=111.230.20.37
Feb 18 00:42:01 moonshine sshd[191941]: Failed password for invalid user forest from 111.230.20.37 port 53846 ssh2
Feb 18 00:42:01 moonshine sshd[191941]: Received disconnect from 111.230.20.37 port 53846:11: Bye Bye [preauth]
Feb 18 00:42:01 moonshine sshd[191941]: Disconnected from invalid user forest 111.230.20.37 port 53846 [preauth]
Feb 18 00:42:15 moonshine sudo[191980]:  matthew : TTY=pts/1 ; PWD=/home/matthew/echo_daemon ; USER=root ; COMMAND=/bin/journalctl -f
Feb 18 00:42:15 moonshine sudo[191980]: pam_unix(sudo:session): session opened for user root(uid=0) by matthew(uid=1000)
Feb 18 00:42:20 moonshine sshd[191736]: fatal: Timeout before authentication for 140.246.225.169 port 47158
```

You or your teammate open a terminal to monitor your echod@ service log

```
[matthew@moonshine ~]$ sudo journalctl -f -u "echo@*”
```

Write data to port 4444 with socat.

```
$ socat - TCP:moonshine:4444
test
Echo Server Received: test
```

```
Feb 17 23:18:39 moonshine systemd[1]:
Started Echo server service
(127.0.0.1:52724).
Feb 17 23:18:42 moonshine systemd[1]:
echo@25-127.0.0.1:4444-
127.0.0.1:52724.service: Deactivated
successfully.
```

Can you write to another team’s echo server?

Clean up our insecure deamon

```
[matthew@moonshine echo_daemon]$ sudo systemctl stop echod.socket
[matthew@moonshine echo_daemon]$ systemctl status echod.socket
○ echod.socket - Echo server
     Loaded: loaded (/usr/lib/systemd/system/echod.socket; disabled; preset: disabled)
     Active: inactive (dead)
     Listen: [::]:4444 (Stream)
   Accepted: 0; Connected: 0;
```

Reenable “Secure ”Linux

```
[matthew@moonshine echo_daemon]$ sudo setenforce Enforcing
[matthew@moonshine echo_daemon]$ sestatus
SELinux status:                 enabled
SELinuxfs mount:                /sys/fs/selinux
SELinux root directory:         /etc/selinux
Loaded policy name:             targeted
Current mode:                   enforcing
Mode from config file:          enforcing
Policy MLS status:              enabled
Policy deny_unknown status:     allowed
Memory protection checking:     actual (secure)
Max kernel policy version:      33
```

The Default Target

```
[matthew@moonshine echo_daemon]$ systemctl status default.target
● multi-user.target - Multi-User System
     Loaded: loaded (/usr/lib/systemd/system/multi-user.target; indirect; preset: disable
     Active: active since Tue 2024-02-06 20:21:25 CST; 1 week 4 days ago
      Until: Tue 2024-02-06 20:21:25 CST; 1 week 4 days ago
       Docs: man:systemd.special(7)
```

The Default Target – Defines a set of daemons to start on boot.

```
[matthew@moonshine echo_daemon]$ systemctl list-dependencies default.target

default.target
● ├─auditd.service
● ├─chronyd.service
● ├─crond.service
● ├─firewalld.service
● ├─irqbalance.service
● ├─kdump.service
○ ├─mdmonitor.service
● ├─NetworkManager.service
○ ├─rpcbind.service
● ├─rsyslog.service
● ├─sshd.service
○ ├─sssd.service
● ├─systemd-ask-password-wall.path
● ├─systemd-logind.service
○ ├─systemd-update-utmp-runlevel.service
● ├─systemd-user-sessions.service
```

List all units…

```
[matthew@moonshine echo_daemon]$ systemctl list-units | head -n 10
  UNIT                                                                                                                LOAD
ACTIVE SUB       DESCRIPTION
  proc-sys-fs-binfmt_misc.automount                                                                                   loaded
active waiting   Arbitrary Executable File Formats File System Automount Point
  sys-devices-pci0000:00-0000:00:01.0-0000:02:00.0-net-eno3.device                                                    loaded
active plugged   NetXtreme BCM5720 Gigabit Ethernet PCIe
  sys-devices-pci0000:00-0000:00:01.0-0000:02:00.1-net-eno4.device                                                    loaded
active plugged   NetXtreme BCM5720 Gigabit Ethernet PCIe
  sys-devices-pci0000:00-0000:00:01.1-0000:01:00.0-net-eno1.device                                                    loaded
active plugged   NetXtreme BCM5720 Gigabit Ethernet PCIe
  sys-devices-pci0000:00-0000:00:01.1-0000:01:00.1-net-eno2.device                                                    loaded
active plugged   NetXtreme BCM5720 Gigabit Ethernet PCIe
  sys-devices-pci0000:00-0000:00:02.2-0000:03:00.0-host1-target1:2:0-1:2:0:0-block-sda-sda1.device                    loaded
active plugged   PERC_H310 EFI\x20System\x20Partition
  sys-devices-pci0000:00-0000:00:02.2-0000:03:00.0-host1-target1:2:0-1:2:0:0-block-sda-sda2.device                    loaded
active plugged   PERC_H310 2
  sys-devices-pci0000:00-0000:00:02.2-0000:03:00.0-host1-target1:2:0-1:2:0:0-block-sda-sda3.device                    loaded
active plugged   PERC_H310 3
  sys-devices-pci0000:00-0000:00:02.2-0000:03:00.0-host1-target1:2:0-1:2:0:0-block-sda.device                         loaded
active plugged   PERC_H310
```

System V

- System V is a very old way to startup User Space programs when the system boots up.
  - It is still used today even though the newer Systemd also starts up daemons.
- System V has “runlevels”. Different startup/shutdown scripts are run during each runlevel.
- There are 6 runlevels

0 — Halt

1 — Single-user text mode

2 — Not used (user-definable)

3 — Full multi-user text mode

4 — Not used (user-definable)

5 — Full multi-user graphical mode (with an X-based login screen)

6 — Reboot

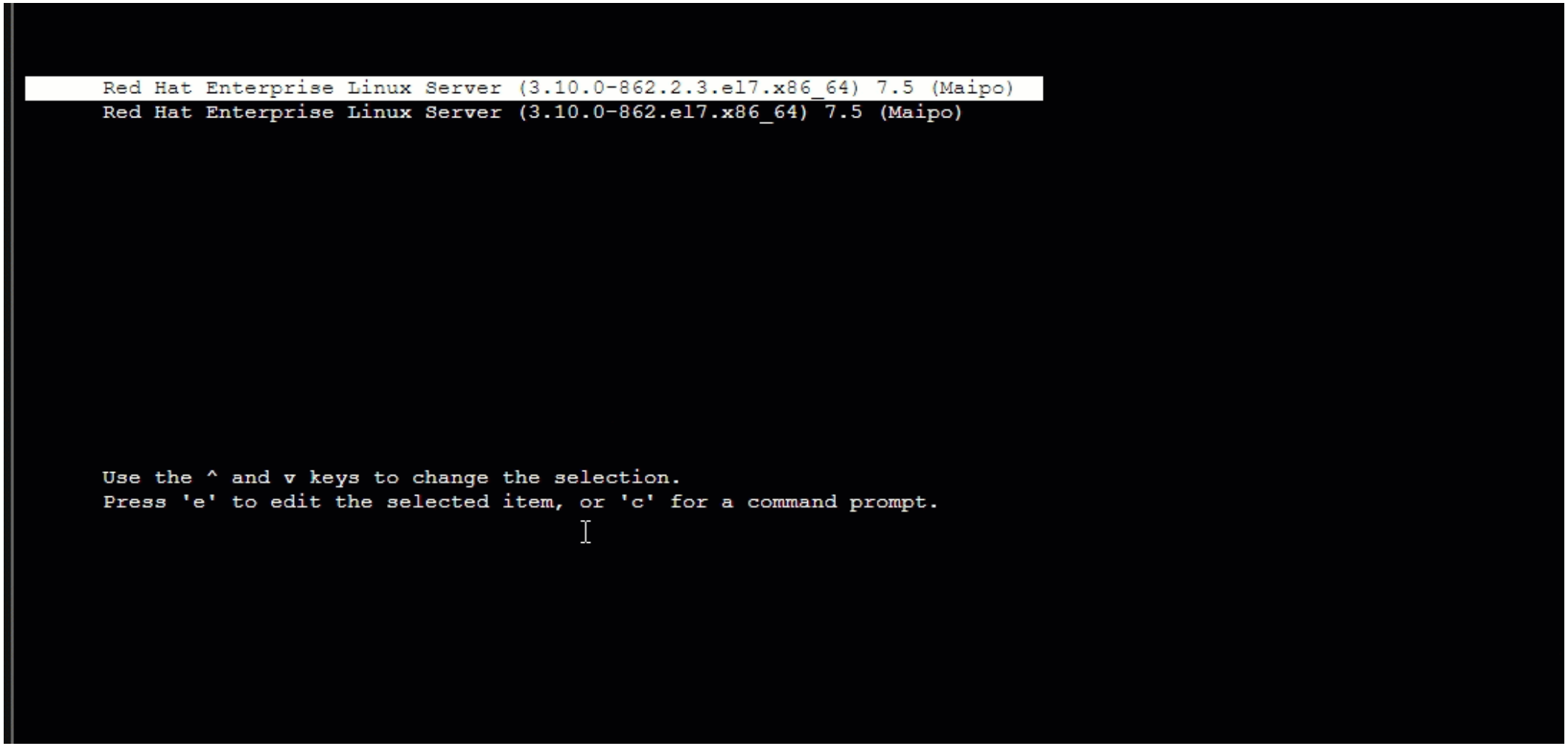
Who –r shows the current runlevel and when it started

```
[matthew@moonshine ~]$ who -r
run-level 3  2024-02-06 20:21

[matthew@moonshine ~]$ ssh wheeler
mfricke@wheeler:~ $ ls /etc/rc.d/
init.d  rc0.d  rc1.d  rc2.d  rc3.d  rc4.d  rc5.d  rc6.d  rc.local
```

Wheeler's OS is old enough that it still has System V scripts. Each of the subdirectories correspond to a runlevel. For example, rc6.d scripts exectute on shutdown.

When troubleshooting a system we often want to reboot into the Single User Text Mode runlevel. This mode has almost nothing extra running which makes debugging easier. (Like 'safe mode" in Windows – but even more barebones.)
The option to boot to single-user mode is currently "rescue.target" in systemd



https://learn.microsoft.com/en-us/troubleshoot/azure/virtual-machines/serial-console-grub-single-user-mode