# Architecture and System Support for Power-Agile Computing


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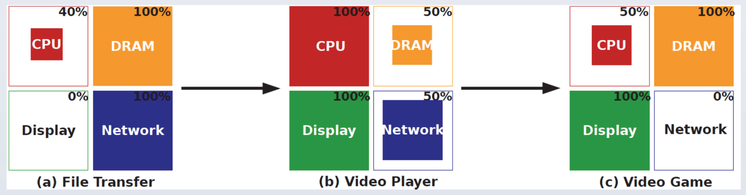
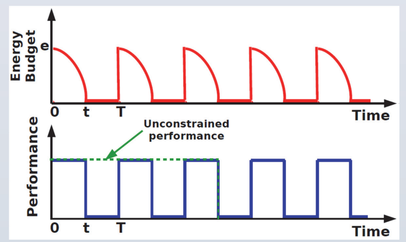
## The Need for Power-Agile Systems

- Battery life is the number one complaint among users
- Mobile devices have multiple hardware components each with its own power-performance tradeoffs
- Current Linux/Android power management methods are not capable of managing next generation hardware with multiple components and power management knobs
- The utilization of hardware components varies dynamically while a workload is executed




- Rate limiting approaches just result in more energy

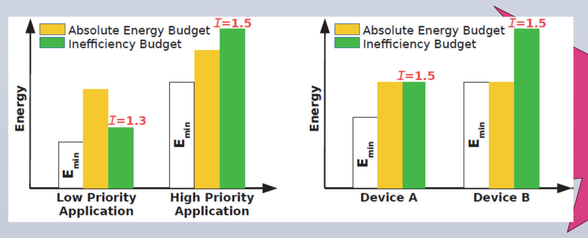



We Need Power-Agile Systems

## New Energy Constraint: Inefficiency

- $E_{min}$ – Minimum energy that the application could have consumed on the same device
- $E_{total}$ – Additional energy that the application can use to improve performance

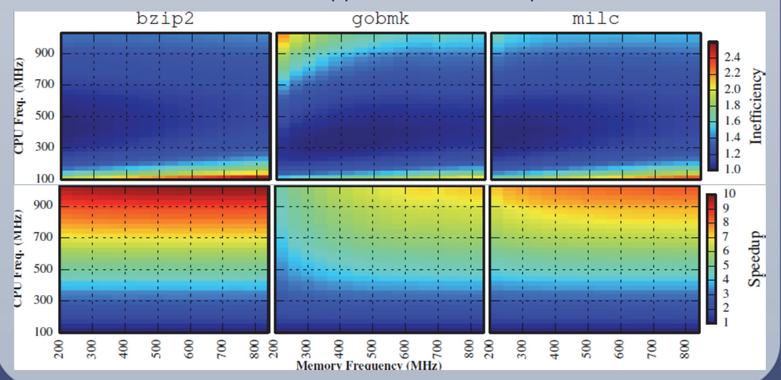
$$Inefficiency = \frac{E_{total}}{E_{min}}$$




Inefficiency is Device and Application Agnostic

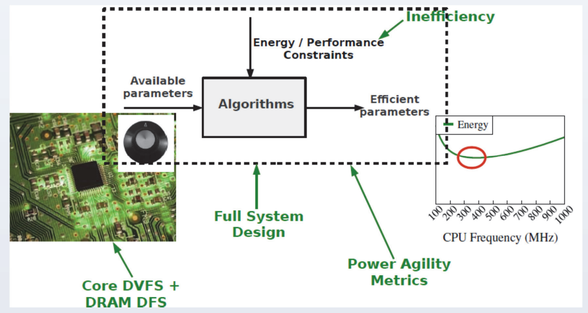
## Implementation Challenges

- Need cross component energy models to predict energy and performance for a new set of frequency settings
- $E_{min}$ is expensive to estimate using brute force methods
- Need management algorithms and system support for *Inefficiency*
- The best performing point is not necessarily the fastest point or highest energy point. It depends on the memory/CPU mix of application
- Need OS and hardware support for multi-component DVFS



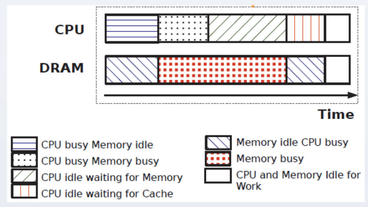

## Memory and Core DVFS under Inefficiency Constraints

### System Overview

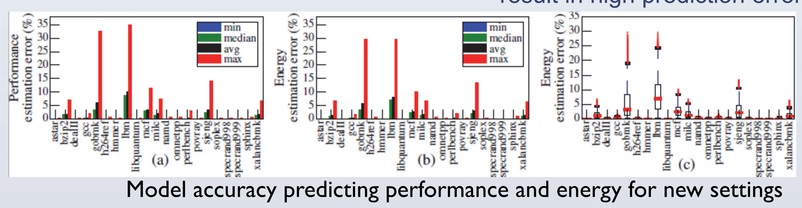



- The system runs a set of energy management algorithms to search for $E_{min}$ and maximize performance under the *Inefficiency* constraint
- To estimate energy and performance, the system collects workload statistics from hardware performance counters every fixed number of instructions and feeds them into the energy/performance model

### Cross-Component Predictive Energy and Performance Models



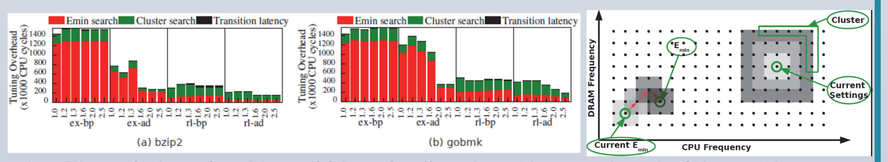

- Use *stats* collected from workload to specify *states*
- Scale *busy, idle, waiting,* and *overlap* states by the new target frequency
- Fixed amount of work makes scaling *easy*
- These models predict performance and energy for a new set of frequency settings with an average error of 4%
- More than 50% of predictions have less than 3% error
- Only two workloads have max errors above 10%
- Large jumps in frequency result in high prediction error




Model accuracy predicting performance and energy for new settings

### Reducing Overhead with Relative Search Algorithms

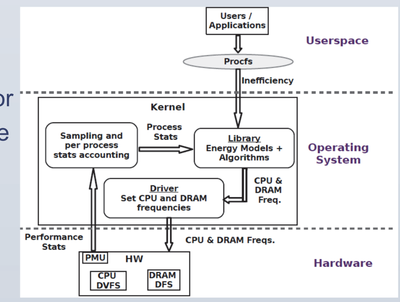
- The exhaustive algorithm (ex) searches all frequency settings for $E_{min}$
- Best performing (bp) does an exhaustive search for the best settings under the *Inefficiency* constraint
- Expensive and brute-force
- Relative (rl) uses the previous $E_{min}$ frequency settings as a starting point
- Stops immediately if new settings found within the Inefficiency constraint
- Adaptive algorithm (ad) skips the search if stats are unchanged (application stable)
- Includes logic to expand search and detect local minima




- The relative algorithms (rl-bp, rl-ad) reduce the overhead of the settings and $E_{min}$ search so that it is cheap enough to include in Android systems

### Simulator Implementation

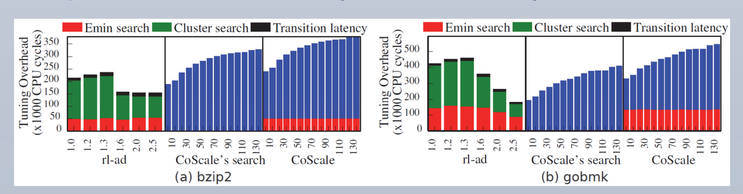
- Modified the gem5 full-system simulator
- Added hardware performance counters
- Added memory frequency scaling




- Modified the frequency governors in Android to implement both core and memory scaling
- Built energy performance models and algorithms into the Android kernel
- Provide *procfs* interface to set *Inefficiency*

## Agile-Android: Putting it All Together: Algorithms under Inefficiency Constraints

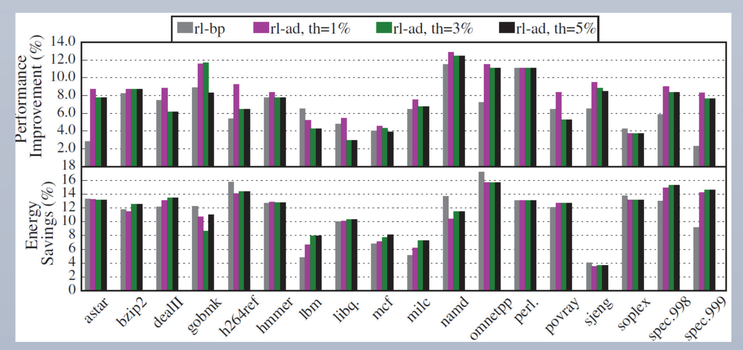
- Compared to CoScale (ASPLOS 2012) our search algorithms reduce overhead and stay under *Inefficiency* constraints
- CoScale uses performance bounds and not *Inefficiency* so we had to use the models to find the appropriate performance bound to stay under *Inefficiency*




### Summary

- Mobile systems must be agile and able to respond to changes in workload to manage energy
- *Inefficiency* provides a relative device and application agonistic constraint for energy management algorithms
- Our system has been implemented in the Android kernel and tested in full-system simulation

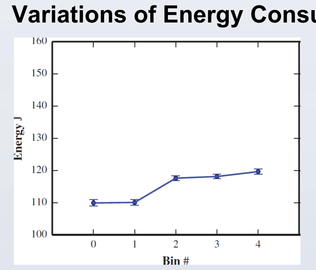
- Through the use of *Performance Clusters* the management algorithm can stay with the current settings if they are within a *performance threshold*
- The plot across all spec benchmarks normalized to *CoScale* for an *Inefficiency* of 1.3
- For a cluster threshold of 1% we see an average energy savings of 9.6% and performance improvement of 8.5% compared to *CoScale*
- Further analysis shows that *CoScale* picks the best performing settings more accurately than *rl-ad* but its search cost is high



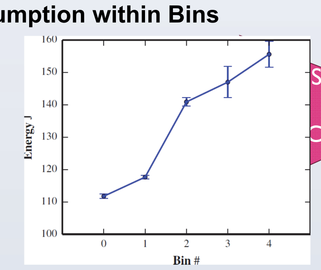

## Addressing Process Variations and Thermal Management for Energy-Efficiency

- The microprocessors for smartphones are not all the same; they are binned after manufacture with different supply voltages
- In addition, when phones get too hot they are throttled either to a lower frequency or fewer cores
- How does this affect energy efficiency and performance?
- We measured phones from different bins in a thermal chamber

### Variations of Energy Consumption within Bins




Default bin voltage

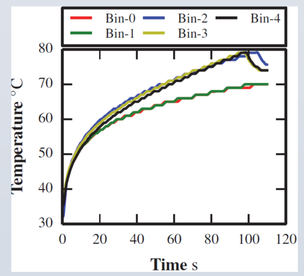


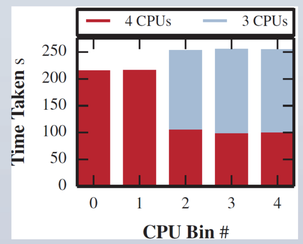

Uniform voltage

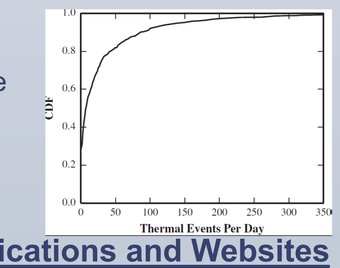
Smartphones are not Created Equal

### Thermal Emergencies Affect Performance

- Measured Energy and performance of Nexus 5 phones
- Without heat sinks or fans phones will heat up and be throttled, reducing performance
- We observed that more power hungry and leaky transistors more thermal emergencies (bins 2,3,4)
- Less efficient bins will spend more time in slower settings and take longer to execute an application
- Used the PhoneLab testbed to observe thermal emergencies per device per day
- Need better methods to reduce thermal emergencies
- Need methods to identify bins when purchasing phones




## For More Information: Publications and Websites


- *Guru Prasad Srinivasa, Rizwana Begum, Scott Haseley, Mark Hempstead, and Geoffrey Challen,* ***Separated by Birth: Hidden Differences Between Seemingly-Identical Smartphone CPUs****. HotMobile 2017.*
- *Rizwana Begum, Guru Prasad Srinivasa, Geoffrey Challen, and Mark Hempstead.* ***Algorithms for CPU and DRAM DVFS Under Inefficiency Constraints****. ICCD, 2016.*
- *Rizwana Begum, Guru Prasad Srinivasa, David Werner, Mark Hempstead and Geoffrey Challen.* ***Energy-Performance Trade-offs on Energy-Constrained Devices with Multi-Component DVFS****. IISWC, 2015.*
- *Rizwana Begum and Mark Hempstead.* ***Power Agility Metrics: Measuring Dynamic Characteristics of Energy Proportionality****. ICCD 2015.*
- *Rizwana Begum, Mark Hempstead, Guru Prasad, and Geoffery Challen,* ***New Interfaces for Achieving Power Agility on Mobile Devices****. HotMobile, Feb 2014.*
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