Algorithms for CPU and DRAM DVFS Under Inefficiency Constraints

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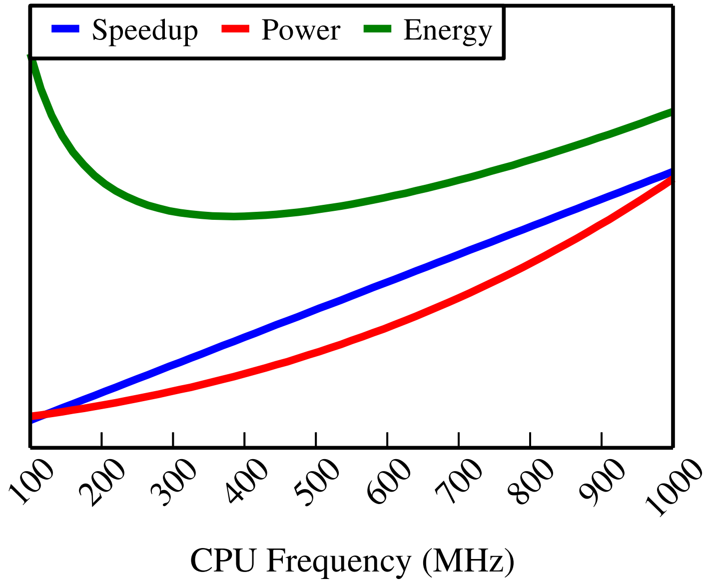
Dynamic Voltage and Frequency Scaling



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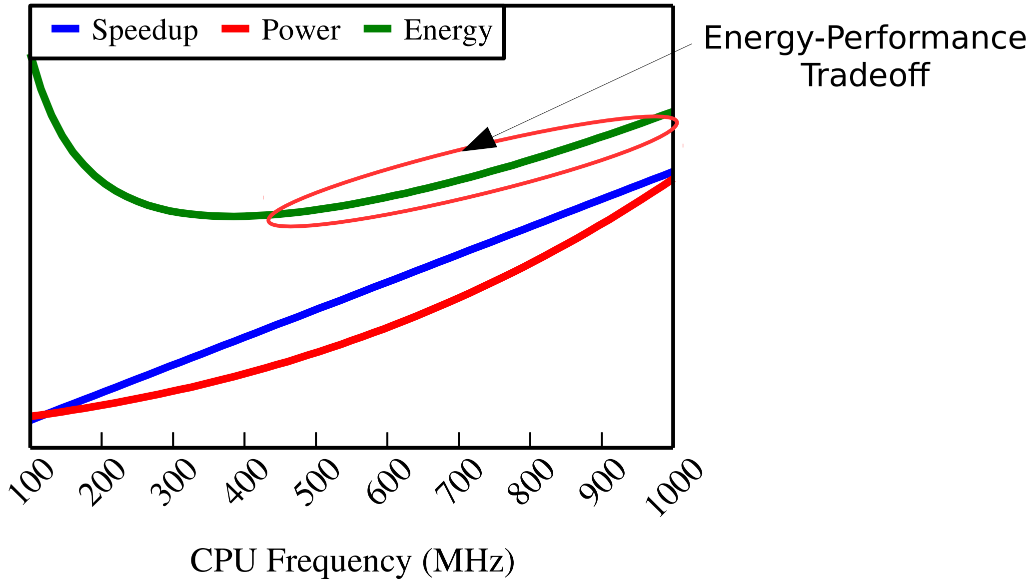

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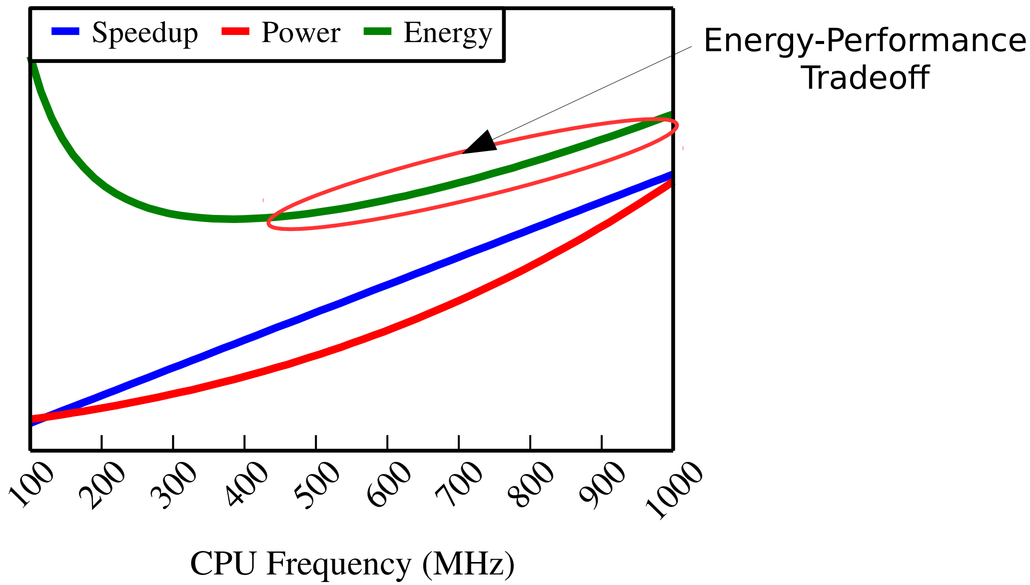
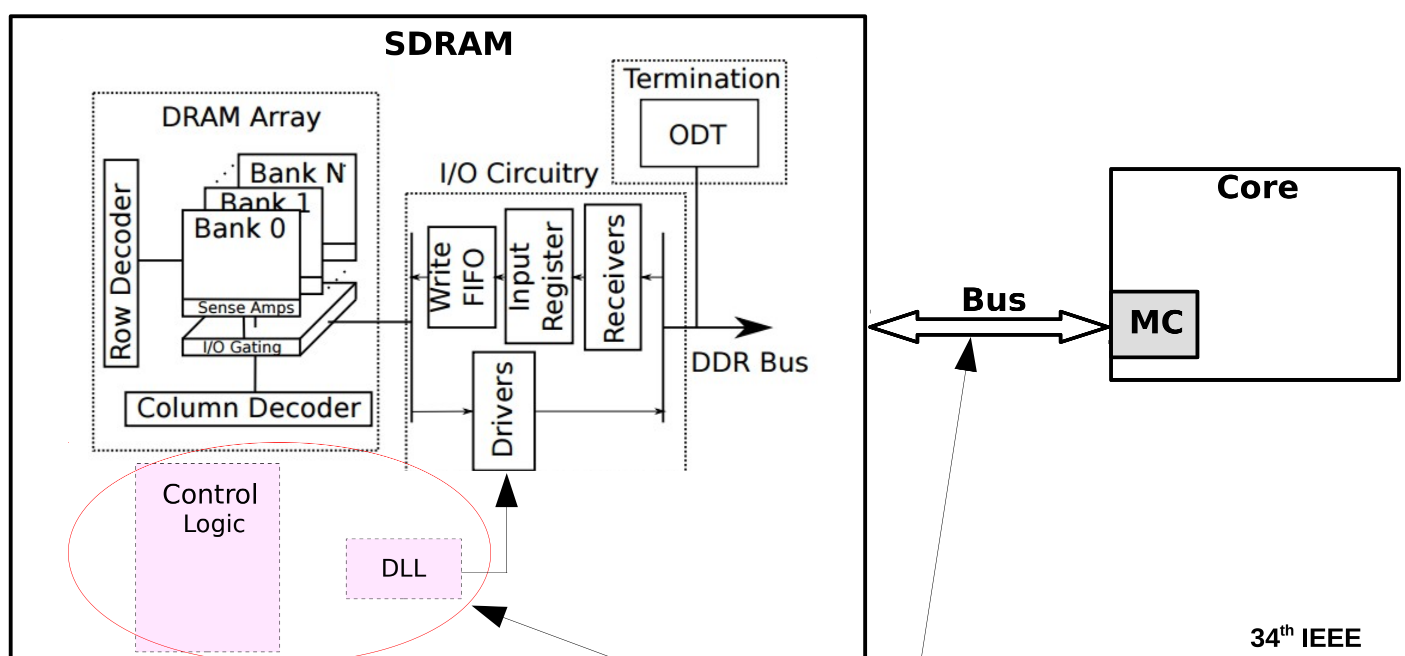


SDRAM Frequency Scaling

DRAM DFS

- Only Frequency Scaling
- Performance and power are proportional to DRAM frequency
- Increase in energy with DRAM frequency is due to scalable and non-scalable parts of DRAM



David, Howard, et al. international conference on Autonomic computing. ACM, 2011.

CPU DVFS and Memory DFS

- Managing Systems - a challenging task

CPU DVFS and Memory DFS

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- CPU intensive applications – higher CPU frequency
- Interplay of performance and energy of CPU and memory frequency scaling is complex

Performance vs. Energy Constraints

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- Servers --- working under performance constraints is imperative
- Mobile systems –-- operating under energy constraints is fitting

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- Previous efforts explored DVFS under performance constraints
- Servers --- working under performance constraints is imperative
- Mobile systems –-- operating under energy constraints is fitting
- Approaches that work under performance constraints are not directly applicable to systems operating under energy constraints

Performance vs. Energy Constraints

- Choosing the right performance bound for desired energy savings is a daunting task --- application and device dependent

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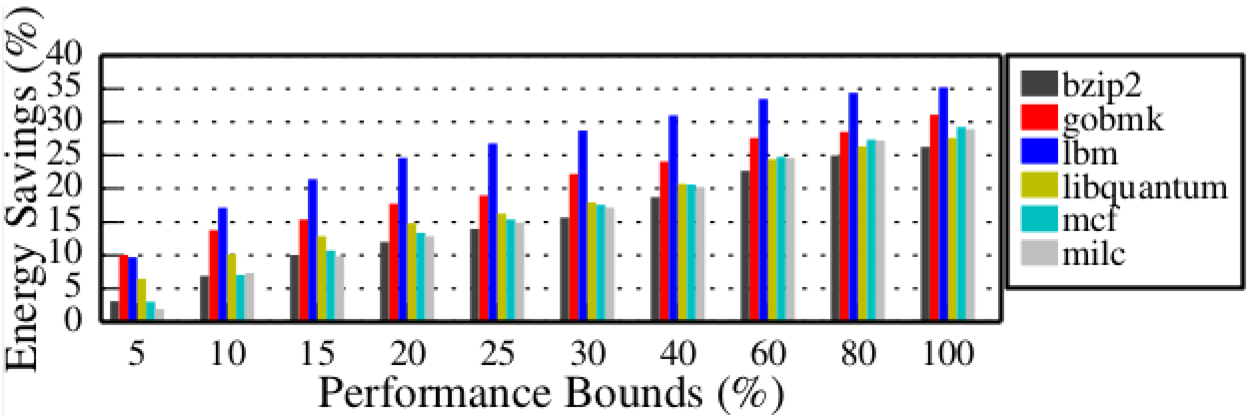

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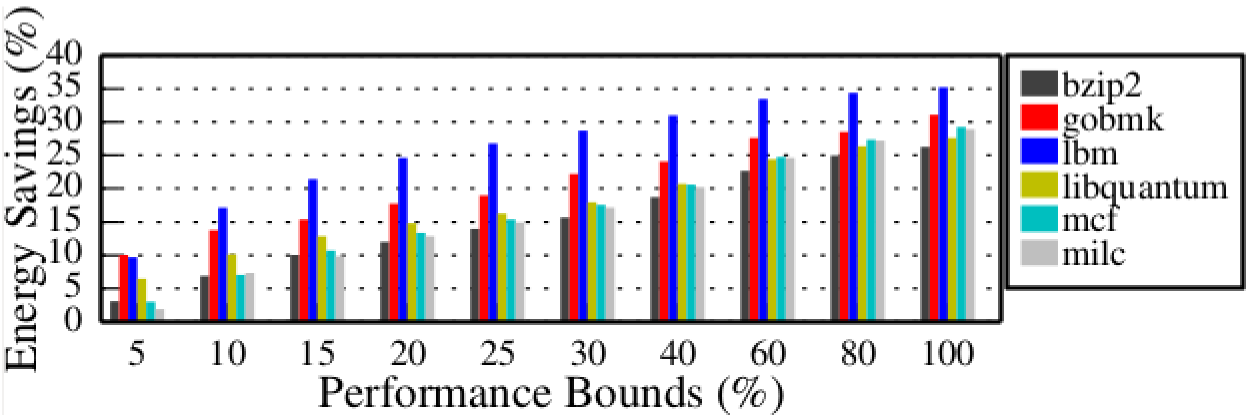

- Energy savings achieved for a specific performance bound vary across applications
- Performance bound of 10% saves 5% - 15% energy
- 20% energy savings require performance bound of 15% - 50% depending upon the application

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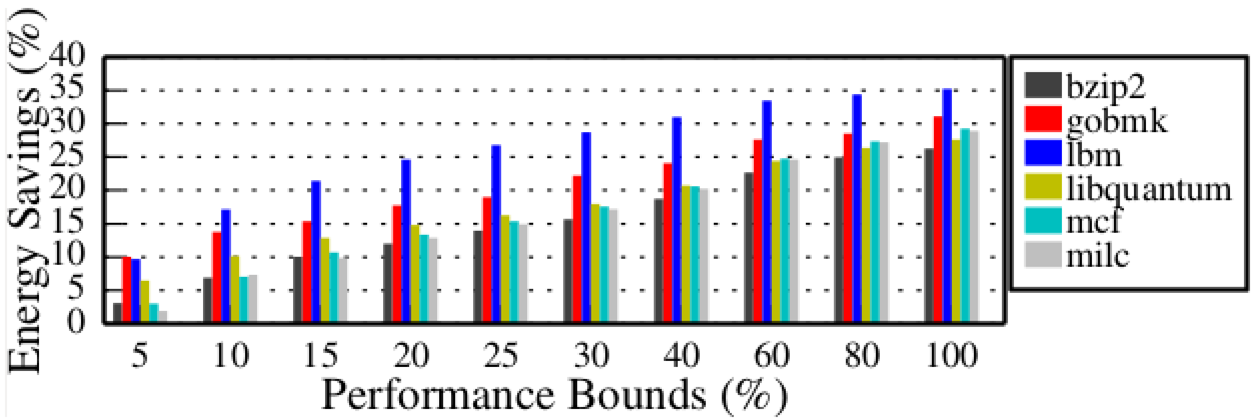

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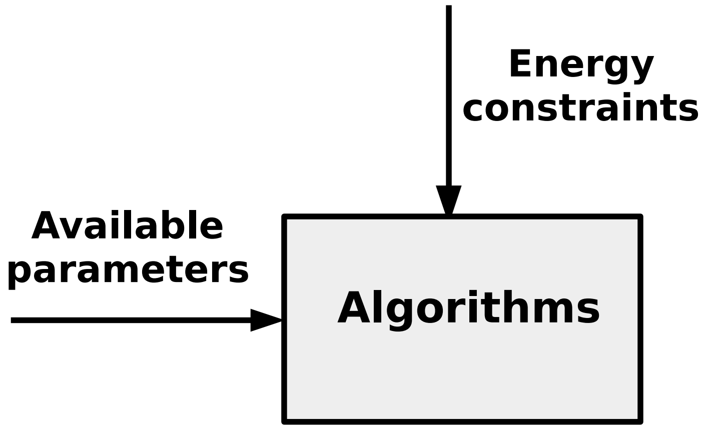
Demands a new energy management design that maximizes performance under given energy constraints

Energy Management Systems

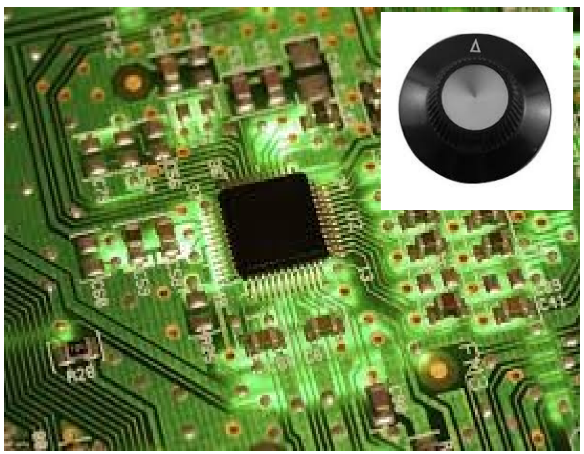


Energy Management Systems

Energy constraints

Available parameters

Algorithms



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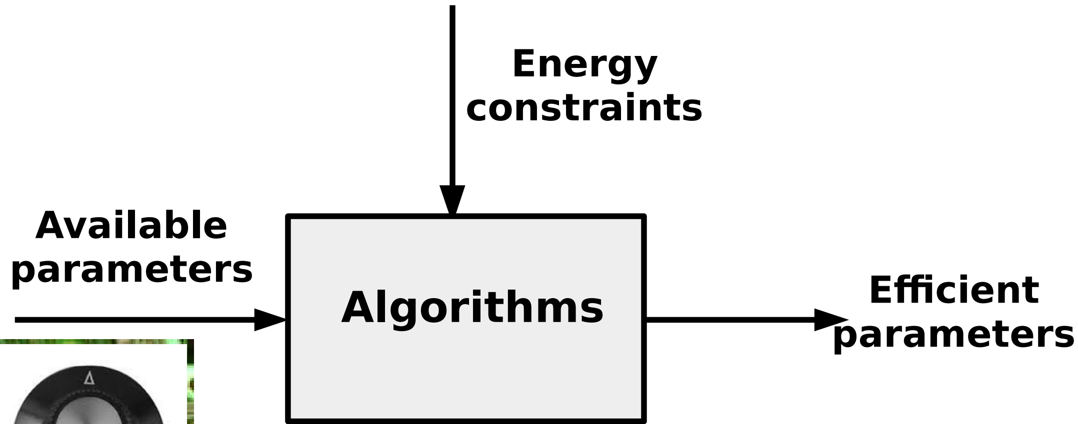

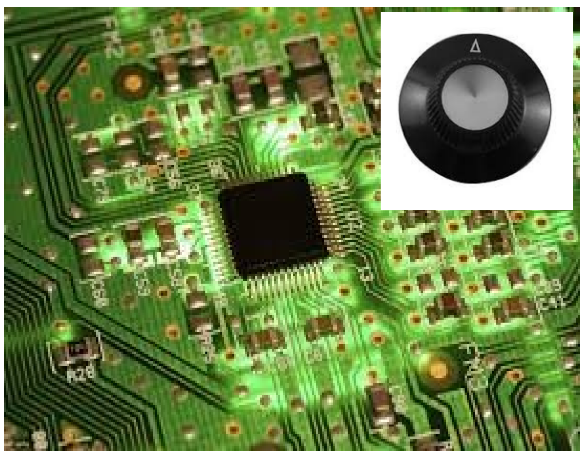

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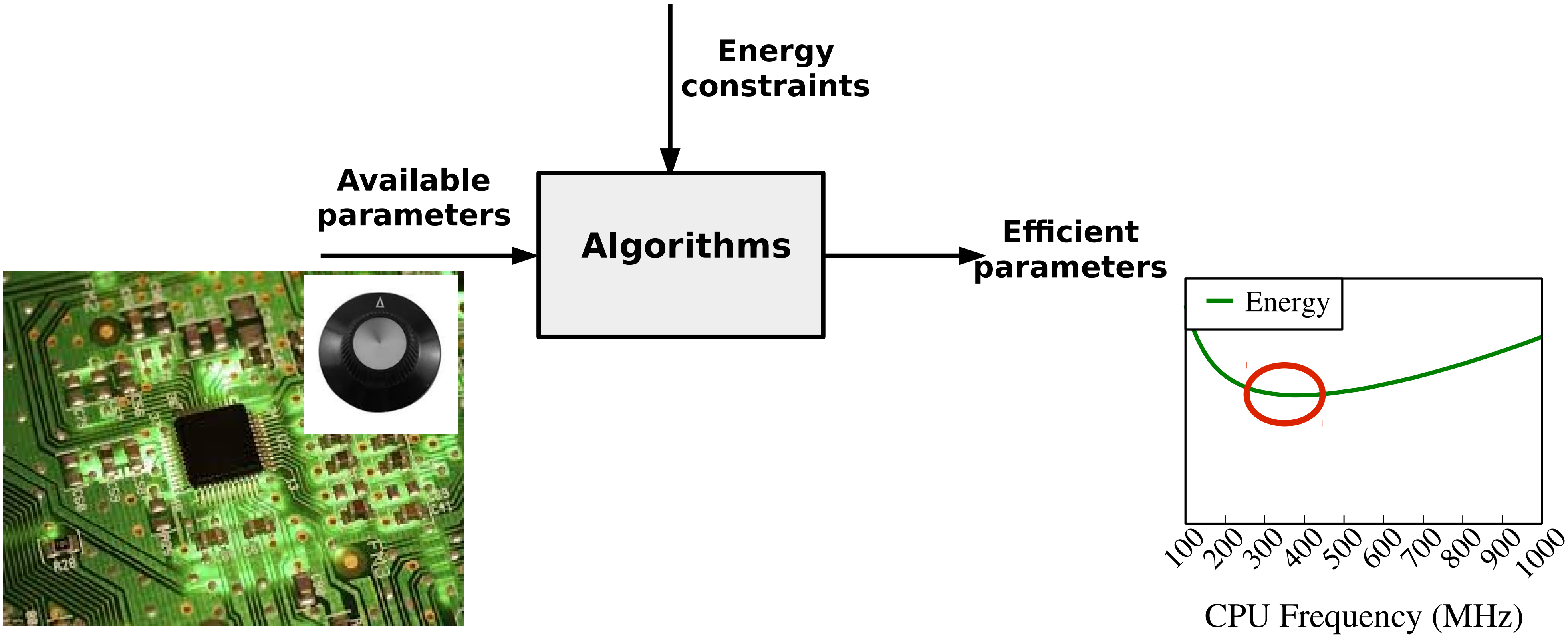

Outline

- Energy constraints
- System Design
- Performance and Energy Models
- Algorithms
- Results
- Conclusions

Energy Constraints

- Absolute energy or rate of energy consumption as energy constraints --- application and device dependent

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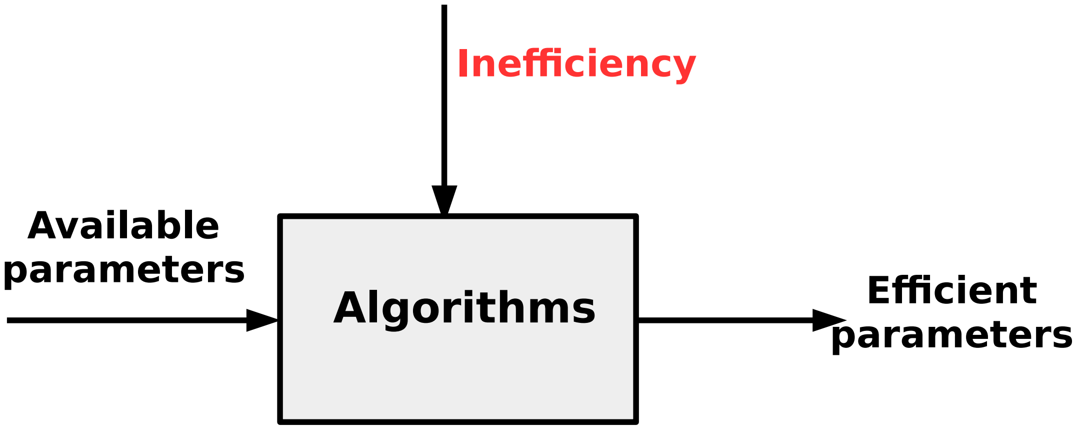
- Need for a new metric –-- ***Inefficiency***

Inefficiency

- Inefficiency: Additional energy that can be used by the *application* to improve performance



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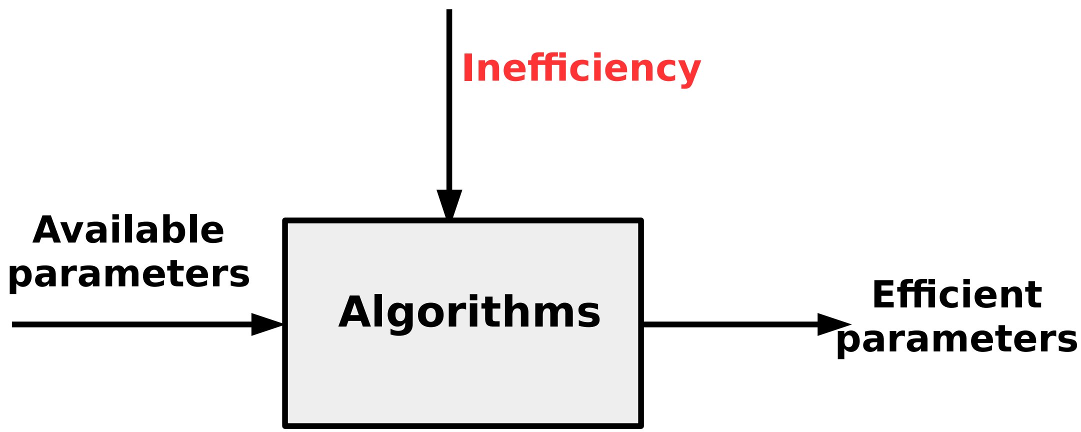

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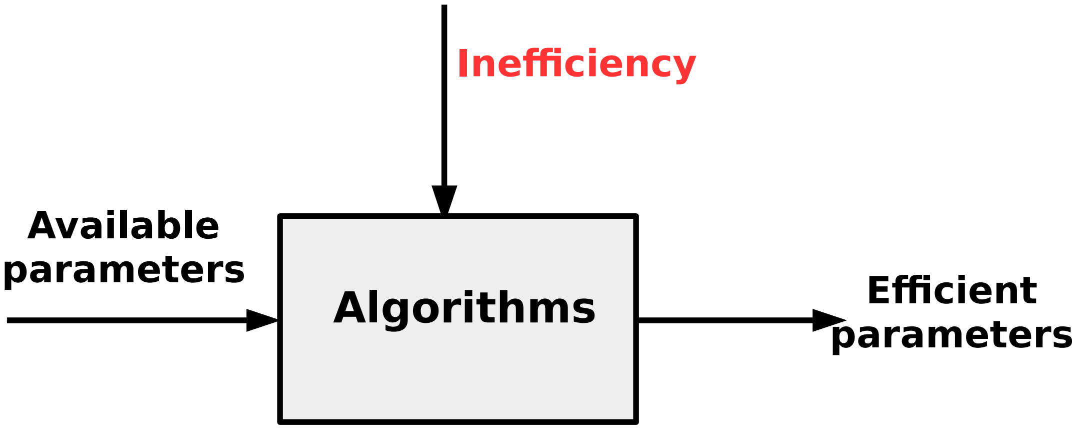


- Inefficiency:

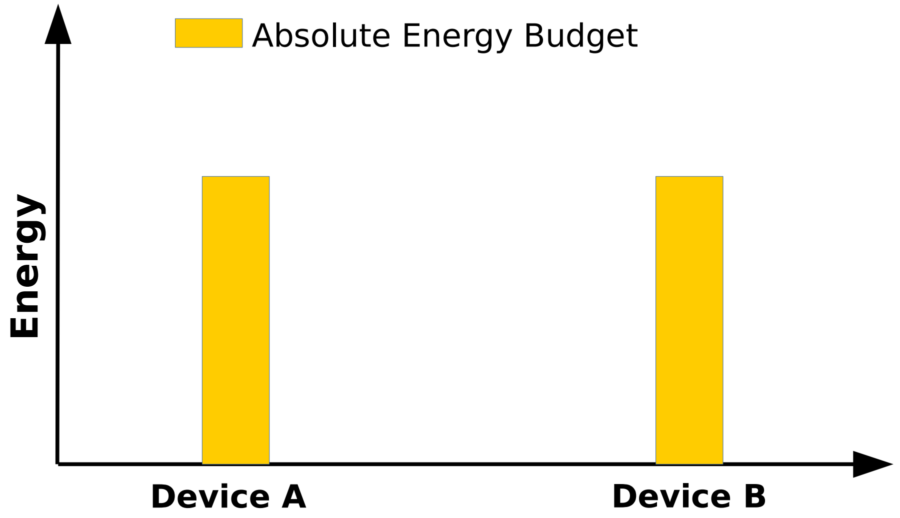
$$\textit{Inefficiency} = \frac{E_{total}}{E_{min}}$$

E_{min} – Minimum energy application could have consumed on the same device

E_{total} – Additional energy application can use to improve performance

Inefficiency as a System Resource

- Agnostic to Devices



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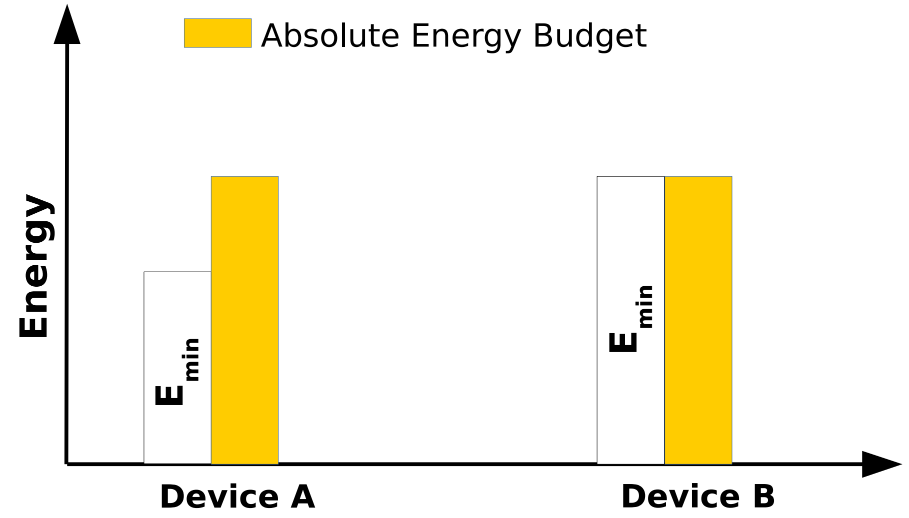

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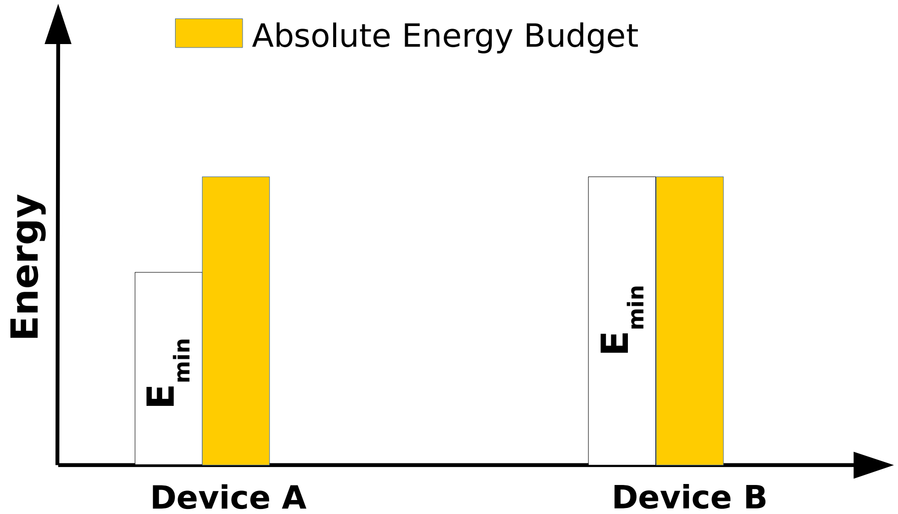
$$E_{total} = Inefficiency \times E_{min}$$



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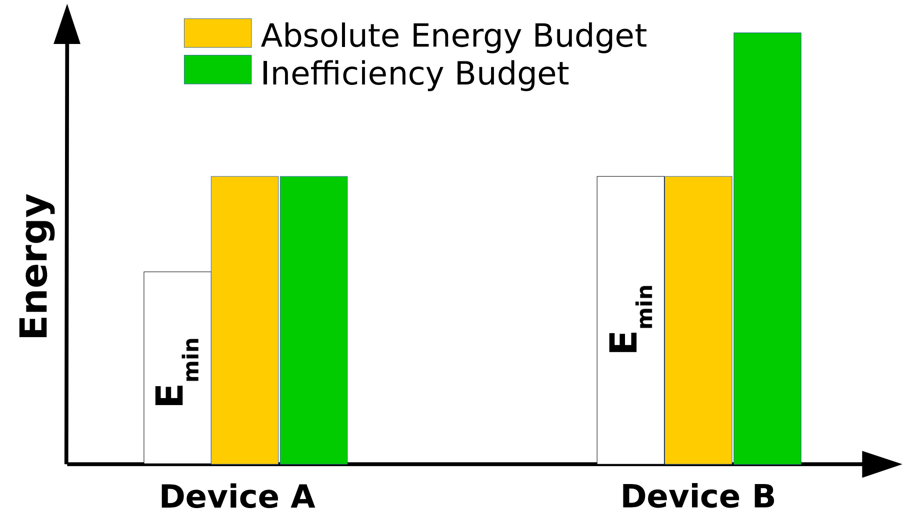

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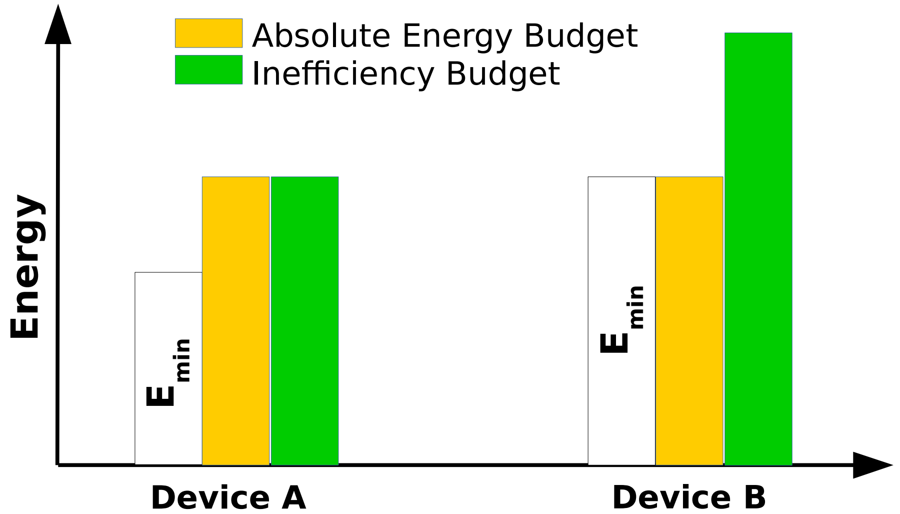

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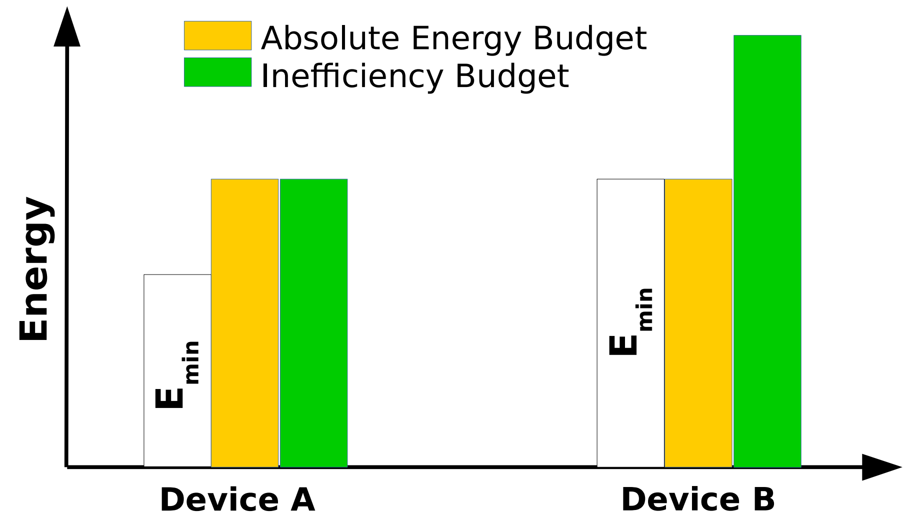

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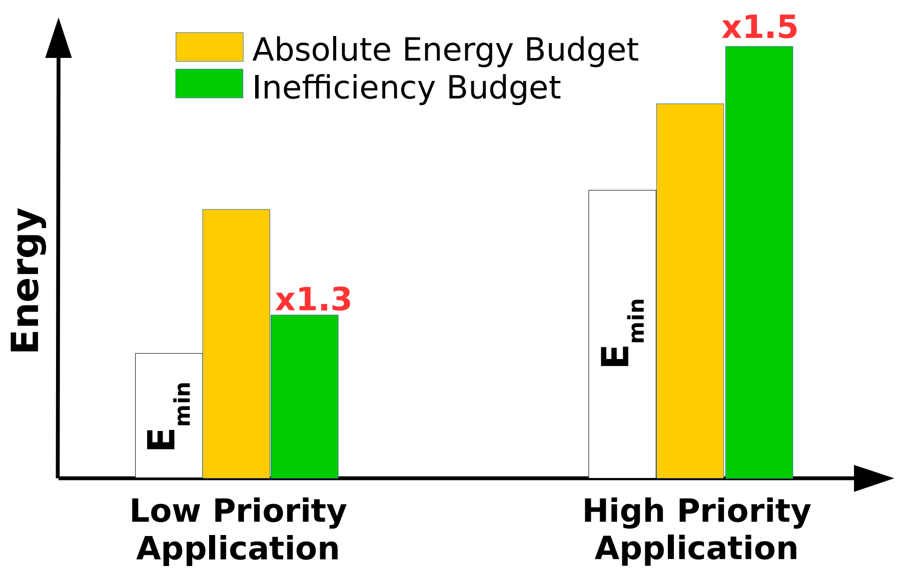

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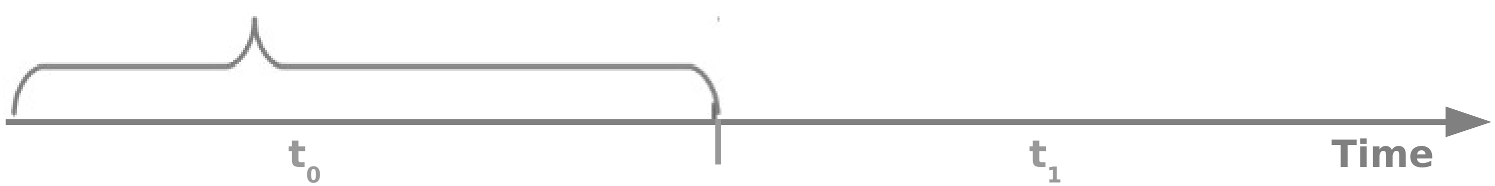

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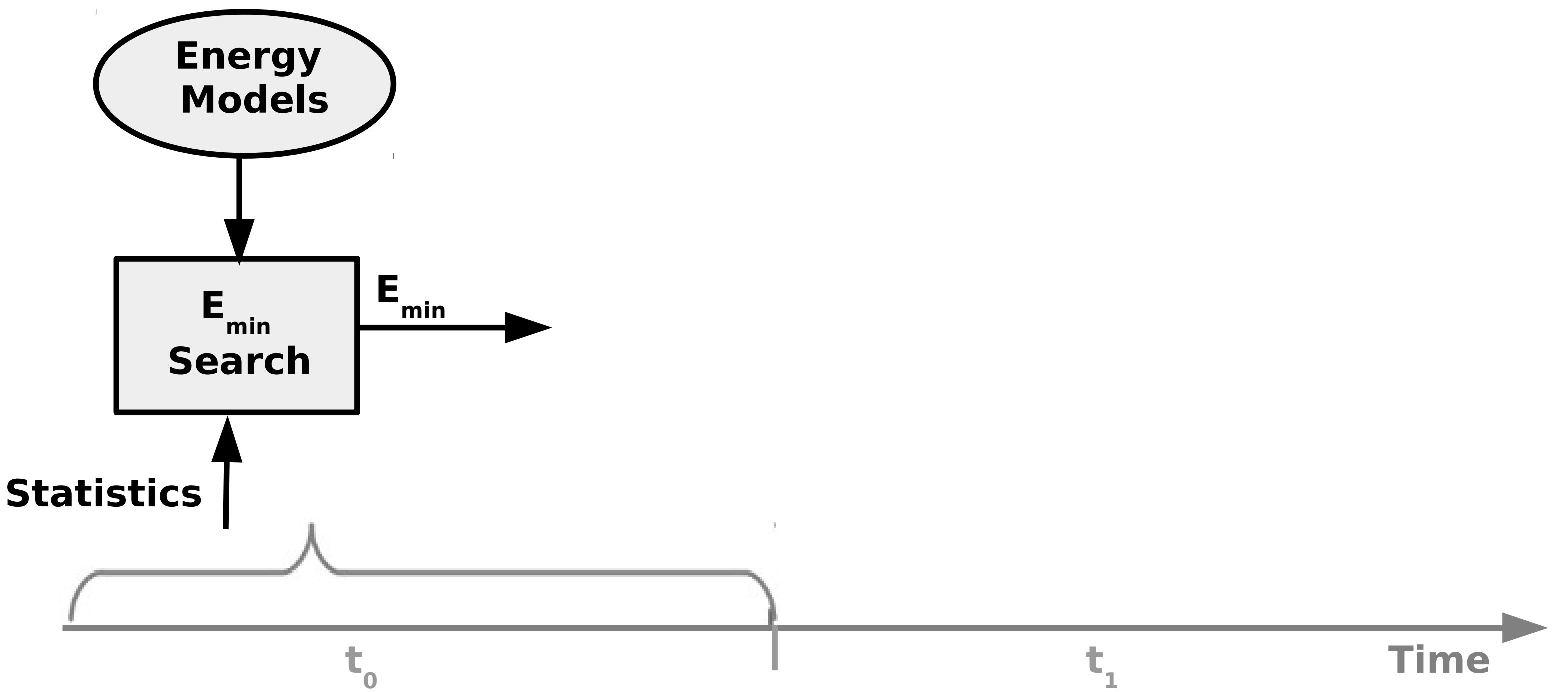

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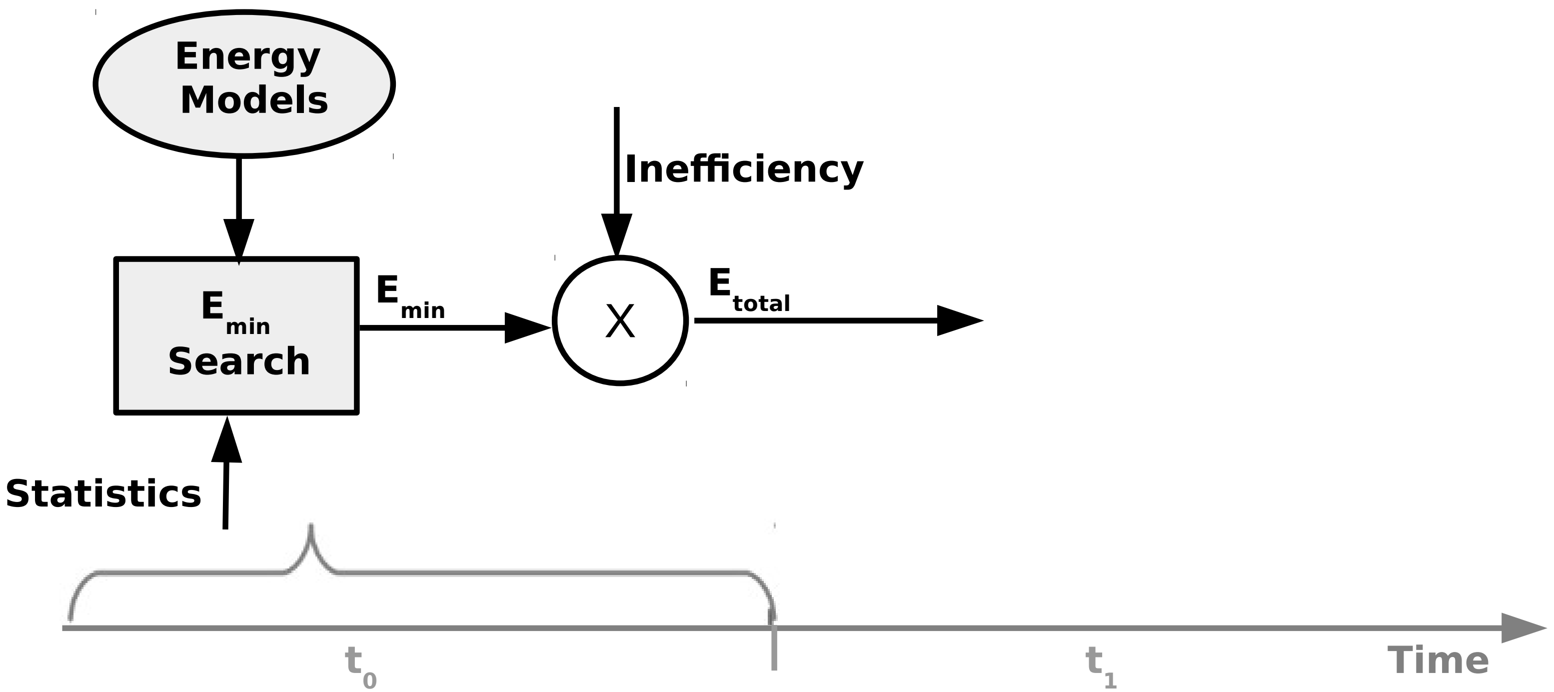

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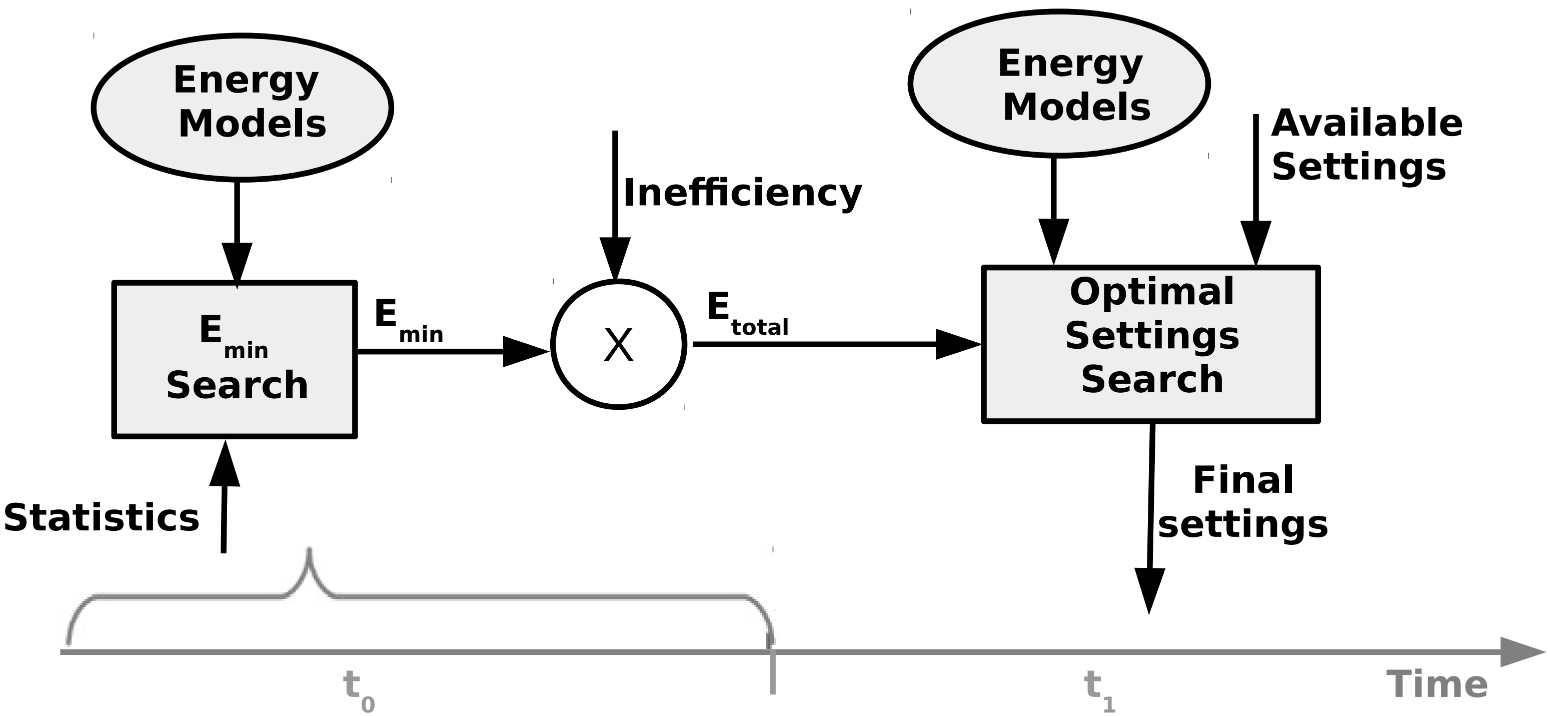

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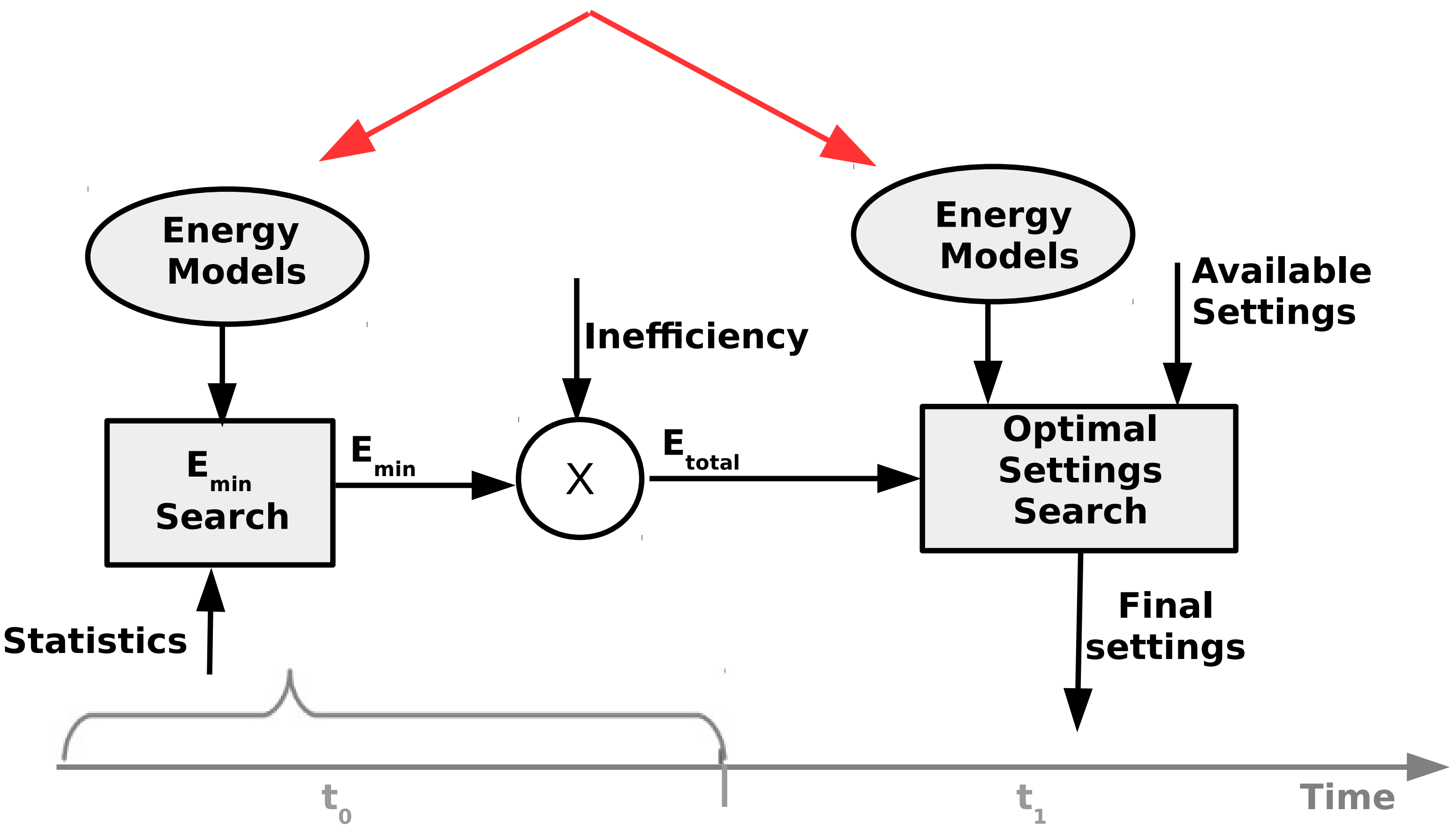

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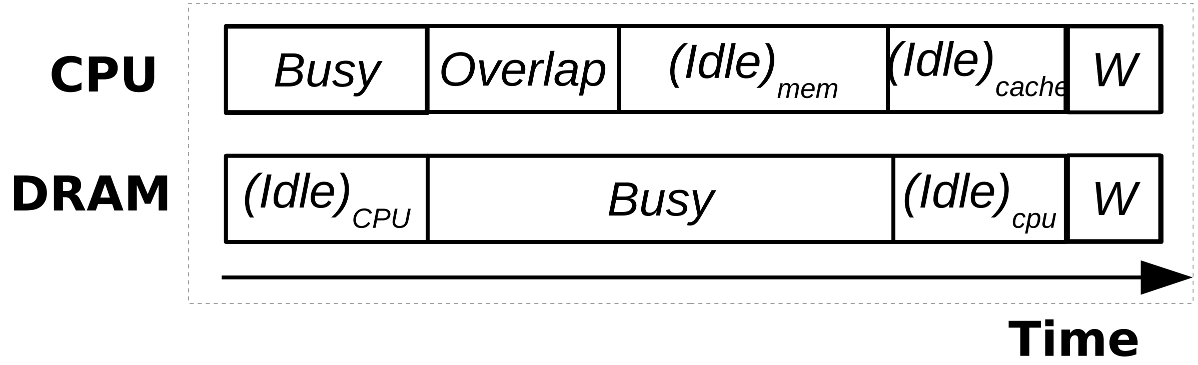

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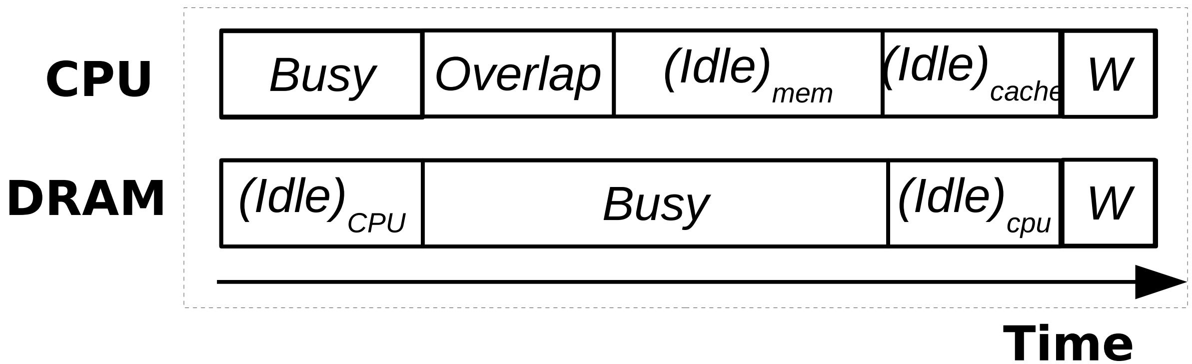

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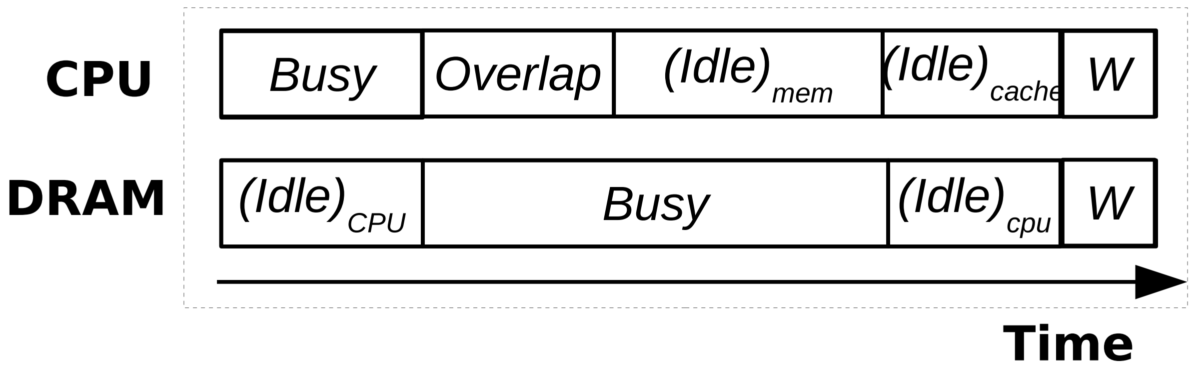

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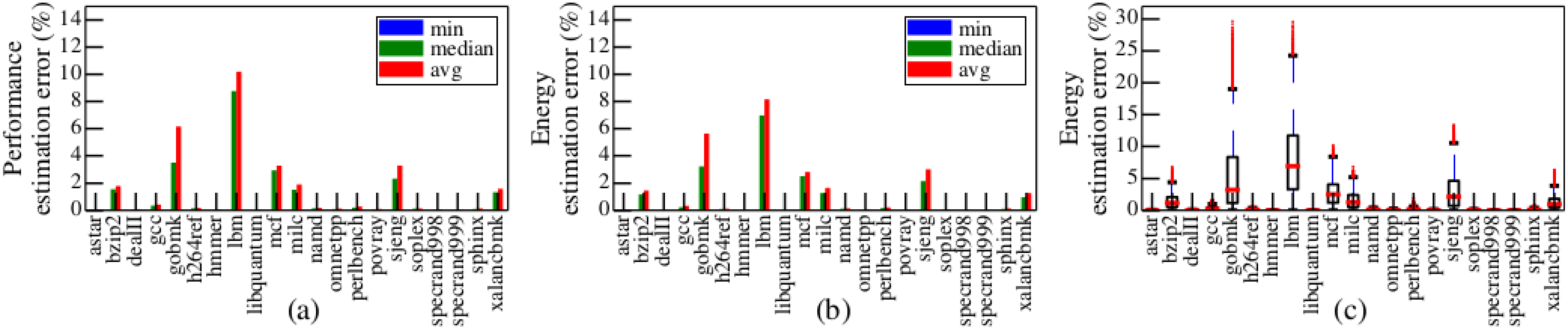
- A total of 14 performance counters are used to track the time spent in each state
- 7 performance counters are newly added, 7 are already included in modern systems
- More details in the paper

Performance and Energy Models



- 12 integer and 9 floating point SPEC CPU2006 benchmarks --- using Gem5 simulator
- Average error is less than 4% except for *Gobmk (6%)* and *Lbm (10%)*
- Model is more than 97% accurate for more than 50% predictions
- Maximum error is less than 10% except for *Gobmk(18%)* and *Lbm(24%)*

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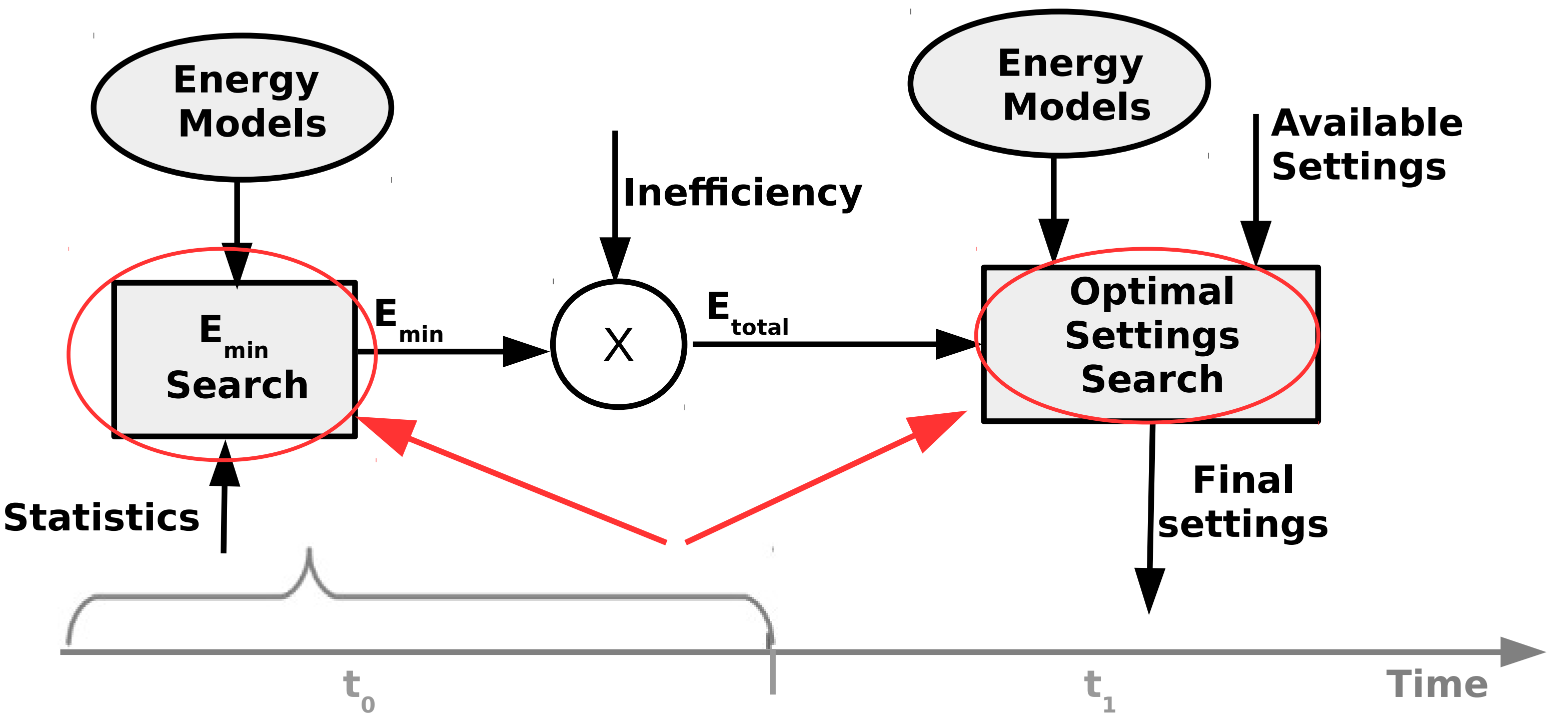

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  - Search for E_{min}
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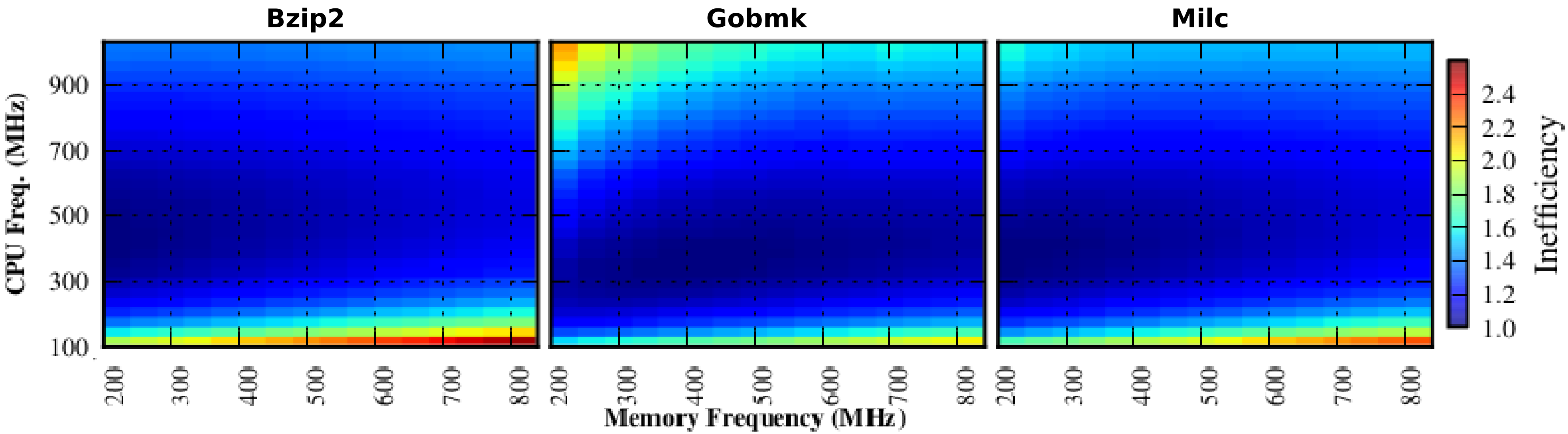
- E_{min} moves every tuning interval making the search complex and expensive



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- We introduce relative and adaptive algorithms to reduce tuning overhead
  - Search ---- 1) Exhaustive Search 2) Relative Search
  - Select ---- 1) Best Performing Selection 2) Adaptive Selection

Search Algorithms

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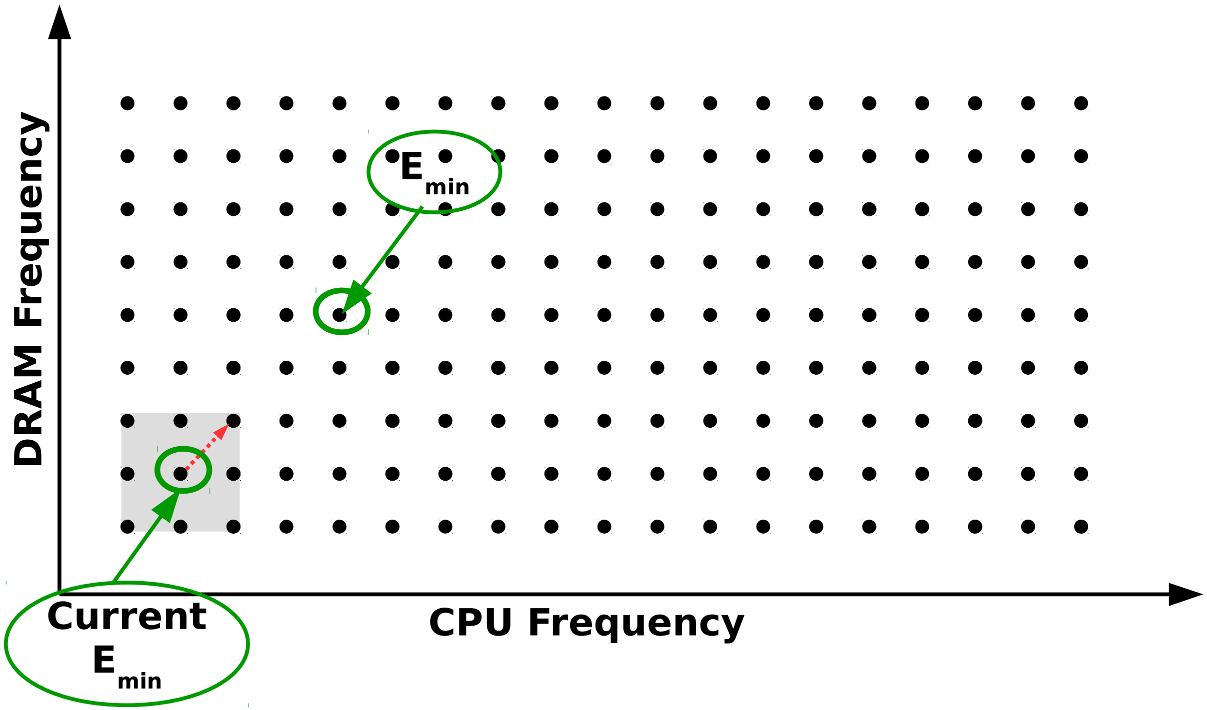

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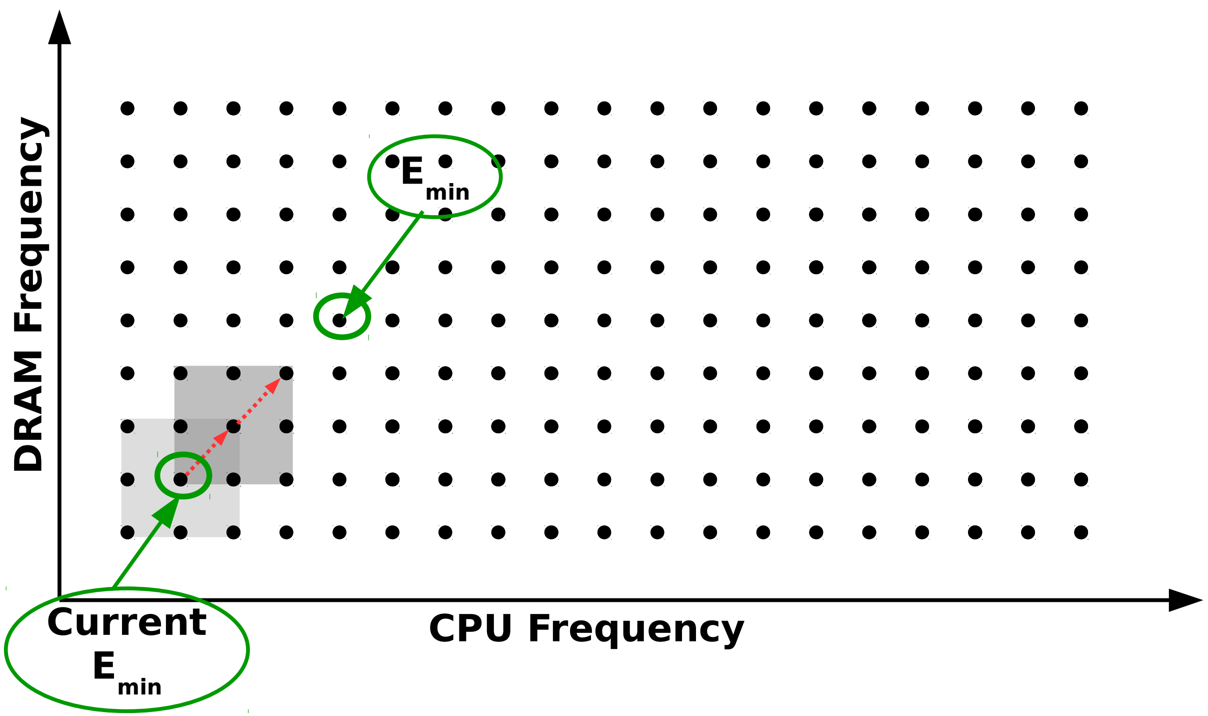

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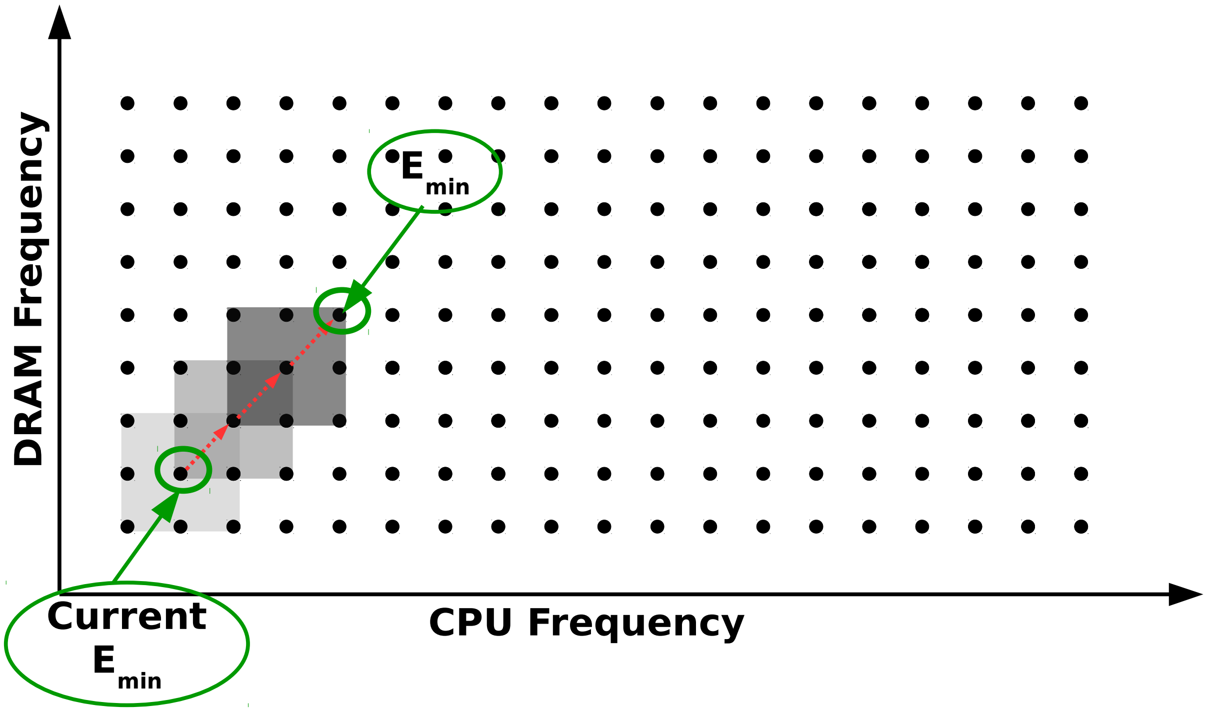

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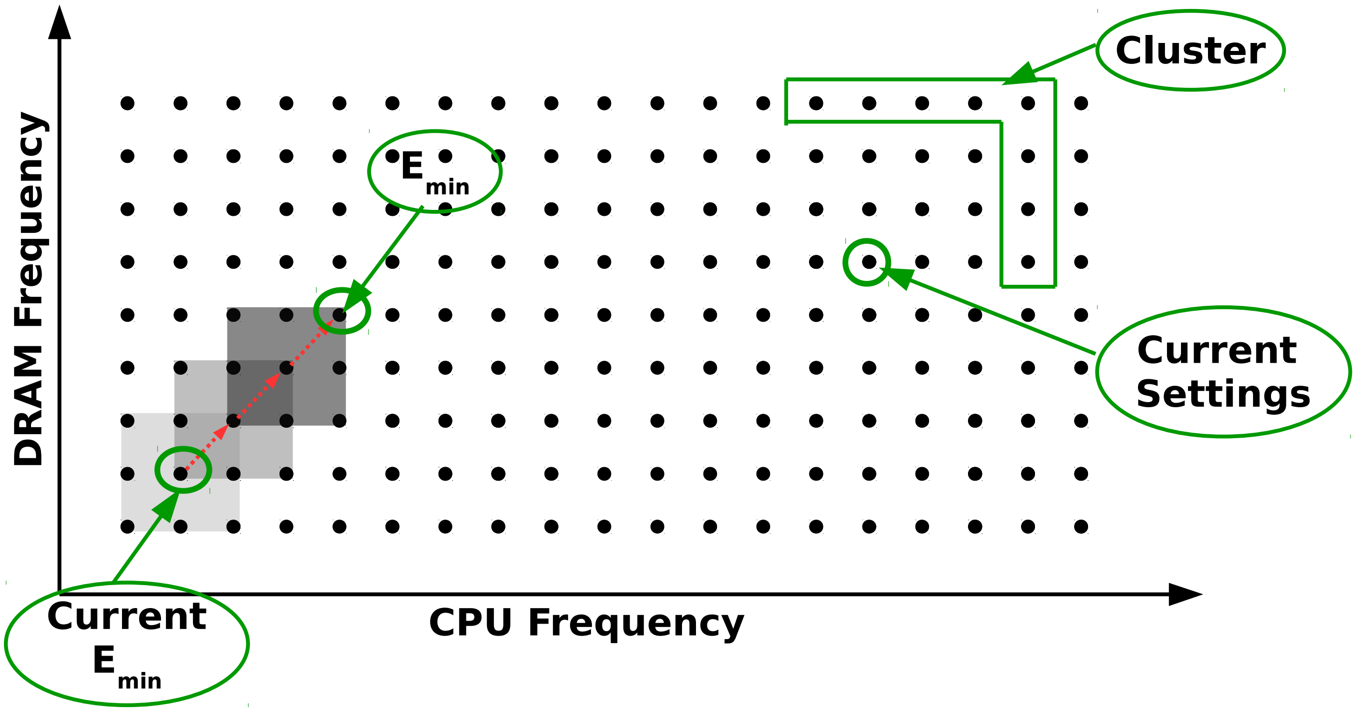

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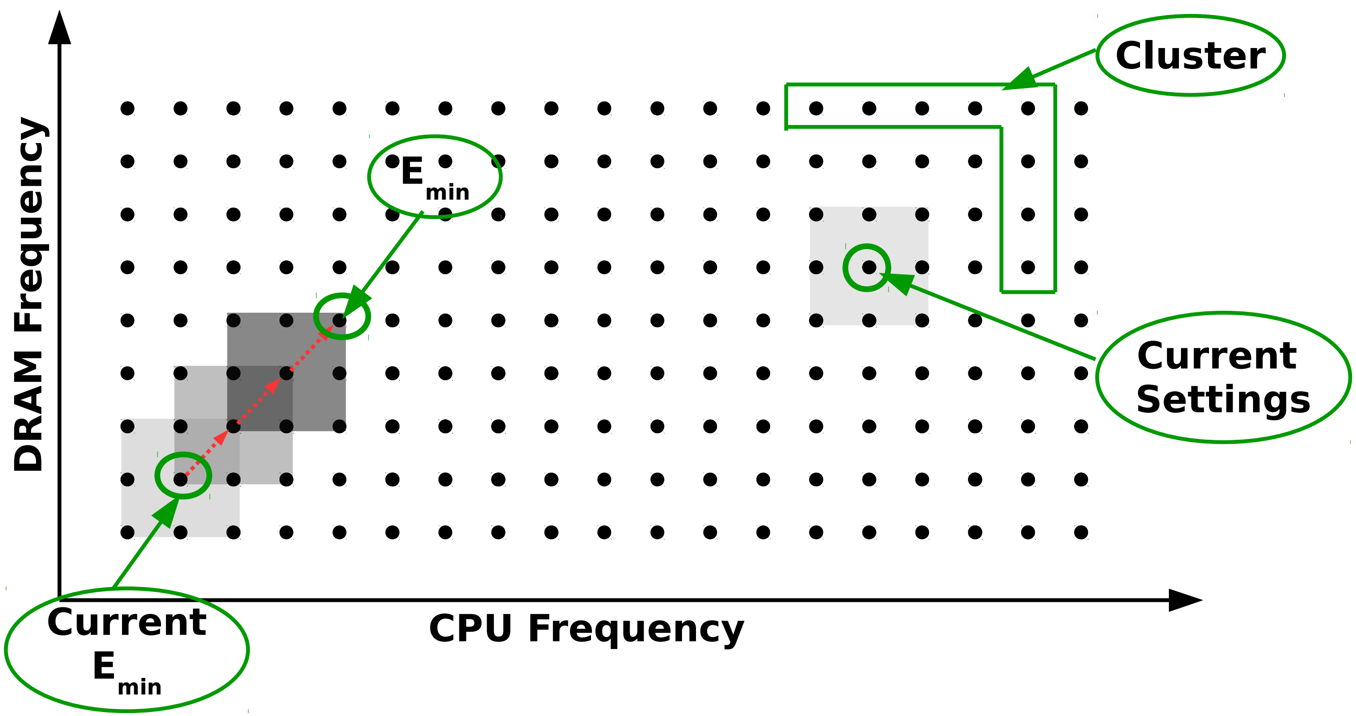

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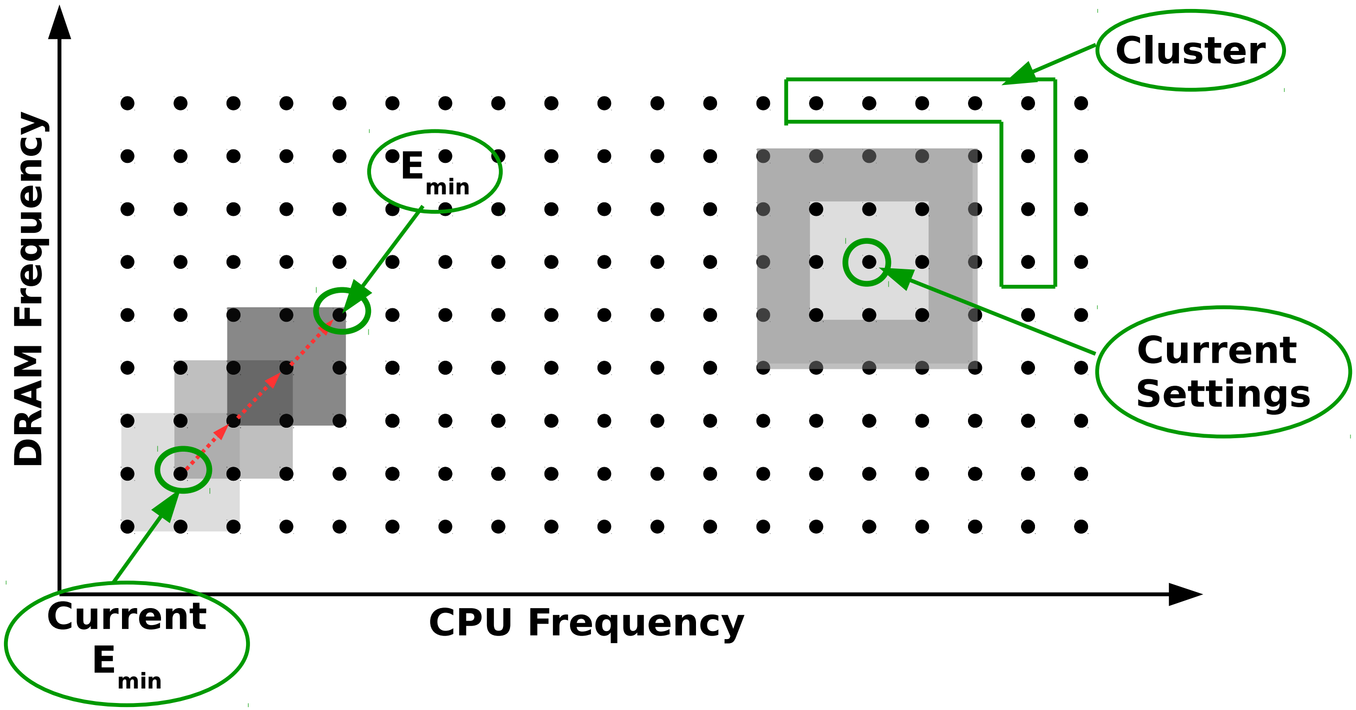

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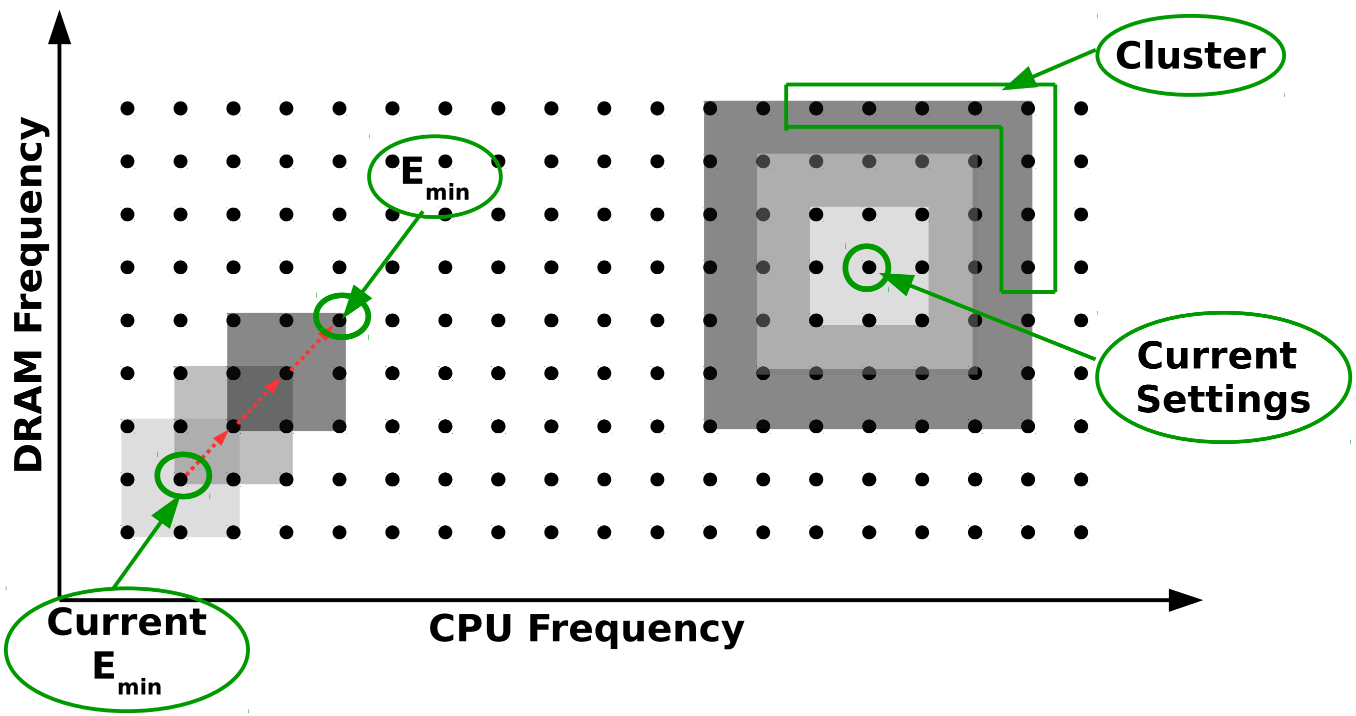

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for settings in cluster
    if settings.performance > best_settings.performance
         best_settings = settings
    if settings == current_settings
         current_settings_found = True
if current_settings_found is True
    performance_loss = difference(best_settings,current_settings)
    if performance_loss is within threshold
         final_settings = current_settings
         skip_tuning_intervals++
        relative_search_steps++
    else
         final_settings = best_settings
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1. **Detects application phases and skips tuning during long stable phases**
2. **Detects possible "stuck in local minima and gives feedback to relative search to exit the local minima region**

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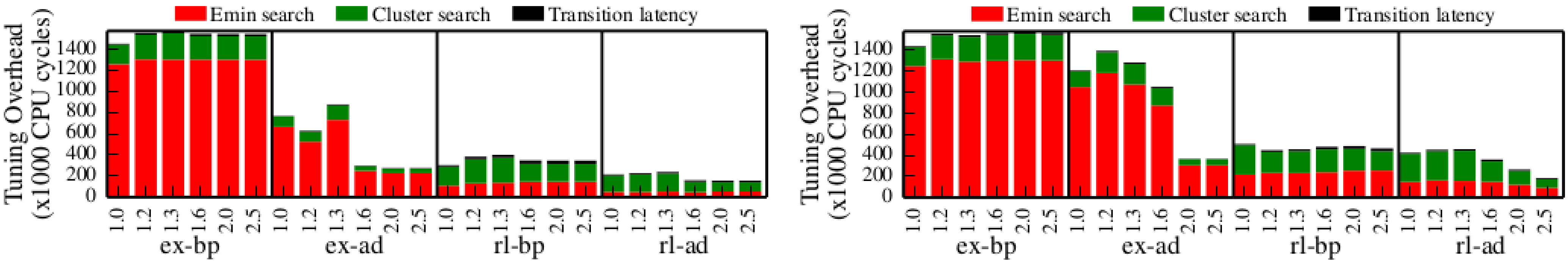
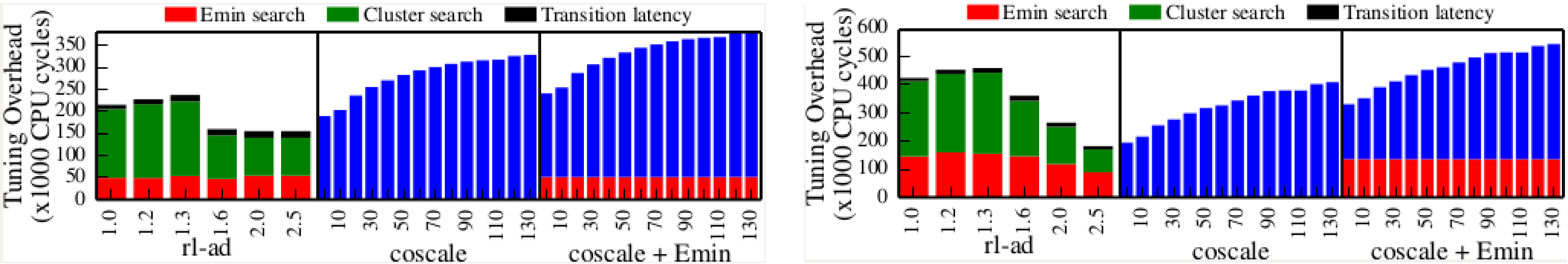
Results



a) Bzip2 b) Gobmk

- 12 integer and 9 floating point SPEC CPU2006 benchmarks --- using Gem5 simulator
- All combinations of search and select algorithms are simulated
- *rl-ad* significantly improves tuning overhead compared to *ex-bp* with less than 3% performance loss --- by selectively tuning and reducing the search space
- Next we compare our algorithms with CoScale's algorithms designed to operate under performance constraints

Results



a) Bzip2

b) Gobmk

- Tuning overhead of *rl-ad* is 32% lower compared to CoScale for *Bzip2,* and 10% higher for *Gobmk*
- Gobmk doesn't provide enough opportunities to skip tuning due to rapidly changing phases
- Comparing tuning overhead to CoScale + E_{min} is fair
- *rl-ad* has 24% lower tuning overhead compared to CoScale
- Algorithms save up to 5% energy with average performance loss of less than 3%

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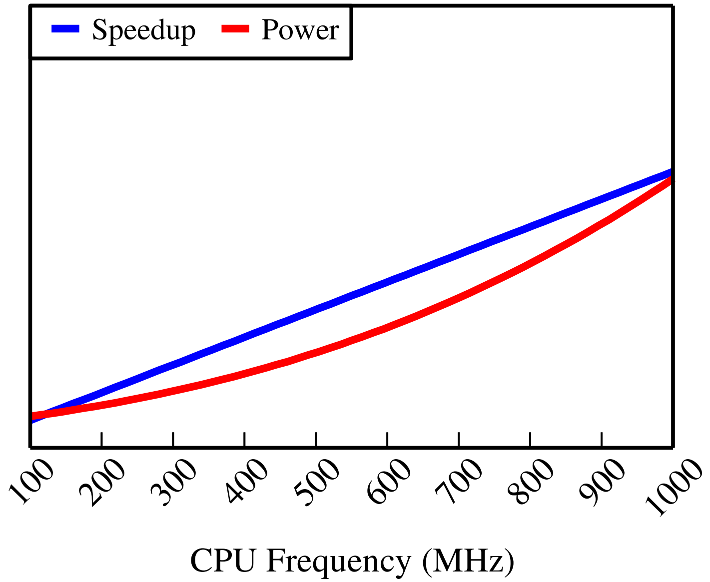
- Presented a holistic approach that works under inefficiency constraint and using the cross-component performance and energy models that we developed, selects optimal frequency settings that deliver best performance staying under given inefficiency budget

Blue.

Questions ?

Dynamic Voltage and Frequency Scaling



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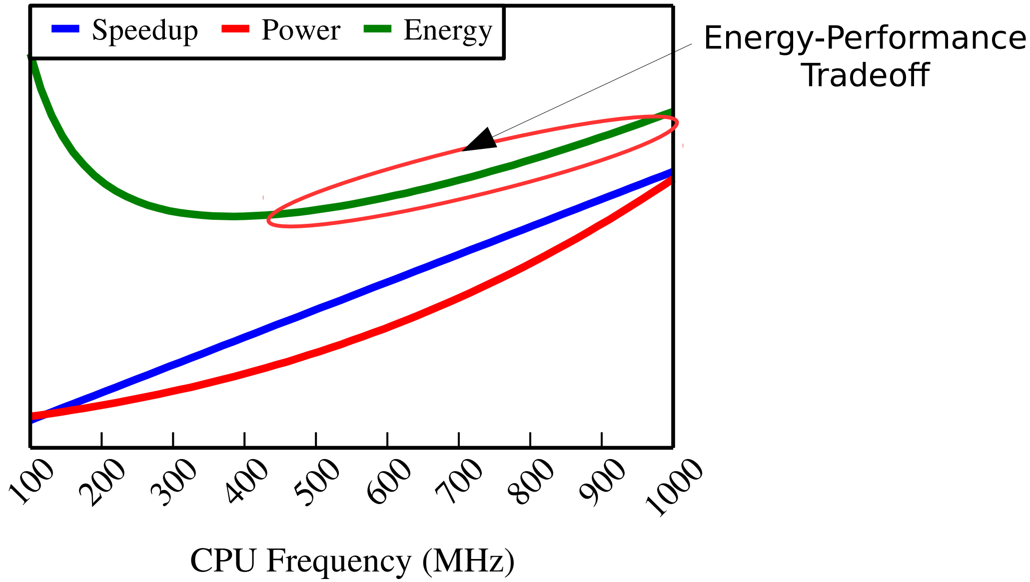
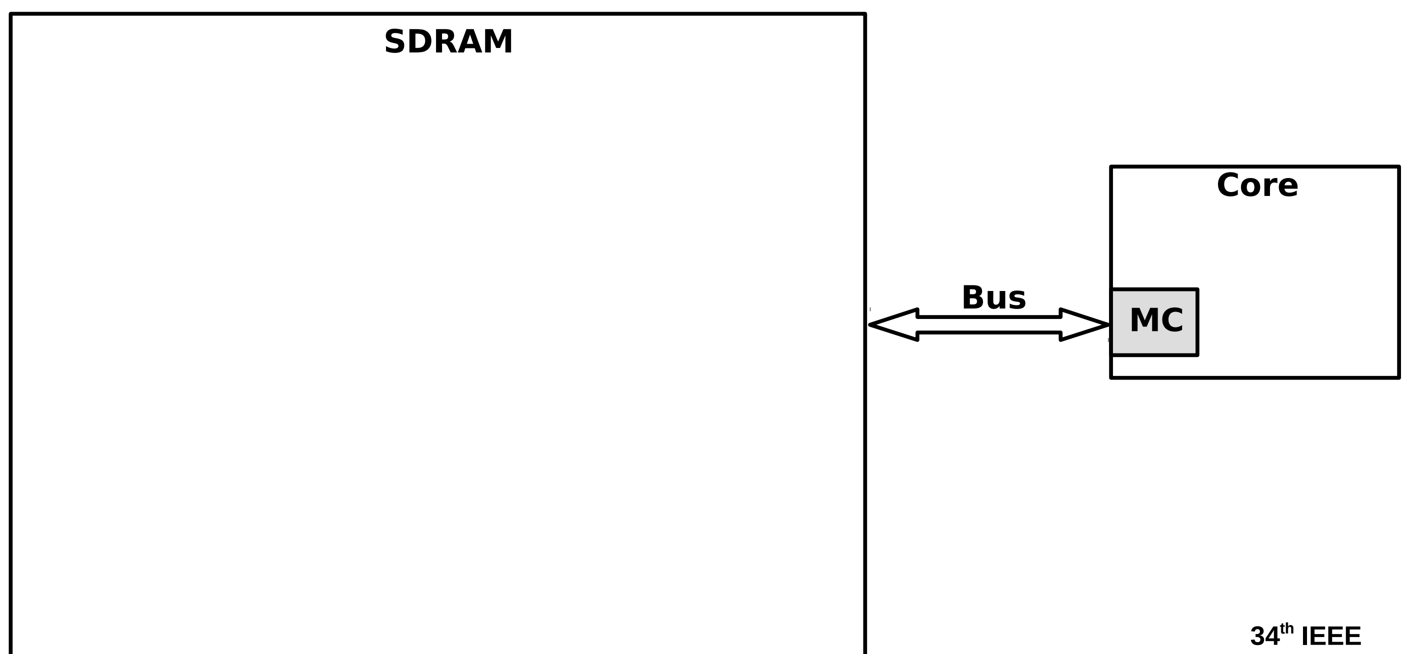


SDRAM Frequency Scaling



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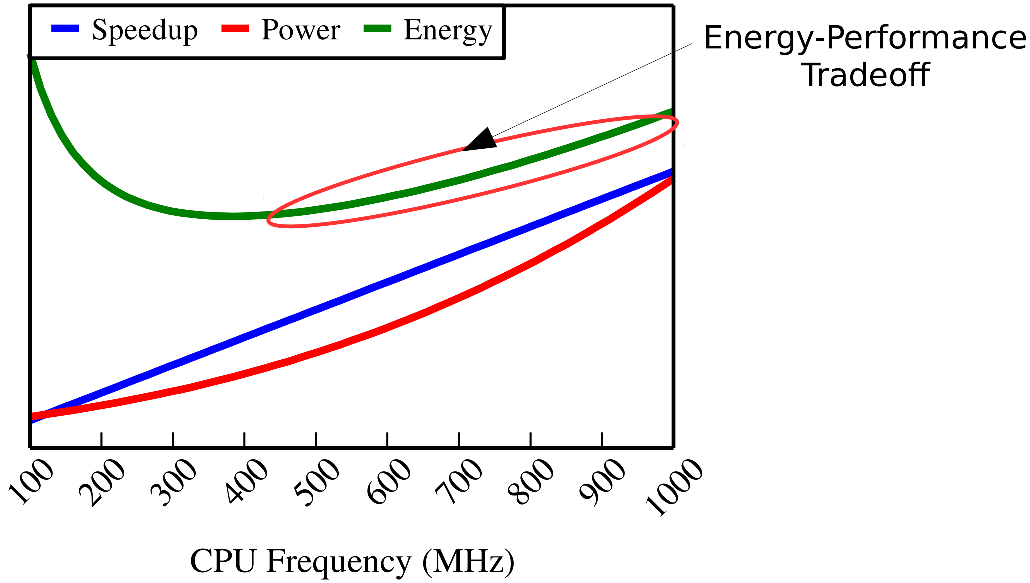

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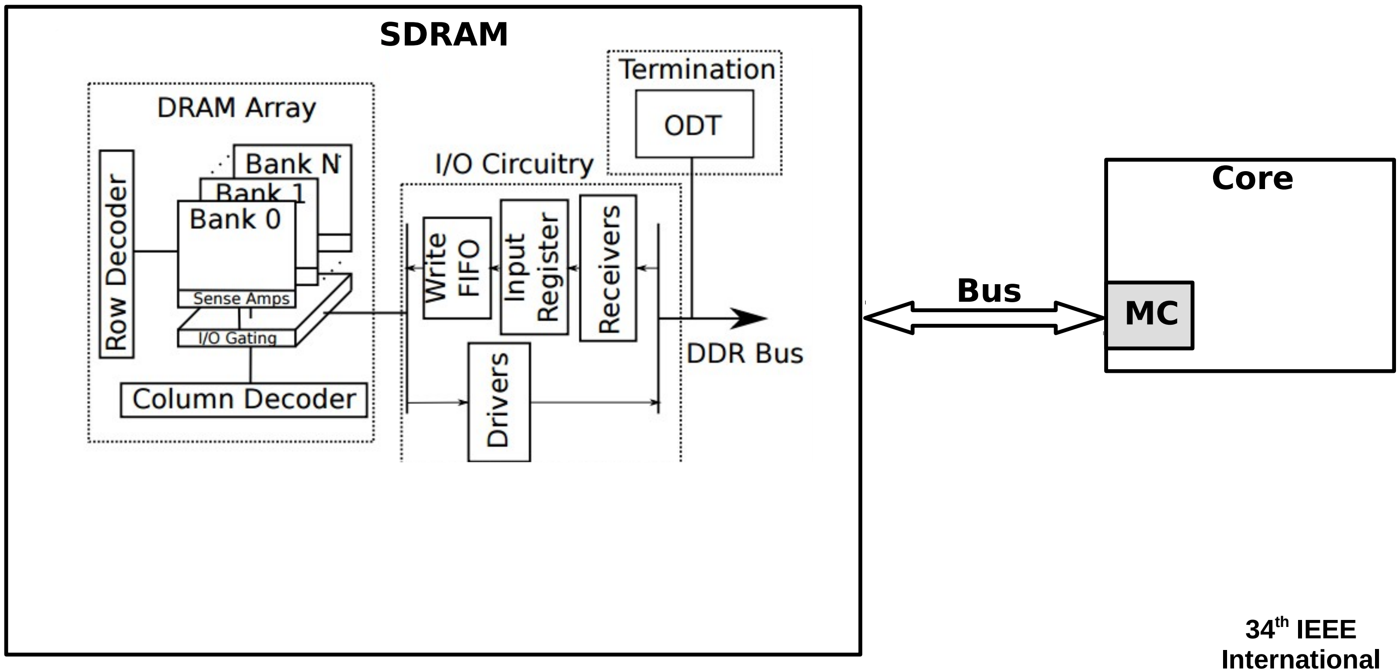

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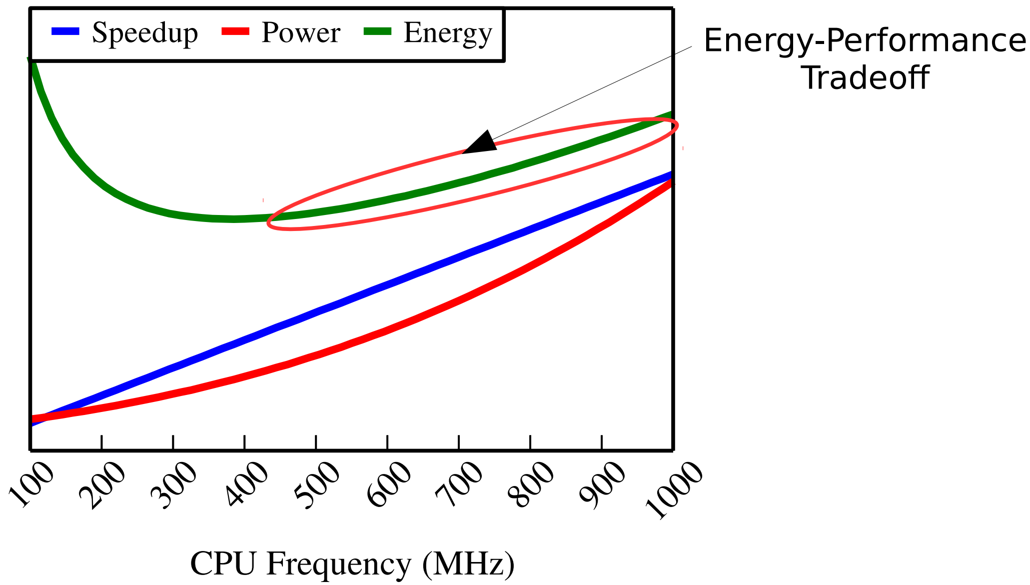

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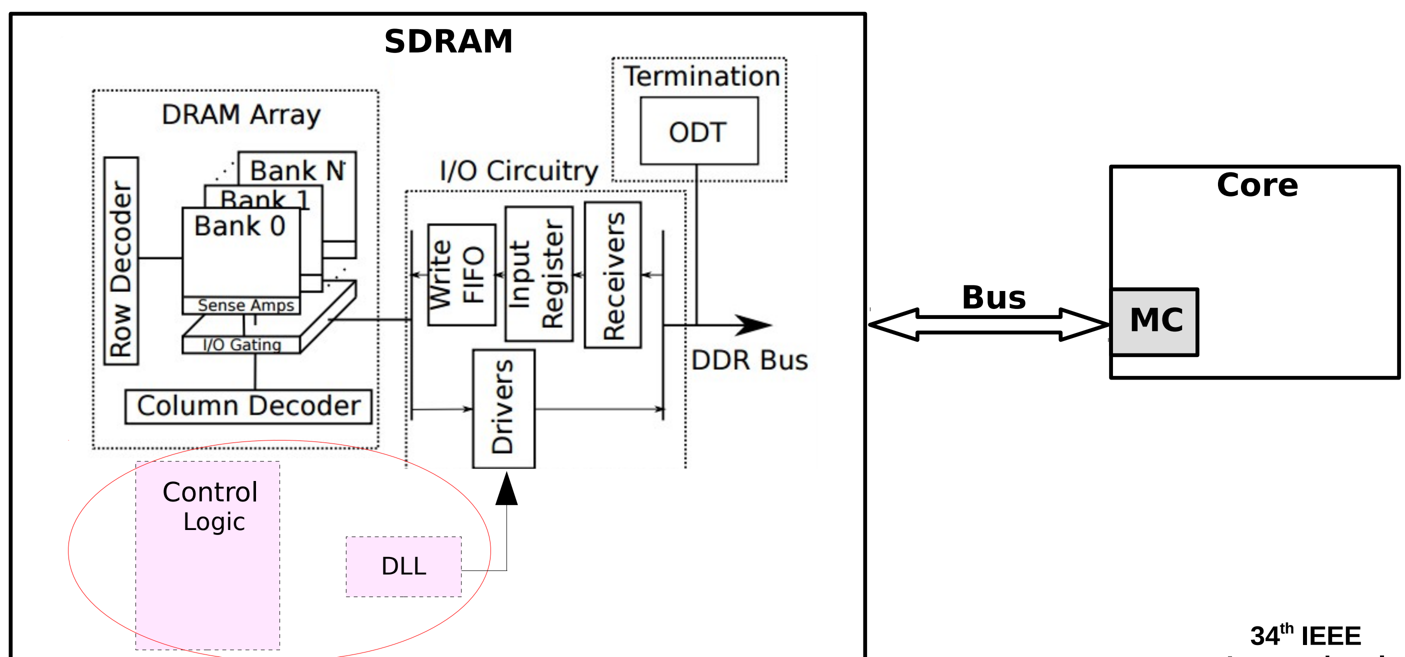


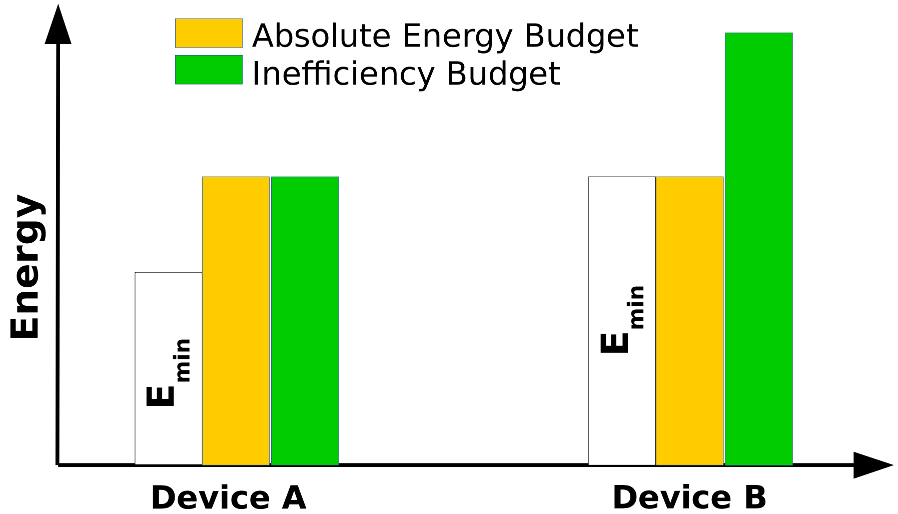
Inefficiency as a System Resource

- Agnostic to Devices

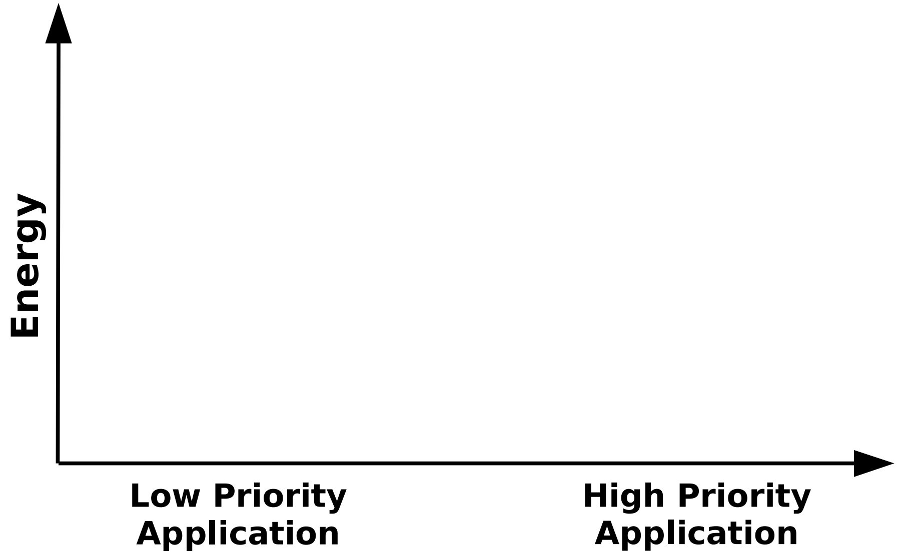
$$Inefficiency = \frac{E_{total}}{E_{min}}$$

$$\Downarrow$$

$$E_{total} = Inefficiency \times E_{min}$$



- Relative to inherent energy needs of the application
  - Inefficiency tied to priority of the applications



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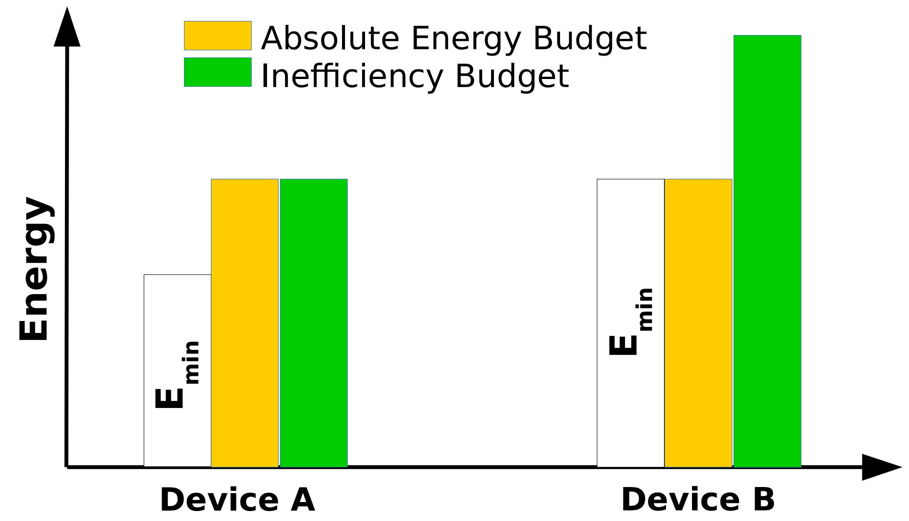

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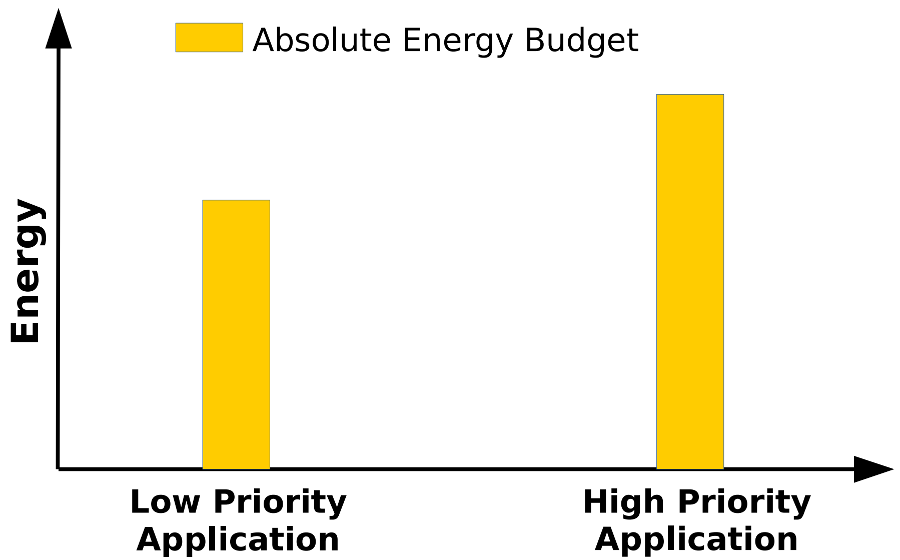

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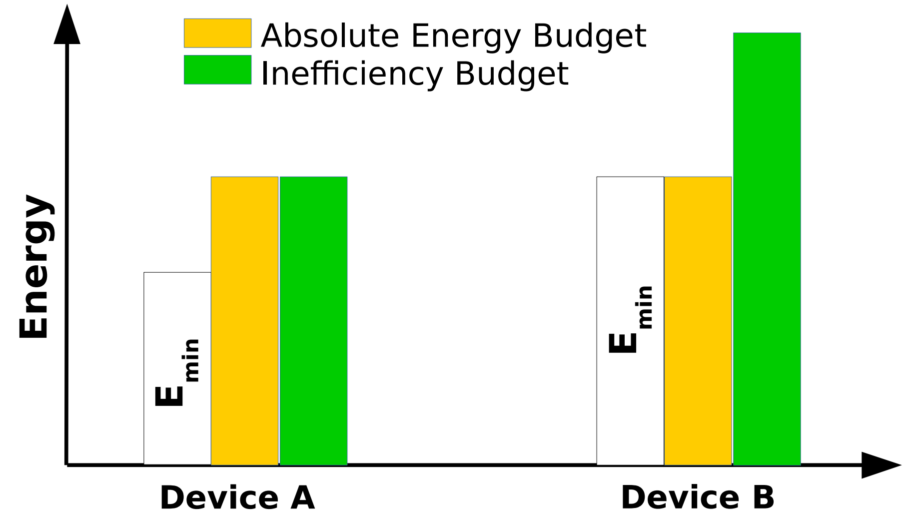

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