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Advanced Operating Systems and Virtualization

[9] Userspace Initialization

DIAG
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Outline

1. **`init`**
2. **`runlevels/targets`**
    1. `systemd`
3. **End of the boot process**

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9. Userspace Initialization

init

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Boot sequence

1. **BIOS/UEFI**
   Actual hardware setup
2. **Bootloader Stage 1**
   Executes the stage 2 bootloader (skipped for UEFI)
3. **Bootloader Stage 2**
   Loads and starts the kernel
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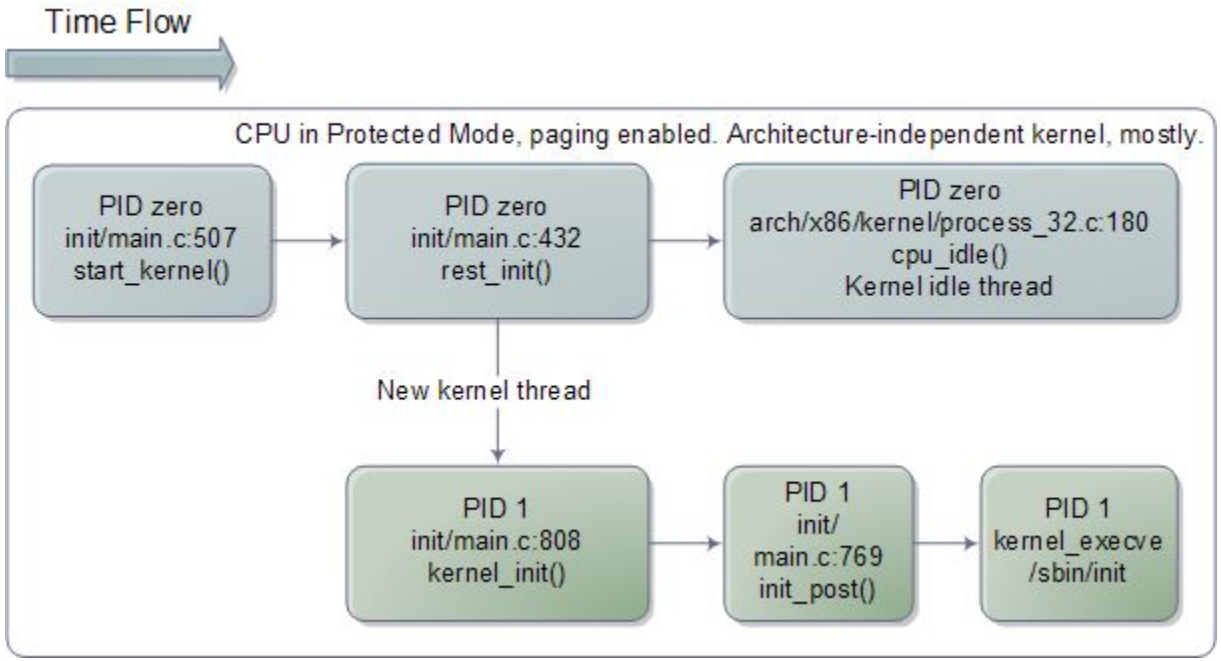
   First process: basic environment initialization
6. **Runlevels/Targets**
   Initializes the user environment

Kernel Boot Flow



Main operations

V5.11

The main operations carried out by `start_kernel()` (`init/main.c`) are:

1. `setup_arch()` that initializes the architecture
2. `build_all_zonelists()` - builds the memory zones
3. `page_alloc_init()` / `mem_init()` - the steady state allocator (Buddy System) is initialized and the boot one removed
4. `sched_init()` - initializes the scheduler
5. `trap_init()` - the final IDT is built
6. `time_init()` - the system time is initialized
7. `kmem_cache_init()` - the slab allocator is initialized
8. `arch_call_rest_init()` / `rest_init()` - prepares the environment
   a. `kernel_thread(kernel_init)` - starts the kernel thread for process 1 is created
      i. `kernel_init_freeable()` -> `prepare_namespace()` -> `initrd_load()` - mounts the initramfs, a temporary filesystem used to start the init process
      ii. `run_init_process()` -> `kernel_execve()` - Execute `/bin/init`
   b. `cpu_startup_entry()` -> `do_idle()` - starts the idle process

`rest_init()`

Obviously we cannot run only the idle process, otherwise we could not be able to spawn any other process. For this reason we have to "leave" the infinite loop in pid `0`.

A new kernel thread is created, referencing `kernel_init()` as its entry point. A call to `schedule()` is issued, to start scheduling the newly-created process, this is done right before PID `0` calls into `cpu_idle()` (before calling `cpu_startup_entry()`).

Starting /sbin/init

`/sbin/init` is the first userspace process ever started. This process is commonly stored into the ramdisk, to speedup the booting process. init will have to load configuration files from the hard drive and this means that the VFS, Device Management, and Interrupt subsystems must be initialized **before** loading init.

In `kernel_init()` we have ⇢

```
1451                 * We try each of these until one succeeds.
1452                 *
1453                 * The Bourne shell can be used instead of init if we are
1454                 * trying to recover a really broken machine.
1455                 */
1456                if (execute_command) {
1457                        ret = run_init_process(execute_command);
1458                        if (!ret)
1459                                return 0;
1460                        panic("Requested init %s failed (error %d).",
1461                              execute_command, ret);
1462                }
1463
1464                if (CONFIG_DEFAULT_INIT[0] != '\0') {
1465                        ret = run_init_process(CONFIG_DEFAULT_INIT);
1466                        if (ret)
1467                                pr_err("Default init %s failed (error %d)\n",
1468                                       CONFIG_DEFAULT_INIT, ret);
1469                        else
1470                                return 0;
1471                }
1472
1473                if (!try_to_run_init_process("/sbin/init") ||
1474                    !try_to_run_init_process("/etc/init") ||
1475                    !try_to_run_init_process("/bin/init") ||
1476                    !try_to_run_init_process("/bin/sh"))
1477                        return 0;
1478
1479                panic("No working init found.  Try passing init= option to kernel. "
1480                      "See Linux Documentation/admin-guide/init.rst for guidance.");
1481        }
```

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9. Userspace Initialization

runlevels/targets

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Startup Services & Runlevels

The main services that are run at startup regard:

- Hostname
- Timezone
- Check the hard drives
- Mount the hard drives
- Remove files from /tmp
- Configure network interfaces
- Start daemons and network services

Level	Mode
1 (S)	Single user
2	Multiuser (no networking)
3	Full Multiuser (with networking)
4	Unused
5	X11
6	Reboot
0	Halt

The **runlevel** describes the mode according to which the machine started, only one runlevel is executed (they are not executed in order). The machine for example started in runlevel 5 when rebooting enters in runlevel 6. Runlevels actions and services may depend on the particular Linux distribution installed.

Lower levels are used for maintenance or for recovering critical situations.

Runlevels

Runlevels exists from the **System V** standard (latest version of UNIX). The actual scripts are located at `/etc/rc.d/init.d/`. In this folder we have the declaration of startup services, in practice we have:

- Symbolic links to `/etc/init.d` scripts
- `S##` - Start scripts
- `K##` - Stop scripts
- `/etc/sysconfig/`: script configuration files

The services can be managed from the shell with the commands:

- `chkconfig <script> on|off`
- `service <script> start|stop|restart`

/etc/inittab

Describes which processes need to be run at which runlevel

The file format is: `id:rl:action:process`

- `id`: uniquely identifies entry
- `rl`: what runlevels the entry applies to
- `action`: the type of action to execute
- `process`: process command line

An example:

```
2:23:respawn:/sbin/getty 38400 tty2
```

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2. runlevels/targets

systemd

DIAG

systemd

Systemd is progressively replacing the System V init architecture but it maintains the compatibility with it, since the init scripts can still be read and used.

Systemd is based on the notion of "units" and "dependencies". However, systemd also offers other services beyond the init system:

- **journald**, systemd-journald is a daemon responsible for event logging
- **logind**, systemd-logind is a daemon that manages user logins and seats in various ways
- **resolved**
- **timesyncd**
- **networkd**, networkd is a daemon to handle the configuration of the network interfaces
- **tmpfiles**, systemd-tmpfiles is a utility that takes care of creation and clean-up of temporary files and directories
- **timedated**, systemd-timedated is a daemon that can be used to control time-related settings
- **udevd**, udev is a device manager for the Linux kernel, which handles the /dev directory and all user space actions when adding/removing devices
- **systemd-boot**, systemd-boot is a boot manager, formerly known as gummiboot

Targets

Regarding the init, the concept of "runlevel" is mapped to "targets" in systemd jargon. Runlevel is defined through a symbolic to one of the runlevel targets, for example:

- Runlevel 3 is mapped to `/lib/systemd/system/multi-user.target`
- Runlevel 5 is mapped to `/lib/systemd/system/graphical.target`

For changing runlevel you need to:

- remove current link /etc/systemd/system/default.target
- add a new link to the desired runlevel

Units

Types

Different unit types control different aspects of the operating system:

- `service`: handles daemons
- `socket`: handles network sockets
- `target`: logical grouping of units (example: runlevel)
- `device`: expose kernel devices
- `mount`: controls mount points of the files system
- `automount`: mounts the file system
- `snapshot`: references other units (similar to targets)

Units

Unit Section

In the .service file you need to specify the unit section.

`[Unit]`

- `Description`: a meaningful description of the unit
- `Requires`: configures dependencies on other units
- `Wants`: configures weaker dependencies
- `Conflicts`: negative dependencies
- `Before`: this unit must be started before these others
- `After`: this unit must be started after these others (unlike Requires, it does not start the unit if not already active)

And other sections if needed.

Units

Other Sections

`[Service]`

- `Type = simple|oneshot|forking|dbus|notify|idle`
- `ExecStart`
- `ExecReload`
- `ExecStop`
- `Restart=no|on-success|on-failure|on-abort|always`

`[Install]`

- `Wantedby=`

Used to determine when to start (e.g. Runlevel).

Complete Example

/usr/lib/systemd/system/docker.service

```
[Unit]
Description=Docker Application Container Engine
Documentation=https://docs.docker.com
After=network-online.target firewalld.service containerd.service
Wants=network-online.target
Requires=docker.socket containerd.service

[Service]
Type=notify
ExecStart=/usr/bin/dockerd -H fd:// --containerd=/run/containerd/containerd.sock
ExecReload=/bin/kill -s HUP $MAINPID
TimeoutSec=0
RestartSec=2
Restart=always

StartLimitBurst=3
StartLimitInterval=60s

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

Cheatsheet

Systemd command	Notes
systemctl start httpd.service	Start a service (not reboot persistent).
systemctl stop httpd.service	Stop a service (not reboot persistent).
systemctl restart httpd.service	Restart a service.
systemctl reload httpd.service	Reloads the configuration files without interrupting pending operations.
systemctl condrestart httpd.service	Restarts if the service is already running.
systemctl status httpd.service	Shows the status of a service.
systemctl list-units --type=service	Displays the status of all services.
systemctl list-unit-files --type=service	List the services that can be started or stopped.
systemctl enable httpd.service	Start service at next boot.
systemctl disable httpd.service	Service won't be started on next boot.
systemctl is-enabled httpd.service	Check if a service is configured to start in the current environment.
systemctl list-unit-files --type=service *or* ls /etc/systemd/system/*.wants/	Print a list of services showing which runlevels they are configured for.
ls /etc/systemd/system/*.wants/httpd.service	Show which runlevels a service is configured for.
systemctl daemon-reload	Run this command after a change in any configuration file (old or new).

https://cheatography.com/tme520/cheat-sheets/systemd/

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End of the Boot Process

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