systemd

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Outline

- Intro to systemd
- Intro to control groups
- systemd unit
  - how to write / edit a systemd unit
- systemd service
- systemd target
- systemd timer
- systemd journal

Systemd

- A system and service manager for Linux
- The default init system for Debian since Debian 8 ("jessie")
- Transactional dependency-based service control logic
- Supports SysV and LSB init scripts and works as a replacement for sysvinit
- Keeps track of processes using Linux control groups

Systemd

- Includes **a logging daemon** and utilities to control
  - hostname
  - time / date
  - locale
  - user sessions
  - system accounts
  - runtime directories
  - network configuration
  - name resolution
  - network time synchornization

Control Groups v2 (cgroups)

- A mechanism to organize processes hierarchically
- Distribute system resources along the hierarchy
  - i.e. CPU, Memory, I/O, PID

```
● linux1
    State: running
    Units: 389 loaded (incl. loaded aliases)
     Jobs: 0 queued
   Failed: 0 units
    Since: Tue 2025-10-07 00:59:21 CST; 1 month 10 days ago
  systemd: 252.39-1~deb12u1
  CGroup: /
          ├─init.scope
          │ └─1 /sbin/init
          ├─system.slice
          │ ├─autofs.service
          │ │ └─1170 /usr/sbin/automount --pid-file /var/run/autofs.pid
          │ ├─cron.service
          │ │ └─1153 /usr/sbin/cron -f
          │ ├─dbus.service
          │ │ └─881 /usr/bin/dbus-daemon --system --address=systemd: --nofork ->n
          │ ├─open-vm-tools.service
          │ │ └─870 /usr/bin/vmtoolsd
          │ ├─rsyslog.service
          │ │ └─885 /usr/sbin/rsyslogd -n -iNONE
          │ ├─system-getty.slice
          │ │ └─getty@tty1.service
          │ │   └─1156 /sbin/agetty -o "-p -- \\u" --noclear - linux
          │ ├─systemd-journald.service
          │ │ └─448 /lib/systemd/systemd-journald
          │ ├─systemd-logind.service
          │ │ └─1154 /lib/systemd/systemd-logind
          │ ├─systemd-timesyncd.service
          │ │ └─872 /lib/systemd/systemd-timesyncd
```

cgroups v2 interface

- Exposed as a filesystem
  - /sys/fs/cgroup, one directory per cgroup
- Core files
  - cgroup.procs: PIDs in this cgroup
  - cgroup.events: populated 0 / 1
  - cgroup.subtree_control: controllers given to children
- No internal process rule
  - Processes only in leaf cgroups
  - .slice groups; .service / .scope run

```
$ cd /sys/fs/cgroup/system.slice/cron.service
$ ls
cgroup.controllers  cgroup.events  cgroup.procs
cpu.max  cpu.weight  memory.current  memory.max
pids.current  pids.max  ...
$ cat cgroup.procs
1153
$ cat cgroup.events
populated 1
frozen 0
$ cat memory.max
max
$ cat /proc/self/cgroup
0::/user.slice/user-1000.slice/session-3.scope
```

Systemd resource control

- Weight
  - Share only when resource is busy
  - CPUWeight=, IOWeight= (default 100)
- Hard limit
  - CPUQuota=, MemoryMax=, TasksMax=
  - Over MemoryMax -> OOM kill
- Throttle
  - Over MemoryHigh= -> slow down, reclaim memory

```
# systemctl edit myapp.service

[Service]
CPUWeight=200       # cpu.weight
CPUQuota=50%        # cpu.max
MemoryHigh=800M     # memory.high
MemoryMax=1G        # memory.max
TasksMax=512        # pids.max

$ systemctl set-property \
    myapp.service MemoryMax=500M

$ systemd-cgtop
```

Systemctl

- systemctl status [unit]
- systemctl cat unit
- systemctl start / stop
- systemctl enable / disable
- systemctl kill
- systemctl mask / unmask
- systemctl list-unit-files
- systemctl list-dependencies
- systemctl daemon-reload

Systemd unit

- [Unit]
  - Generic information about the unit
- [Service]
  - Service specific configuration
  - Including options in systemd.exec
- [Install]
  - Installation information for the unit
  - Used by enable / disable

```
# /usr/lib/systemd/system/sshd.service
[Unit]
After=network.target sshdgenkeys.service
Before=ssh-access.target
Description=OpenSSH Daemon
Documentation=man:sshd(8) man:sshd_config(5)
Wants=sshdgenkeys.service ssh-access.target

[Service]
Type=notify-reload
ExecStart=/usr/bin/sshd -D
KillMode=process
Restart=always

[Install]
WantedBy=multi-user.target
```

Systemd drop-in snippet

- systemctl edit [unit]
- Edit or replace a drop-in snippet
  - Or the main unit file if --full is specified
- Using default editor

```
### Editing
/etc/systemd/system/sshd.service.d/override.conf
### Anything between here and the comment below will
become the contents of the drop-in file



### Edits below this comment will be discarded


### /usr/lib/systemd/system/sshd.service
# [Unit]
# After=network.target sshdgenkeys.service
# Before=ssh-access.target
# Description=OpenSSH Daemon
# Documentation=man:sshd(8) man:sshd_config(5)
# Wants=sshdgenkeys.service ssh-access.target
#
# [Service]
# Type=notify-reload
# ExecStart=/usr/bin/sshd -D
# KillMode=process
# Restart=always
#
# [Install]
# WantedBy=multi-user.target
```

Systemd unit search path

- System
  - /etc/systemd/system/*
  - /usr/local/lib/systemd/system/*
  - /usr/lib/systemd/system/*
- User
  - $XDG_CONFIG_DIRS/systemd/user/*
  - /etc/systemd/user/*
  - $XDG_DATA_HOME/systemd/user/*
  - $XDG_DATA_DIRS/systemd/user/*
  - /usr/local/lib/systemd/user/*
  - /usr/lib/systemd/user/*

Systemd unit dependencies

```
# /usr/lib/systemd/system/sshd.service
[Unit]
After=network.target sshdgenkeys.service
Before=ssh-access.target
Description=OpenSSH Daemon
Documentation=man:sshd(8) man:sshd_config(5)
Wants=sshdgenkeys.service ssh-access.target

[Service]
Type=notify-reload
ExecStart=/usr/bin/sshd -D
KillMode=process
Restart=always

[Install]
WantedBy=multi-user.target
```

- Requires=
  - List the dependencies for this unit
  - **All the dependencies will be executed in parallel**
  - If one of the dependencies failed, this unit file will be labeled as failed
- Wants=
  - Similar to Requires but less restrictive
  - If one of the dependencies failed, this unit file **will not** be labeled as failed
  - Recommend in most cases
- BindsTo=
  - Similar to Requires but more restrictive
  - If one of the dependencies crashed, this unit file **will stop**
- Upholds=
  - Similar to BindsTo but more aggressive
  - If one of the dependencies crashed, **the dependencies will be restarted**

Systemd default dependencies

- Some dependencies are added unless `DefaultDependencies=no` is set
  - `Requires=sysinit.target`
  - `After=sysinit.target basic.target`
  - `Conflicts=shutdown.target`
  - `Before=shutdown.target`

Systemd unit orders

- Before=
  - This unit should run **before** the units listed in Before=
- After=
  - This unit should run **after** the units listed in After=
- These **is not** dependencies
  - Only startup order is specified, use Requires=, Wants=, BindsTo= for dependencies

```
# /usr/lib/systemd/system/sshd.service
[Unit]
After=network.target sshdgenkeys.service
Before=ssh-access.target
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Wants=sshdgenkeys.service ssh-access.target

[Service]
Type=notify-reload
ExecStart=/usr/bin/sshd -D
KillMode=process
Restart=always

[Install]
WantedBy=multi-user.target
```

Systemd unit installation

- Use `systemctl enable / disable` to install and uninstall systemd unit
- systemctl will install a symlink in `[target-name].wants/` directory

```
# /usr/lib/systemd/system/sshd.service
[Unit]
After=network.target sshdgenkeys.service
Before=ssh-access.target
Description=OpenSSH Daemon
Documentation=man:sshd(8) man:sshd_config(5)
Wants=sshdgenkeys.service ssh-access.target

[Service]
Type=notify-reload
ExecStart=/usr/bin/sshd -D
KillMode=process
Restart=always

[Install]
WantedBy=multi-user.target
```

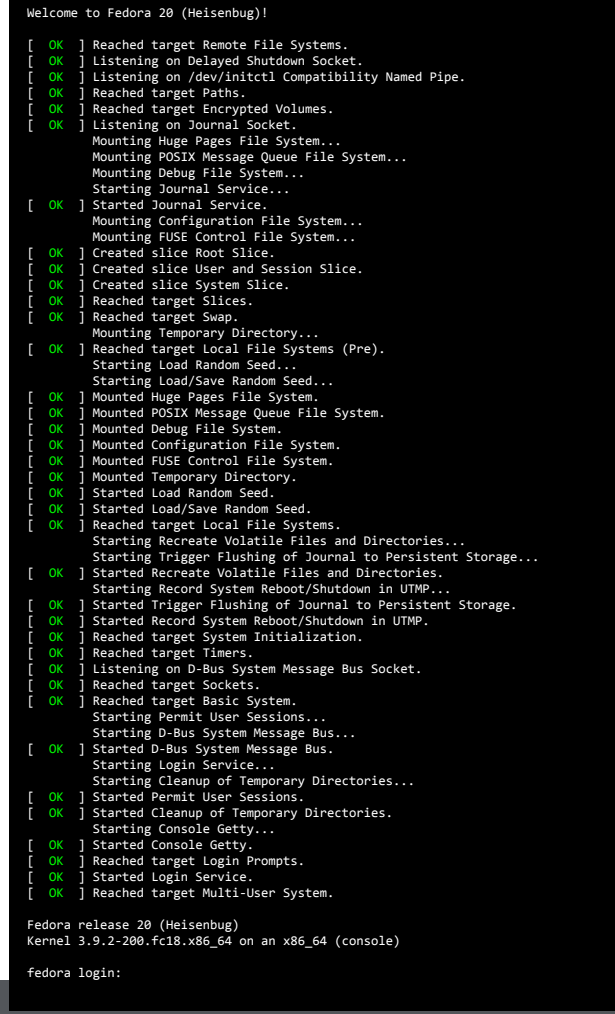
```
> sudo systemctl enable sshd.service
Created symlink '/etc/systemd/system/multi-user.target.wants/sshd.service' →
'/usr/lib/systemd/system/sshd.service'.
```

Systemd Target

- Systemd tasks are organized as **units** (e.g. `ssh.service`)
- **Targets** are groups of units
- Targets call units to put the system together
  - graphical.target calls all units that are necessary to start a workstation with graphical user interface
- Targets can build on top of another or depend on other targets
- At boot time, systemd activates the target **default.target**
  - Alias for another target, e.g. `graphical.target`
  - Try `systemctl get-default`

Common systemd targets

SysV Runlevel	systemd Target	Notes
0	poweroff.target	Halt the system
1	rescue.target	Single user mode
2, 3, 4	multi-user.target	Multi-user, non-graphical, users can usually login via multiple consoles or via the **network**
5	graphical.target	Multi-user, graphical
6	reboot.target	Reboot
-	emergency.target	Emergency shell
-	network-online.target	Network is online



Systemd target hierarchy

- graphical.target
  - sddm.service (desktop manager)
  - multi-user.target
    - basic.target
      - sockets.target
      - slices.target
      - sysinit.target
      - timers.target
    - getty.target
    - remote-fs.target
    - ...

```
systemctl list-dependencies multi-user.target
multi-user.target
● ├─dbus-broker.service
○ ├─nftables.service
● ├─nix-daemon.service
● ├─sshd.service
● ├─systemd-ask-password-wall.path
● ├─systemd-logind.service
● ├─systemd-networkd.service
● ├─systemd-user-sessions.service
● ├─basic.target
● │ ├─-.mount
● │ ├─tmp.mount
● │ ├─paths.target
● │ ├─slices.target
● │ │ ├─-.slice
● │ │ └─system.slice
● │ ├─sockets.target
```

Systemd service type

```
# /usr/lib/systemd/system/sshd.service
[Unit]
After=network.target sshdgenkeys.service
Before=ssh-access.target
Description=OpenSSH Daemon
Documentation=man:sshd(8) man:sshd_config(5)
Wants=sshdgenkeys.service ssh-access.target

[Service]
Type=notify-reload
ExecStart=/usr/bin/sshd -D
KillMode=process
Restart=always

[Install]
WantedBy=multi-user.target
```

- oneshot
  - After the main process **exits**
- simple
  - Change state to **started immediately** after the main service process has been **forked**
  - After fork()
- exec
  - Similar to simple but **immediately after** the binary has been **executed**
  - After fork() returned
- notify, notify-reload
  - Similar to simple but expect the **service sends a "READY=1"** via sd_notify(3)
  - Reload supported by sending signal **SIGHUP** to the process

Systemd service restart policy

- Restart=
  - Configure whether the service shall be restarted

	no	always	on-success	on-failure	on-abnormal	on-abort
Clean exit code	❌	✅	✅	❌	❌	❌
Unclean exit code	❌	✅	❌	✅	❌	❌
Unclean signal	❌	✅	❌	✅	✅	✅
Timeout	❌	✅	❌	✅	✅	❌
OOM	❌	✅	❌	✅	✅	❌

Systemd exec

- ExecStart=
  - Commands that are executed when this service is started
- ExecStartPre=, ExecStartPost=
  - Additional commands that are executed **before or after** the command in ExecStart=
  - Can be prefixed with a “-”, allowing this command to fail and not affect the rest
- ExecReload=
  - Commands to execute to trigger a configuration reload
- ExecStop=
  - Commands to execute to stop the service started via ExecStart=
- TimeoutSec=, TimeoutStartSec=, TimeoutStopSec=
  - The time to wait for startup and stop

Systemd exec - paths

- WorkingDirectory=
  - Working directory, relative to the service’s root directory
- RootDirectory=
  - Service root directory, relative to the host’s root directory

Systemd exec - users

- User=, Group=
  - Set the UNIX user and group that the processes are executed as
  - Default is **root**
- DynamicUser=
  - If set, a UNIX user and group pair is allocated dynamically when the unit is started
  - Allocated from the UID / GID range 61184-65519

Systemd exec - resources

- LimitCPU=, LimitFSIZE=, ...
  - Set soft and hard limits on various resources for executed processes
  - e.g. `LimitCPU=` equals to `ulimit -t`
- Nice=
  - Set the default nice level (scheduling priority) for executed processes
- CPUSchedulingPolicy=
  - Set the CPU scheduling policy.
  - Takes one of **other, batch, idle, fifo, rr**
- CPUSchedulingPriority=
  - Set the CPU scheduling priority processes
- CPUAffinity=
  - Controls the CPU affinity of the executed processes

Systemd exec - unit directories

- RuntimeDirectory=
  - Below path /run/ for system units
  - Use RuntimeDirectoryPreserve= to preserve runtime directory
- StateDirectory=
  - Below path /var/lib/ for system units
- CacheDirectory=
  - Below path /var/cache/ for system units
- LogsDirectory=
  - Below path /var/log/ for system units
- ConfigurationDirectory=
  - Below path /etc/ for system units

Systemd environment

- Environment=
  - Set environment variables for executed processes
  - e.g. `Environment=”VAR1=word1 word2” “VAR2=word3”`
- EnvironmentFile=
  - Read environment variables from a text file
  - Optionally prefixed with “-”, allowing the file to be absent

Systemd standard I/O and logging

- StandardInput=
  - Controls where file descriptor 0 (stdin) of the executing processes is connected to
  - Takes one of *null, tty, file:path, socket, fd:name, ...*
- StandardOutput=, StandardError=
  - Controls where file descriptor 1 (stdout) and 2 (stderr)
  - Takes one of *inherit, null, **journal**, kmsg, file:path, append:path, truncate:path, socket, fd:name*

systemd-journald

- A system service collects logs
  - Stores logs into a structured, indexed journals
  - From kmsg, syslog, service unit, ...
- Stores log data in either
  - Persistent in /var/log/journal
  - Volatile in /run/log/journal, lost at reboot

systemd.timer (5)

- A “systemd” way to control periodic process
- A timer named **X.timer** will trigger **X.service**
- Usually installed as dependency of *timers.target*
  - *multi-user.target* =(depends)=> *basic.target* =(depends)=> *timers.target*

systemd.time (7)

- OnCalendar is similar to cron time format
  - *weekday year-month-date hour:minute:second*
- RandomizedDelaySec can prevent timers on multiple machines from executing at the same time
- Use systemd-analyze to check syntax

```
> systemd-analyze calendar '*-*-* 00:00:00'
Normalized form: *-*-* 00:00:00
   Next elapse: Mon 2025-10-27 00:00:00 CST
      (in UTC): Sun 2025-10-26 16:00:00 UTC
      From now: 8h left
```

```
# /lib/systemd/system/apt-daily-upgrade.timer
[Unit]
Description=Daily apt upgrade and clean activities
After=apt-daily.timer

[Timer]
OnCalendar=*-*-* 6:00
RandomizedDelaySec=60m
Persistent=true

[Install]
WantedBy=timers.target
```

systemd unit template

- Unit name can be parameterized by a single argument
  - The argument is called “instance name”
- Must have a single “@” at the end of the unit name prefix
  - e.g. btrfs.scrub@.service, wg-quick@.service
- Use `%i` or `%I` specifier in unit file to get the instance name

```
[Service]
Type=oneshot
RemainAfterExit=yes
ExecStart=/usr/bin/wg-quick up %i
ExecStop=/usr/bin/wg-quick down %i
ExecReload=/bin/bash -c 'exec /usr/bin/wg syncconf %i <(exec /usr/bin/wg-quick strip %i)'
Environment=WG_ENDPOINT_RESOLUTION_RETRIES=infinity
```

Example - sshd.service

```
# /usr/lib/systemd/system/sshd.service
[Unit]
After=network.target sshdgenkeys.service
Before=ssh-access.target
Description=OpenSSH Daemon
Documentation=man:sshd(8) man:sshd_config(5)
Wants=sshdgenkeys.service ssh-access.target

[Service]
Type=notify-reload
ExecStart=/usr/bin/sshd -D
KillMode=process
Restart=always

[Install]
WantedBy=multi-user.target
```

Example - haproxy.service

```
# /usr/lib/systemd/system/haproxy.service
[Unit]
Description=HAProxy Load Balancer
After=network-online.target
Wants=network-online.target

[Service]
EnvironmentFile=-/etc/default/haproxy
EnvironmentFile=-/etc/sysconfig/haproxy
Environment="CONFIG=/etc/haproxy/haproxy.cfg" "PIDFILE=/run/haproxy.pid" "EXTRAOPTS=-S
/run/haproxy-master.sock"
ExecStart=/usr/bin/haproxy -Ws -f $CONFIG -p $PIDFILE $EXTRAOPTS
ExecReload=/usr/bin/haproxy -Ws -f $CONFIG -c $EXTRAOPTS
ExecReload=/bin/kill -USR2 $MAINPID
KillMode=mixed
Restart=always
SuccessExitStatus=143
Type=notify

[Install]
WantedBy=multi-user.target
```

Example - apt-daily@.timer / .service

```
# /lib/systemd/system/apt-daily.service
[Unit]
Description=Daily apt download activities
Documentation=man:apt(8)
ConditionACPower=true
After=network.target network-online.target
systemd-networkd.service NetworkManager.service
connman.service

[Service]
Type=oneshot
ExecStartPre=-/usr/lib/apt/apt-helper wait-online
ExecStart=/usr/lib/apt/apt.systemd.daily update
```

```
# /lib/systemd/system/apt-daily.timer
[Unit]
Description=Daily apt download activities

[Timer]
OnCalendar=*-*-* 6,18:00
RandomizedDelaySec=12h
Persistent=true

[Install]
WantedBy=timers.target
```

Other utilities

- systemd-hostnamed (8) / hostnamectl (1)
- systemd-timedated / timedatectl (1)
- systemd-localed (8) / localectl (1)
- systemd-logind (8) / loginctl (1)
- systemd-sysusers (8)
- systemd-networkd (8) / networkctl (1)
- systemd-resolved (8) / resolvectl (1)
- systemd-timesyncd (8) / timedatectl (1)
- systemd-boot (7) / bootctl (1)
- systemd-nspawn (1) / machinectl (1)

Reference

- systemd.unit (5)
- systemd.service (5)
- systemd.timer (5)
- systemd.exec (5)
- systemctl (1)
- Debian Wiki - systemd https://wiki.debian.org/systemd
- Control Group v2 - The Linux Kernel documentation https://docs.kernel.org/admin-guide/cgroup-v2.html#