Constrained Power Management

an holistic approach to power management

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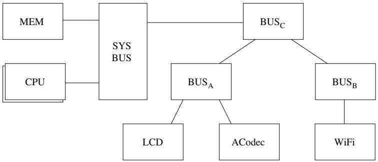
Outline

- Highlight some issues of current Linux kernel PM support
- Advance a proposal to tackle these problems
  - not a finale solution
  - try to focus attention on the topic
  - trigger a discussion to improve this kind of support

Power Management Techniques

- Focusing on devices and interconnections
  - almost any direct applications input
- Device specific's policies
  - multiple policies for single device
- System-wide Policies
  - tracks subsystem's *specific* dependencies
  - dependency tree



Simple representation of a complex system

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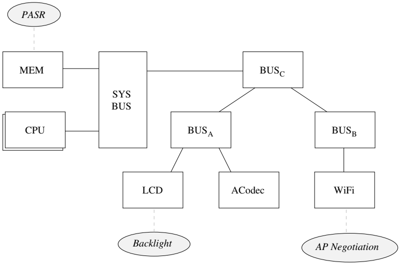

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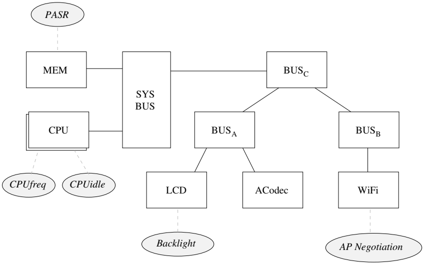

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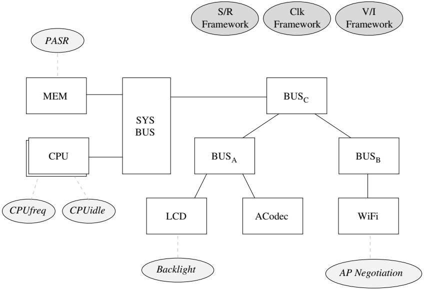

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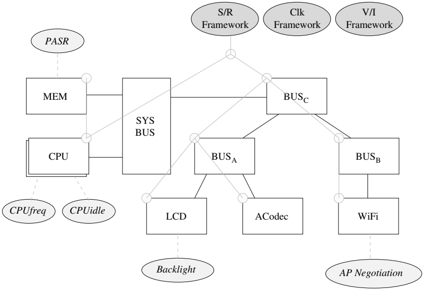

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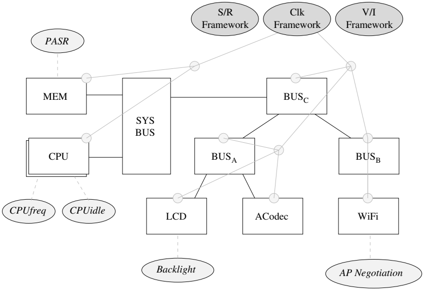

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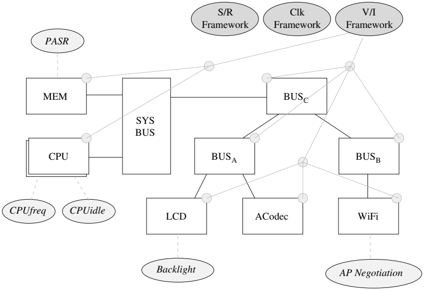

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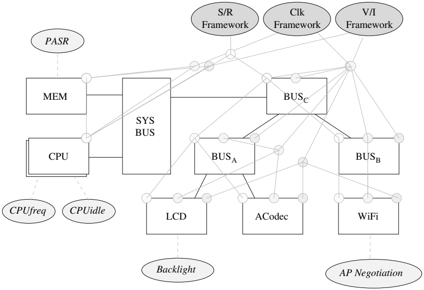
Multiple *disjoint* policies



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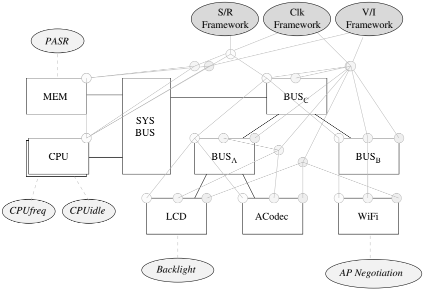

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Multiple *disjoint* policies

How can we achieve system-wide optimization?

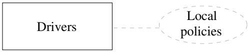
Multiple-Policy Approach: Potential Issues

- Multiple decision points
  - difficult inter-dependencies tracking
  - risk of conflicting decisions
- Only indirect info about applications QoS requirements
  - user-space know the requirements, kernel should support them
  - application requirements should drive kernel frameworks tuning
- No proper aggregation on applications requirements
  - only some frameworks provide it (e.g V/I fw, “new” clock fw)
  - risk of code duplication
- No feed-back on resources availability
  - applications could require resources from multiple devices
  - behavior depends on effective availability of all the required resources

The composition of almost independent optimization policies cannot grant a system-wide optimization

Constrained Power Management

- drivers' local policies
  - targeted to power reduction
  - fine-details, low-overhead
- *coordination entity*
  - exploit system-wide view
  - track resource availability and devices' inter-dependencies
- global optimization policy
  - multi-objective, low-frequency
- single user-space interface
  - collects QoS requirements
  - feedback on resource availability
- constraint assertion
  - QoS requirements
  - set constraint on local policies



Distributed control model

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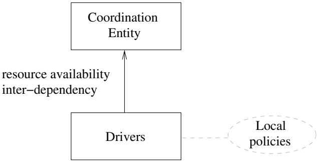

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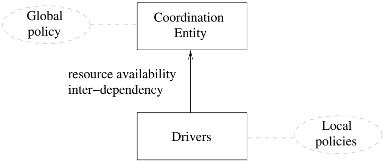

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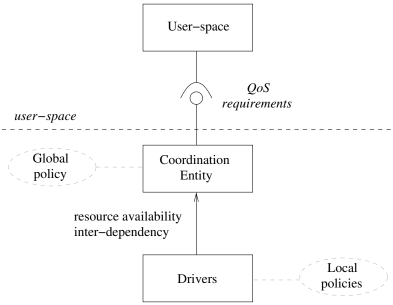

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  QoS requirements

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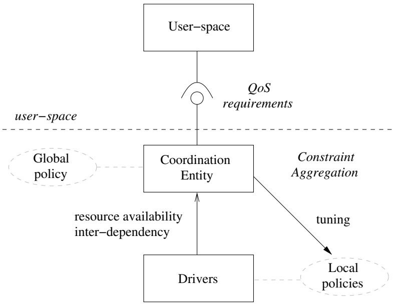


Distributed control model

The PM QoS interface

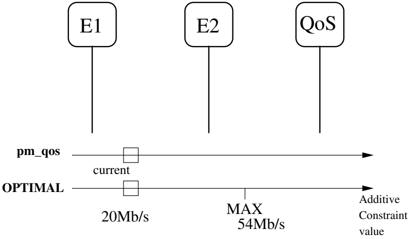
Linux kernel infrastructure to implement a coordination mechanism among drivers (capabilities) and application (QoS requirements)

- Developed by Intel for iwl4965 WiFi driver on x86
  - since Linux 2.6.25 (`linux/pm_qos_params.h`)
- Defines a (limited) set of "abstract" QoS parameters
  - i.e. latencies, timeouts and throughput
  - maintains a list of QoS requests and *aggregate* requirements
    - restrictive aggregation only, i.e. Min/Max
    - this aggregation generates a constraint
  - provides notification chain for constraint update
    - drivers subscribe to parameters of interests
      e.g. CPUidle is constrained by 'system latency'
  - Drivers' local policies *should* grant required constraints
    - no failures handling on notify chain calls

Limitations of the PM QoS Interface

"The notion of constraint based PM has been rattling around for a while now. PMQoS is just an early application of it. I think a lot more could be done in this area." M. Gross

- Missing support for platform-specific parameters
- No **additive constraints** concepts support
- Only **best-effort** approach



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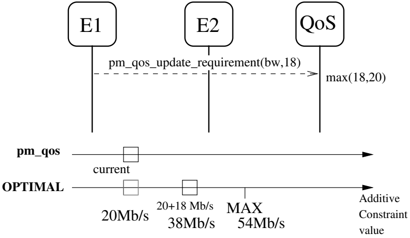

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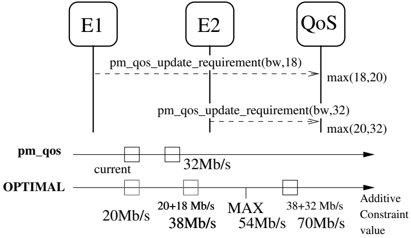

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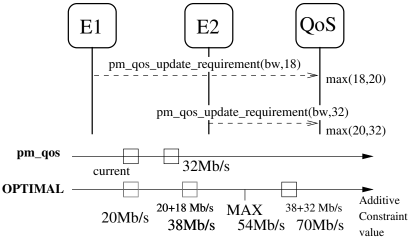

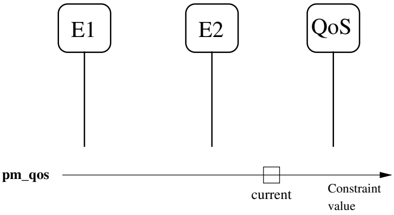

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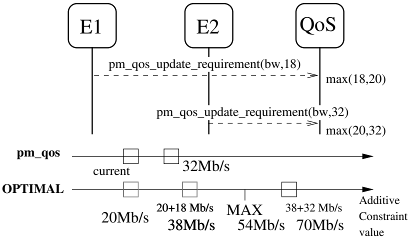

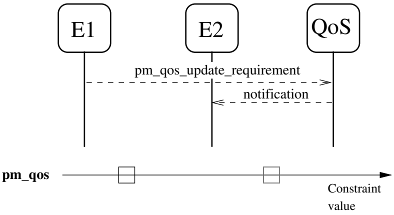

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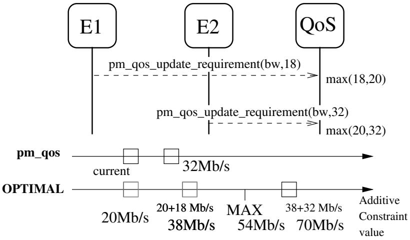
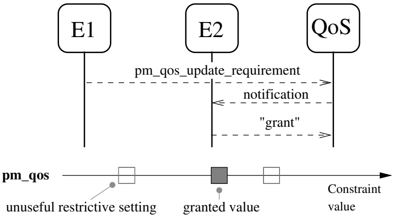




Our Goals

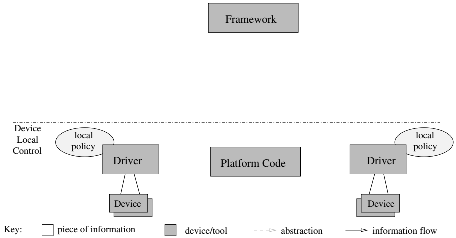
- Define a **formal model** for system-wide *performance vs power* control
  - based on **constraints-based** approach
  - drivers could **collaborate** to find the optimal system-wide configuration

    with respect to *all* QoS requirements
  - support multi-objective optimizations
- **Implementation** based on latest Linux kernel
  - overcoming current QoSPM limitations
- **Validate** the model and the implementation on real hardware
  - STM's Nomadik platform
  - evaluate overheads and performances

Abstracting the Reality, Modeling the Abstraction

Hierarchical Distributed Control

- Devices' local control
- Abstracting reality
- Modeling Abstraction
- Model optimization
- Considering QoS requirements
- Constraint local policies



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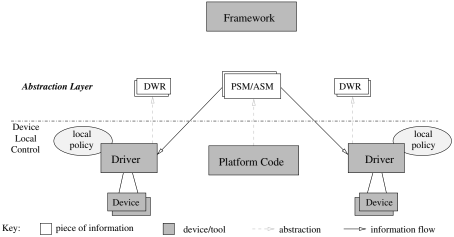

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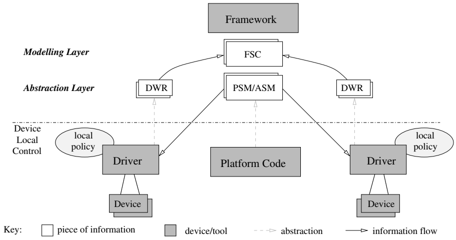

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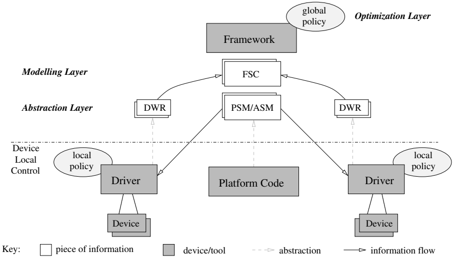

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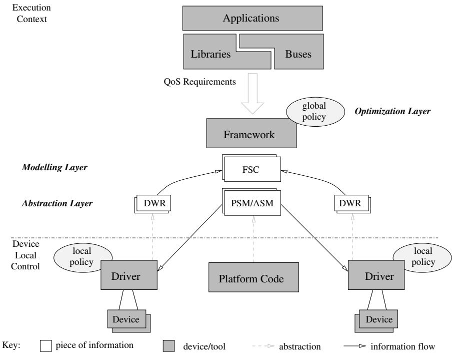

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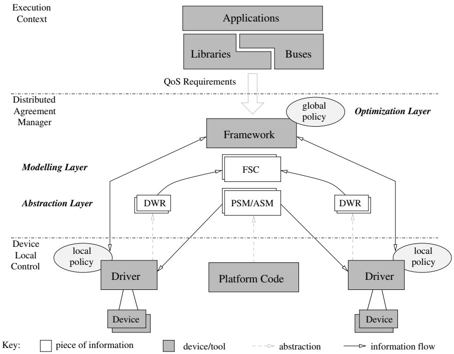


System-Wide Metric (SWM)

A parameter describing the behaviors of a running system and used to track resources availability

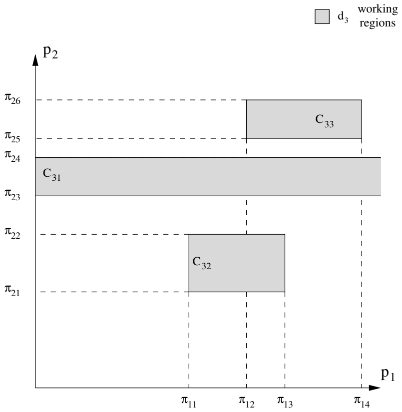
- QoS requirements: are expressed as *validity ranges* on SWM
  mainly upper/lower bounds
- Different abstraction levels
  - *Abstract System-wide Metric (ASM)*, platform independent
    exposed to user-land
    e.g. ambient light/noise, power source, specific application requirements
  - *Platform System-wide Metric (PSM)*, platform dependent
    private to platform code and platform drivers
    e.g. bus bandwidth, devices' latency
- Allow to track QoS inter-dependencies
  - platform drivers and code can translate ASM's requirements into PSM's constraints

▸ Code Example

Device Working Region (DWR)

The mapping on SWMs' range of a device operating mode

- A device could have different working modes
  - different QoS => different SWM range
- Defined by the device driver
- Implicitly allows devices *dependencies tracking*
- Graphic representation



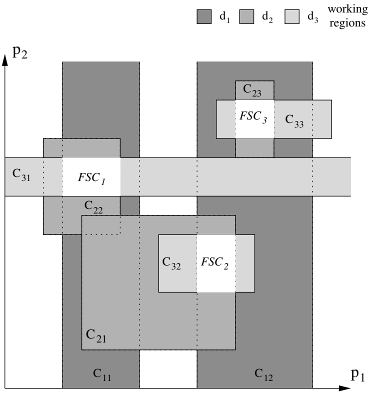
A device with 3 DWR (c_{dm}) mapping 2 SWM (p_i)

▸ Code Example

Feasible System-wide Configurations (FSC)

The intersection of a least a DWR for each device

- QoS requirements within a FSC
  - all devices can support the required QoS level
  - no conflicts
- identify *all and only* the feasible system's working modes
  - all the possible solutions for the PM optimization problem
  - define an abstract model for system-wide optimizations



The 3 FSCs existing on this system

A Formal Optimization Framework

- Using Linear Programming (LP)
  - well known mathematical *multi-objective* optimization framework
- Two-fold goal
  - formally justify the proposal
    - through the equivalence with a well known exact method for optimal solution search
  - guide the design of an efficient implementation
    - we don't want to solve an LP problem
    - identify possible simplifications
    - exploit problem specificities

Use LP formulation to identify a solution-equivalent and efficient optimization strategy

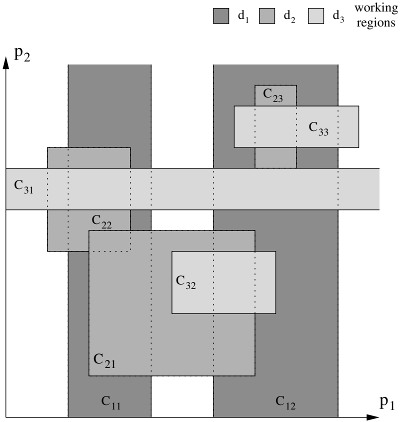
Go to Formulation

Putting it All Together

1. DWRs registration
2. FSC identification
3. Constraint aggregation
4. FSC validation
5. FSC selection
   - optimization policy $\overrightarrow{o_g}$

- Different time domains
  - boot-time: steps 1-2
  - run-time: steps 3-5
- step 5 can be simplified by FSC pre-ordering
  - policy defined

    e.g. FSC_3, FSC_1, FSC_2



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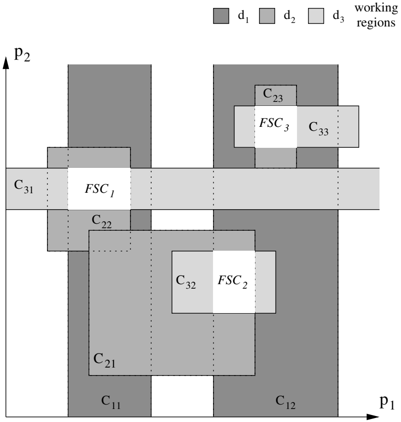

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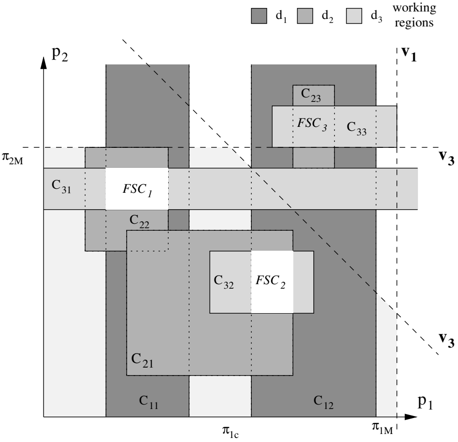

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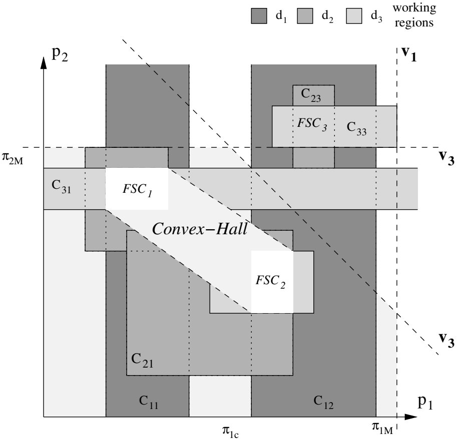

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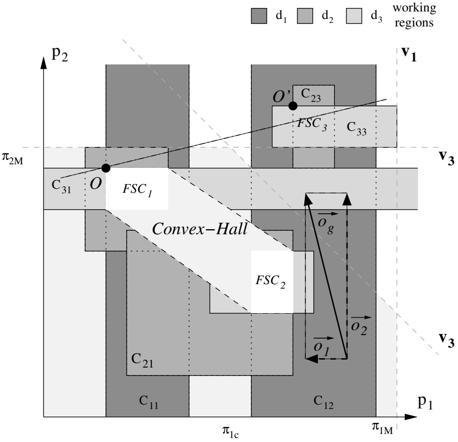

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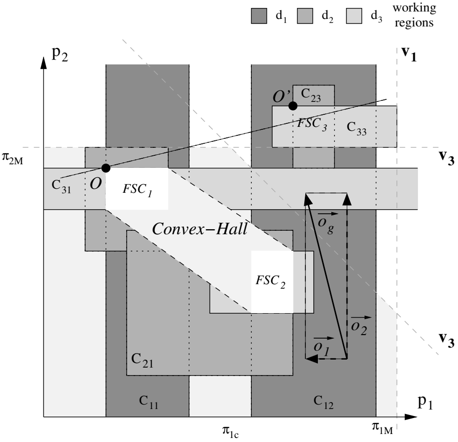

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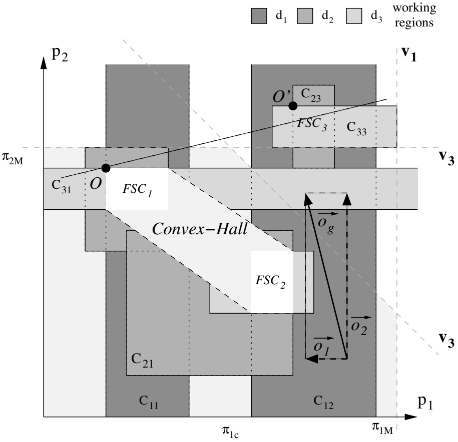

A Real Optimization Framework

- Translate the formal (LP) model into an efficient implementation
- Exploit tree different *time domains*
  - boot time => FSC Identification (FI)
  - policy update time => FSC Ordering (FO)
  - constraint assertion time => FSC Selection (FS)
- Support complexity partitioning
  - high-overhead operations (FI) are executed once
- Modular design
  - split operations on “governor” and policy
  - better support operation optimization
    - off-line computation (FI)
    - HW acceleration, e.g. look-up based implementation (FO, FS)

Go to Overheads Graph

Framework Design

- framework core
  - data types, ASM
  - glue code
  - user-space API
- platform code
  - PSM definition
- device drivers
  - DWR definition
  - constraints auth.
- governor
  - FSC identification
- policy
  - FSC ordering
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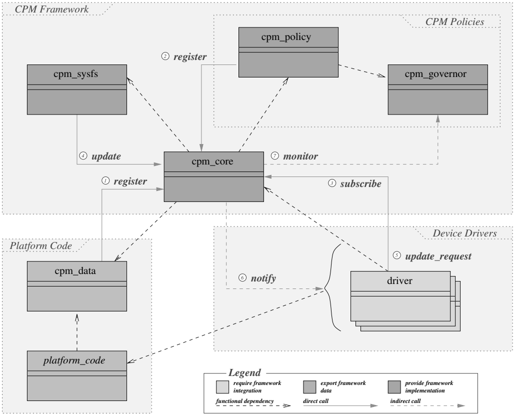

Main framework components and their relationship

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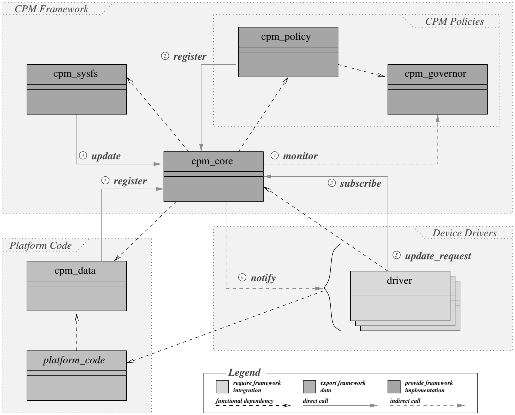

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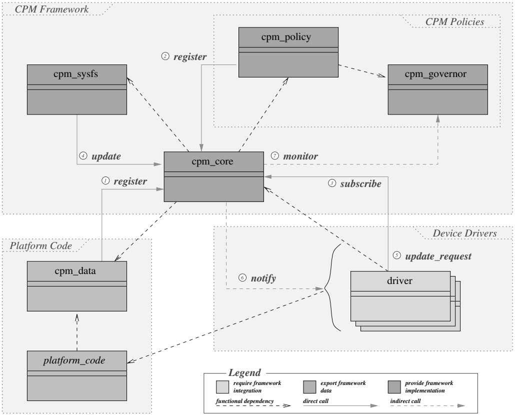

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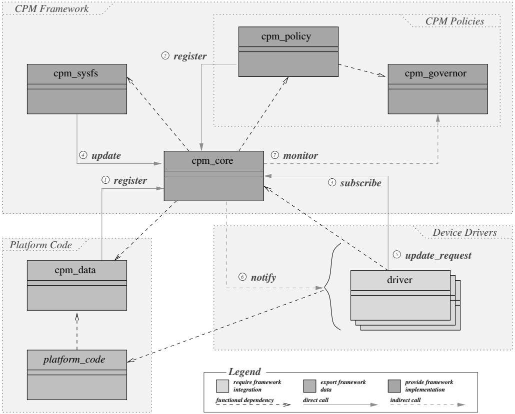

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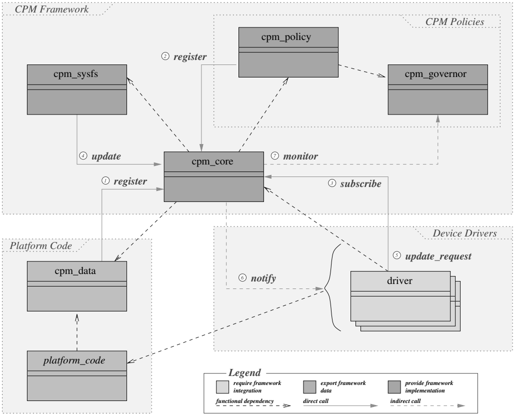


Main framework components and their relationship

Resuming the Proposal

- Distributed approach for performances vs power trade-off control
  - supports constraint based PM
  - scalable on upcoming more and more complex architectures
  - provides multi-objective optimizations
- Layered design
  - optimization layer on top of an abstraction layer
  - improved code reuse and portability
- Simple platform code and drivers interface
  - few modifications required
  - easily exploits platform and devices fine-details
- Validated using a formal optimization model
- Up-to-date implementation, rebased on mainline Linux kernel
  - providing a sysfs interface and some dummy test modules to support testing and benchmarking

Looking Forward

- The implementation is going to be released in ML for RFC
  - basic implementation of the designed software architecture
  - public GIT repository: still missing!
  - discuss, review, rework. . . community feedbacks are welcome!
- Find real-world applications
  - the constrained PM concept should be pushed

    . . . the QoS PM interface is almost unused
  - try it: it's free!
- Provide guidelines for DWR definition
  - distributed control assign different target to different levels
  - local policies should fit well within the model
- Improve the user-space interface
  - integration within a resource management system framework
  - automate constraint assertion
- Investigate on HW acceleration possibilities

Q&A

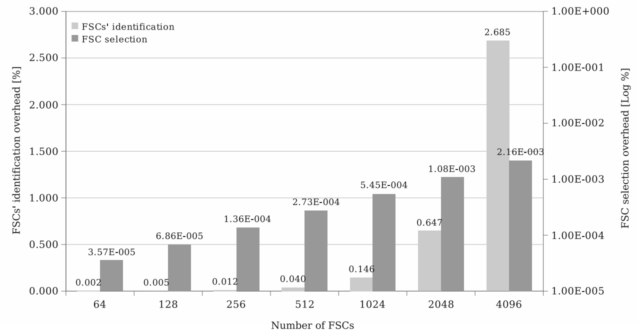
Linear Programming (LP) Formulation

- The PM optimization problem can be formulated as an LP problem
- LP elements:
  - *solution space* – SWMs Domain
  - *objective function* – vector representing QoS optimization directions
  - *constraints* – QoS requirements
    - dynamically reduce the number of valid FSCs
  - *convex hall* – the smallest convex polygon including all valid FSCs
  - *valid solution* – every point inside the convex hall
  - *optimal solutions* – vertexes or edges of the convex hall
    - can always be mapped to 1 or 2 FSCs

▸ Go to Motivations

CPM Overheads

- Worst-Case Analysis
  - synthetic drivers to configure the worst operating conditions
  - running on VirtualBox, host: Intel Core 2@1.6GHz
  - note: non-Cartesian logarithmic X axis



Hoverheads % wrt 60s timeframe

Go to Implementation Notes

Implementation Summary

```
$ git diff 4be3bd78.. --stat
Documentation/cpm/00-INDEX.txt        |   61 +
Documentation/cpm/core.txt            |  264 +++
Documentation/cpm/governors.txt       |  146 ++
Documentation/cpm/overview.txt        |  131 ++
Documentation/cpm/platform.txt        |  123 ++
Documentation/cpm/policies.txt        |  131 ++
Documentation/cpm/testing.txt         |   67 +
Documentation/cpm/user-guide.txt      |  139 ++
drivers/Kconfig                       |    2 +
drivers/Makefile                      |    1 +
drivers/cpm/Kconfig                   |  112 ++
drivers/cpm/Makefile                  |   10 +
drivers/cpm/cpm_core.c                | 3402 +++++++++++++++++++++++++++++++++
drivers/cpm/cpm_governor_exhaustive.c |  420 ++++
drivers/cpm/cpm_policy_dummy.c        |  122 ++
drivers/cpm/cpm_policy_performance.c  |  199 ++
drivers/cpm/test/Kconfig              |   38 +
drivers/cpm/test/Makefile             |    7 +
drivers/cpm/test/cpm_test_bandwidth.c |  218 +++
drivers/cpm/test/cpm_test_dummy.c     |  459 +++++
drivers/cpm/test/cpm_test_mp3gsm.c    |  316 +++
include/linux/cpm.h                   |  491 +++++
22 files changed, 6859 insertions(+), 0 deletions(-)
```

Example - System-Wide Metrics Definitions

```
// SWM Identifiers definitions
#define SWM_AMBA_BANDWIDTH       CPM_ASM_TOT+0
#define SWM_ADSP_CLK             CPM_ASM_TOT+1

// Platform specific SWM (PSM) definition
struct cpm_swm cpm_platform_psm[] = {
  CPM_PLATFORM_SWM("AMBA_BANDWIDTH", CPM_TYPE_GIB, CPM_USER_RW,
    CPM_COMPOSITION_ADDITIVE, 0, 8000),
  CPM_PLATFORM_SWM("ADSP_CLK", CPM_TYPE_GIB, CPM_USER_RO,
    CPM_COMPOSITION_ADDITIVE, 0, 266),
};

// PSM Registration
struct cpm_platform_data cpm_platform_data = {
        .swms = cpm_platform_psm,
        .count = ARRAY_SIZE(cpm_platform_psm),
};
cpm_register_platform_psms(&cpm_platform_data);
```

Go to Definition

Example - Device Working Region

```
struct cpm_swm_range vdsp_dwr0_ranges[] = { /* V-DSP MPEG4 decoding mode */
        DEV_DWR_ASM(CPM_VCODEC, 1, 1, CPM_ASM_TYPE_RANGE),
        DEV_DWR_ASM(CPM_DSP_CLK, 40, 132, CPM_ASM_TYPE_RANGE),
};
struct cpm_swm_range vdsp_dwr1_ranges[] = { /* V-DSP OFF mode */
        DEV_DWR_ASM(CPM_VCODEC, 0, 0, CPM_ASM_TYPE_RANGE),
        DEV_DWR_ASM(CPM_DSP_CLK, 0, 132, CPM_ASM_TYPE_RANGE),
};
struct cpm_dev_dwr vdsp_dwrs_list[] = { /* V-DSP working mode */
        DEV_DWR("Mpeg4", vdsp_dwr0_ranges, ARRAY_SIZE(vdsp_dwr0_ranges)),
        DEV_DWR("OFF", vdsp_dwr1_ranges, ARRAY_SIZE(vdsp_dwr1_ranges)),
};
static struct cpm_dev_data vdsp_data = { /* V-DSP DWR's registration */
        .notifier_callback = vdsp_cpm_callback,
        .dwrs = vdsp_dwrs_list,
        .dwrs_count = ARRAY_SIZE(vdsp_dwrs_list),
};
ret = cpm_register_device(&vdsp.dev, &vdsp_data);
```

Go to Definition

Example - Real Use-Case

- Youtube and Torrent
  - 3 ASM:
    - acodec, vcodec, bandwidth
  - 2 PSM:
    - cpu_freq, cpu_dsp_platform
  - devices(dwr):
    - modem(5), vcodec(4), acodec(4), cpu(7), platform(7)
  - Identified FSC: 415
    - 10% out of 3920 of worst case analysis