Benchmarking of Dynamic Power Management Solutions

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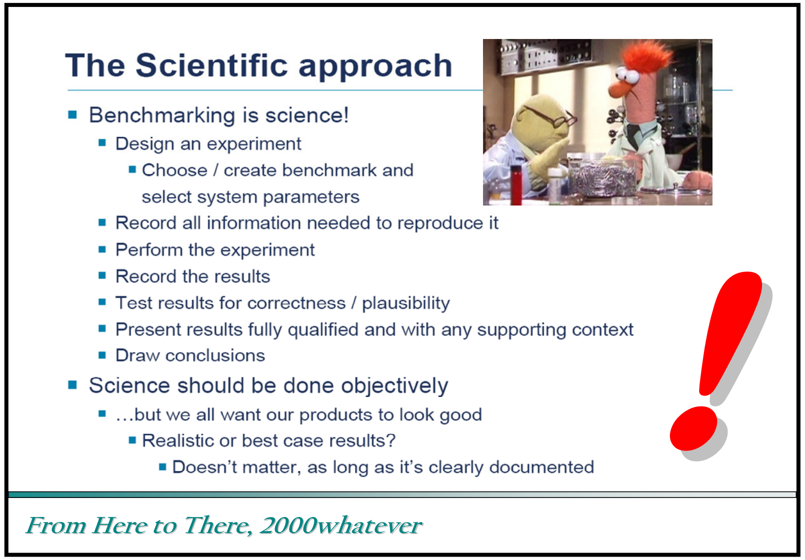
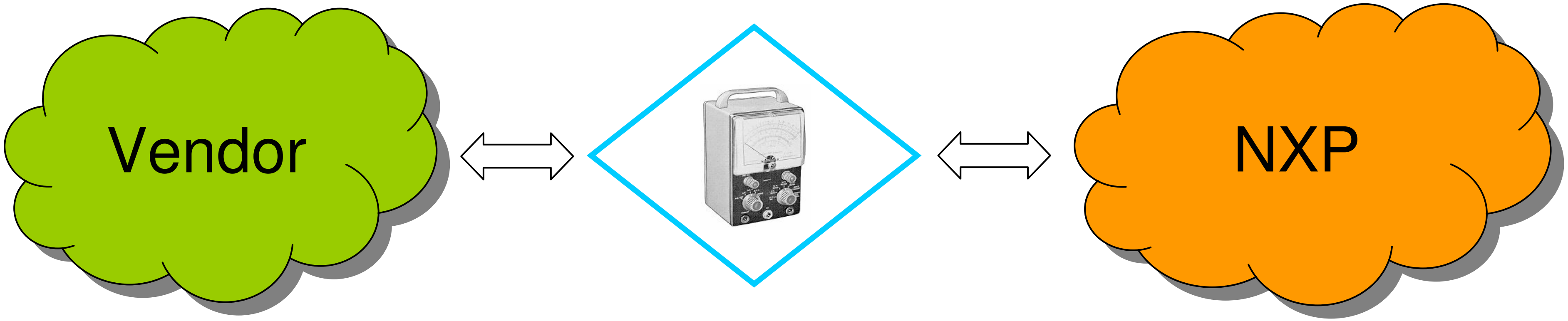
Why Benchmarking?



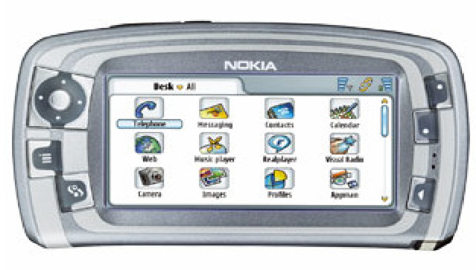


What do we get?

Presentation Outline:

- The context;
  - Power management concepts.
  - Hardware and software.
- Benchmarks;
  - The process.
  - Metrics.
  - Findings.
- Conclusions.
  - Relation to other work.
  - What’s next.

Area Of Interest

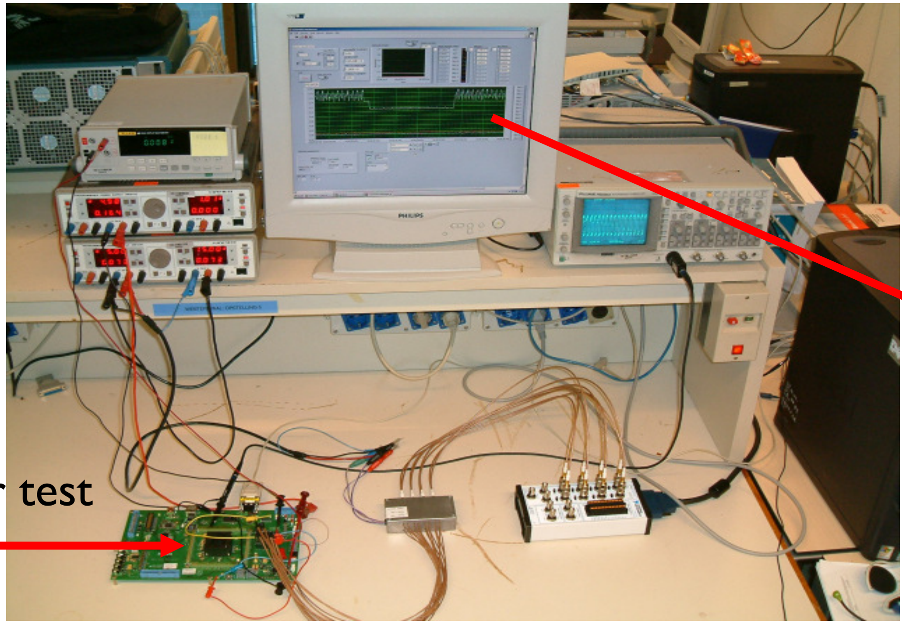


- Mobile/portable devices mostly exist of:
  1. Battery.
  2. Storage (flash disk, hard disk, …).
  3. Display (LCD, …).
  4. Speaker.
  5. Broadband I/O (Bluetooth, UMTS, …).
  6. Processing (CPU)

- We are initially only focusing on the optimization of the “Processing” power consumption.
  – As next, we are also taking 1-5 into account.

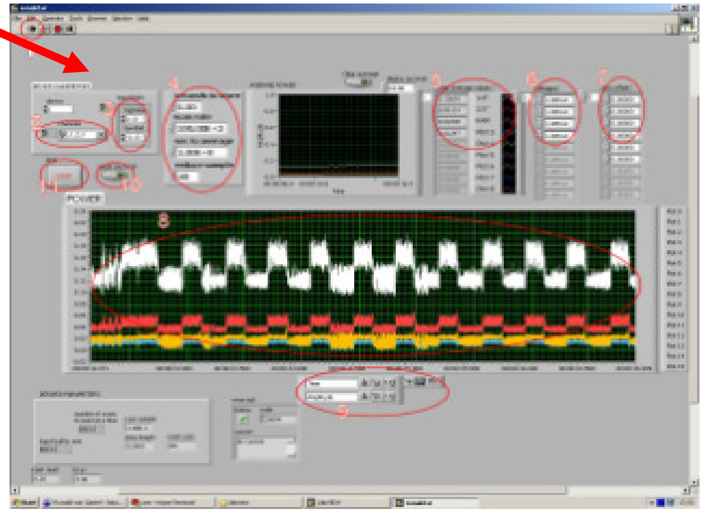
Power Measurements

A board under test



Measurements equipment: high precision DMM (digital Multi-Meters)

LabView



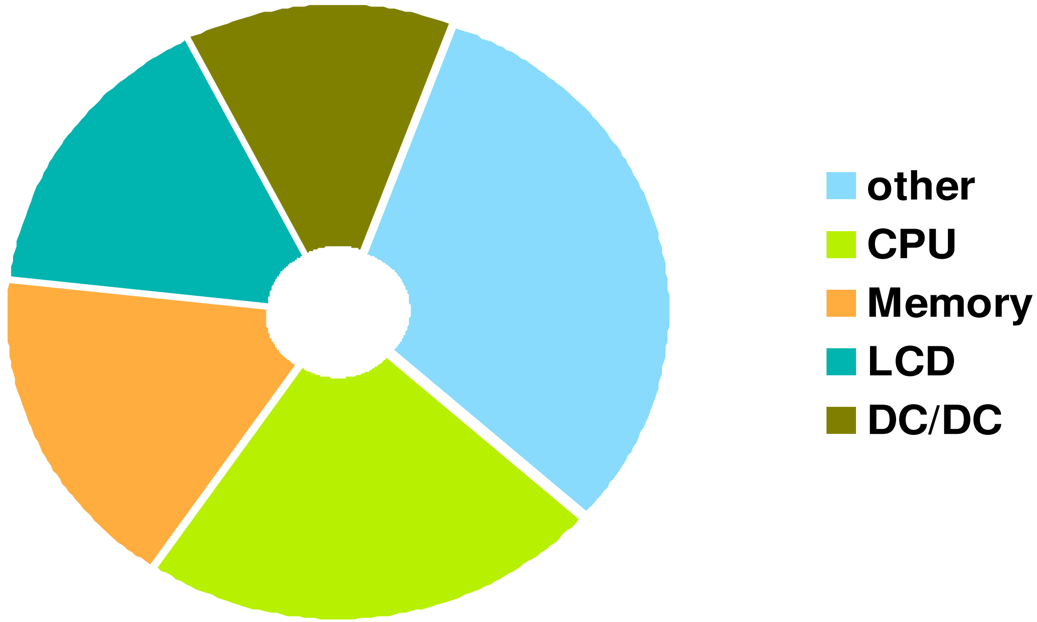
Mp3 playback – LabView measurements

Energy Consumers

- Energy saving methods trade performance or functionality for energy:
  - Scaling performance of processors, memories and buses;
  - Using various stand-by modes of peripherals.

- Energy saving is about supplying the right amount of performance at the right time.

- However, the future is unknown!



Energy consuming components in a typical audio/video playing mobile device.

Power Dissipation Basics

$$E = \int_0^t (C(V_{DD})^2 f_c + V_{DD} I_Q)dt$$

Total Power Dissipation

$$\int_0^t C(V_{DD})^2 f_c$$

Dynamic Power Dissipation

\+

Leakage Power Dissipation

$$\int_0^t V_{DD} I_{lkg}$$

- **Reduce capacitance switched.**
- **Reduce switching currents.**
- **Reduce operating voltage.**

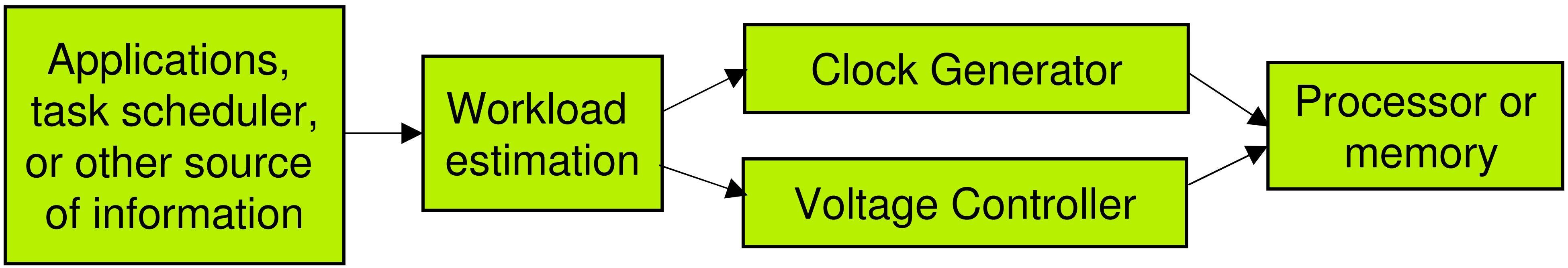
- **Reduce leakage current in active and standby modes of operation.**
- **Reduce operating voltage.**

Dynamic Voltage Frequency Scaling (DVFS)

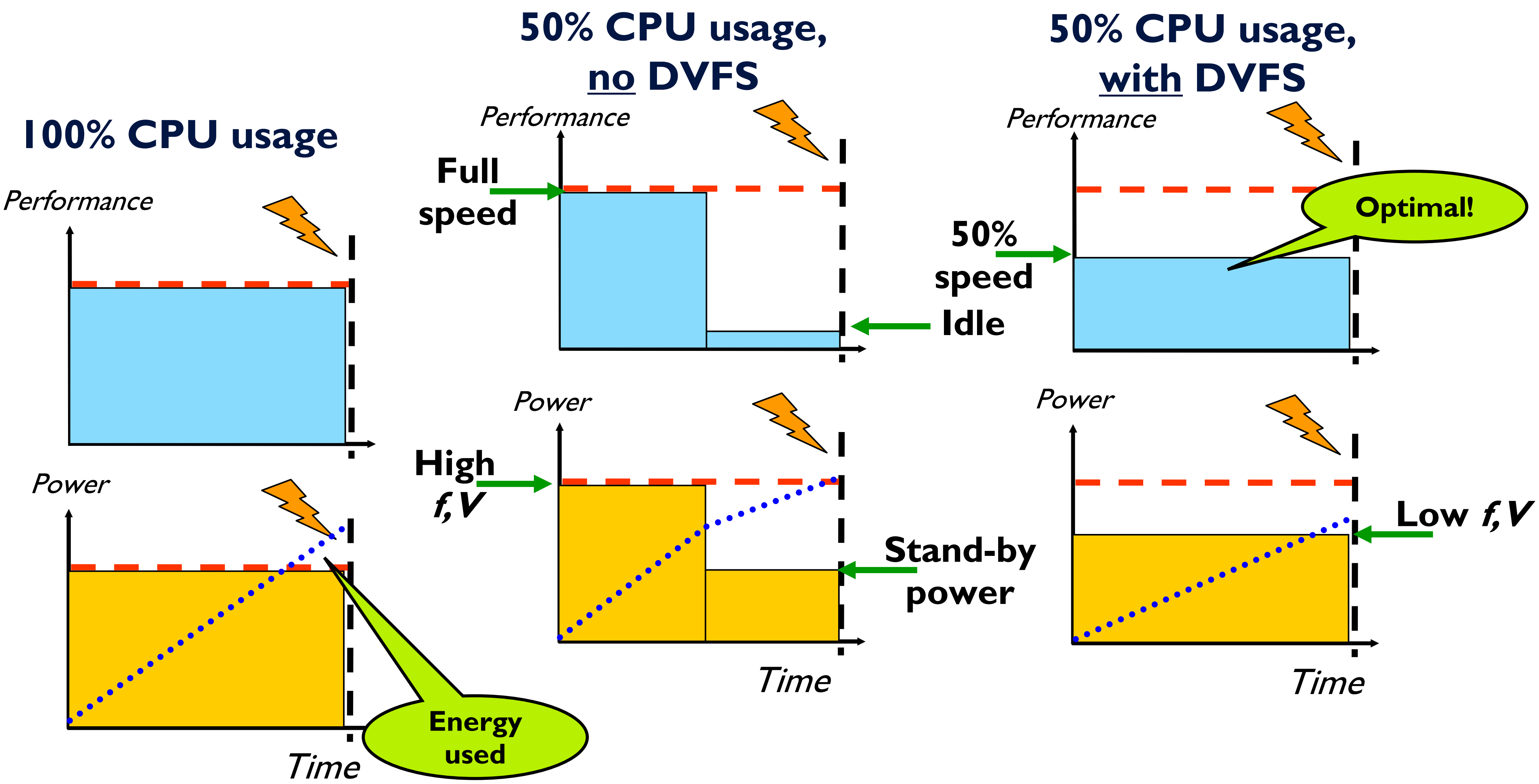
- Scales performance according to demand (using an estimation of future workload).
- Based on the fact that energy per clock cycle rises with frequency:

$$P \mathrel{\hat{=}} V^2 \cdot f$$

- Implemented by switching between **operating points** (voltage and frequency pairs).

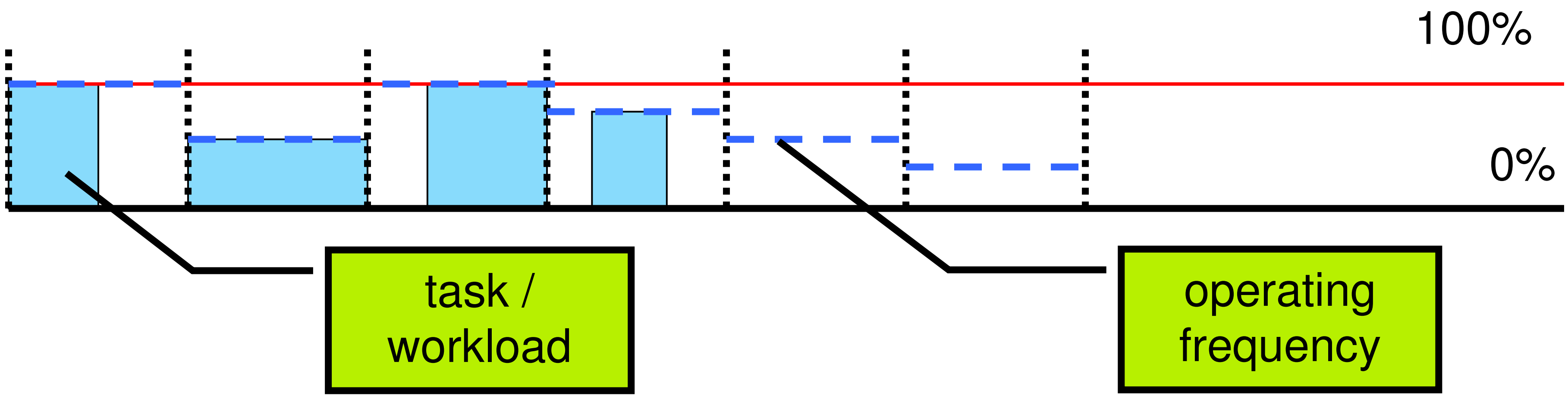


DVFS: How Does it Save Power

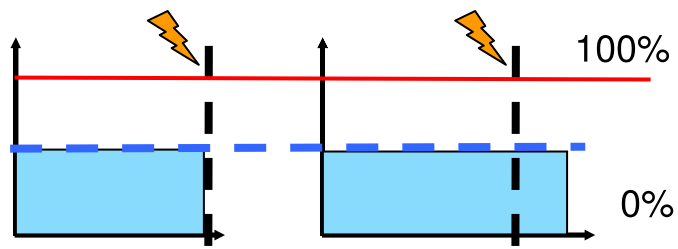


Performance Prediction Methods

Interval-based: use CPU-usage of previous interval(s) to determine frequency for next interval.

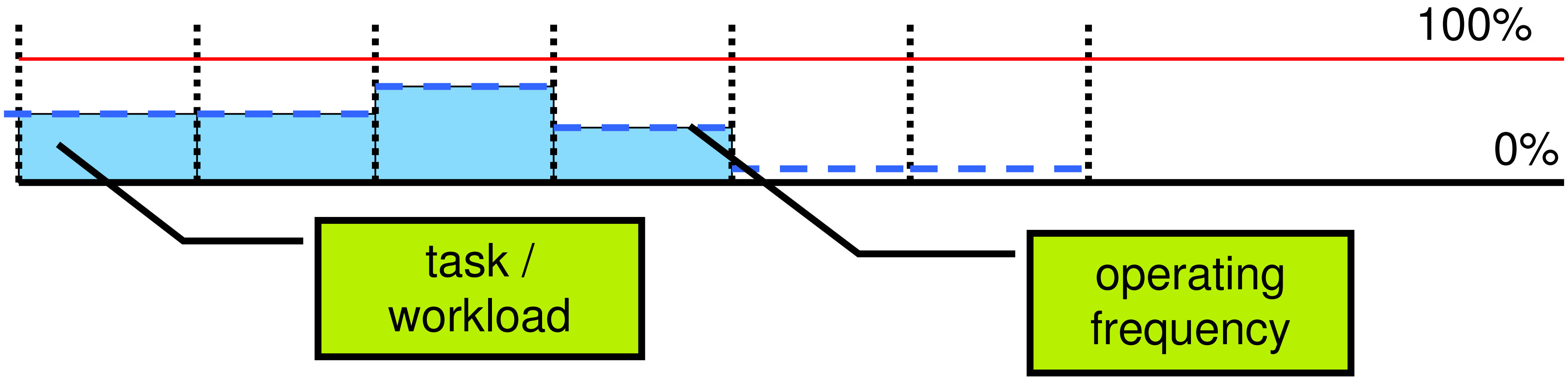


Problem: late reaction on changing workloads → missed deadlines



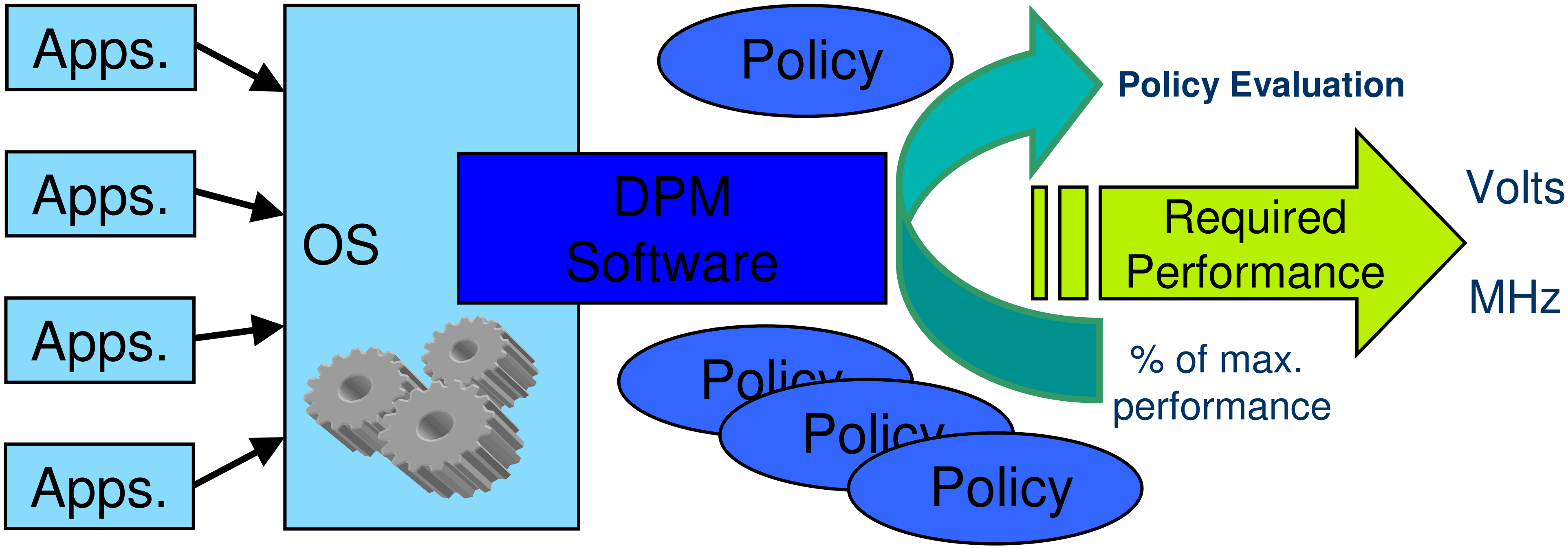
Performance Prediction Methods

Application-directed: use information from the application to change frequencies.



Problems: requires changes in the application; not always possible (interactive applications).

Dynamic Power Management (DPM) Concept



- DPM software connects to OS kernel and collects data,
  - with collected data, and usage of policies, try to predict future workload.
- Multiple policies categorize software workload.
- Single global prediction of future performance is made.

Application directed DVFS

- Two main groups of mobile applications:

Interactive

- Internet browsing
- Gaming

Future workload unknown (depends on user input)

Streaming

- Audio decoding
- Video decoding

Future workload known to application

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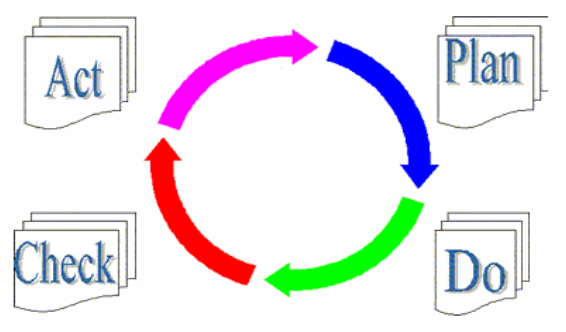
Benchmark Process

- Plan:
  - Define Key Performance Indicators (KPI).
  - Define test to measure KPI.
- Do:
  - Measurement on evaluation platform.
- Check:
  - Analyze gained results and can they be explained.
  - When necessary, cross verify with Vendor.
- Act:
  - Take necessary actions on gained results.



Key Performance Indicators (KPI)

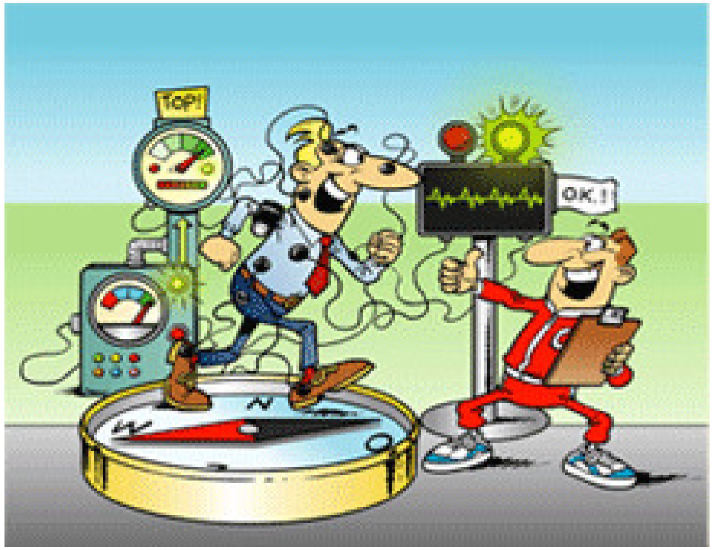
- Memory usage.
  - Footprint of DPM framework and administration.
- CPU usage.
  - Cycles consumed by DPM framework.
  - System behavior, predictability & reproducibility.
- System idleness.
  - Prediction of optimum frequency (minimization of idleness).
- Real time behavior.
  - Application deadlines missed.
  - Responsiveness (latency on events).
  - DPM Policy prediction accuracy.

Test / Use Cases

- Synthetic (fine-grained) benchmark,
  - Simulate different workload levels,
  - Test corner cases.
    - LMbench as available from Open Source; lat_proc, lat_syscall, memory, clock, idle, …
- Application level (coarse-grained) benchmark:
  - Whetstone & Dhrystone (artificial system load).
  - Hartstone (real time behavior).
- Video decoding,
  - ffplay mpeg video decoding use case.
    - use *ffplay*, part of *ffmpeg*.
- Audio decoding,
  - mp3 audio decoding use case.
    - use ARM MP3 decoding library.

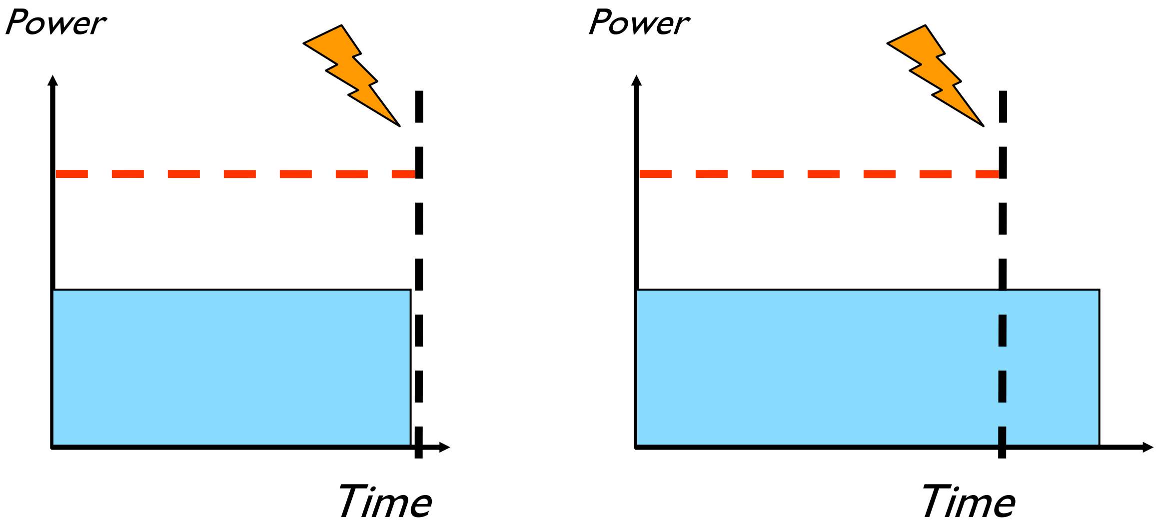
Metrics for SW based Benchmarking

- Missed deadlines;
- Overdue time;
- Idle time;
- Jitter;
- Responsiveness.



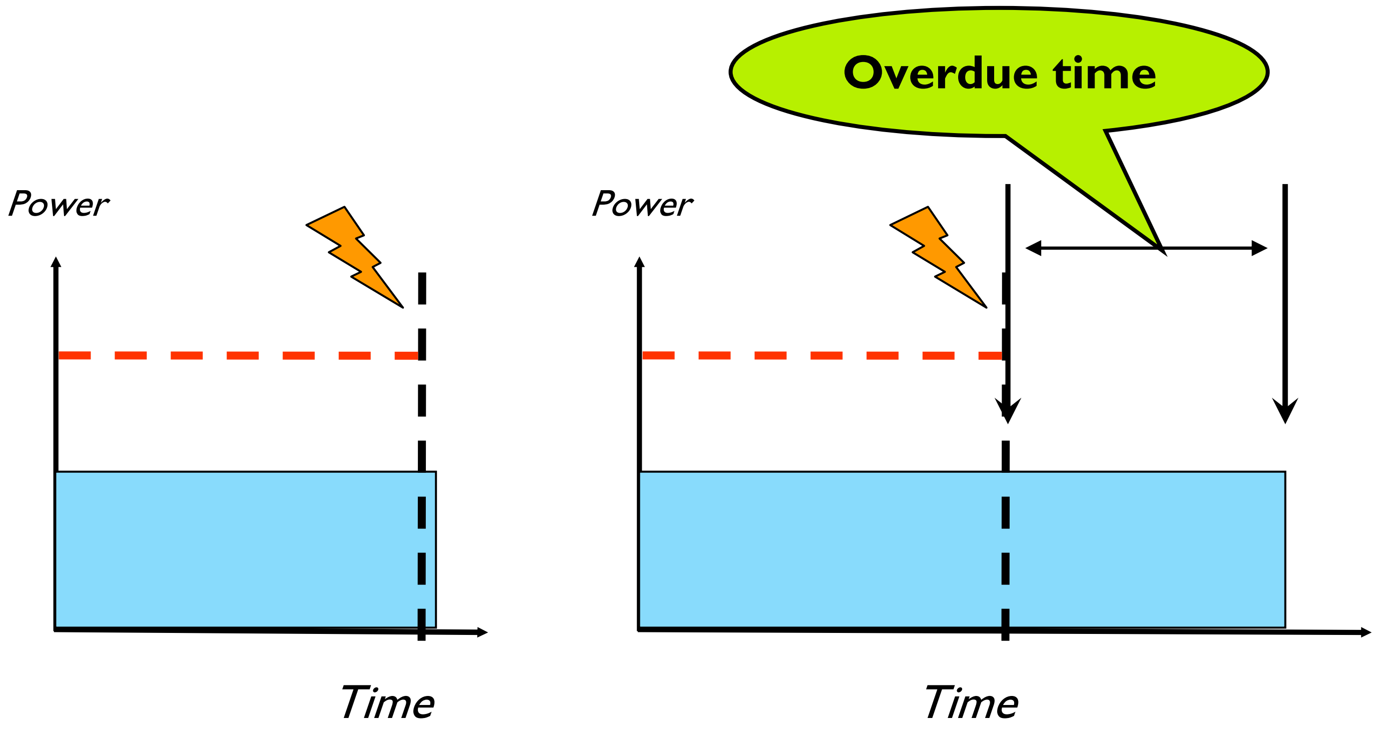
Missed Deadlines

- When operating frequency is too low, deadlines are missed:



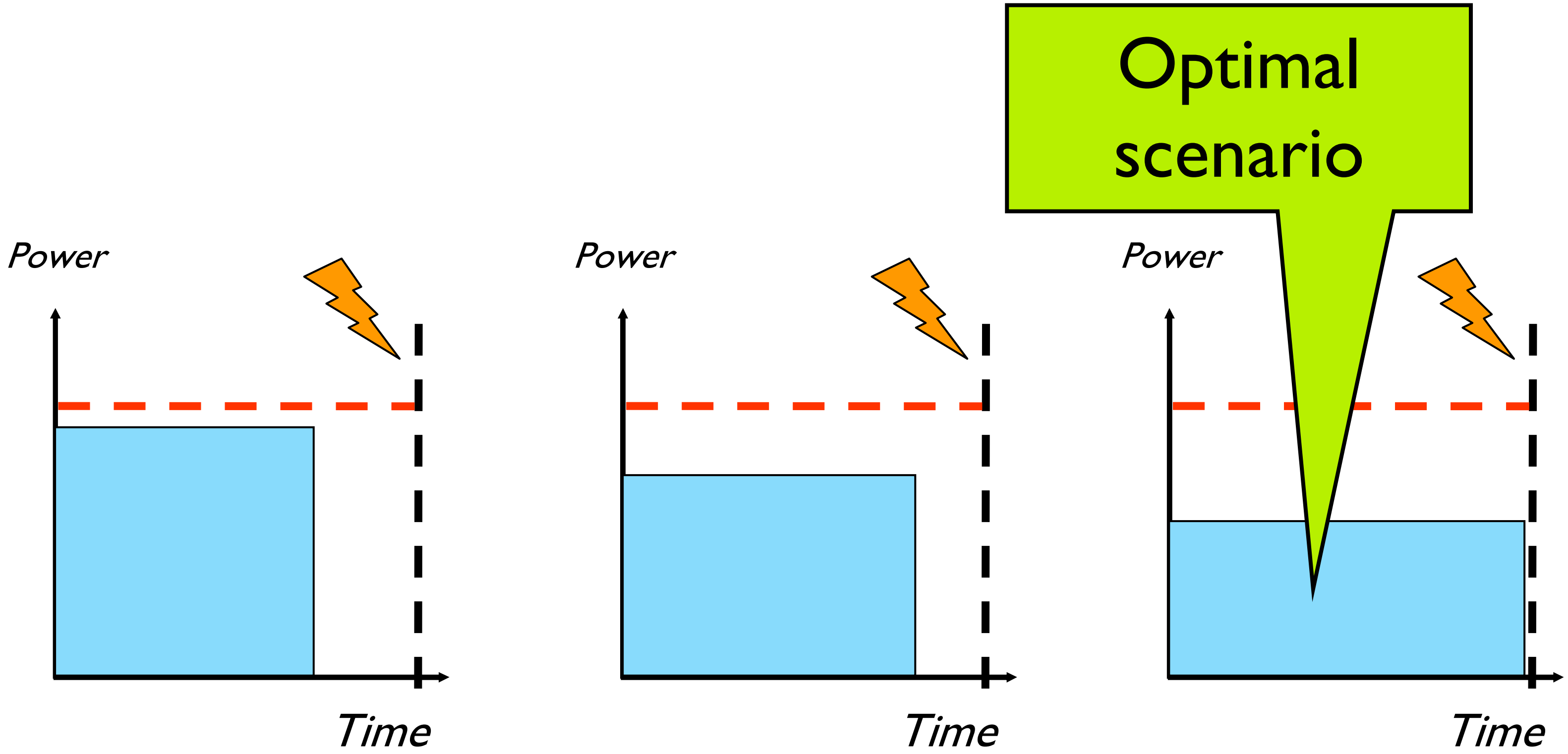
Overdue Time

- Are missed deadlines caused by timing inaccuracy, or by performance deficiency?



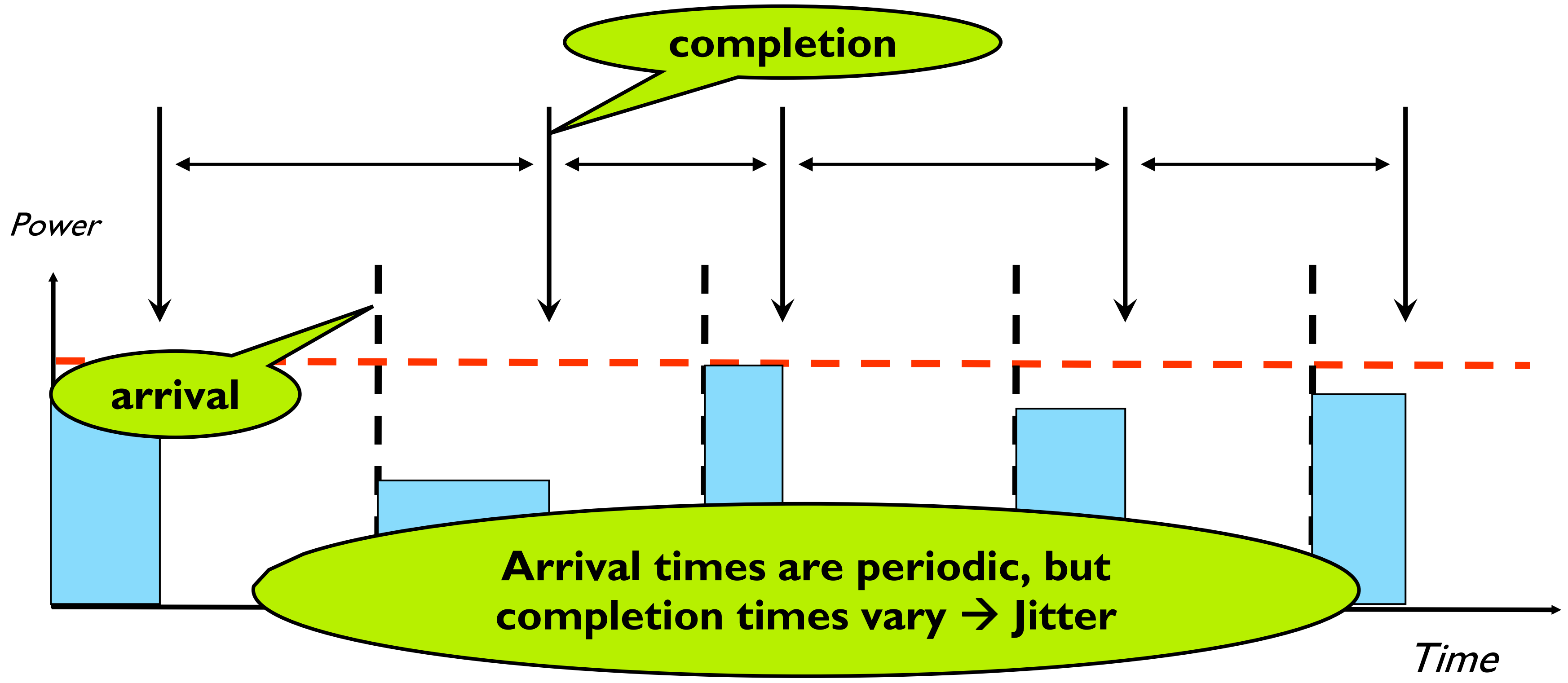
Idle Time

- When operating frequency is too high, extra slack time is introduced, and power is wasted:



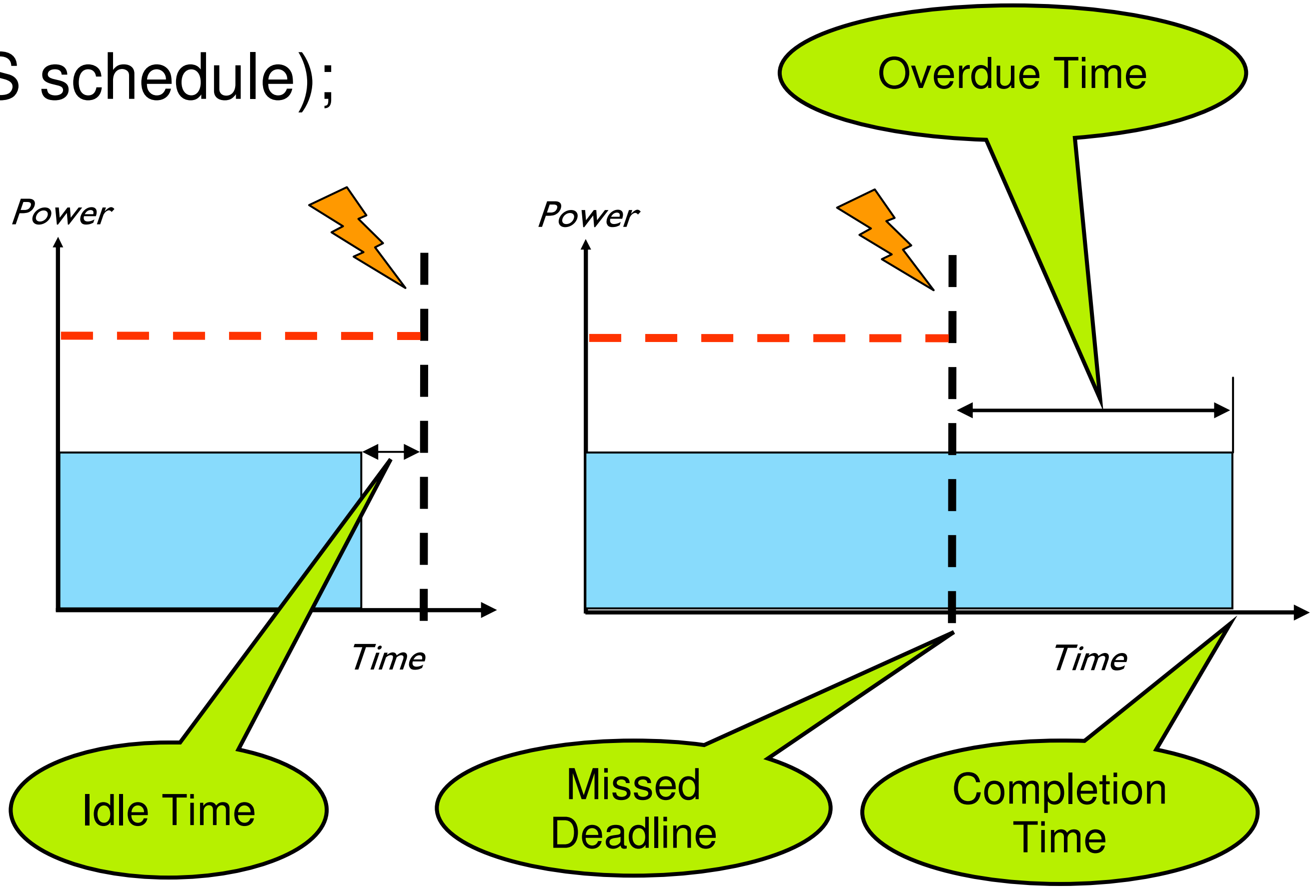
Jitter

- Execution times vary, so time of completion varies as well:



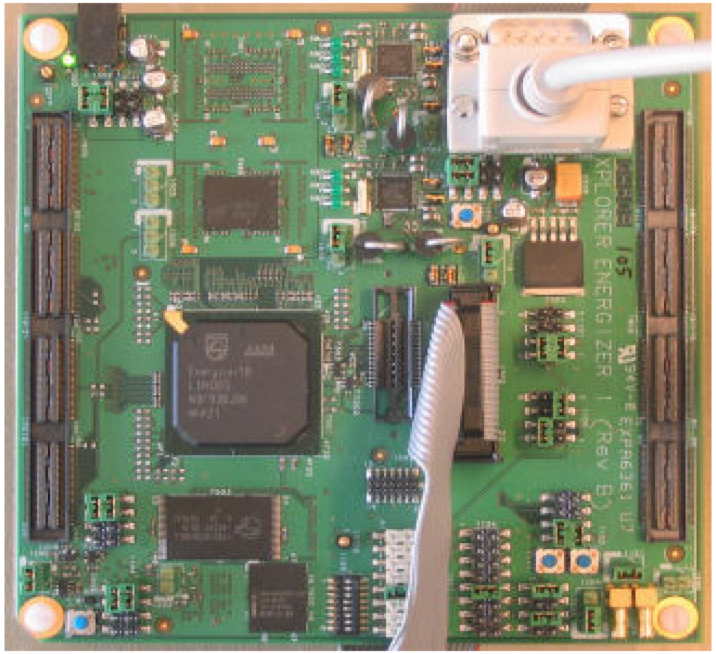
In Summary, DPM Metrics

- Missed deadlines (OS schedule);
- Overdue time;
- Idle time;
- Jitter (fluctuation in Completion time);
- Responsiveness.



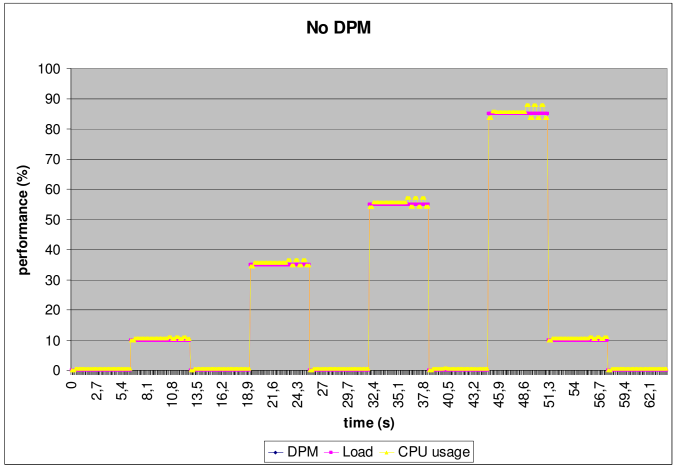
NXP's DVFS Benchmark Platform

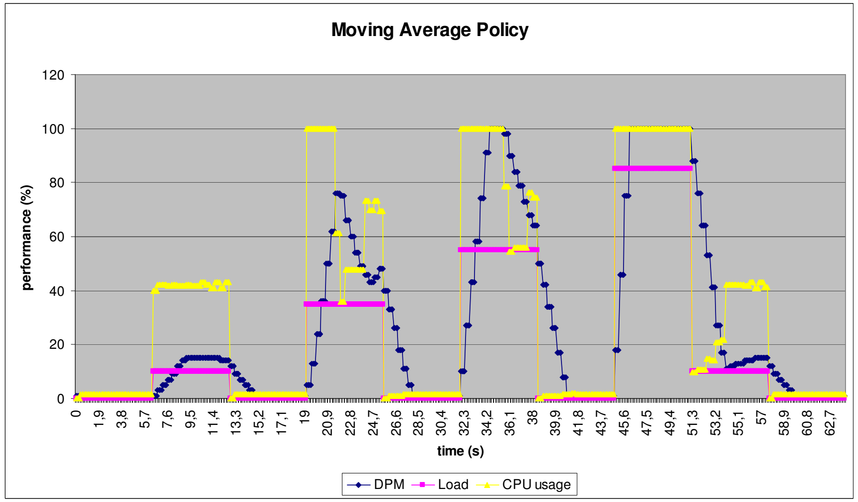
- Energizer I SoC;
  - ARM1176JZF-s,
  - DVFS-enabled (core also),
  - CPU voltage can be set in 25 mV increments,
  - CPU frequency can be set using 2 PLL's (300MHz and 400MHz by default) and a divider.
- Energizer I Software;
  - Linux 2.6.15,
  - CPUfreq and PowerOP.
  - MV's DPM framework ported but not used.

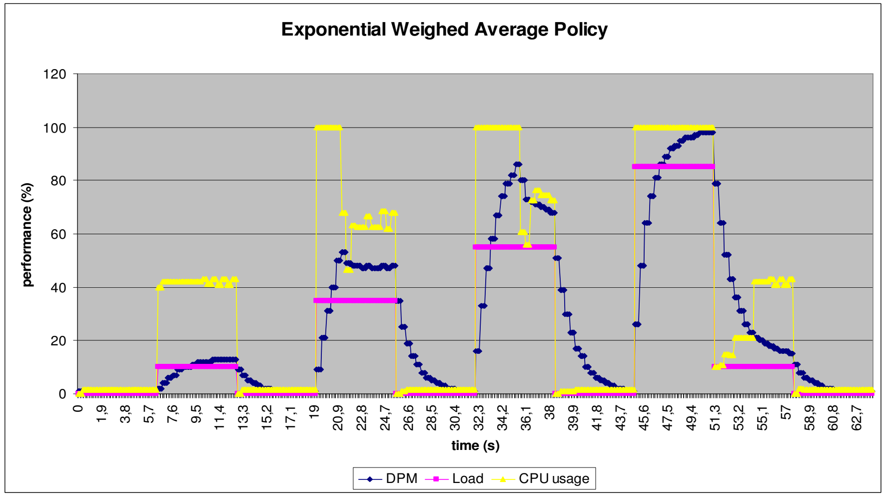


CPU Usage Characteristics

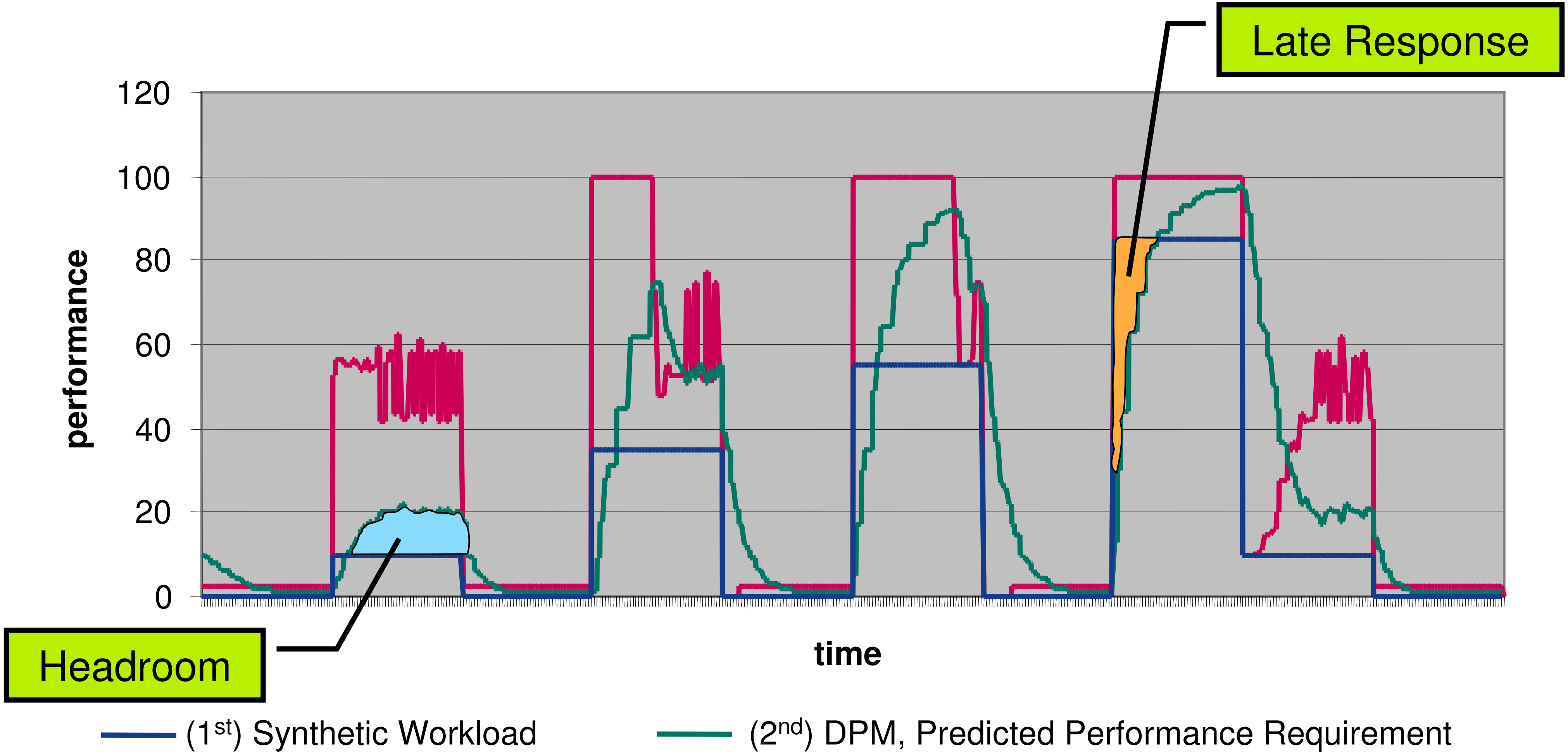
- CPU usage,
  applied policy reacts slow
  on required performance.







DPM; Synthetic Workload



(*Exponential Weighed Average Policy*)

Application Level Benchmark

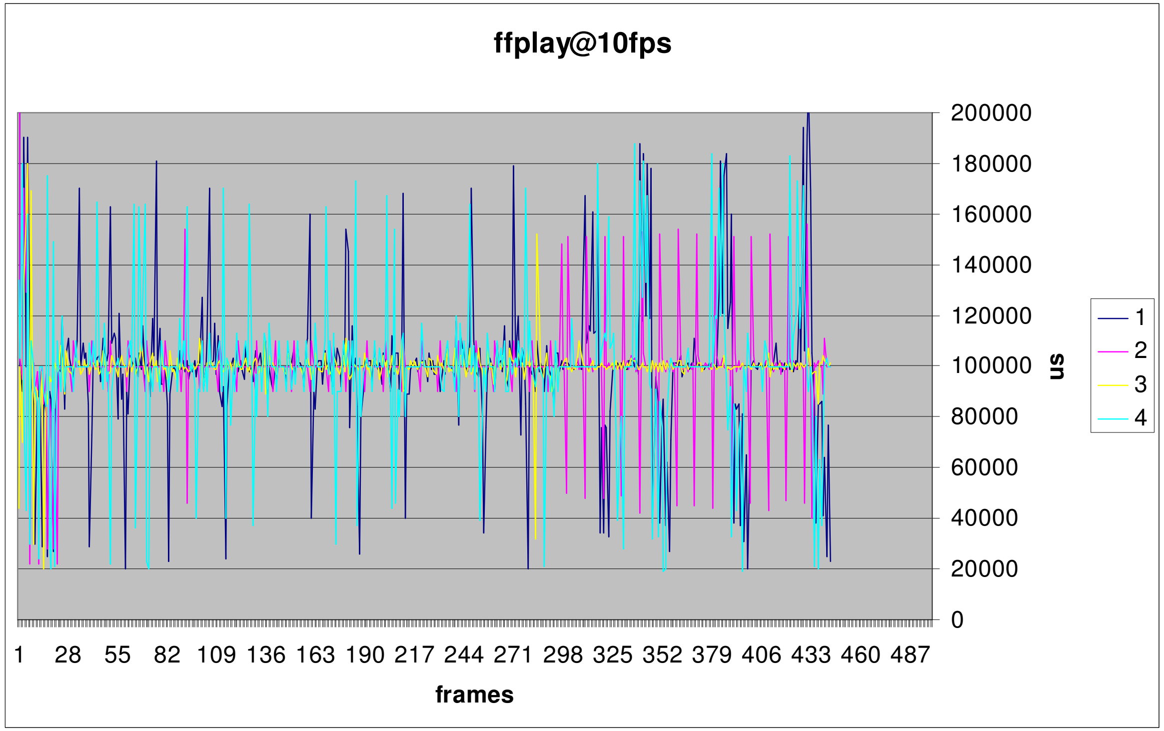
- Video playback (DivX).
  - Open-Source ffplay using frame-buffer device.
  - Instrumented with time measurements.

- Evaluation:
  - How many hard deadlines are missed with & without DPM.

ffplay Deadlines

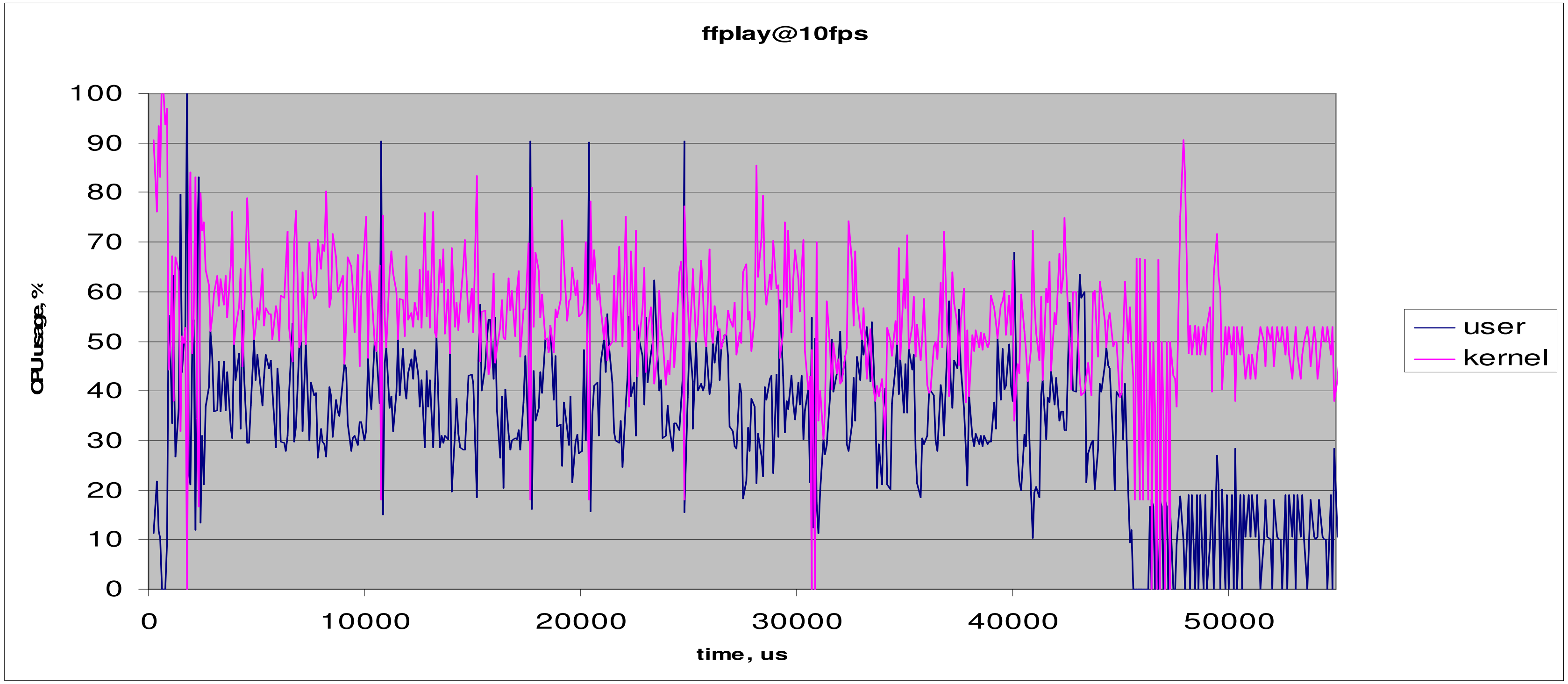
- ffplay deadline: time interval in between displaying of successive (decoded) frames.
  - For 10 fps movie -> the deadline is 100 ms.

- With DPM activated, fluctuation increases.
- **REMARK**: video output (display) on CompactPresen-ter via Compact flash interface, results in high fluctuation oops !! (see next slide).

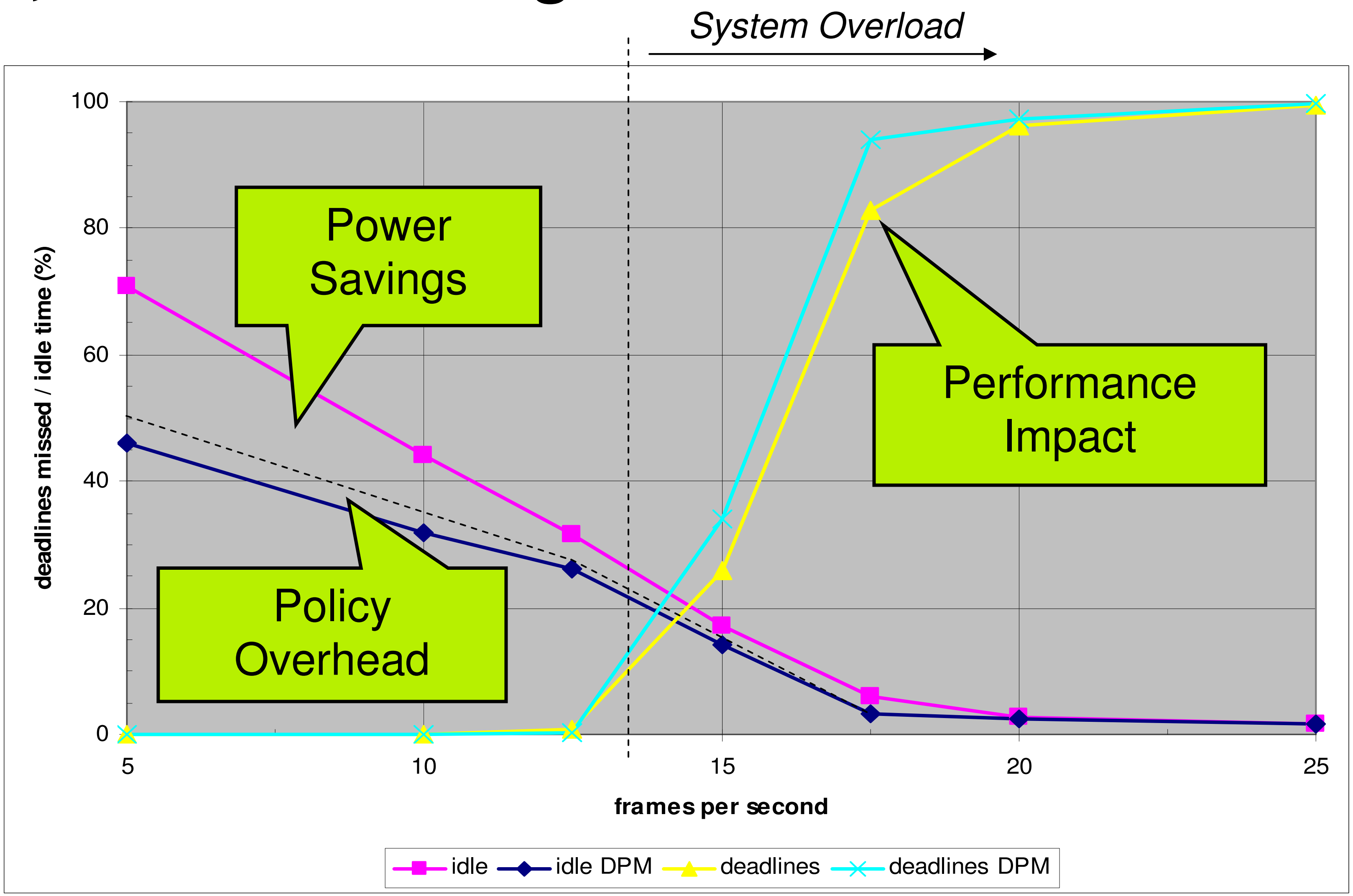


Kernel & User Space Activity

- While running ffplay, sample the CPU activity in both kernel and user space (based on /proc/stat).
- Kernel activity dominates during the video playback.

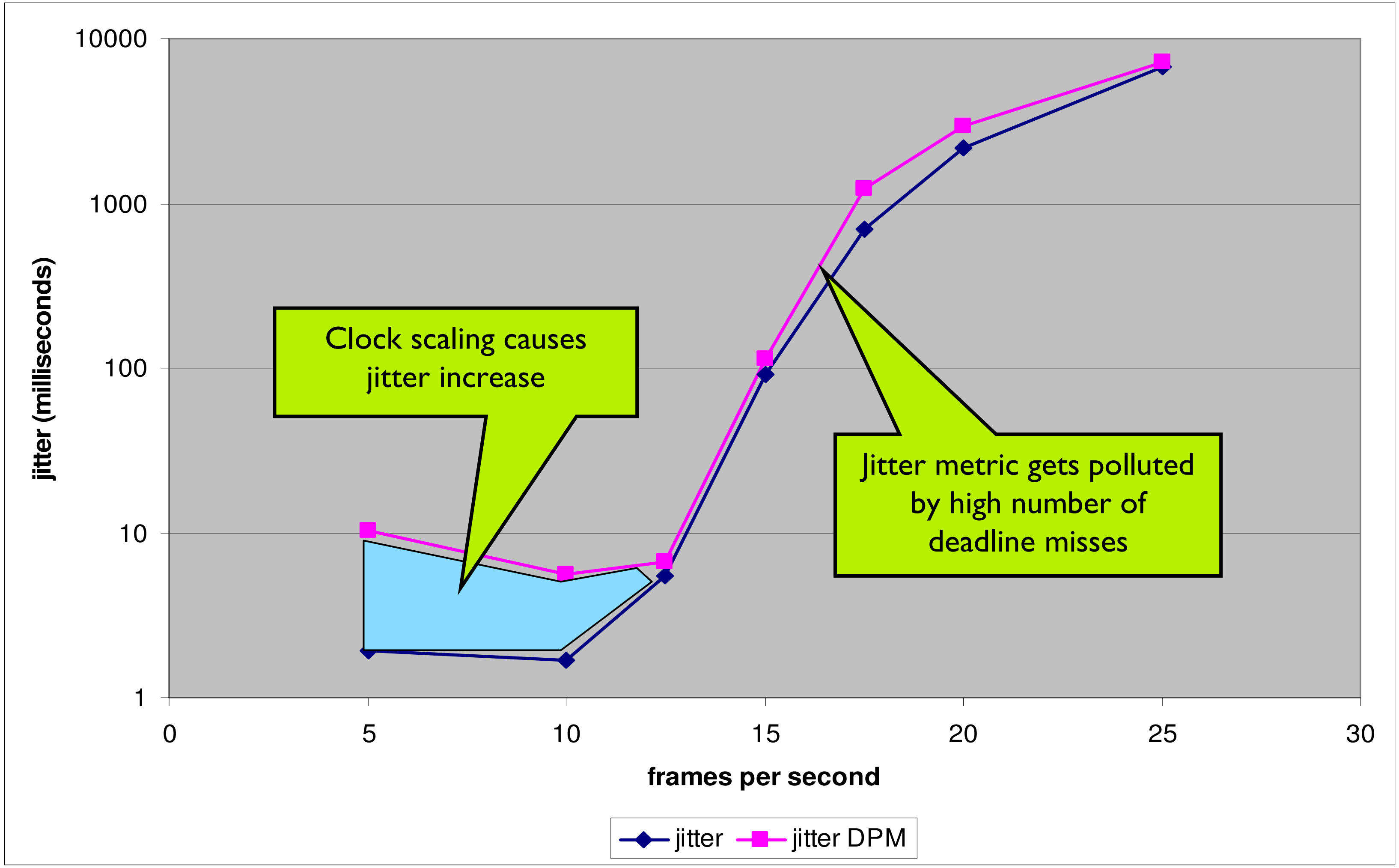


DPM; Video Decoding

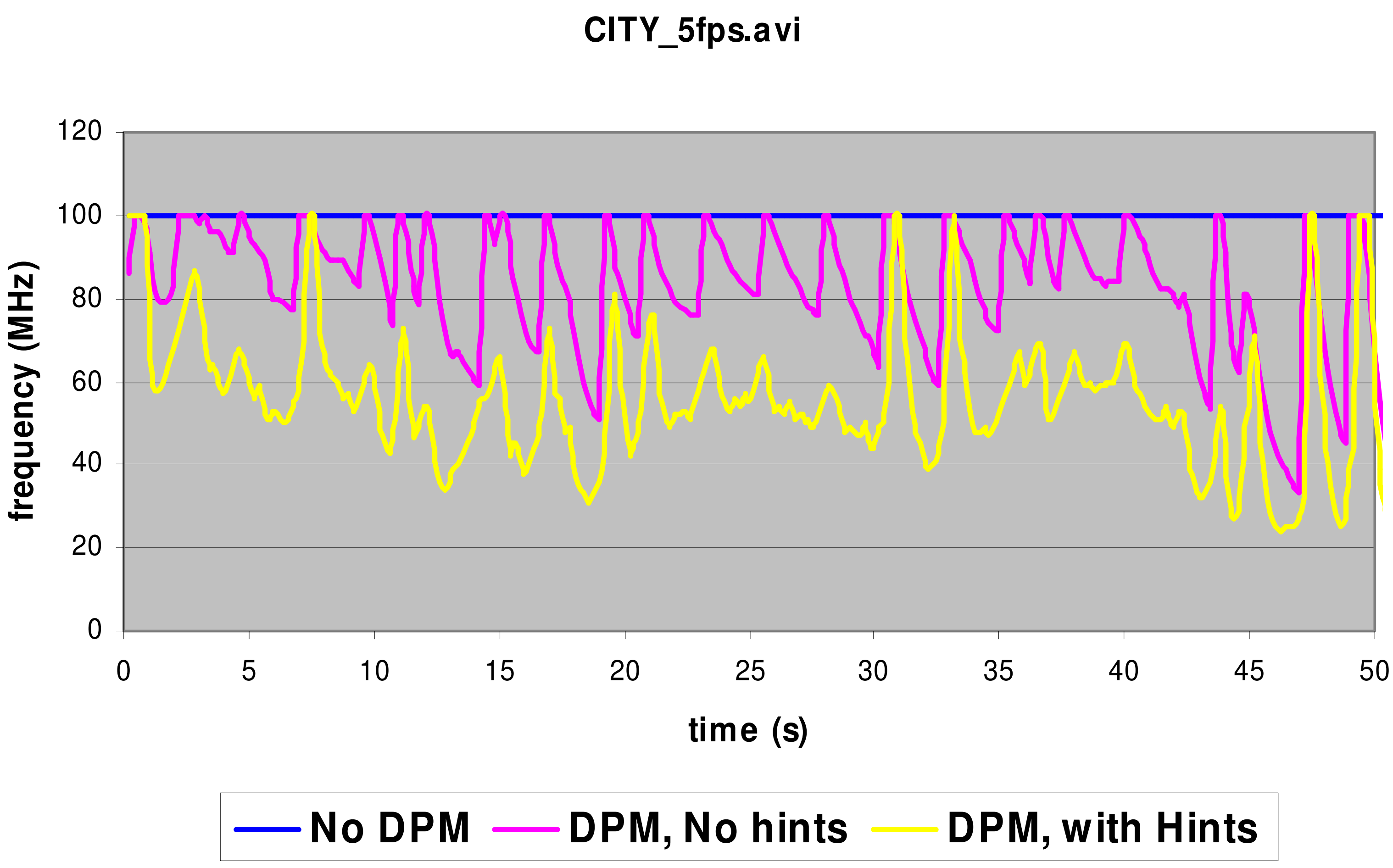


(*Exponential Weighed Average Policy*)

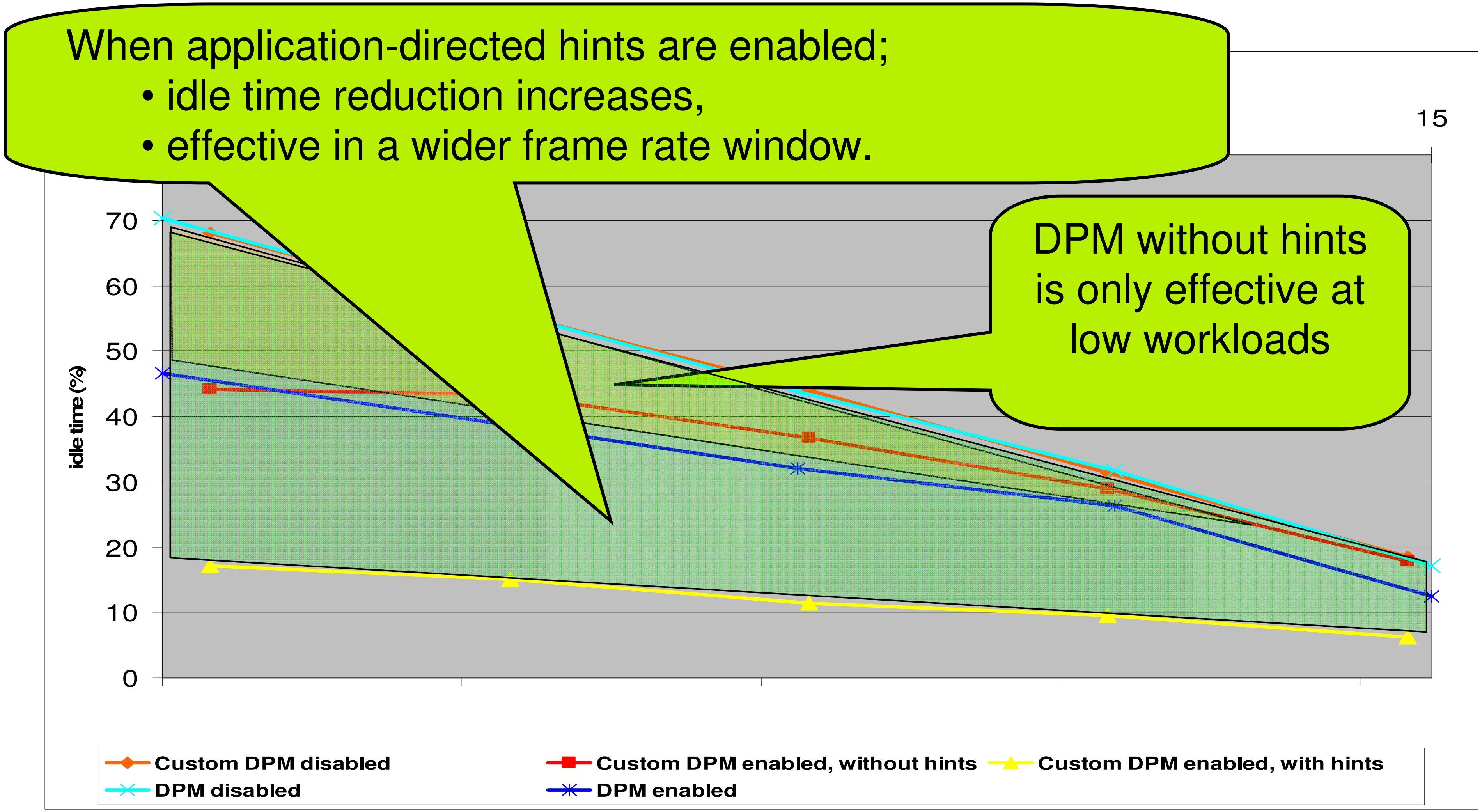
Video Decoding Jitter



Video Decoding and Hints



Comparison



When application-directed hints are enabled;
• idle time reduction increases,
• effective in a wider frame rate window.
DPM without hints is only effective at low workloads
15
70
60
50
40
30
20
10
0
idle time (%)
Custom DPM disabled
Custom DPM enabled, without hints
Custom DPM enabled, with hints
DPM disabled
DPM enabled

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Technology Conclusions

- Dynamic Power Management (DPM).
  - Added value is in policies.
  - Performs best on low workloads.
  - Adaptation to changing workload is heavily dependent on chosen policy.
  - As application developer, you have to develop your own policies.
  - Be aware, policy adds overhead.
- Applications cannot feed data directly into DPM.
  - Performance prediction based on logging application history does not always work.
  - The best performance prediction may come from the application itself (feed forward)!
  - Hinting can give improvements over an interval based approach.

Conclusions

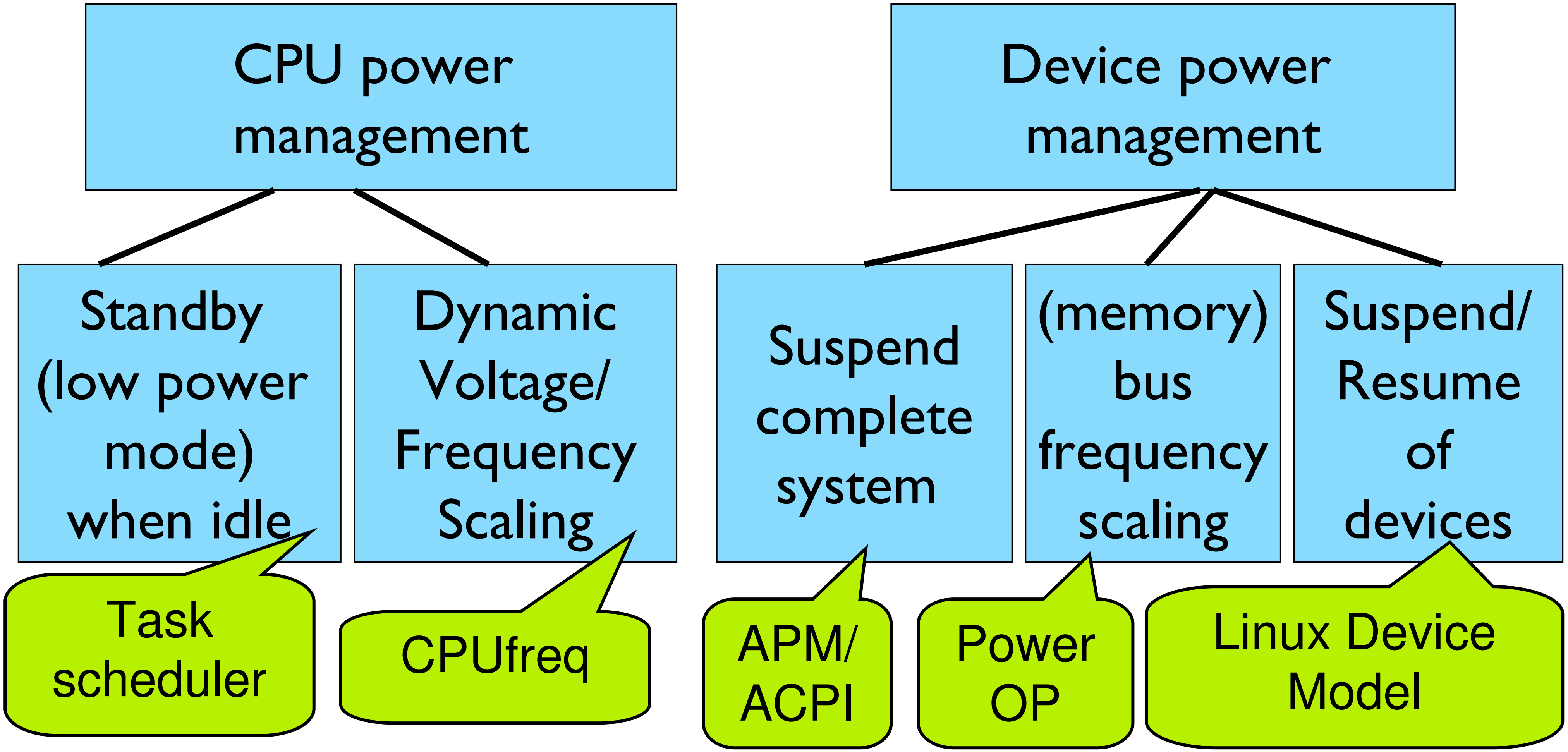
- Interval based DPM at CPU-level results in higher CPU utilisation, but seems only really effective at low workloads;
- Precise energy saving figures should be measured using HW measuring tools, but SW benchmarks give good insight in saving potentials and consequences on real-time behaviour.
- SoC is not the biggest power consumer.
  - Backlight, DC/DC converters & power amplifiers are big consumers, by optimizing these, most can be gained.

What's Next

1. CELF (you guys), MIPI PM working group
   - Matt Locke and his team
2. Mode switching.
3. Correlation between hardware and software;
   - What to solve at which level?
4. Deadline based scheduling, from priority based to time based.
5. Start contributing to the Community on this.

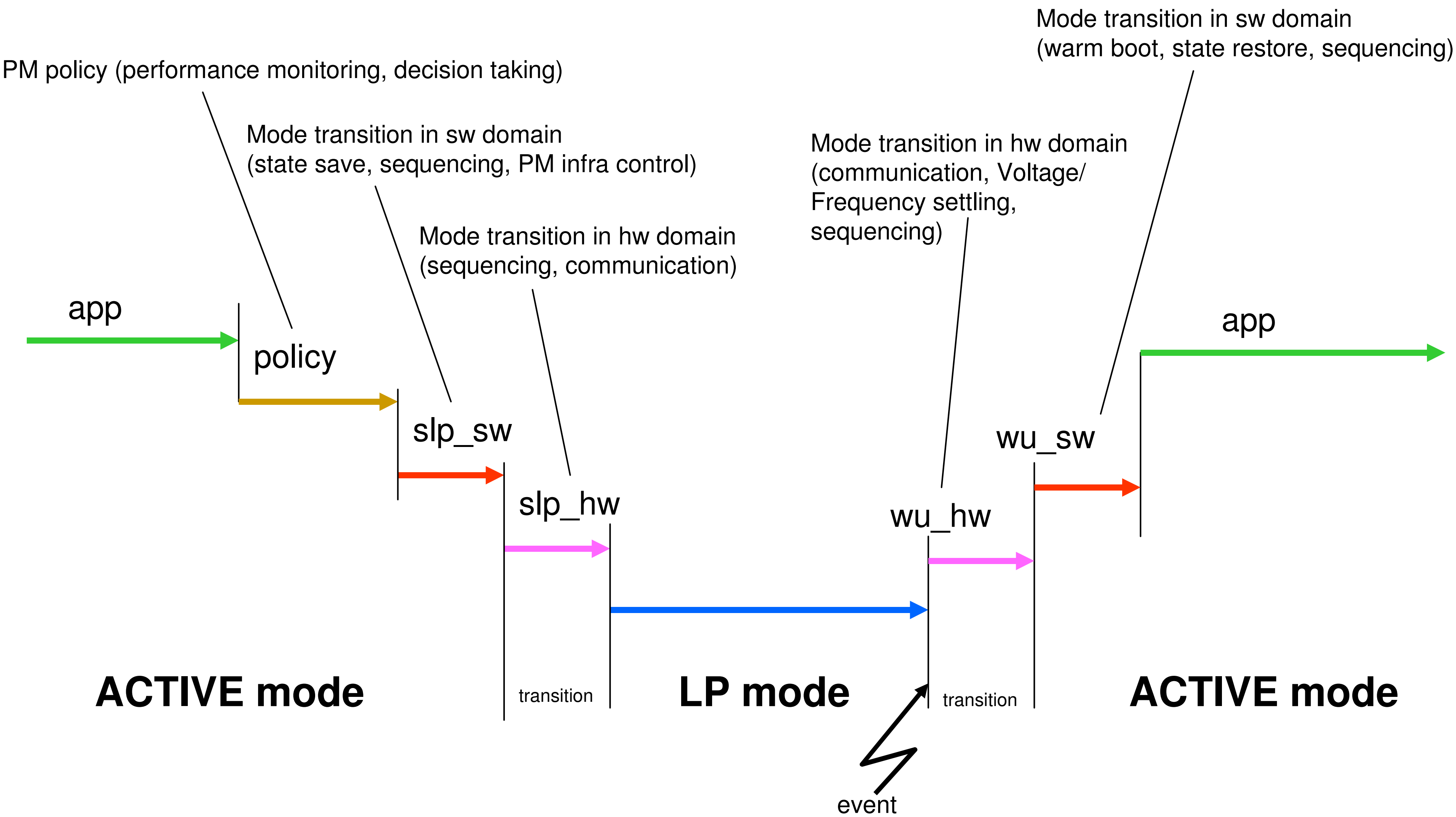
Regarding bullet 1, 2 & 3, see extra slides

Overview of Open Source Power Mgt. Software



(*also look at Mark Gross presentation*)

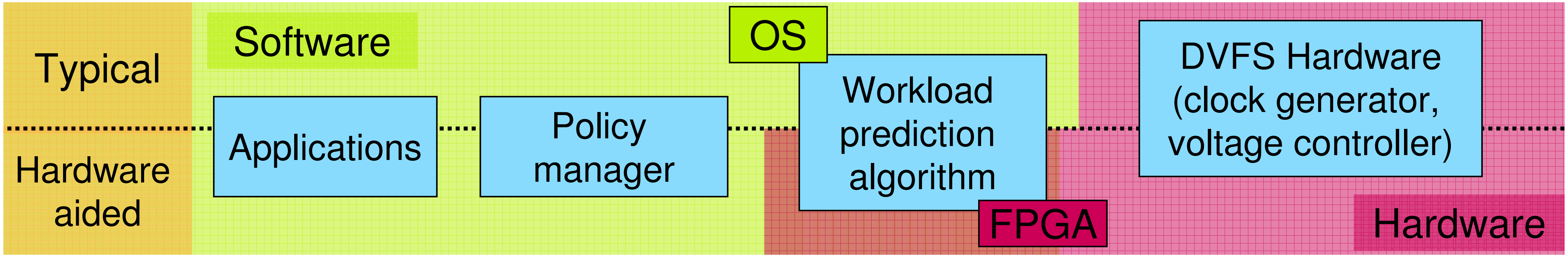
Mode Transitions



Improving power management

through co-design of hardware and software

- Other ideas for improving power management
  - Performance counters for other peripherals:
    - Cache miss rate is an indicator for memory bus usage of the CPU.
  - Hardware aided workload prediction algorithms (in embedded FPGA):
    - DVFS algorithm in FPGA, instead of software;
    - Enables fast calculation of estimations and quick operating point changes;
    - Algorithm can be changed for every use case because of the use of an FPGA.

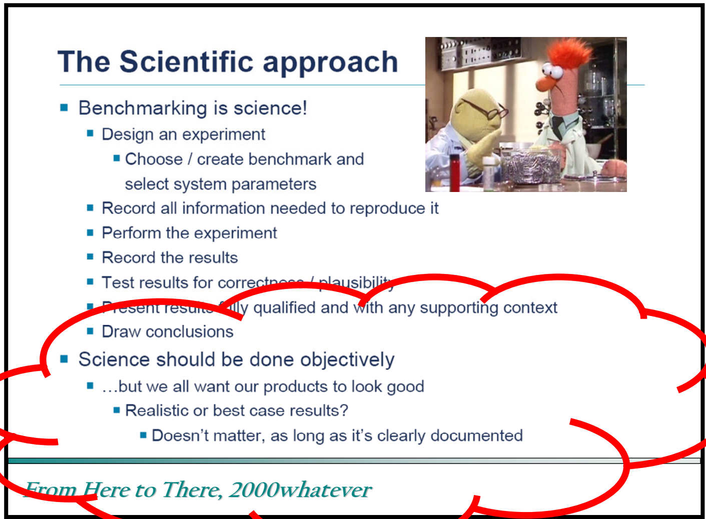


  - More hardware acceleration for specific applications:
    - Needs discussion with SW developers in early stage about which parts can be accelerated;
    - Enables running on a lower frequency, and as such saving energy.

To come to the End.

We Started With the Question:

"Why Benchmarking?"



The Scientific approach

- Benchmarking is science!
  - Design an experiment
    - Choose / create benchmark and select system parameters
  - Record all information needed to reproduce it
  - Perform the experiment
  - Record the results
  - Test results for correctness / plausibility
  - Present results fully qualified and with any supporting context
  - Draw conclusions
- Science should be done objectively
  - …but we all want our products to look good
    - Realistic or best case results?
      - Doesn't matter, as long as it's clearly documented

From Here to There, 2000whatever

Do your homework,

don't bring in the Trojan Horse!

NXP Semiconductors

- Established in 2006 (formerly a division of Philips)
- Builds on a heritage of 50+ years of experience in semiconductors
- Provides engineers and designers with semiconductors and software that deliver better sensory experiences
- Top-10 supplier with Sales of € 4.960 Bln (2006)
- Sales: 35% Greater China, 31% Rest of Asia, 25% Europe, 9% North America
- Headquarters: Eindhoven, The Netherlands
- Key focus areas:
  - Mobile & Personal, Home, Automotive & Identification, Multimarket Semiconductors
- Owner of NXP Software: a fully independent software solutions company

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