Deep dive into Linux Hibernation: From kernel flows to Modern tools
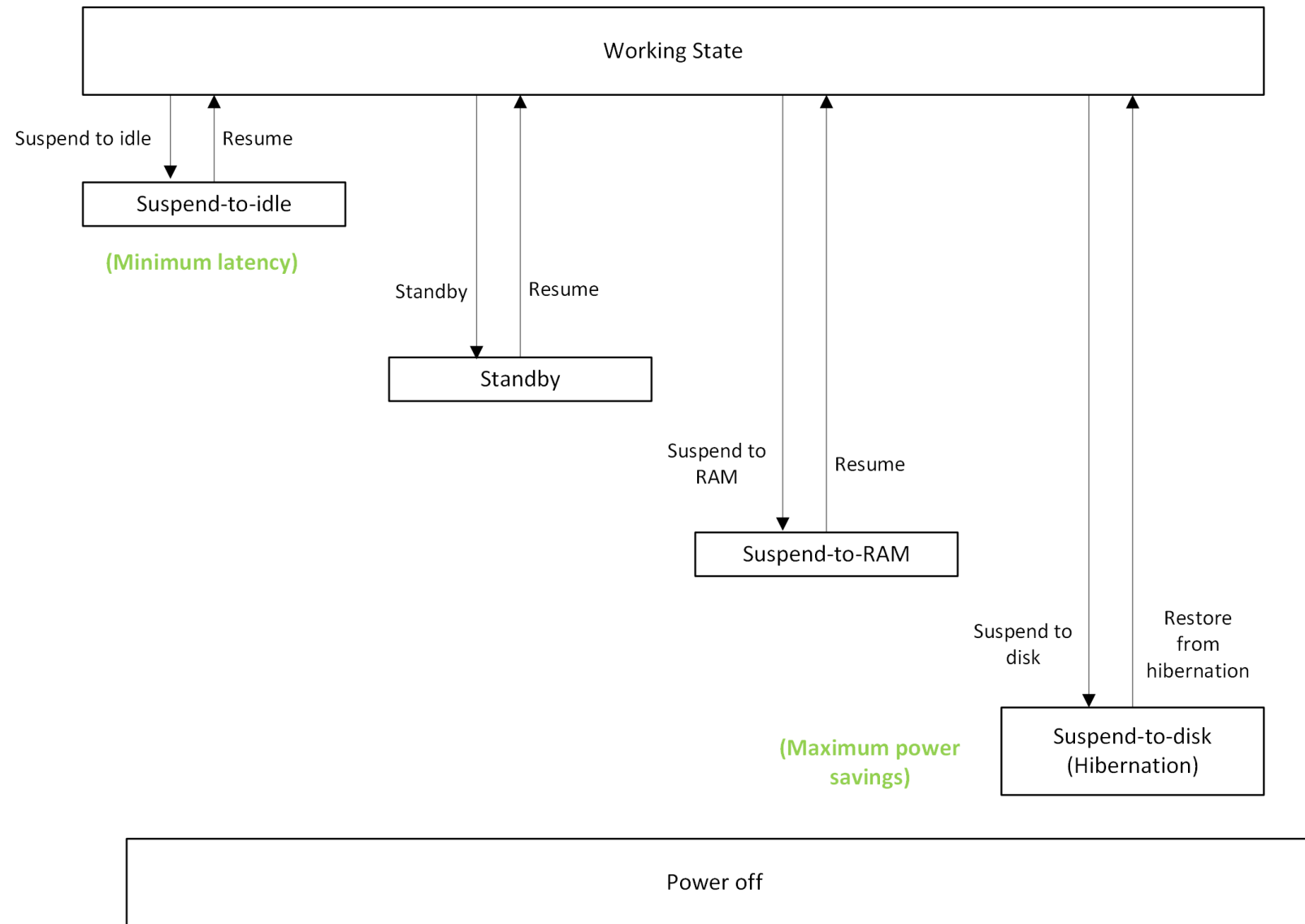
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Power Management States in the Linux kernel

Working State

Suspend to idle — Resume
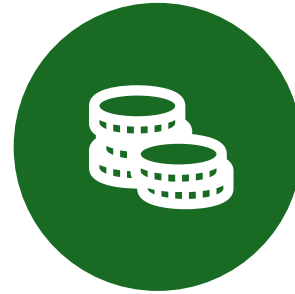
Suspend-to-idle

(Minimum latency)

Standby — Resume

Standby

Suspend to RAM — Resume

Suspend-to-RAM

Suspend to disk — Restore from hibernation

(Maximum power savings)

Suspend-to-disk (Hibernation)

Power off

System Power Management Sleep States

Features	Suspend-to-Idle (S0ix)	Standby (S1)	Suspend-to-RAM (S3)	Hibernation (S4)
What Happens	CPU enters deepest idle state while keeping system in working state	CPU and some devices powered down while memory remains on	Most components powered off except memory which preserves system state	System state saved to disk and system powered off completely
ACPI State	S0ix	S1	S3	S4
Power Consumption	**Highest**	**<S0ix but >S3**	**<S1 but >S4**	Lowest
Wake-up Time	Minimum	>S0ix but <S3	>S1 but <S4	Maximum
CPU State	- Deepest idle state - Core voltage reduced - Most clocks stopped - Caches maintained	- Non-boot CPU stopped - Context maintained - Some clocks running - Voltage still present	- Powered off - Context saved to RAM - All clocks stopped - Voltage off	- Completely powered off - Context saved to disk - Mostly all power rails off
Memory State	- Fully operational - Running at low power - All contents preserved - Memory controller active	- Fully powered - Normal operation - Full refresh rate - All contents preserved	- Self-refresh mode - Minimal power mode - Contents preserved	- Completely off - Contents saved to disk - No power consumption
Device State	- Devices in low power - Some peripherals suspended - Wake-capable devices active	- Some devices active - Most in low power mode - Clocks may be running	- Wake devices in low power - Most devices are suspended - Minimal power state	- All devices off - State saved to disk - Minimum power consumption
Debug Interface	/sys/power/mem_sleep /sys/power/pm_debug	/sys/power/state /proc/acpi/sleep	/sys/power/state /sys/power/mem_sleep	/sys/power/disk /sys/power/state

Source: System Sleep States — The Linux Kernel documentation

Why hibernation?

Minimum Power Consumption
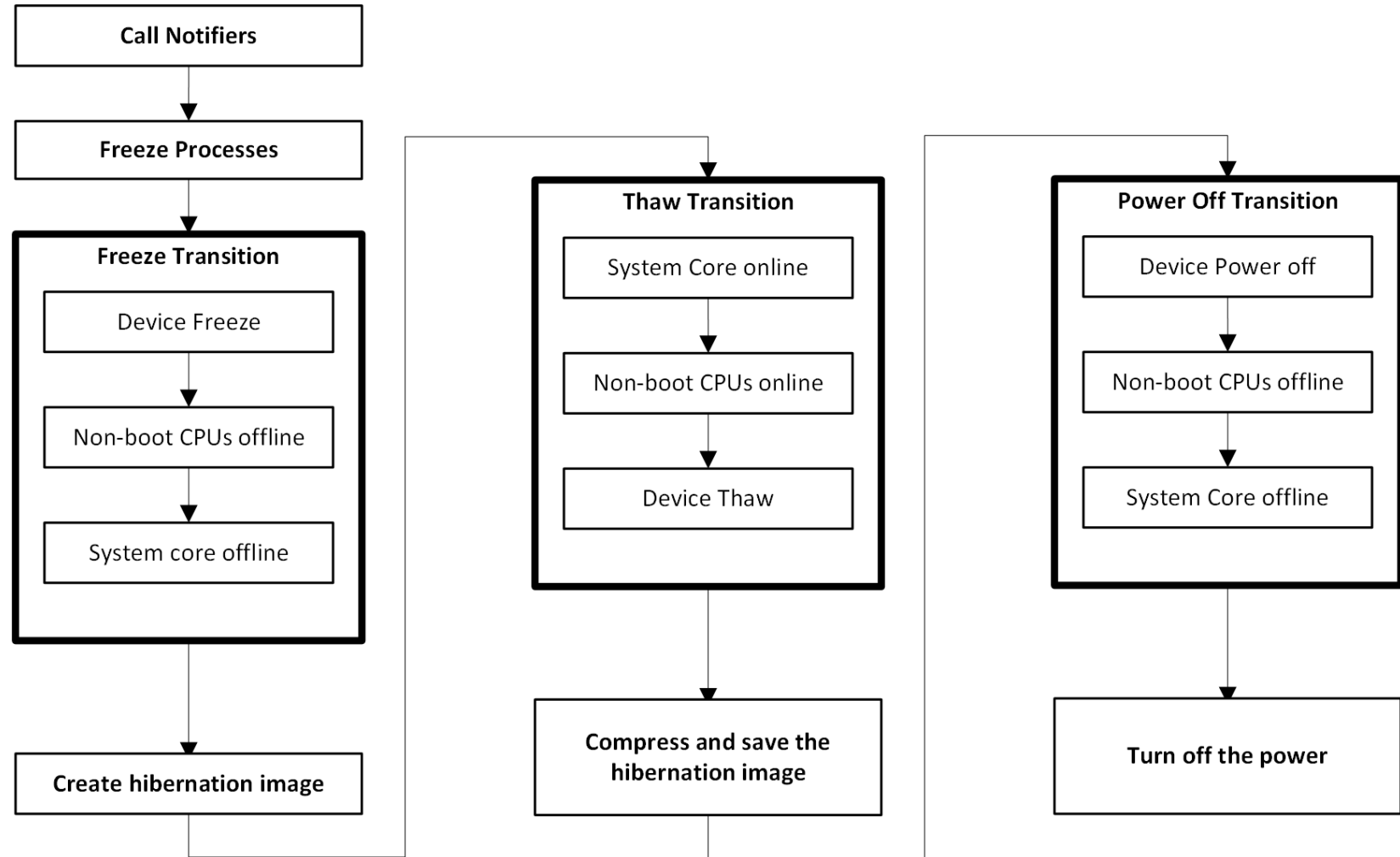
Cost Efficient

State Preservation

Faster boot time

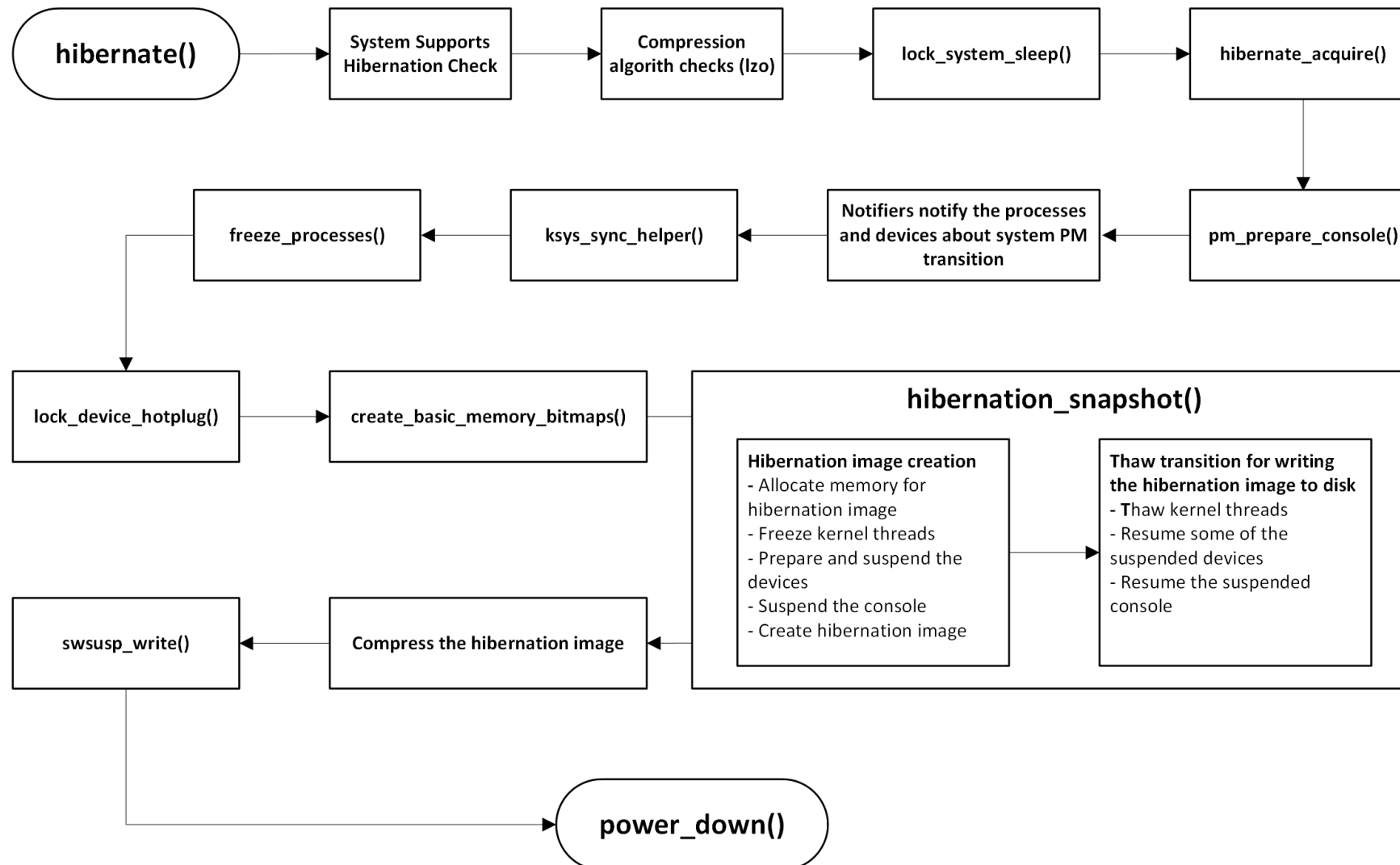# Understanding Linux hibernation

- A system power-saving state aka Suspend-to-disk

- Saves complete system state to a non-volatile memory (disk/swap)

- System enters a special low-power state

- Restores system state on next boot

- Kernel config: **CONFIG_HIBERNATION**

- Disabled when secure boot or kernel_lockdown feature are enabled on the system

- Commonly supported on almost all Linux distros

Code walkthrough (Basic Flow)

Call Notifiers

Freeze Processes

Freeze Transition
- Device Freeze
- Non-boot CPUs offline
- System core offline

Create hibernation image

Thaw Transition
- System Core online
- Non-boot CPUs online
- Device Thaw

Compress and save the hibernation image

Power Off Transition
- Device Power off
- Non-boot CPUs offline
- System Core offline
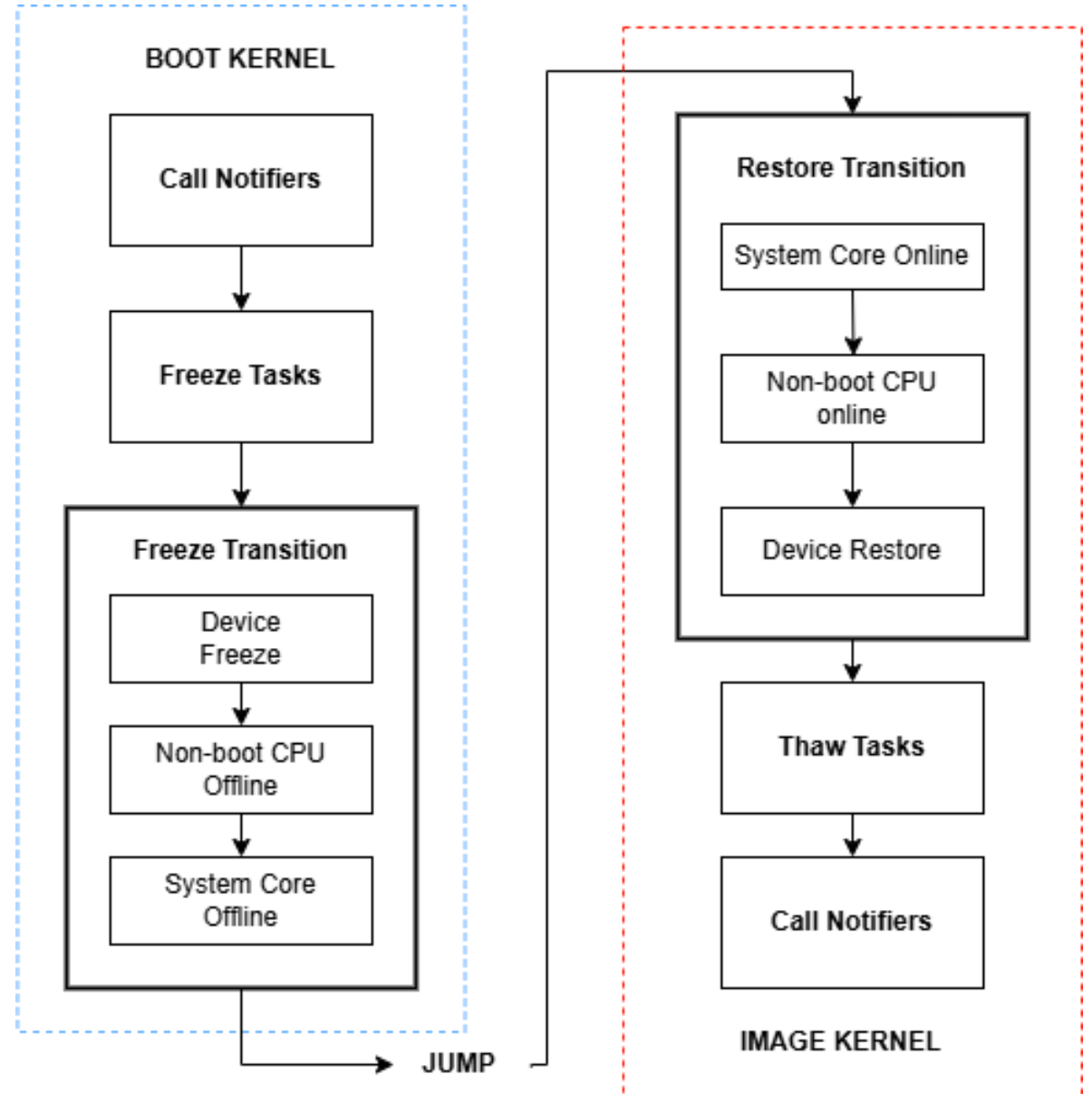
Turn off the power
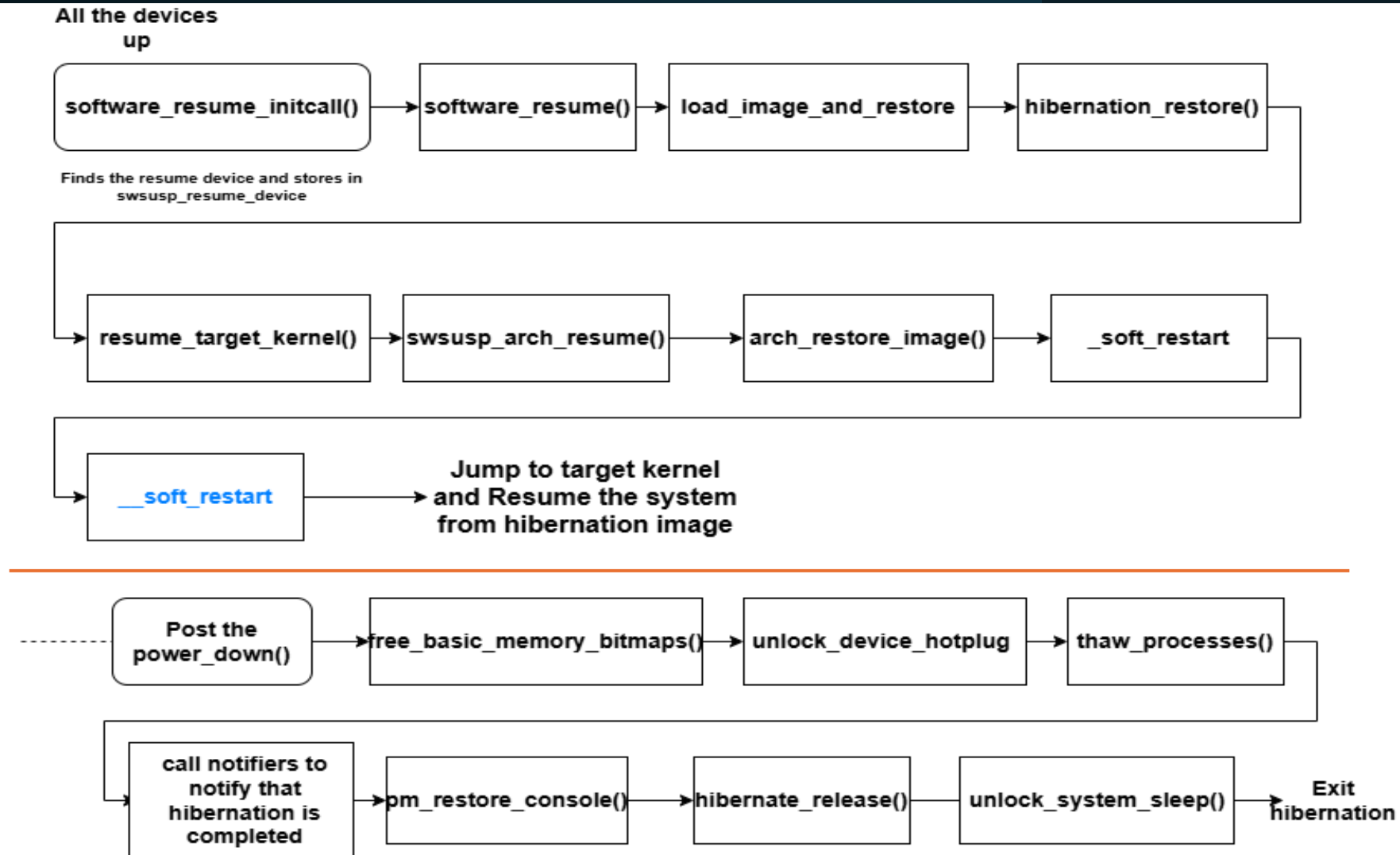
Code walkthrough (Detailed Flow)

Code Walkthrough (Resume Flow)

Resume flow (detailed)

Sysfs interface

The interface exists in /sys/power directory

/sys/power/state:

This controls the system power state

Reading from this file returns what sleep states are supported:
- **standby**: Power-on Suspend
- **freeze**: Suspend-to-idle
- **mem**: Suspend-to-RAM
- **disk**: Suspend-to-disk (hibernate)

Writing one of these strings to this file causes the system to transition into that state

Sysfs interface

/sys/power/disk:

Controls the operating mode of the Hibernation mechanism.

Reading from this file returns supported operating modes and the currently selected ones in brackets:
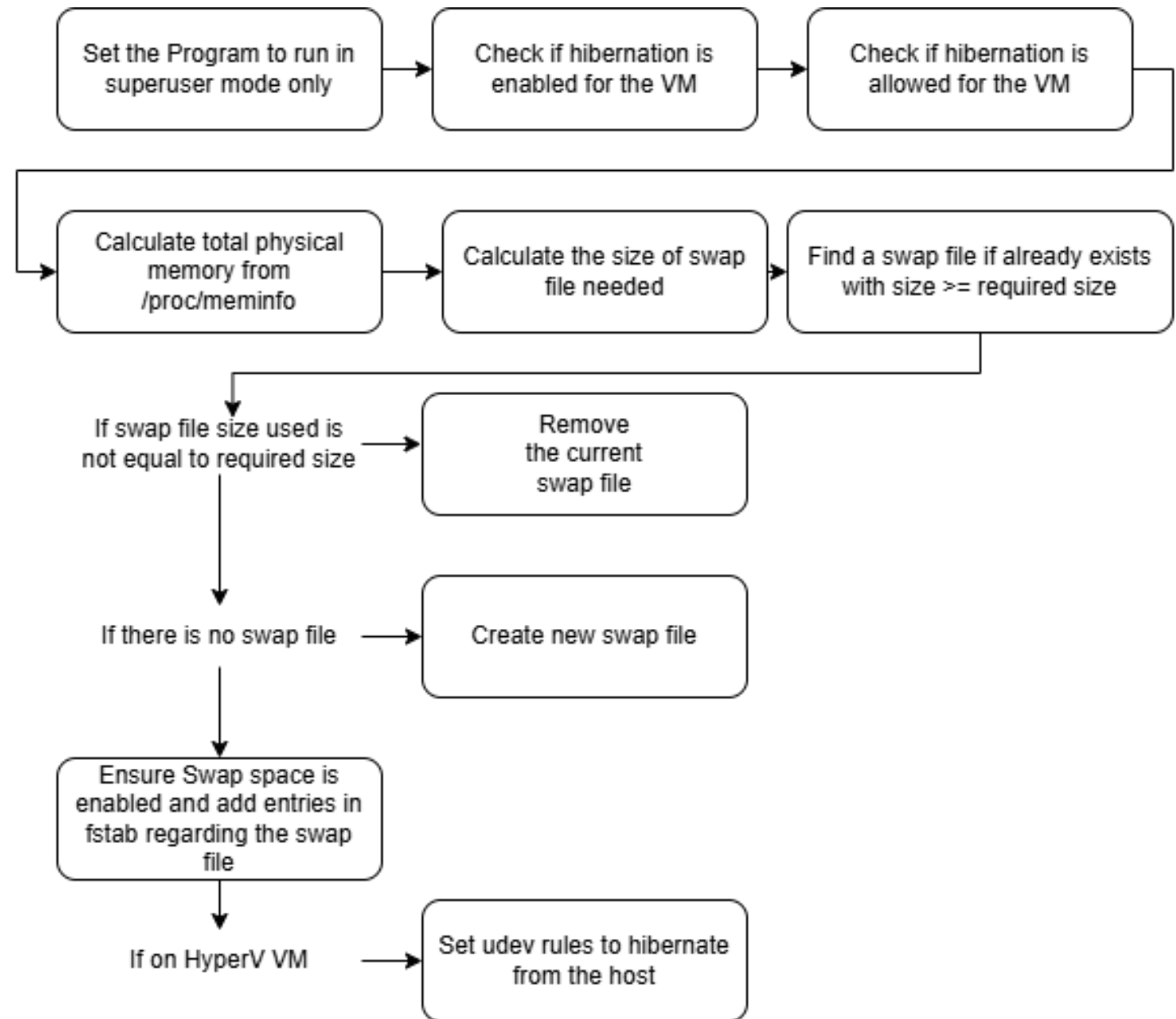
- **platform**: Default mode - uses platform driver for hibernation
- **shutdown**: Powers off the system after hibernation image creation without platform-specific calls
- **reboot**: Reboot the system after hibernation image creation
- **suspend**: Creates hibernation image but doesn't power down - keeps system in low-power state
- **test_resume**: Test mode - creates and resumes from hibernation image without powering down
- **noresume**: Prevents resume from hibernation image on next boot

Writing one of these strings to this file will select the corresponding mode for hibernation

Hibernation setup tool

- An open-source tool developed by Microsoft to configure and enable hibernation in Linux

- Creates optimized swap file according to the system RAM

- Configures kernel and boot parameters for immediate hibernation and resume operations

- Primarily supports distributions using GRUB2 bootloader and initramfs-tools

- Uses system hooks to track hibernation success, failures, and cold boot scenarios and store them in the system logs

- This is specifically designed for hibernating Linux VMs.

https://github.com/microsoft/hibernation-setup-tool

How does this tool work?

Set the Program to run in superuser mode only → Check if hibernation is enabled for the VM → Check if hibernation is allowed for the VM →

Calculate total physical memory from /proc/meminfo → Calculate the size of swap file needed → Find a swap file if already exists with size >= required size →

If swap file size used is not equal to required size → Remove the current swap file

If there is no swap file → Create new swap file

Ensure Swap space is enabled and add entries in fstab regarding the swap file

If on HyperV VM → Set udev rules to hibernate from the host

Let us hibernate a VM using the hibernation-setup-tool!

Challenges with hibernation

MAX WAKE-UP TIMES

STORAGE REQUIREMENT

MEMORY STATE INCONSISTENCY

PLATFORM DEPENDENCIES

ENCRYPTED SYSTEMS

References

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- Hibernation in Linux 2.6.29

- System Sleep States — The Linux Kernel documentation

- Power management/Suspend and hibernate – ArchWiki

- Hibernation - Debian Wiki

- Demystifying Hibernation in Linux: Why Isn't It Intuitive?

- kernel_lockdown(7) - Linux manual page

- Hibernation overview - Azure Virtual Machines | Microsoft Learn

- microsoft/hibernation-setup-tool: Tool to set up a Linux computer to hibernate

THANK YOU!