CPU Governors and Frequencies

```
Module Code: ELEE1119

Module Name: Advanced Computer Engineering

Credits: 30

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Crystal Oscillator - Base Clock

- 100 million times a second – cycle is $10ns$
- Base clock, tempo, is multiplied by a frequency multiplier to increase the rate of instructions executed
- Multiplying by 35 we get 3.5Ghz, which $0.3ns$ per cycle

Clock Speeds

The clock speed measures the number of cycles your CPU executes per second, measured in GHz or MHz (giga/megahertz).

A “cycle” is technically a pulse synchronized by an internal oscillator, but for our purposes, they’re a basic unit that helps understand a CPU’s speed. During each cycle, billions of transistors within the processor open and close.

Clock Speeds

$$T = \frac{1}{f}$$

1. So how fast is the Intel i5-1135G7 @ 4.2GHz?
   - ▶ Answer
2. So how fast is the Intel i9-14900kf @ 9.1GHz?
   - ▶ Answer
3. or ARM Cortex-A72 @ 1.5GHz
   - ▶ Answer

Frequency Locations

```
/sys/devices/system/cpu/cpu*/cpuFreq/scaling_cur_freq
/sys/devices/system/cpu/cpuFreq/scaling_cur_freq
/sys/devices/system/cpu/*
```

```
$ cat /sys/devices/system/cpu/cpu*/cpufreq/scaling_cur_freq
```

```
1422065
3236006
2477400
1580429
1300215
1245918
1200226
1200471
```

Setting Speeds....

```
## Govenor should be set as userspace to use.

# change the operating freq of nodes update min and max to be the same to ensure true speed.
FREQ=$1
CPU="/sys/devices/system/cpu/"
MAX="scaling_max_freq"
MIN="scaling_min_freq"

CORES=$(lscpu | grep -w "CPU(s):*" | awk 'NR==1 {print$2}')
# make sure in sudo mode
sudo echo
for (( c=0; c<${CORES}; c++))
do
    echo -e ${FREQ} > ${CPUDIR}cpu${C}/cpufreq/${MIN}
    echo -e ${FREQ} > ${CPUDIR}cpu${C}/cpufreq/${MAX}
done
```

CPU Performance: Cycles Per Instruction (CPI)

Computers run synchronously utilising a CPU clock running at a constant clock rate:

Each instruction is compromised of a number of elementary or micro operations which vary in number and complexity depending on the instruction.

So a single machine instruction may take one or more CPU cycles to complete -> Cycles Per Instruction (CPI)

CPU Execution Time Pt1

A program is compromised of a number of instructions executed:

- Measured in : instructions/program, **I**

The average instruction executed takes a number of cycles per instruction (CPI) to be completed:

- Measured in: cycles/instruction, **CPI**

CPU has a fixed clock cycle time C = **1/clock rate**:

- Measured in: seconds/cycle

CPU execution time is the product of the above three parameters as follows:

$$CPU_T = \frac{Instructions}{Program} \cdot \frac{Cycles}{Instruction} \cdot \frac{Seconds}{Cycle}$$

$$T = I \cdot CPI \cdot C$$

CPU Execution Time Pt2

$$CPU_T = \frac{Instructions}{Program} \cdot \frac{Cycles}{Instruction} \cdot \frac{Seconds}{Cycle}$$

So if the Instructions is 100, CPI is 2.5, Clock cycle is 1400MHz what is the Execution Time:

▶ Answer

Factors Affecting the CPU Performance

$$CPU_T = \frac{Instructions}{Program} \cdot \frac{Cycles}{Instruction} \cdot \frac{Seconds}{Cycle}$$

	Instruction Count I	**CPI**	**Clock Cycle**
Program	x	x	
Compiler	x	x	
Instruction Set Architecture (ISA)	x	x	
Organistaion		x	x
Technology(VSLI)			x
Programmer	x	s	x

CPU Frequency Governors PT1

However all this speed comes at the expense of components, power and heat.

So can we manage the speed of the CPU to offset the heat produced through the relationship of power?

What if we could change the speed of the clock programmatically?

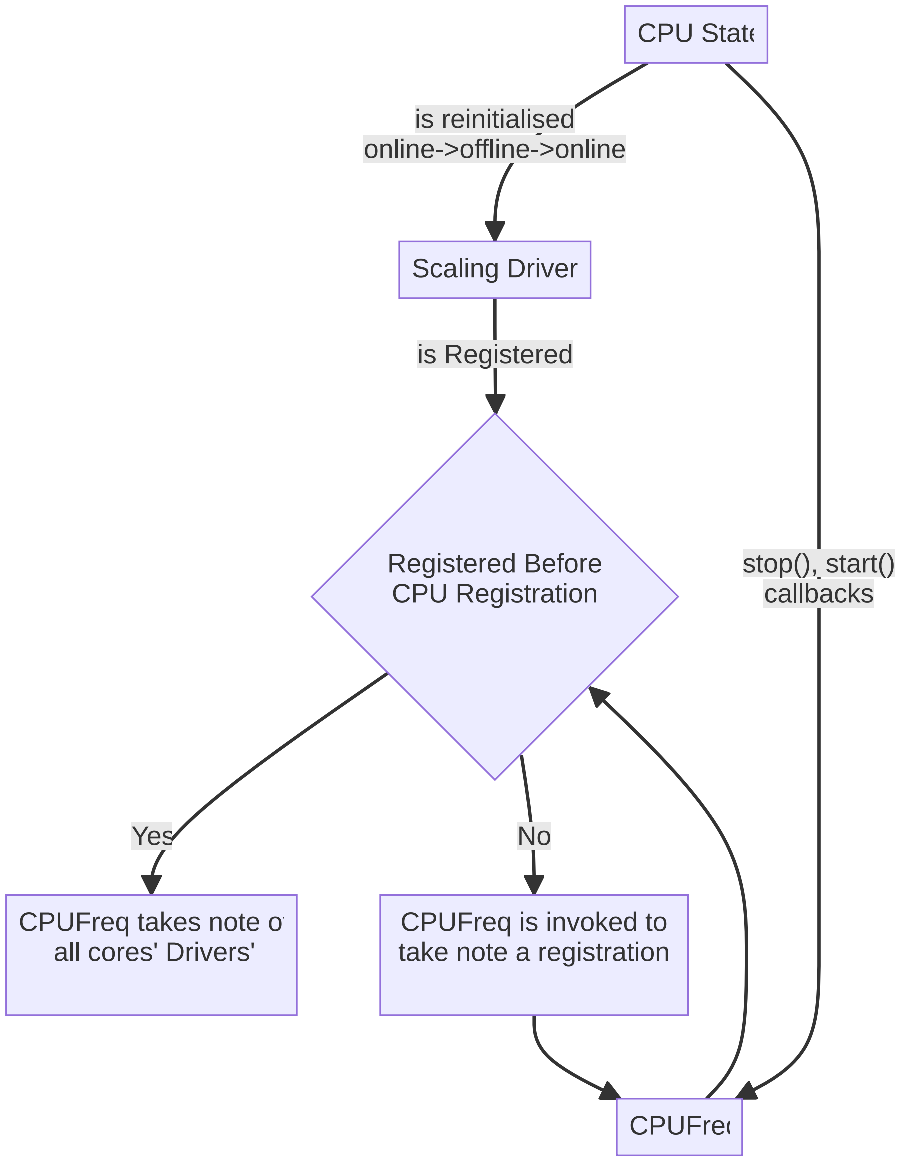
CPU Frequency Governors PT1

- One of the most effective ways to reduce power consumption and heat output on your system is to use **CPUfreq**.
    - **CPUfreq** — also referred to as CPU speed scaling allows the clock speed of the processor to be adjusted on the fly.
- This enables the system to run at a reduced clock speed to save power. The rules for shifting frequencies, whether to a faster or slower clock speed, and when to shift frequencies, are defined by the **CPUfreq governor**.
- The **governor** defines the power characteristics of the system CPU, which in turn affects CPU performance.
- Each governor has its own unique behaviour, purpose, and suitability in terms of workload.

The Concept of CPU Performance Scaling PT1

- The majority of modern processors are capable of operating in a number of different clock frequency and
  voltage configurations = **P-states**, **Performance-states**
- As a rule, the higher the **clock frequency** and the higher the **voltage**.
- Therefore there is a natural trade-off between the CPU **capacity** (the **number of instructions** that can be
  executed over a **unit of time**) and the **power drawn** by the CPU

CPU Initialisation Flow...



CPU Initialisation

- It also may not be physically possible to maintain **maximum** CPU **capacity** for too long for **thermal** or **power** supply **capacity** reasons or similar.
- To cover those cases, there are hardware interfaces allowing CPUs to be switched between **different** frequency/voltage **configurations**) or to be put into different P-states.
- Typically, they are used along with **algorithms** to **estimate** the required CPU **capacity**, so as to decide which P-states to put the CPUs into.
- Of course, since the utilisation of the system generally **changes** over time, that has to be done **repeatedly** on a **regular** basis.
- The activity by which this happens is referred to as CPU **performance scaling** or CPU **frequency scaling** (because it involves **adjusting** the **CPU clock frequency**).

Policy Interface in `sysfs`

- During the initialisation of the **kernel**, the CPUFreq core creates a sysfs directory (kobject) called cpufreq under `/sys/devices/system/cpu/`.
- That directory contains a **policyX** subdirectory (where X represents an integer number) for every policy object maintained by the CPUFreq core.
- Each **policyX** directory is pointed to by cpufreq symbolic links under `/sys/devices/system/cpu/cpuY/` (where represents an integer that may be different from the one represented by X) for all of the CPUs associated with (or belonging to) the given policy.
- The **policyX** directories in `/sys/devices/system/cpu/cpufreq` each contain policy-specific attributes (files) to control CPUFreq behaviour for the corresponding policy objects (that is, for all of the CPUs associated with them).

Policies in `sysfs` 1/8

affected_cpus

- List of online CPUs belonging to this policy (i.e. sharing the hardware performance scaling interface represented by the policyX policy object).

bios_limit

- If the platform firmware (BIOS) tells the OS to apply an upper limit to CPU frequencies, that limit will be reported through this attribute (if present).
  -The existence of the limit may be a result of some (often unintentional) BIOS settings, restrictions coming from a service processor or another BIOS/HW-based mechanisms.
- This does not cover ACPI thermal limitations which can be discovered through a generic thermal driver.
- This attribute is not present if the scaling driver in use does not support it.

Policies in `sysfs` 2/8

cpuinfo_cur_freq

- Current frequency of the CPUs belonging to this policy as obtained from the hardware (in KHz)
- This is expected to be the frequency the hardware actually runs at. If that frequency cannot be determined, this attribute should not be present.

cpuinfo_max_freq

- Maximum possible operating frequency the CPUs belonging to this policy can run at (in kHz).

cpuinfo_min_freq

- Minimum possible operating frequency the CPUs belonging to this policy can run at (in kHz).

Policies in `sysfs` 3/8

cpuinfo_transition_latency

- The time it takes to switch the CPUs belonging to this policy from one P-state to another, in nanoseconds.
- If unknown or if known to be so high that the scaling driver does not work with the ondemand governor, -1 (CPUFREQ_ETERNAL) will be returned by reads from this attribute.

related_cpus

- List of all (online and offline) CPUs belonging to this policy.

Policies in `sysfs` 4/8

scaling_available_governors

- List of CPUFreq scaling governors present in the kernel that can be attached to this policy or (if the intel_pstate scaling driver is in use) list of scaling algorithms provided by the driver that can be applied to this policy.
- [Note that some governors are modular and it may be necessary to load a kernel module for the governor held by it to become available and be listed by this attribute.]

Policies in `sysfs` 5/8

scaling_cur_freq

- Current frequency of all of the CPUs belonging to this policy (in kHz).
- In the majority of cases, this is the frequency of the last P-state requested by the scaling driver from the hardware using the scaling interface provided by it, which may or may not reflect the frequency the CPU is actually running at (due to hardware design and other limitations).
- Some architectures (e.g. x86) may attempt to provide information more precisely reflecting the current CPU frequency through this attribute, but that still may not be the exact current CPU frequency as seen by the hardware at the moment.

Policies in `sysfs` 6/8

scaling_driver

- The scaling driver currently in use.

scaling_governor

- The scaling governor currently attached to this policy or (if the intel_pstate scaling driver is in use) the scaling algorithm provided by the driver that is currently applied to this policy.
- This attribute is read-write and writing to it will cause a new scaling governor to be attached to this policy or a new scaling algorithm provided by the scaling driver to be applied to it (in the intel_pstate case), as indicated by the string written to this attribute (which must be one of the names listed by the scaling_available_governors attribute described above).

Policies in `sysfs` 7/8

scaling_max_freq

- Maximum frequency the CPUs belonging to this policy are allowed to be running at (in kHz).
- This attribute is read-write and writing a string representing an integer to it will cause a new limit to be set (it must not be lower than the value of the scaling_min_freq attribute).

scaling_min_freq

- Minimum frequency the CPUs belonging to this policy are allowed to be running at (in kHz).
- This attribute is read-write and writing a string representing a non-negative integer to it will cause a new limit to be set (it must not be higher than the value of the scaling_max_freq attribute).

Policies in `sysfs` 8/8

scaling_setspeed

- This attribute is functional only if the userspace scaling governor is attached to the given policy.
- It returns the last frequency requested by the governor (in kHz) or can be written to in order to set a new frequency for the policy

Generic Scaling Governors

- CPUFreq provides generic **scaling governors** that can be used with all **scaling drivers**. As stated before, each of them implements a single, possibly parametrised, performance scaling algorithm.
- **Scaling governors** are attached to policy objects and different policy objects can be handled by different scaling governors at the same time (although that may lead to suboptimal results in some cases).
- The **scaling governor** for a given policy object can be changed at any time with the help of the **scaling_governor** policy attribute in **sysfs**.
- Some governors expose **sysfs** attributes to control or fine-tune the scaling algorithms implemented by them.

Generic Scaling Governors 1/4

performance

- When attached to a policy object, this governor causes the **highest frequency**, within the **scaling_max_freq** policy limit, to be requested for that policy.
- The request is made once at that time the governor for the policy is set to performance and whenever the **scaling_max_freq** or **scaling_min_freq** policy limits **change** after that.

powersave

- When attached to a policy object, this governor causes the **lowest frequency**, within the **scaling_min_freq** policy limit, to be requested for that policy.
- The request is made once at that time the governor for the policy is set to **powersave** and whenever the **scaling_max_freq** or **scaling_min_freq** policy limits **change** after that.

Generic Scaling Governors 2/4

userspace

- This governor does not do anything by itself. Instead, it allows **user space** to set the **CPU frequency** for the policy it is attached to by writing to the **scaling_setspeed** attribute of that policy.

schedutil

- This governor uses **CPU utilisation** data available from the **CPU scheduler**. It generally is regarded as a part of the CPU scheduler, so it can access the scheduler's **internal data structures directly**.
- It runs entirely in scheduler context, although in some cases it may need to invoke the scaling driver **asynchronously** when it decides that the CPU frequency should be changed for a given policy (that depends on whether or not the driver is capable of changing the CPU frequency from scheduler context).

Generic Scaling Governors 3/4

ondemand

- This governor uses **CPU load** as a **CPU frequency** selection metric.
- In order to **estimate** the **current CPU** load, it measures the time elapsed between **consecutive invocations** of its worker routine and **computes the fraction of that time** in which the given CPU was **not idle**. The ratio of the non-idle (active) time to the total CPU time is taken as an estimate of the load.
- If this governor is attached to a policy shared by multiple CPUs, the load is estimated for all of them and the greatest
result is taken as the load estimate for the entire policy.

Generic Scaling Governors 4/4

conservative

- This governor uses **CPU load** as a **CPU frequency** selection metric.
- It estimates the CPU load in the **same** way as the ondemand governor described above, but the CPU frequency selection **algorithm implemented** by it is **different**.
- Namely, it **avoids changing** the **frequency** significantly over **short time intervals** which may not be suitable for systems with limited power supply capacity (e.g. battery-powered). To achieve that, it changes the frequency in relatively small steps, one step at a time, up or down - depending on whether or not a (configurable) threshold has been exceeded by the estimated CPU load.

Script to see all available cores' frequencies and governor

```
CPUDIR=/sys/devices/system/cpu/cpu0/cpufreq/
NTHCORE=$(lscpu | grep -w "CPU(s):*" | awk 'NR==1 {print$2}')
COLUMNS=''
HEADER="SCPU Policies\t| CORES 0:${NTHCORE}-->"

for (( c=0; c<=${NTHCORE}; c++ ))
do
  COLUMNS="${COLUMNS} -"
done

echo -e ${HEADER}

for i in ${CPUDIR}{cpuinfo,scaling}_*; do #iterate over the all cput frequencies
  PNAME=$(basename $i)

  [[ "${PNAME}" == *available* ]] || [[ "${PNAME}" == *transition* ]] || \
  [[ "${PNAME}" == *driver* ]]    || [[ "${PNAME}" == *setspeed* ]] && continue

  echo "${PNAME}: "

  for (( j=0; j<${NTHCORE}; j++ ))
  do
  # replace cpu0 with cpuj for  /sys/devices/system/cpu/cpuj/cpufreq...
    KPARAM=$(echo $i | sed "s/cpu0/cpu$j/")
    cat "${KPARAM}"
  done
done | paste ${COLUMNS} | column -t
```

Setting governors

```
GOVDIR="/sys/devices/system/cpu/cpu*/cpufreq/scaling_governor"
AVAILGOVS=$(cat /sys/devices/system/cpu/cpu0/cpufreq/scaling_available_governors)
CORES=$(lscpu | grep -w "CPU(s):*" | awk 'NR==1 {print$2}')

while [[ 1 ]]; do
        echo "Please select from the following governors:"
        echo  "${AVAILGOVS}"

        read GOV
        # use grep to match input with sub string of AVAILGOVS
        if grep -q "$GOV" <<< "${AVAILGOVS}"; then
                break
        fi
done

echo -n "Changing the scaling_governor all ${CORES} to "

echo "${GOV}" | sudo tee ${GOVDIR}
echo "Success your new Scaling Governor is ${GOV}"
```