SUSE

Understanding Kernel Control Groups

WHAT?

From granular resource allocation to real-time performance monitoring and isolation, control groups (cgroups) enable you to manage how system resources like CPU, memory, and network bandwidth are distributed among your processes in an organized way.

WHY?

This article provides a comprehensive overview of managing system resources and process isolation through the use of kernel control groups (cgroups).

EFFORT

The average reading time of this article is approximately 30 minutes.

GOAL

You will be able to manage and isolate your system's hardware resources efficiently using kernel control groups (cgroups).

REQUIREMENTS

- Use Btrfs, Ext4, or XFS to ensure the kernel can properly track and charge background I/O operations to the correct groups.
- Ensure that BFQ scheduler or IOCost are active on your block devices to enable the proportional weighting and prioritization of disk traffic.
- For resource management within user sessions, you must explicitly delegate controllers to the user's systemd instance via drop-in configuration files.

Publication Date: 09 Jul 2026

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1 Introduction to Control Groups

Kernel control groups provide a hierarchical framework for organizing processes to monitor, isolate, and limit their consumption of system resources like CPU, memory, and I/O.

Every process is assigned to exactly one administrative control group (cgroup). These cgroups are organized into a unified hierarchical tree structure, allowing you to manage resource allocation for individual processes or entire branches of the hierarchy simultaneously. You can define specific limitations for system resources.

1.1 The role of `systemd` slices

On SUSE Linux Enterprise Server, `systemd` serves as the primary manager for cgroups. Instead of requiring administrators to interact with the raw cgroup file system manually, `systemd` abstracts this management by organizing all processes into logical units called slices (`.slice` units).

This integration bridges the gap between `systemd` service management and the kernel's resource tracking through several key mechanisms:

- **Direct hierarchical mapping**: Slices represent inner nodes in a tree that maps directly onto the kernel's cgroup directory structure
- **Built-in partitioning**: By default, systemd automatically organizes the operating system into distinct root slices to prevent workloads from interfering with each other. `systemd` uses these root slices:
  - `system.slice` for services
  - `user.slice` for user sessions
  - `machine.slice` for managing resources of virtual machines
  - `init.scope` to host the PID1 process itself

To visualize your current system organization, use the `systemd-cgls` command to display the hierarchy tree.

1.2 The unified hierarchy (cgroup v2)

The Linux kernel previously supported two API variants (v1 and v2). SLES exclusively utilizes the unified (v2) hierarchy as the default and recommended mode.

Unified hierarchy (cgroup v2)

A single hierarchy where all resource controllers are managed under a unified structure, providing better consistency and easier resource accounting.

Hybrid/Legacy cgroup support (v1)

`cgroup v1` is functionally obsolete and unsupported in SUSE Linux Enterprise Server 16.0. If cgroup v1 needs to be used, switch to older SLES releases.

2 Configuring resource limits and accounting

Beyond simply organizing processes, the integration between `systemd` and cgroups provides you with the dual capability to both measure and restrict resource consumption. Before applying strict constraints, `systemd` allows you to audit exactly how much CPU, memory, or I/O a workload uses. Once you establish these baselines, you can enforce runtime limitations dynamically to protect system stability.

2.1 Resource accounting

Organizing processes into different `cgroups` can be used to obtain per-cgroup resource consumption data. The accounting has comparatively small but non-zero overhead, whose impact depends on the workload. Activating accounting for one unit also implicitly activates it for all units in the same slice, and for all its parent slices, and the units contained in them.

The accounting can be set on a per-unit basis with directives such as `MemoryAccounting=` or globally for all units in `/etc/systemd/system.conf` with the directive `DefaultMemoryAccounting=`.

2.2 Setting resource limits

Note: Implicit resource consumption

Be aware that resource consumption implicitly depends on the environment where your workload executes (for example, size of data structures in libraries/kernel, forking behavior of utilities, computational efficiency). Hence it is recommended to (re)calibrate your limits should the environment change.

Limitations to `cgroups` are primarily set with the **`systemctl set-property`** command. The command syntax follows:

```
> sudo systemctl set-property [--runtime] NAME PROPERTY1=VALUE[PROPERTY2=VALUE]
```

- `NAME`: A `systemd` service, scope, or slice name.
- `--runtime`: Optional. Use this if you do not want values to persist after reboot.
- `PROPERTY`: for a complete list, see **`man systemd.resource-control`**.

3 Preventing fork bombs with `TasksMax`

`systemd` provides the `TasksMax` parameter to limit the number of tasks (processes and threads) within a unit or slice. This serves as a critical defense against “fork bombs” and runaway processes that could otherwise exhaust the system's Process ID (PID) pool.

While upstream `systemd` defaults to 15% of the kernel global limit (viewable via **`sysctl kernel.pid_max`**), SLES overrides this behavior to provide maximum compatibility for high-performance workloads.

3.1 Identifying default TasksMax values

In SLES, the default `TasksMax` value for both system units and user slices is set to `infinity`. This means no restriction is enforced by default. These overrides are located in the following vendor configuration files:

- System units: `/usr/lib/systemd/system.conf.d/25-defaults-SLE.conf`
- User slices: `/usr/lib/systemd/system/user-.slice.d/25-defaults-SLE.conf`

To verify the effective `DefaultTasksMax` on your system, run:

```
systemctl show --property DefaultTasksMax
```

Important

While `infinity` prevents service disruption due to reaching task limits, it leaves the system vulnerable to resource exhaustion. We recommend setting explicit limits for services that might be prone to exploits.

For more information, you can also refer to Configuring and tuning process and threads limits (https://support.scc.suse.com/s/kb/Configuring-and-tuning-process-and-threads-limits?language=en_US)

3.2 Overriding the DefaultTasksMax value

To set a global default limit for all system units, create a drop-in file at `/etc/systemd/system.conf.d/90-system-tasksmax.conf`. For example, to limit each unit to 256 tasks:

```
[Manager]
DefaultTasksMax=256
```

Apply the configuration and verify the change:

```
sudo systemctl daemon-reload
systemctl show --property DefaultTasksMax
```

3.2.1 Setting per-service limits

Specific applications, such as large databases, often require more tasks than the global default. You can override the limit for a specific service (for example, MariaDB) using **`systemctl set-property`**:

```
sudo systemctl set-property mariadb.service TasksMax=8192
```

This command creates a persistent drop-in file at `/etc/systemd/system/mariadb.service.d/50-TasksMax.conf`. Verify the new limit in the `Tasks:` line of the service status:

```
Tasks: 30 (limit: 8192)
```

3.3 Configuring task limits for user sessions

User sessions often require higher limits than system services. To set a custom default for all users, create `/etc/systemd/system/user-.slice.d/40-user-taskmax.conf`:

```
[Slice]
TasksMax=16284
```

Tip

If a `TasksMax` limit is too restrictive, the system logs will report errors such as `Failed to fork (Resource temporarily unavailable)`. Incrementally increase the limit until the workload stabilizes.

4 I/O Control with cgroups

The following section outlines how to prioritize, isolate, and throttle disk input/output (I/O) operations by using `systemd` to manage the Linux kernel's block I/O controller. It defines the mandatory file system and storage scheduler prerequisites, demonstrates how to enforce limits on both persistent services and transient scopes, and details critical behavioral nuances—such as direct versus buffered I/O—that impact resource distribution across the system.

4.1 Prerequisites

Before configuring I/O control, ensure your system meets the following requirements. These settings generally cannot be changed during runtime.

4.1.1 File System Support

You must use a file system that supports cgroup writeback to enable accurate writeback charging. Supported file systems include:

- Btrfs (v4.3+)
- Ext4 (v4.3+)
- XFS (v5.3+)

4.1.2 Block I/O Scheduler

Proportional I/O control requires a specific scheduler. SUSE recommends the `BFQ` controller.

To verify the current scheduler for a device (for example, `sda`):

```
cat /sys/class/block/sda/queue/scheduler
mq-deadline kyber bfq [none]
```

To switch the scheduler to `BFQ`:

```
echo bfq > /sys/class/block/sda/queue/scheduler
```

Note

Apply this setting to the disk device itself, not a partition. The optimal way to set this attribute is a udev rule specific to the device. SLES includes `udev` rules that automatically enable BFQ for rotational drives. As an alternative to BFQ, the io.cost-based I/O controller operates independently of the I/O scheduler. However, this proportional control mechanism requires manual tuning of its cost-based model parameters.

4.2 Configuring Control Quantities

Apply I/O limits permanently to services using **`systemctl`**:

```
sudo systemctl set-property fast.service IOWeight=400
sudo systemctl set-property slow.service IOWeight=50
sudo systemctl set-property throttled.service IOReadBandwidthMax="/dev/sda 1M"
```

Alternatively, use **`systemd-run`** to apply limits to transient scopes:

```
sudo systemd-run --scope -p IOWeight=400 high_prioritized_command
```

4.3 I/O control behavior and expectations

The following list items describe I/O control behavior, and what you should expect under different conditions.

- I/O control works best for direct I/O operations (bypassing page cache). The situations where the actual I/O is decoupled from the caller (typically writeback via page cache) may manifest variously. For example, delayed I/O control or even no observed I/O control (consider little bursts or competing workloads that happen to never "meet," submitting I/O at the same time, and saturating the bandwidth). For these reasons, the resulting ratio of I/O throughput does not strictly follow the ratio of configured weights.
- systemd performs scaling of configured weights (to adjust for narrower BFQ weight range), hence the resulting throughput ratios also differ.
- The writeback activity depends on the amount of dirty pages, besides the global sysctl knobs (`vm.dirty_background_ratio` and `vm.dirty_ratio`)). Memory limits of individual cgroups come into play when the dirty limits are distributed among cgroups, and this in turn may affect I/O intensity of affected cgroups.
- Not all storages are equal. The I/O control happens at the I/O scheduler layer, which has ramifications for setups with devices stacked on these that do no actual scheduling. Consider device mapper logical volumes spanning multiple physical devices, MD RAID, or even Btrfs RAID. I/O control over such setups may be challenging.
- There is no separate setting for proportional I/O control of reads and writes.
- Proportional I/O control is only one of the policies that can interact with each other (but responsible resource design perhaps avoids that).

- The I/O device bandwidth is not the only shared resource on the I/O path. Global file system structures are involved, which is relevant when I/O control is meant to guarantee certain bandwidth; it does not, and it may even lead to priority inversion (prioritized cgroup waiting for a transaction of slower cgroup).
- So far, we have been discussing only explicit I/O of file system data, but swap-in and swap-out can also be controlled. Although if such a need arises, it points to improperly provisioned memory (or memory limits).

4.4 Resource Control in User Sessions

SLES ships with a default `systemd` configuration that delegates no controllers for performance reasons. To enable resource control within a user session, create a drop-in file at `/etc/systemd/system/user@.service.d/60-delegate.conf`:

```
[Service]
Delegate=pids memory
```

After modifying the configuration, notify the instances:

```
sudo systemctl daemon-reload
systemctl --user daemon-reexec
```

Alternatively, the affected user may log out and log in instead of applying the second line to restart their user instance.

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