A bright idea for Embedded Systems
System-Wide Dynamic Power Management

Review on the IBM and MontaVista Software proposal for Embedded Systems Power Management.

Patrick Bellasi

bellasi@elet.polimi.it

Research Assistant
Departement of Electronics and Information Technology
Politecnico di Milano

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Outline

1. Power Management
   - The Problem Space
   - The Solution Space

2. Proposed Architecture
   - Policy Architecture
   - Implementation
   - Usage

The DynamicPower Project

- a SourceForge project
  (registered 2003-09-18, last update 2006-04-14)
- sponsored by IBM Research Labs and MontaVista Software
- is a patchset against linux kernel 2.6.16
  (status: alpha-stable)
- platforms currently supported: Intel Centrino Enhanced Speedstep, TI OMAP, PowerPC 405LP Arctic III and Intel PXA27x
  - some configuration example are also provided
  - userspace tools for DPM configuration and policy management

Introduction

- traditionally the focus was on regulating the power consumption in static modes (sleep and suspend)
- DPM refers to power management schemes implemented *while programs are running*
- should exploit recent processor support for very dynamic power management strategies
  - based on dynamic voltage and frequency scaling
- power states control must be implemented in the operating system
  - highly integrated System-On-a-Chip (SOC) processors typically do not include a traditional BIOS

DynamicPower Proposals

- attempts to standardize a dynamic power management and policy framework
- support different power management strategies
  - under control of operating system components
  - or user-level policy managers
- provide a flexible framework, mostly architectural independant
  - exploiting last 2.6 linux kernel features
    (e.g. LDM, Hotplug, . . .)
- addressed to system-wide power management

Functional Requirements

- reduce *system-wide* energy consumption
    - voltage and frequency scaling the processor core may be of limited use
    - scaling bus frequencies
    - manage devices power consumption
- look for *highly dynamic* power management strategies that encompass the entire system
- *fine grained* power and performance characteristics definitions

    task-specific dynamic power management will become a hard requirement in highly energy-constrained systems

Implementation Requirements

- simplicity and flexibility

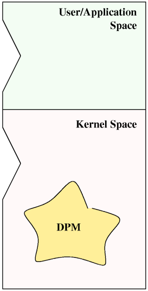
  leaving the workings of the dynamic power management system completely transparent to most tasks, and even to the core of the operating system itself
- safety and portability
  - don't actually manage device state
  - relay on low-level device drivers
- support "pluggable" power management policies

  most effective way to manage energy consumption are highly "application" dependent
- exploit the capabilities of state-of-the art systems and techniques for PM provided by modernn SoC devices

Architectural Overview

The DPM Core

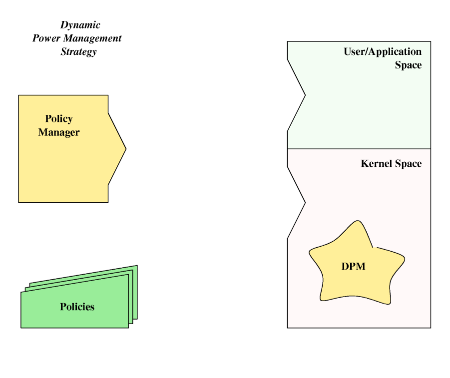
- a low-level DP component: implemented in the kernel space
- not a self-contained device driver: requires enhancements at a few key places



ARCHITECTURAL OVERVIEW

DPM strategy components

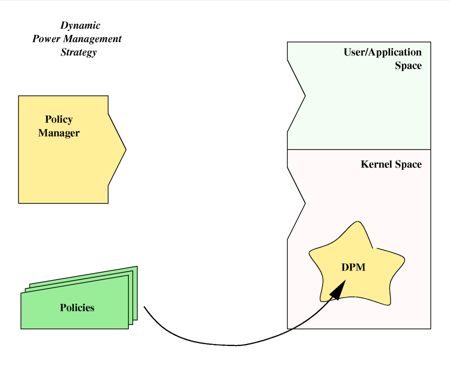
- predefined set of policies
- policy manager that manage policies activation



Architectural Overview

The Policies

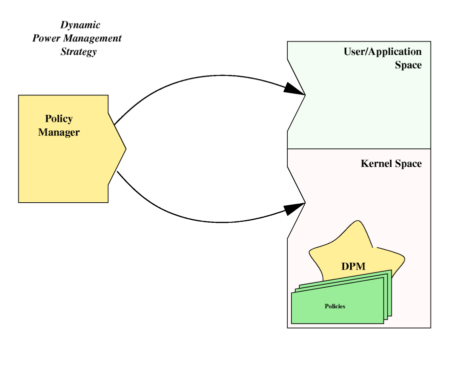
- are named data structures
- installed into the operating system kernel for efficiency
- specify the component and device-state transitions that ensure reliable operation in line with the power management strategy



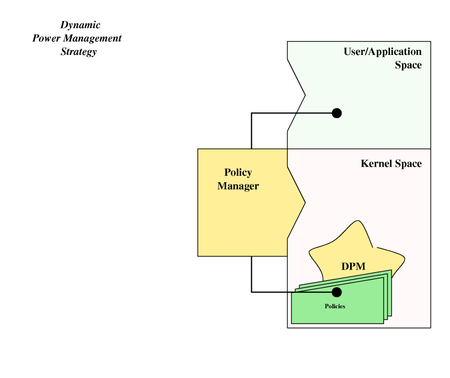
Architectural Overview

The Policy Manager

- can execute either as part of the kernel or in user space (or both) as required by the strategy
- provide to activate a suitable policy based on system state or user requests



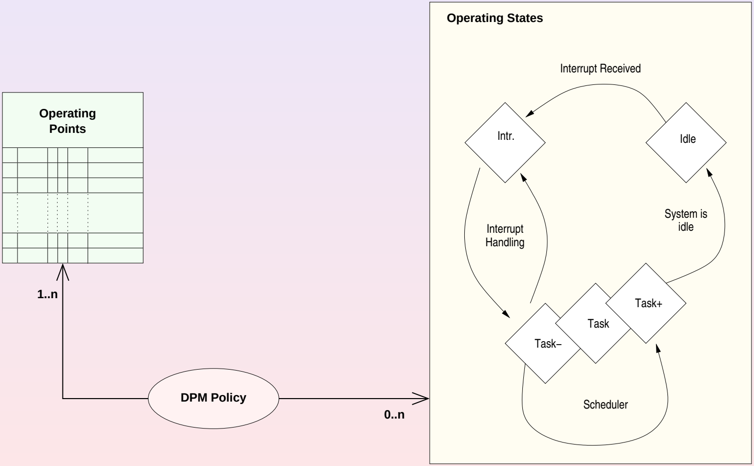
Architectural Overview



Policy Management

- activate policies by name
- may be very active or more passive
- effective strategies may even consist of a single policy installed at system initialization

DPM Policy Overview



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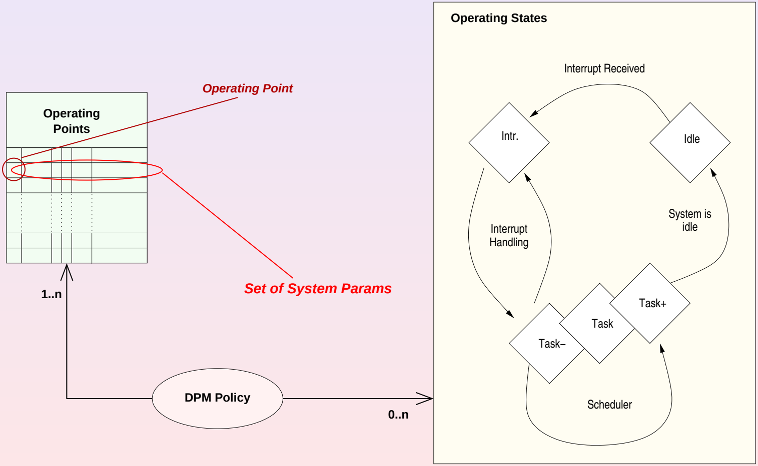

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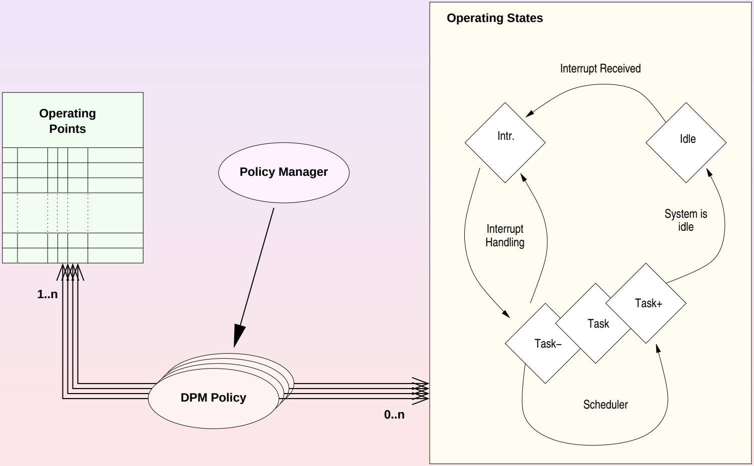

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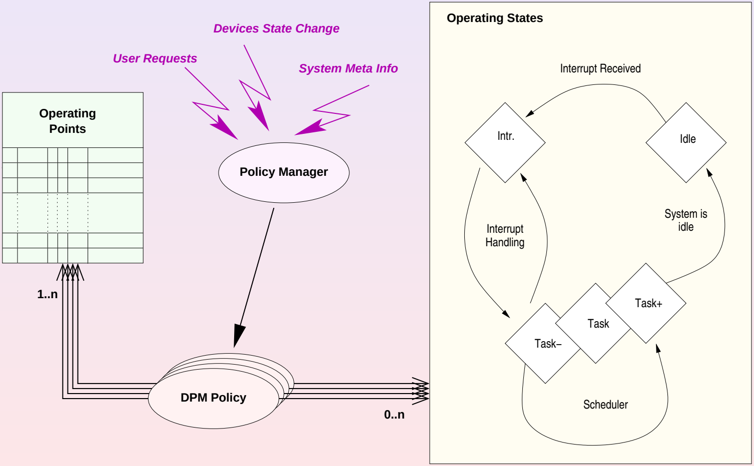


Operating Points

Operating Point

An Operating Point (OP) encapsulates the minimal set of inter-dependent, physical and discrete parameters that define a specific system performance level and energy cost.

- are processor and system dependent
- a system:
  - has many OP
  - at any given point in time is executing at a particular OP

Operating States

Operating State

An operating system can be thought of as a state machine moving through different states in response to events. Each one of these system states is an Operating State (OS).

- each operating state may be associated with an operating point
  - specific to the requirements of that state
- support task-specific operating points for power-aware tasks
  - tasks with special requirements may specify, or be specified to run in different *task states*, each of which may be associated with a different operating point

Congruence Class

Congruence Class

A Congruence Class (CC) is a subset of operating points that the system designer considers equivalent for specific operating states modulo a power management strategy

- given an OS each OP in the corresponding CC is acceptable
- *device constraints* might render some members of the class invalid
- *power considerations* might cause one OP to be preferred over other valid OP in the class

Device Constraint

Device Constraint

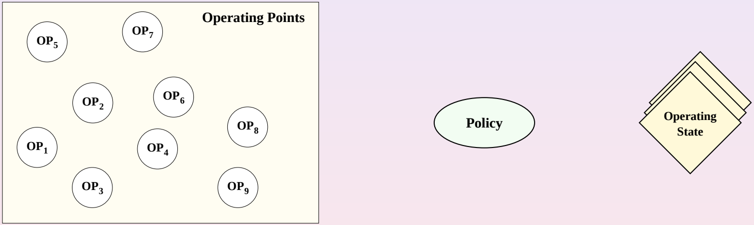
A Device Constraint (DC) is a device requirement associated with particular device state

LCD Example:

Active State pixel clock range $16 \div 25 MHz$

Idle State pixel clock range *undefined*

DPM Policy Reviewd



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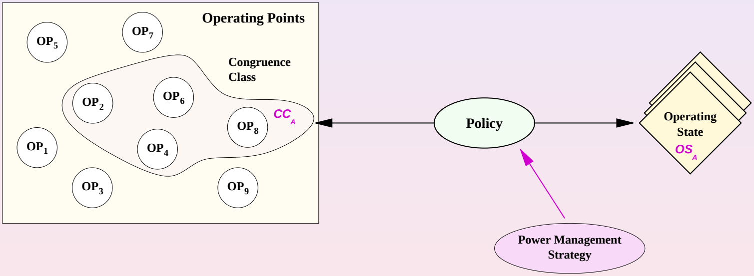

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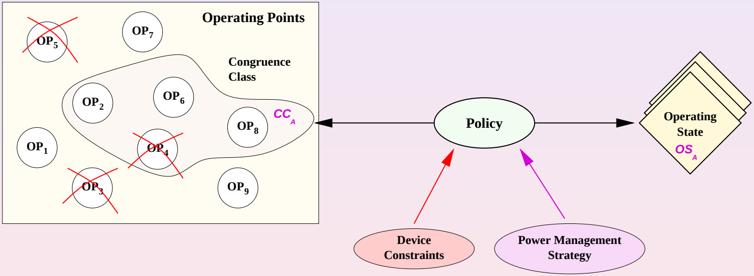

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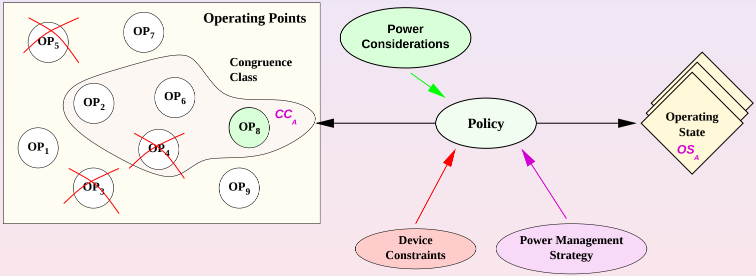


Strategy

Power Management Strategy

A Power Management Strategy (PMS) is a collection Policy P

- a DPM system has at least one Policy
- each policy is adressed to different running context (e.g. run on Battery, run on AC, . . .)

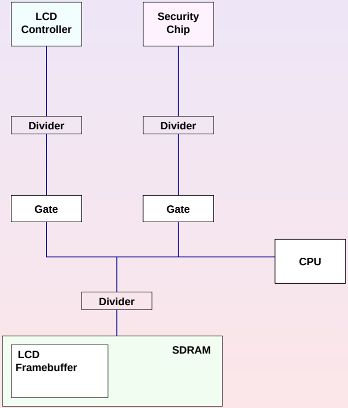
Policy Manager

Policy Manager

A Policy Manager (PM) is the component that activate a policy in reason of some events

- the decision of what policy to activate come from some collected information (e.g. Operatin System state, user preferences, running programs, phisical devices state, . . .)
- location, type of information collected and actions taken are implementation dependent

Operating Point View



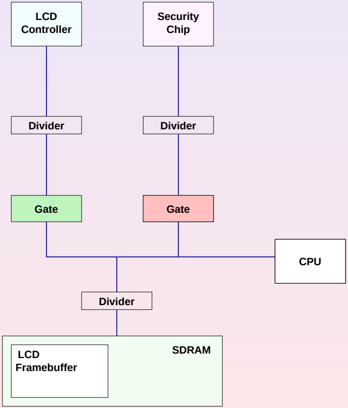
Running State

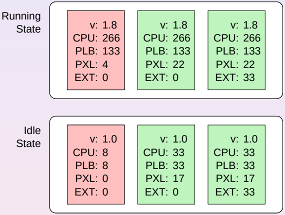
v: 1.8	v: 1.8	v: 1.8
CPU: 266	CPU: 266	CPU: 266
PLB: 133	PLB: 133	PLB: 133
PXL: 4	PXL: 22	PXL: 22
EXT: 0	EXT: 0	EXT: 33

Idle State

v: 1.0	v: 1.0	v: 1.0
CPU: 8	CPU: 33	CPU: 33
PLB: 8	PLB: 33	PLB: 33
PXL: 0	PXL: 17	PXL: 17
EXT: 0	EXT: 0	EXT: 33

Operating Point View





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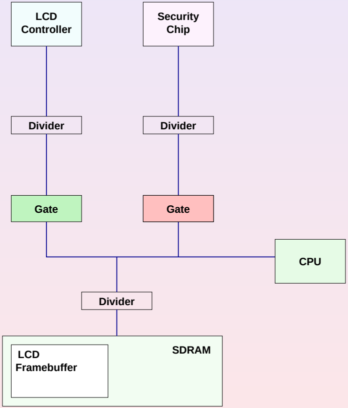

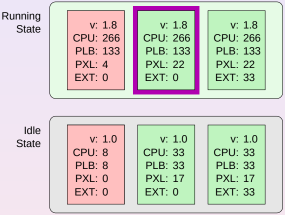

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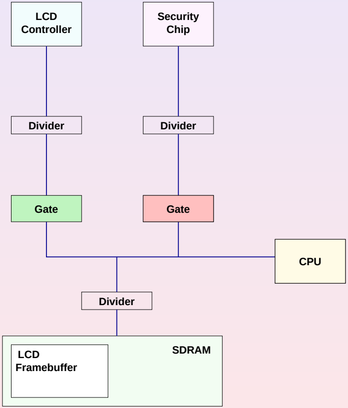

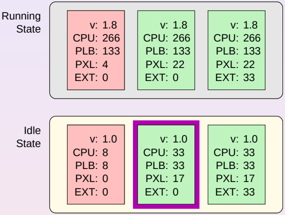

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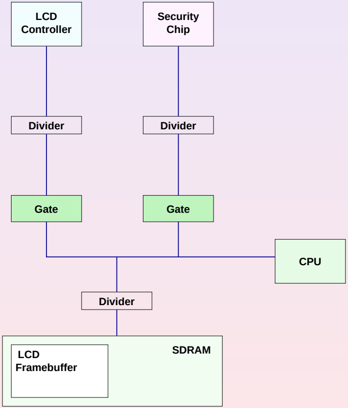

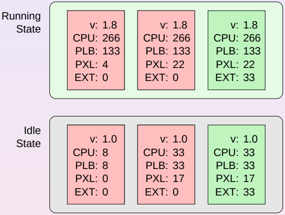

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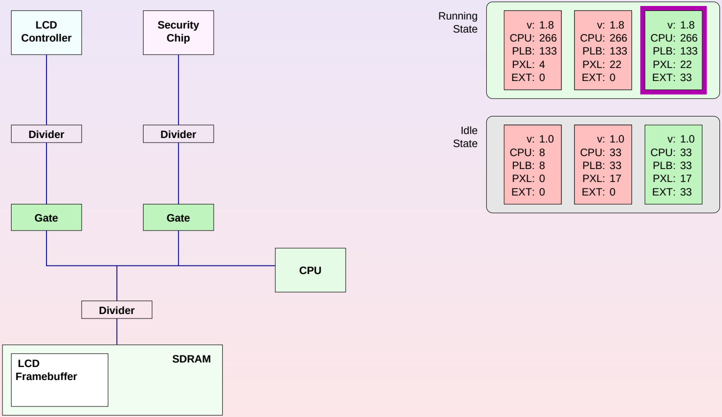

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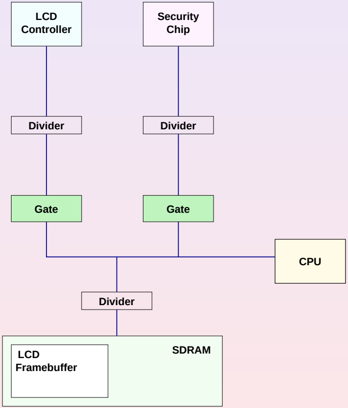

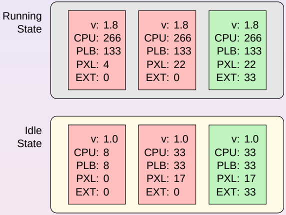

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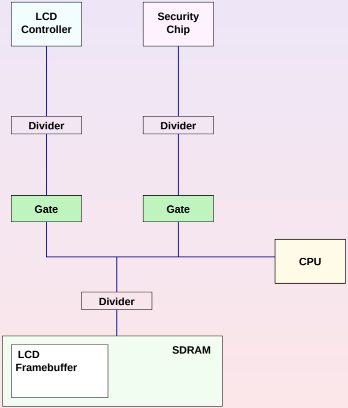

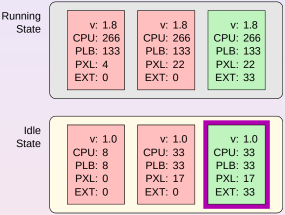

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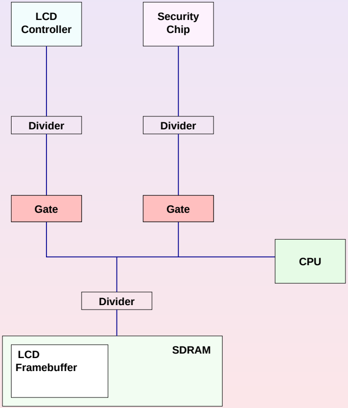

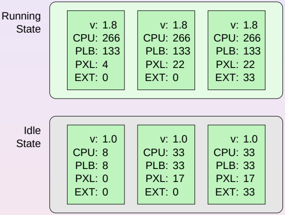

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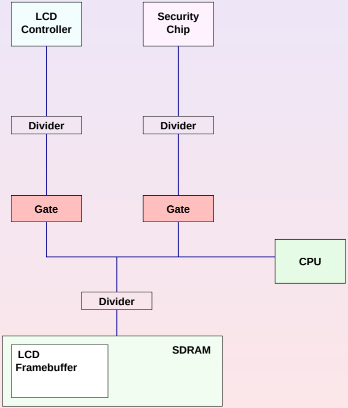
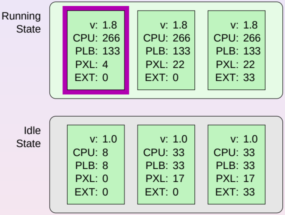




NOTES

- OP could be range-defined (insted of enumerated)

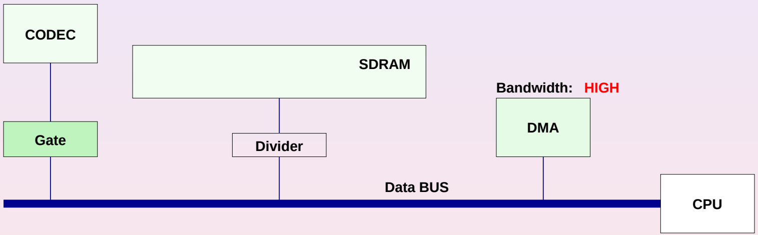
  OP ranges, device contraints and strategy rules provide a system whose solution is the optimal operating point to be activated

- OPs, Consguence Classes and Policy must be pre-coded; device contraints instead are knowe run-time and modify the set of valid OPs
- OP and device state changes must be transparent to the Operating System, which is free to move from state to state

  even if device state changes shuld be performed by low-level device drivers:

  no single Device Driver has a complete view on how a new operating point will be reached

NOTES



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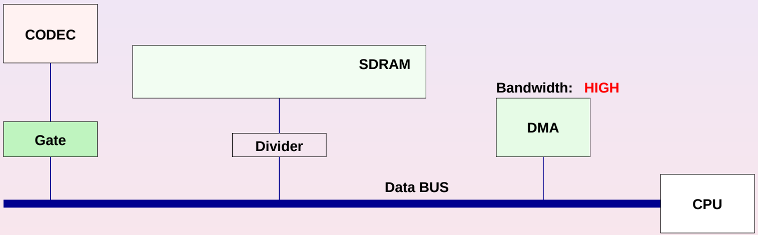

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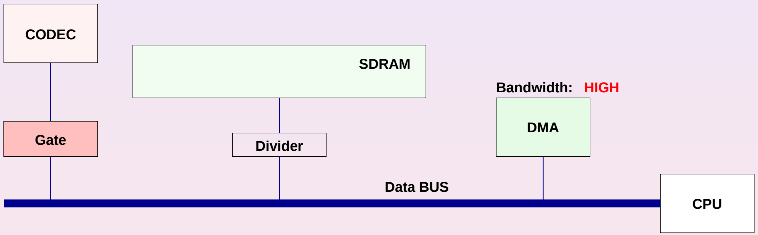

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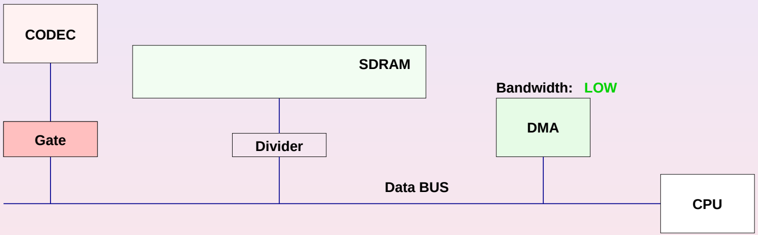


PATCHSET COMPOSITION

- `include/linux`: DPM data structure definition, and update of some subsystems (process scheduler, device and power management)
- `include/linux/asm-(arm|i386))`: platform dependant DPM definitions (e.g. task states, board dependant callbacks, . . .)
- `drivers/dpm`: platform independent DPM core implementation, DPM callbacks and userspace interface (as a subsystem: `/sysfs/dpm`)
- `drivers/base/power`
- `arch/(arm|i386)/kernel/cpu/dpm)`: processor dependent DPM's handlers (processor voltage and frequency scaling support)

DPM Entry Points

1. `assert_constraints`
2. `remove_constraints`
3. `set_operating_state`
4. `set_policy`
5. `set_task_state`

- first tree in kernel context only, the last two also in user context (syscall)
- different callers (device drivers, scheduler, event handlers, Policy Manager or user)

Robustness

- an OP is valid $\iff$ it satisfies all device constraints
- a CC is valid $\iff$ at least one of its OP is valid
- a P is valid $\iff$ map each OS into a valid CC/P

Given that the system is initially running on a valid policy P

DPM implementation ensure that the current P will never become invalid

Task State

- support for task-specific OP

  a policie maps task-states to CC/OP
- `struct task` embeds a task-state descriptor that could be used by the scheduler (`set_operating_state`)

  RT processes and high power processes may not be correlated (e.g. MP3 player)
- syscall (`set_task_state`) to allow user-space changes
- the special task-state "`no-state`" allow a new scheduled task to run on current policy

  useful for system threads (`keventd`, `softirqd_*`), and frequent short run process, to avoid short duratono changes on OP

Example Power Srategies

Static

- one P only
- each task-state mapped to a single CC
- no needs for a userspace power manager

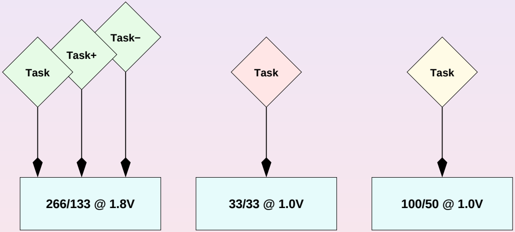
Simple Dynamic

- multiple (static) P
- use P settings to move the system throught OPs
- policy manager nedded

Task-State Dynamic

- like simple dynamic
- P associated to *“meta-info”* (e.g. battery level)
- *meta-info* changes trigger a P change

Static Power Srategy Example



Static Policy : no Policy Manager required

Dynamic Power Srategy Example

POLICY	TASK[−/+]	IDLE	IDLE−TASK
LowPower	OP_3	OP_0	OP_3
MediumPower	OP_4 OP_3	OP_0 OP_1	OP_3
HighPower	OP_5 OP_4 OP_3	OP_5 OP_2	OP_5 OP_4 OP_3

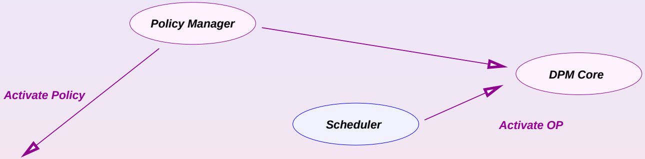
Dynamic Power Srategy Example

Policy Manager

Activate Policy

POLICY	TASK[−/+]	IDLE	IDLE−TASK
LowPower	OP_3	OP_0	OP_3
MediumPower	OP_4 OP_3	OP_0 OP_1	OP_3
HighPower	OP_5 OP_4 OP_3	OP_5 OP_2	OP_5 OP_4 OP_3

DYNAMIC POWER SRATEGY EXAMPLE



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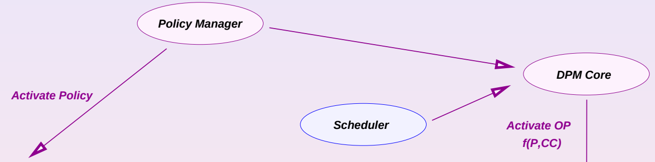

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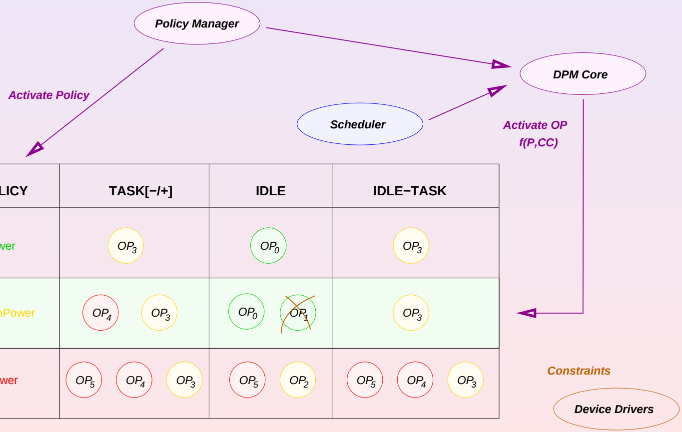
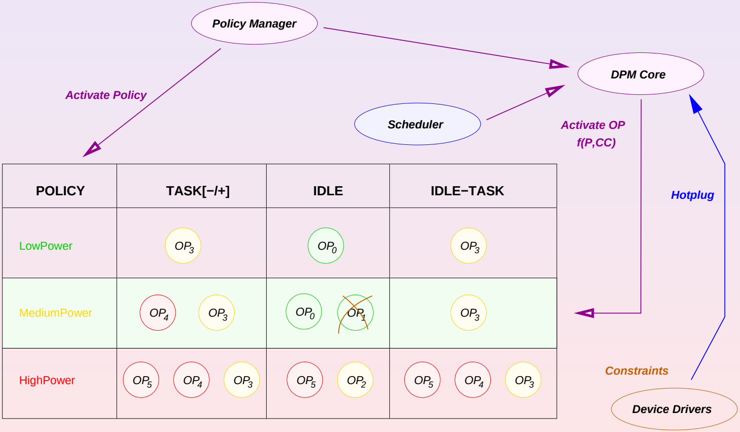


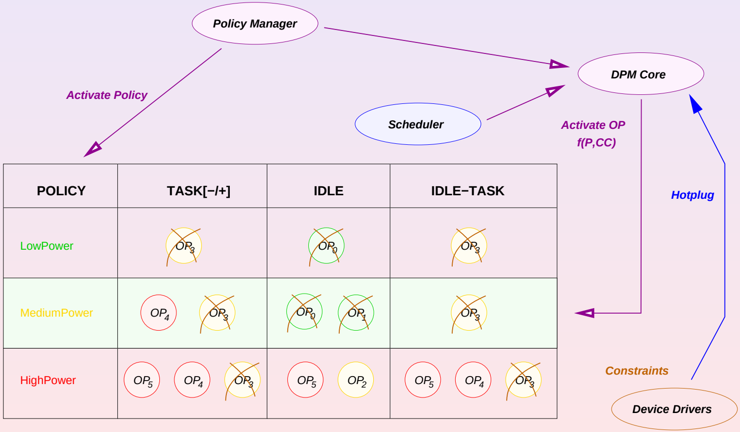
POLICY	TASK[−/+]	IDLE	IDLE−TASK
LowPower	OP_3	OP_0	OP_3
MediumPower	OP_4 OP_3	OP_0 $\cancel{OP_1}$	OP_3
HighPower	OP_5 OP_4 OP_3	OP_5 OP_2	OP_5 OP_4 OP_3

Dynamic Power Srategy Example



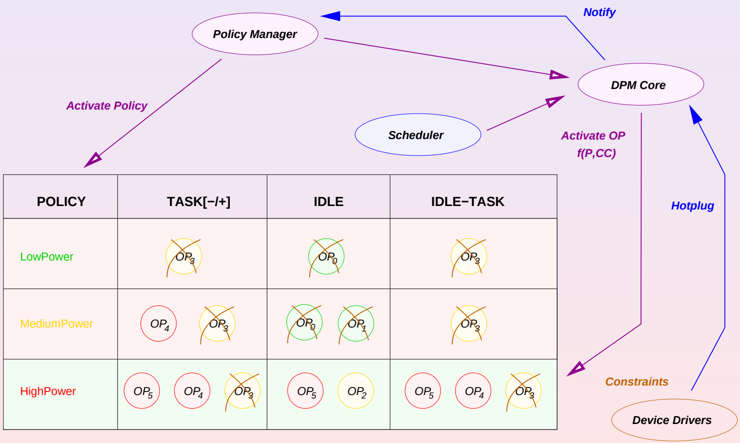
POLICY	TASK[−/+]	IDLE	IDLE−TASK
LowPower	OP_3	OP_0	OP_3
MediumPower	OP_4 OP_3	OP_0 $\cancel{OP_1}$	OP_3
HighPower	OP_5 OP_4 OP_3	OP_5 OP_2	OP_5 OP_4 OP_3

Dynamic Power Srategy Example



POLICY	TASK[−/+]	IDLE	IDLE−TASK
LowPower	$\cancel{OP_3}$	$\cancel{OP_0}$	$\cancel{OP_3}$
MediumPower	OP_4 $\cancel{OP_3}$	$\cancel{OP_0}$ $\cancel{OP_1}$	$\cancel{OP_3}$
HighPower	OP_5 OP_4 $\cancel{OP_3}$	OP_5 OP_2	OP_5 OP_4 $\cancel{OP_3}$

DYNAMIC POWER SRATEGY EXAMPLE



POLICY	TASK[−/+]	IDLE	IDLE−TASK
LowPower	~~OP_3~~	~~OP_0~~	~~OP_3~~
MediumPower	OP_4 ~~OP_3~~	~~OP_0~~ ~~OP_1~~	~~OP_3~~
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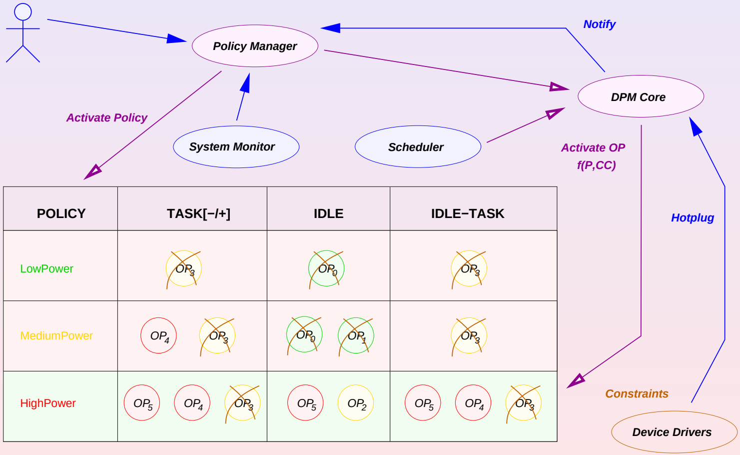
DYNAMIC POWER SRATEGY EXAMPLE



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LowPower	$\cancel{OP_3}$	$\cancel{OP_0}$	$\cancel{OP_3}$
MediumPower	OP_4 $\cancel{OP_3}$	$\cancel{OP_0}$ $\cancel{OP_1}$	$\cancel{OP_3}$
HighPower	OP_5 OP_4 $\cancel{OP_3}$	OP_5 OP_2	OP_5 OP_4 $\cancel{OP_3}$

Userspace Interaction

- Sysfs support for OP, CC and Policy management
- hotplug events generation (on constraints changes, policy update, . . .)
- userspace (hotplug) power agent (could dinamically manage policy using the sysfs interface)
- userspace tools for initial configuration and runtime policy management

THE SYSFS INTERFACE

- Operating Points definition (`/sys/dpm/op/control`)
  syntax: *create <OP_name> [<OP_param>...]*
- Classes definition (`/sys/dpm/class/control`)
  syntax: *create <Class_name> [(<OP>)...]*
- Policies definition (`/sys/dpm/policy/control`)
  syntax: *create <Policy_name> [(<OP>|<CC>)...]*
- Active policies management
- DPM subsystem management (init, enable, disable)

Example of OP params for NDK10

System Clock Source (SCLK/CLK)

PLL, Low Speed Oscillator or High Speed Oscillator

PLL1 Multiplier (HCLK)

SDRAM frequency

PLL2 Gating

devices control

OP changes trigger a NDK run mode change or simply activate/deactivate some devices

The End