A Hardware Evaluation of Cache Partitioning to Improve Utilization and Energy-Efficiency while Preserving Responsiveness

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Responsiveness (In The Cloud)

- Introducing server-side search result delays of **< 0.5** seconds impacts critical business metrics
  - Time to click, satisfaction, daily searches per user
- The cost of added delay increases over time and **persists** afterwards
- Results were so negative that some A/B experiments were halted **ahead of schedule**

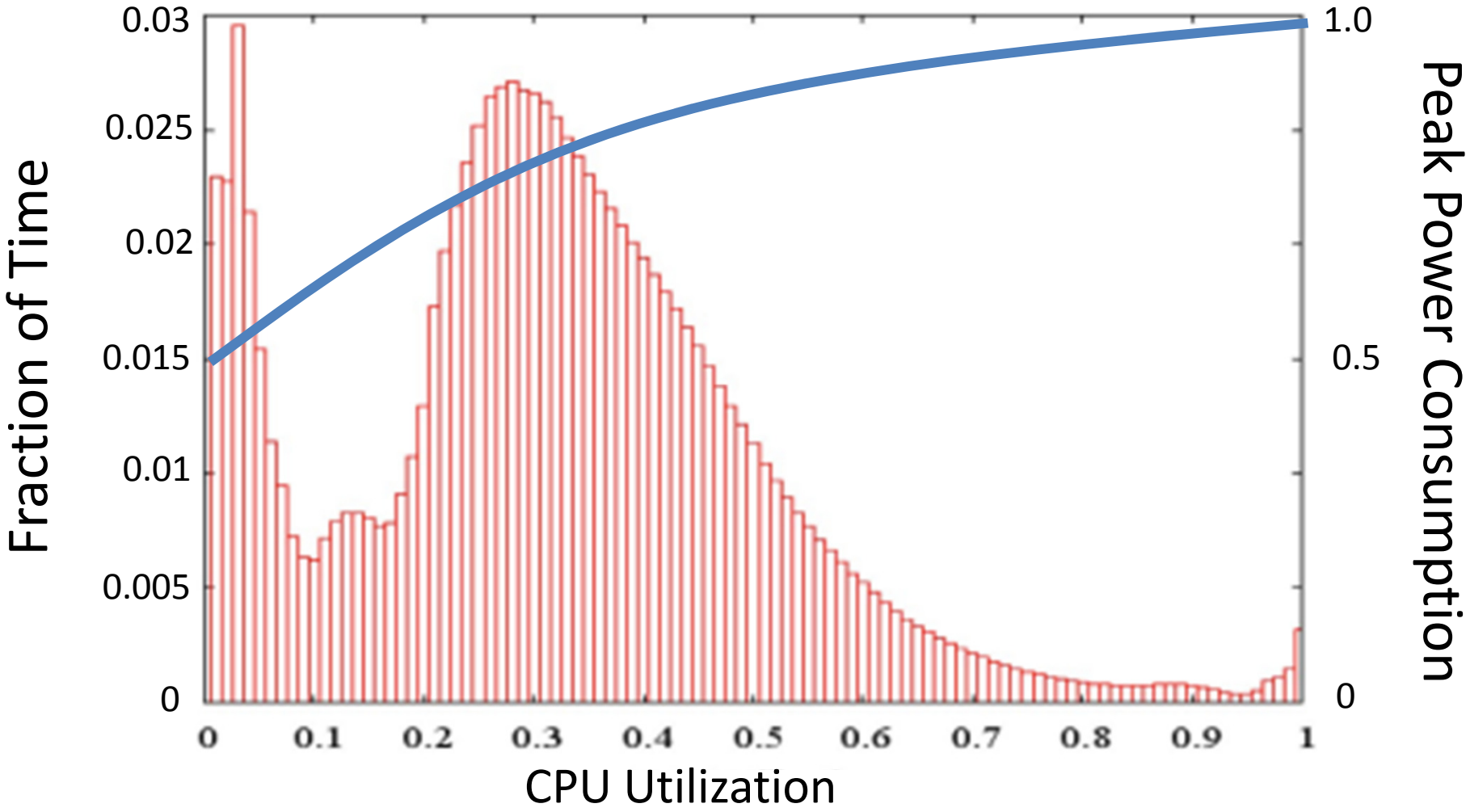
E. Schurman and J. Brutlag. The user and business impact of server delays, additional bytes, and http chunking in web search. In Velocity, 2009.

Responsiveness (On The Client)

- "Save user data and app state information. …This step is necessary because your app might be quietly killed while in the background **for any number of reasons**."
- "Using these calls causes your app to be killed immediately."
- "When your app is suspended, if it is found to be using a **shared resource**, the app is killed."

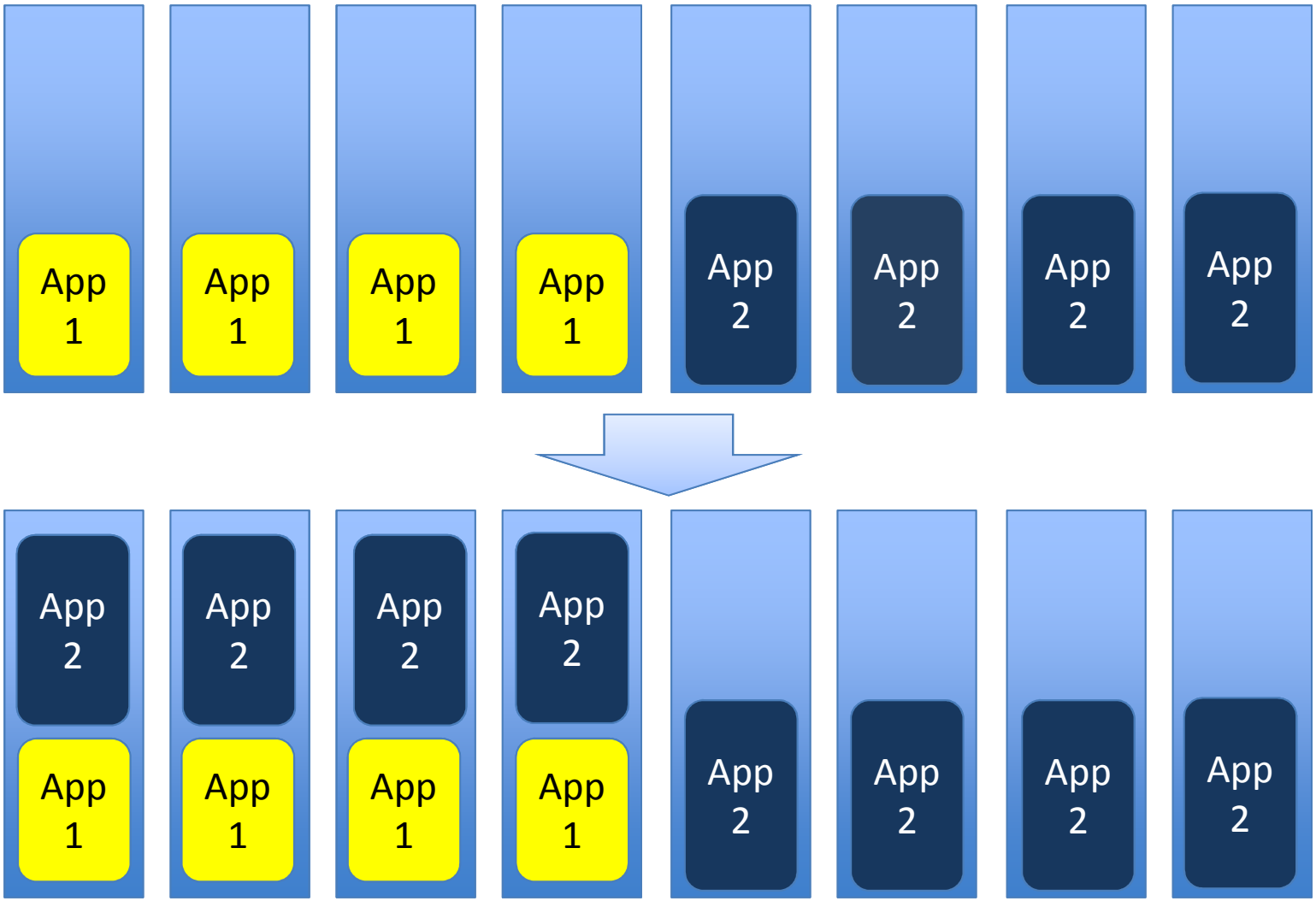
Apple iOS Developer Library, Chapter 3: App States and Multitasking, 2013

Underutilization



"The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines"
Luiz André Barroso and Urs Hölzle, 2009.

Consolidation Challenge



A Well-Studied Problem

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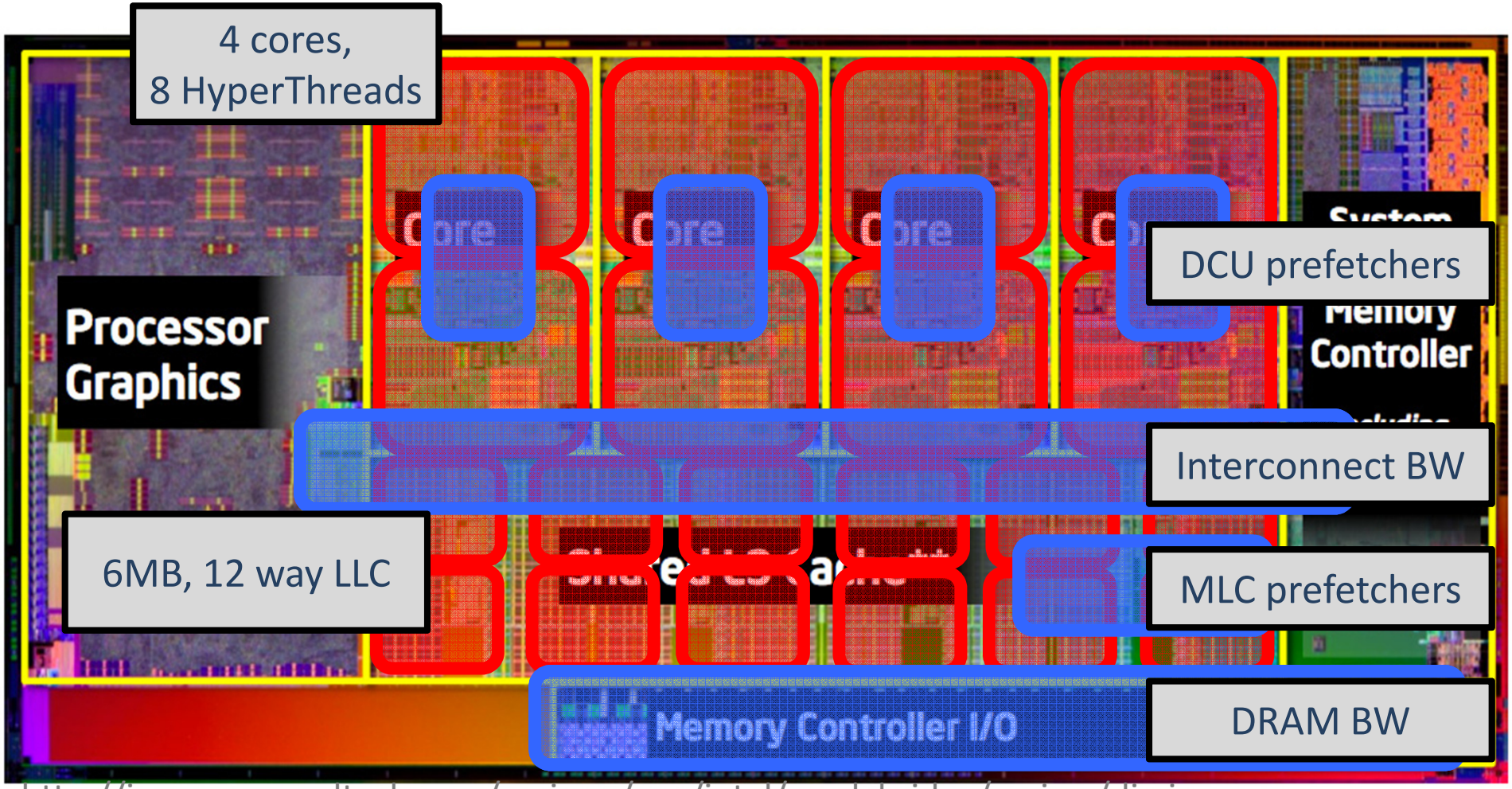
A New Opportunity

- Sandy Bridge client device prototype HW
  - Way-based LLC partitioning
  - Energy counters
- Full size parallel benchmarks, full system stack

- Goal: Evaluate the energy-saving potential of consolidation with HW for cache partitioning

Machine Resources

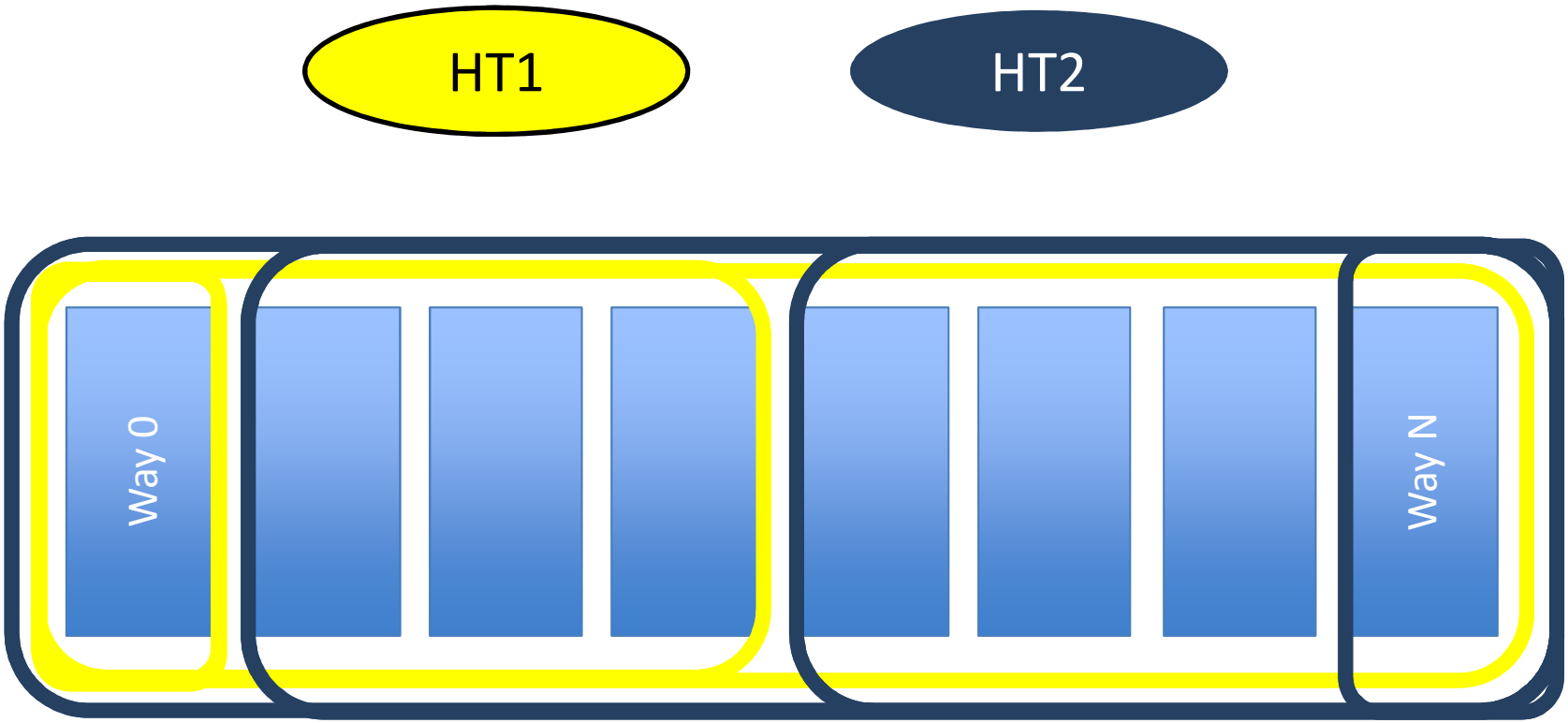


http://images.anandtech.com/reviews/cpu/intel/sandybridge/review/die.jpg

Partitionable

Unpartitionable

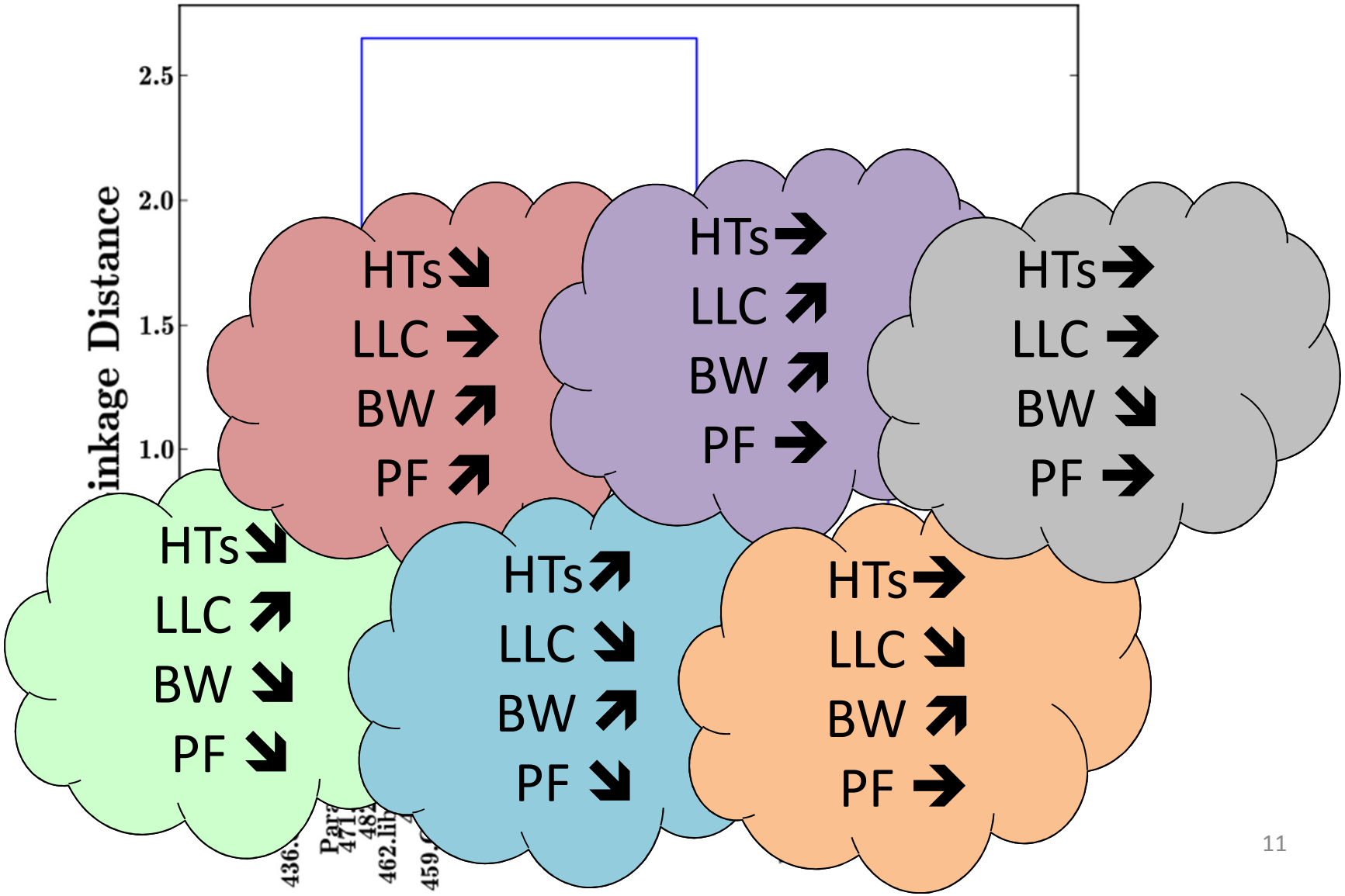
Way-Based Partitioning



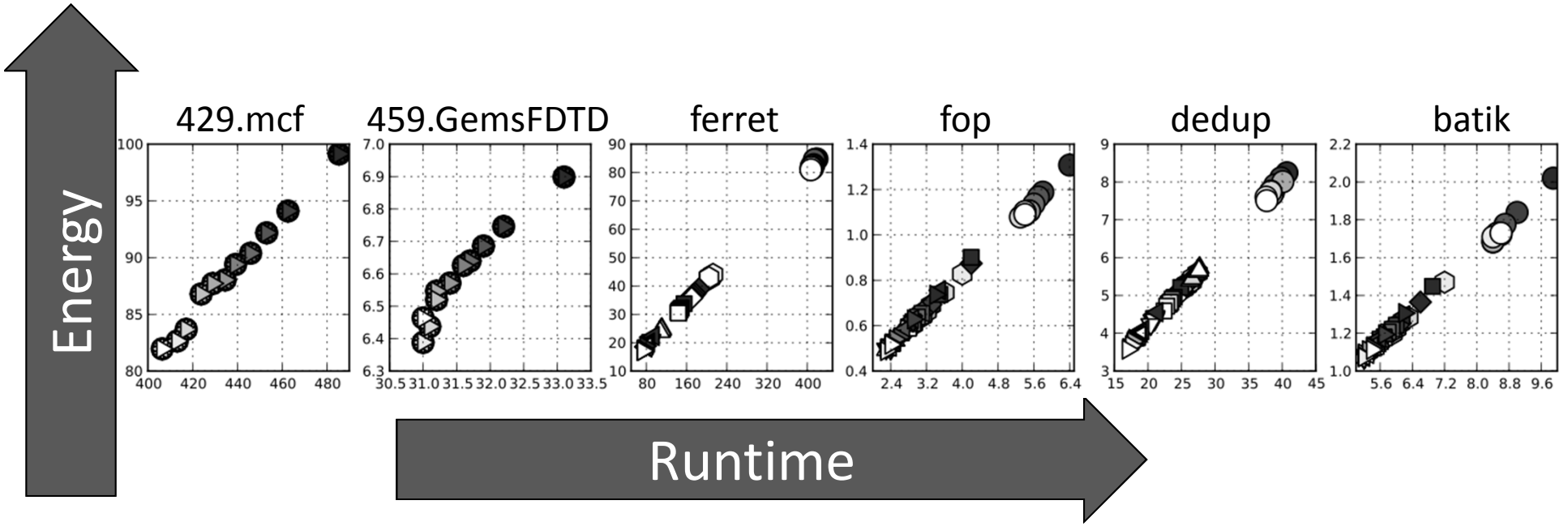
Methodology

- Multiple benchmark suites
  - Spec2006, PARSEC, DaCapo, other parallel kernels
  - **Full/large/native** input sets
- Unmodified Linux 2.6.36
- `Libpfm` library built on `perf_events`
- Running Average Power Limit (**RAPL**) interfaces
  - 16us granularity
- ACme external power meter
  - 1 sec granularity
  - http://acme.cs.berkeley.edu

Hierarchical K-means Clustering

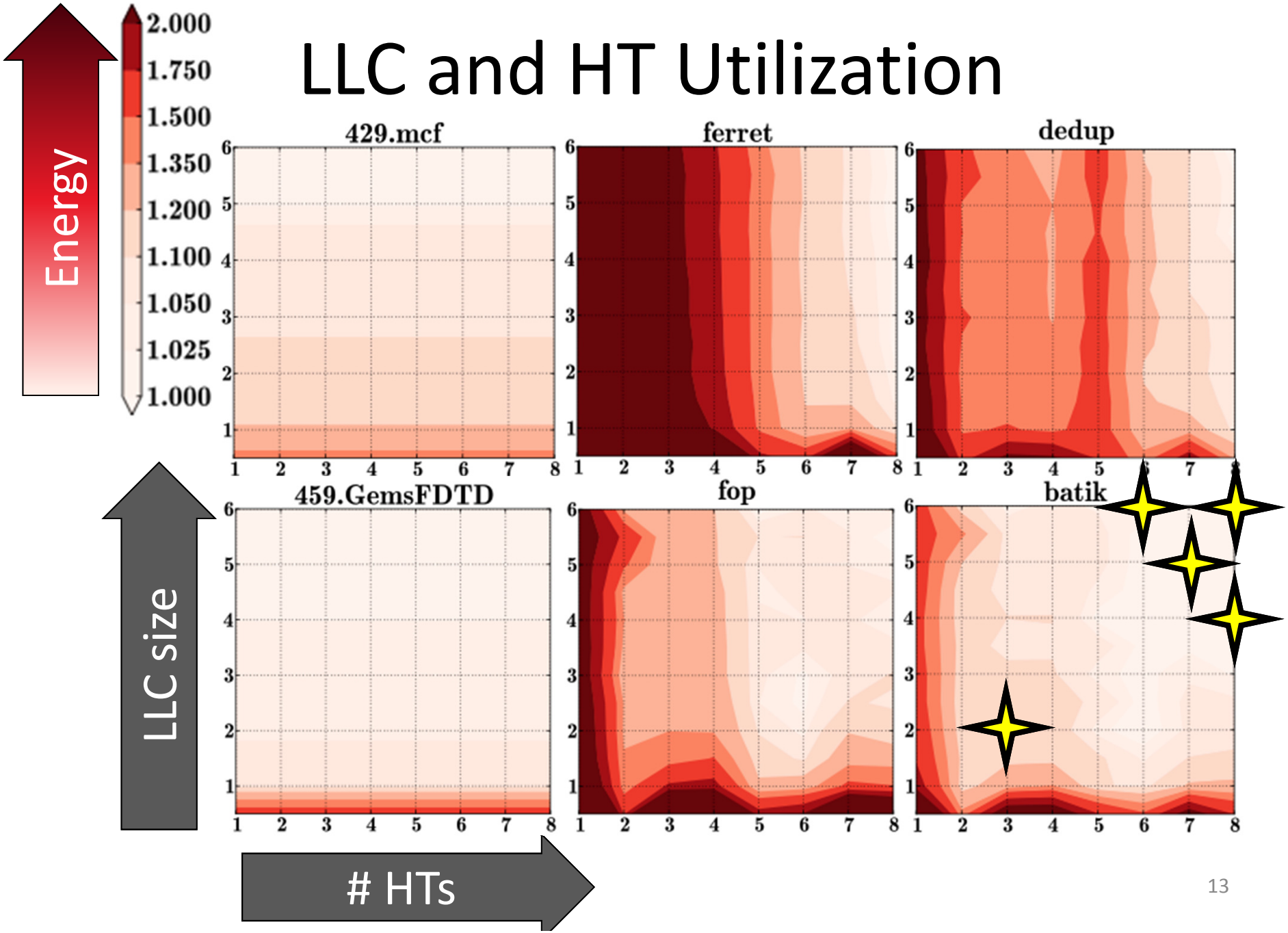


Race to Halt

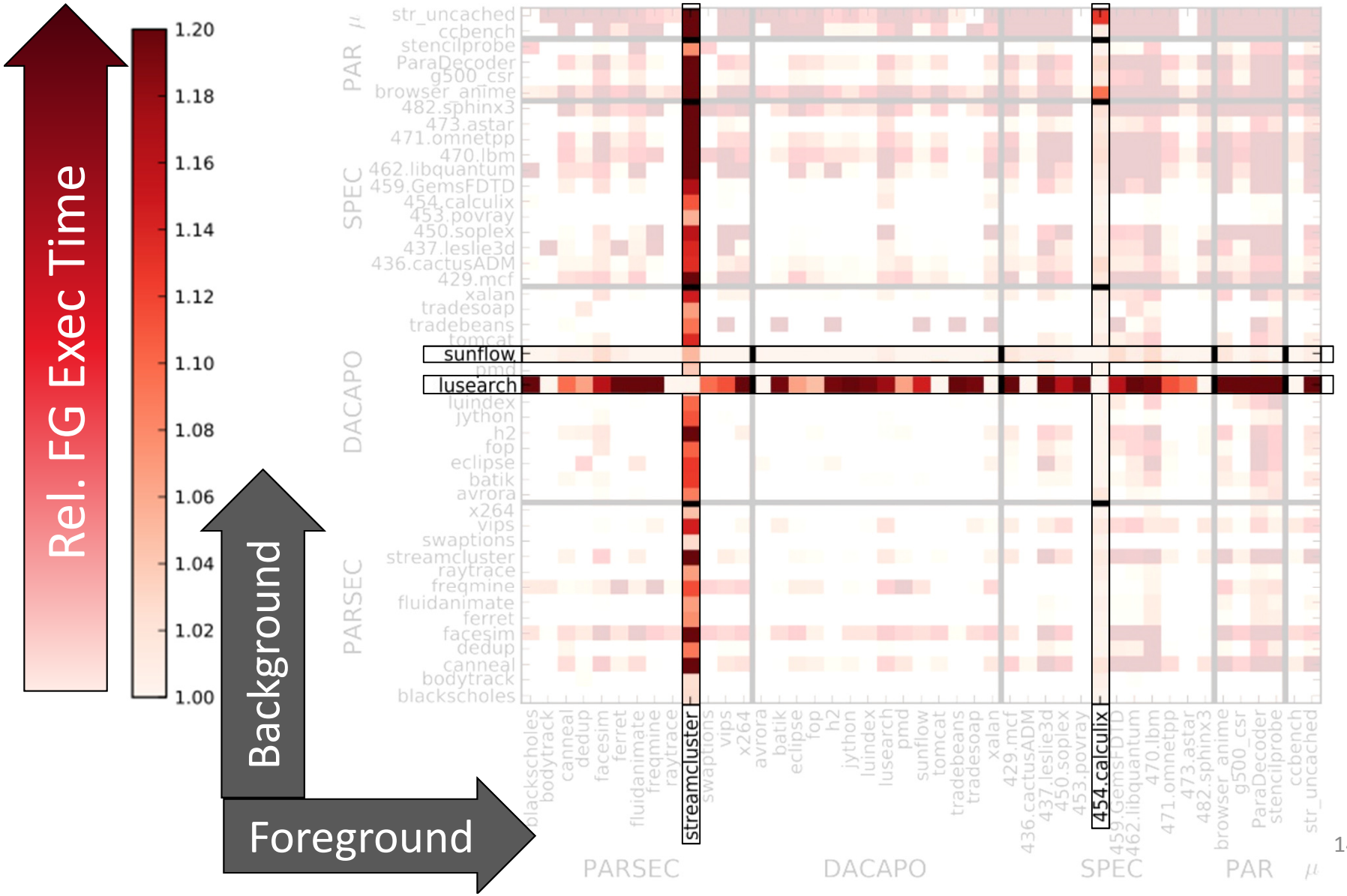


- Scattered points are the 8x12 possible allocations
- Energy α performance
- Applies across all benchmarks and allocations

LLC and HT Utilization



Multiprogram Contention



Static Partitioning: Unpartitioned

- Baseline for measuring foreground app degradation is to just let apps share each way of the LLC
- Replacement policy evicts based on usage patterns

Static partitioning	Average slowdown	Worst-case slowdown
Unpartitioned	5.9%	34.0%

Static Partitioning: Fair Partitioning

- Fair partitioning gives each app half of the cache, regardless of need
- Most naïve use of partitioning

Static partitioning	Average slowdown	Worst-case slowdown
Unpartitioned	5.9%	34.0%
Fair	6.0%	16.3%

Static Partitioning: Ideal Partitioning

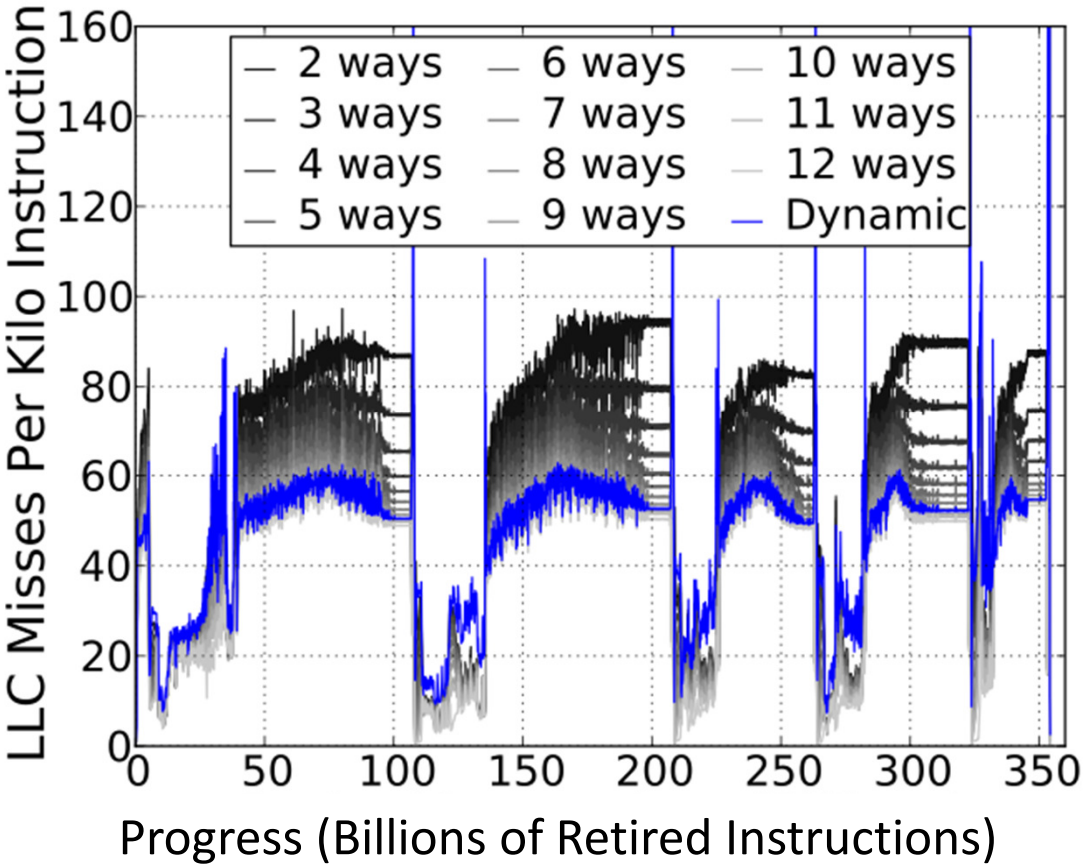
- Ideal partitioning uses the "best" allocation
  - Heuristic is: smallest FG alloc whose perf was within 1% of giving FG the whole machine, yet allows BG to run in remainder
- Oracular static partitioning

Static partitioning	Average slowdown	Worst-case slowdown
Unpartitioned	5.9%	34.0%
Fair	6.0%	16.3%
Ideal	2.3%	7.4%

Static Partitioning: Takeaways

- Partitioning mitigates worst-case degradation
- For metrics like energy or weighted speedup, consolidation is effective but differences between sharing strategies are small on average
- High variance across application pairs
- Pairing strategy >> sharing strategy

Applications Have Phases

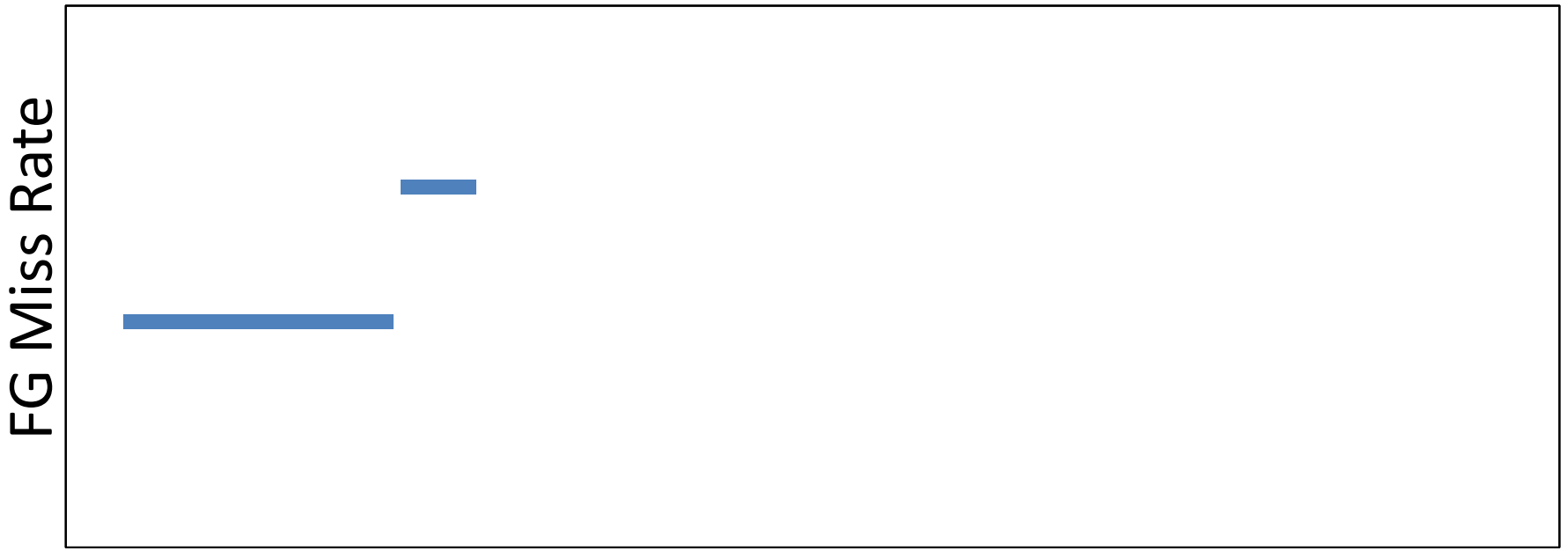


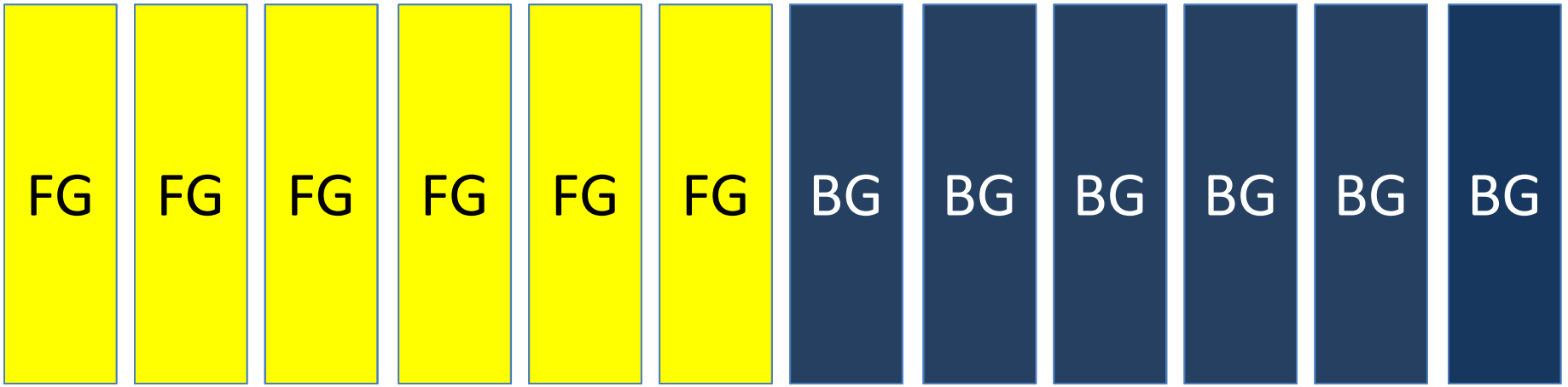
- Can we dynamically determine the LLC requirements and further consolidate?

Dynamic Algorithm

- Use performance counters to detect changes in required LLC alloc, via miss rate
- When a phase change is detected, explore allocations to determine new required size
- Give FG maximum alloc, then shrink alloc until miss rate is negatively impacted
- Hold allocation fixed until another change in miss rate is detected

Dynamic Algorithm

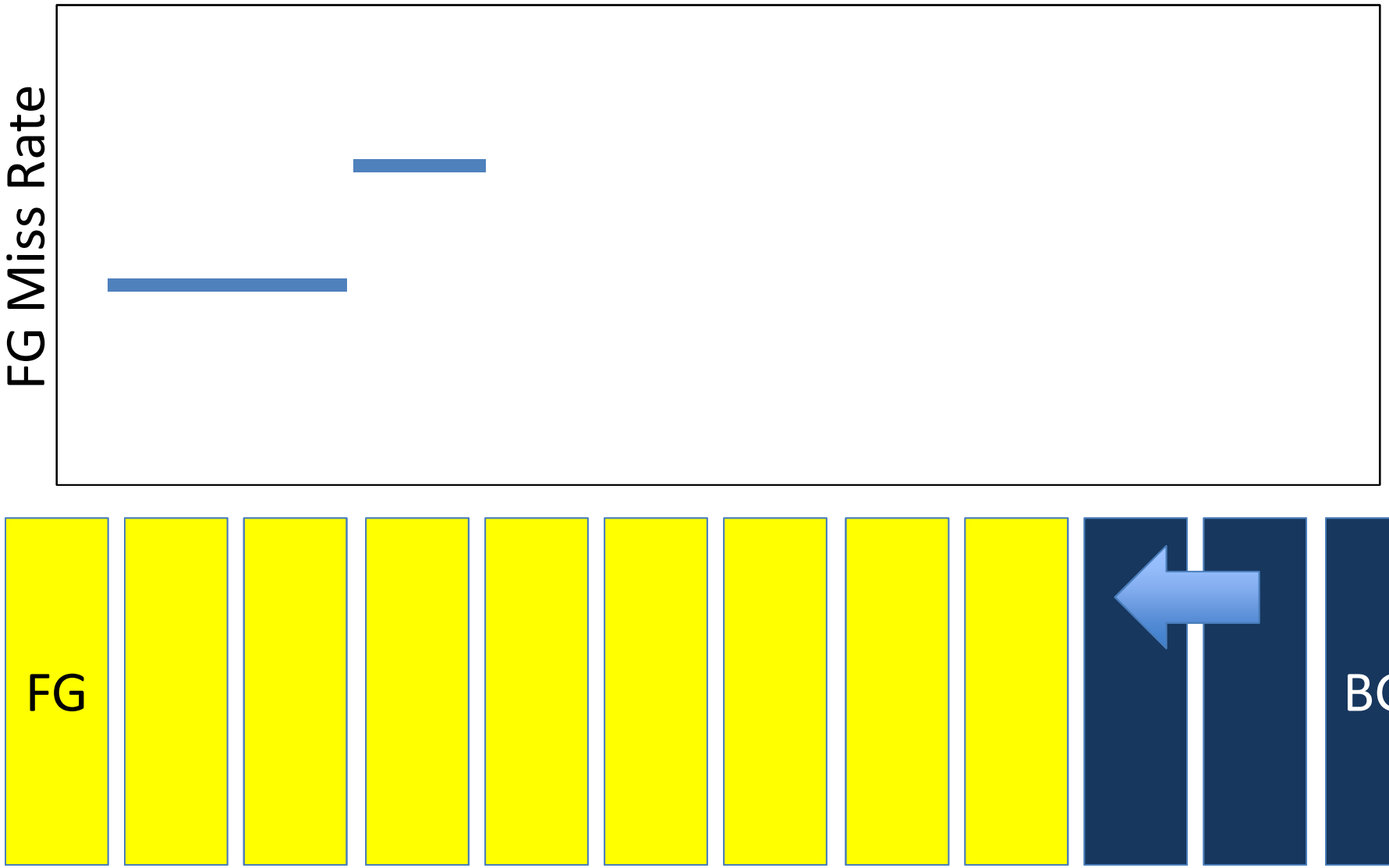




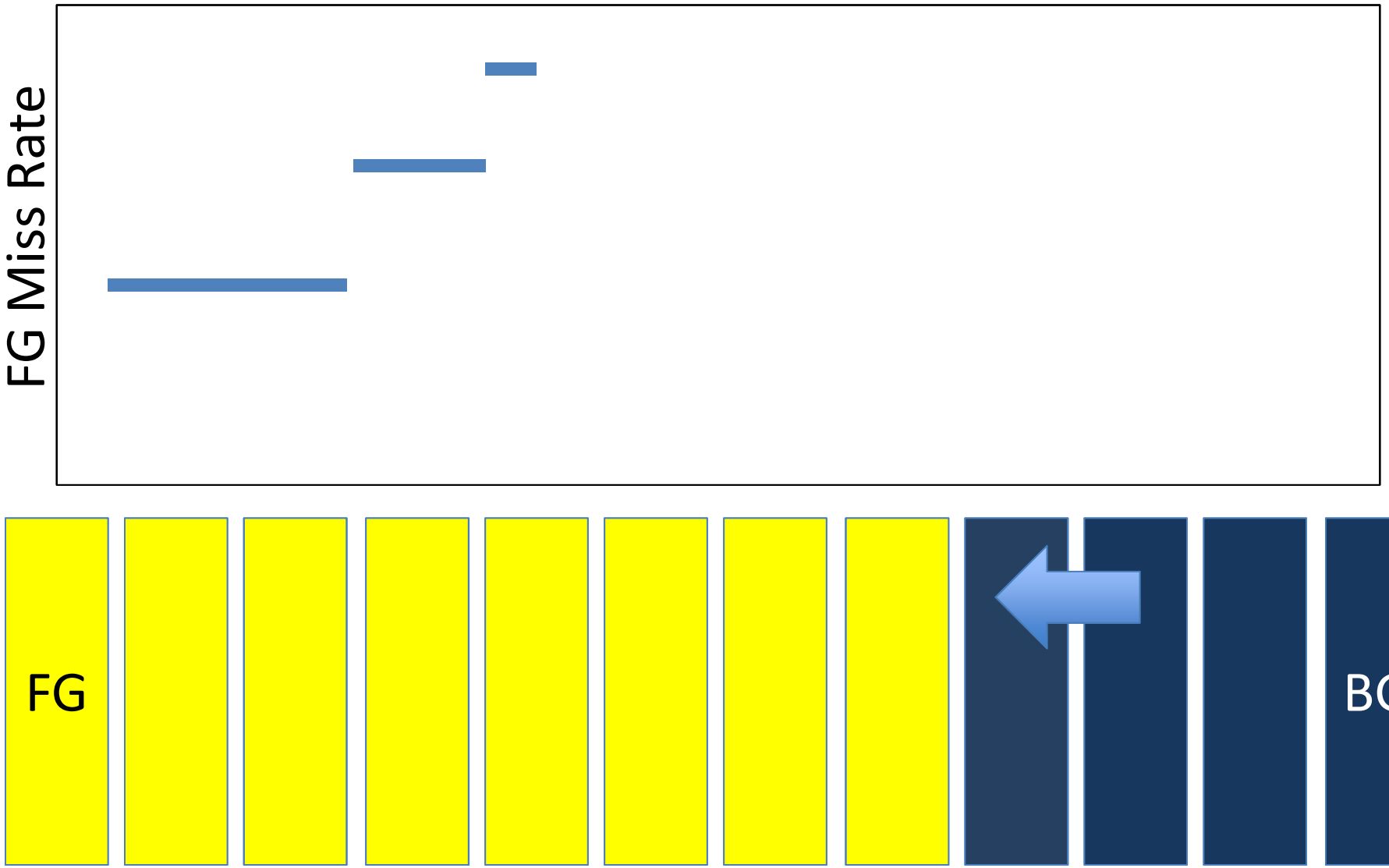
Dynamic Algorithm

Dynamic Algorithm

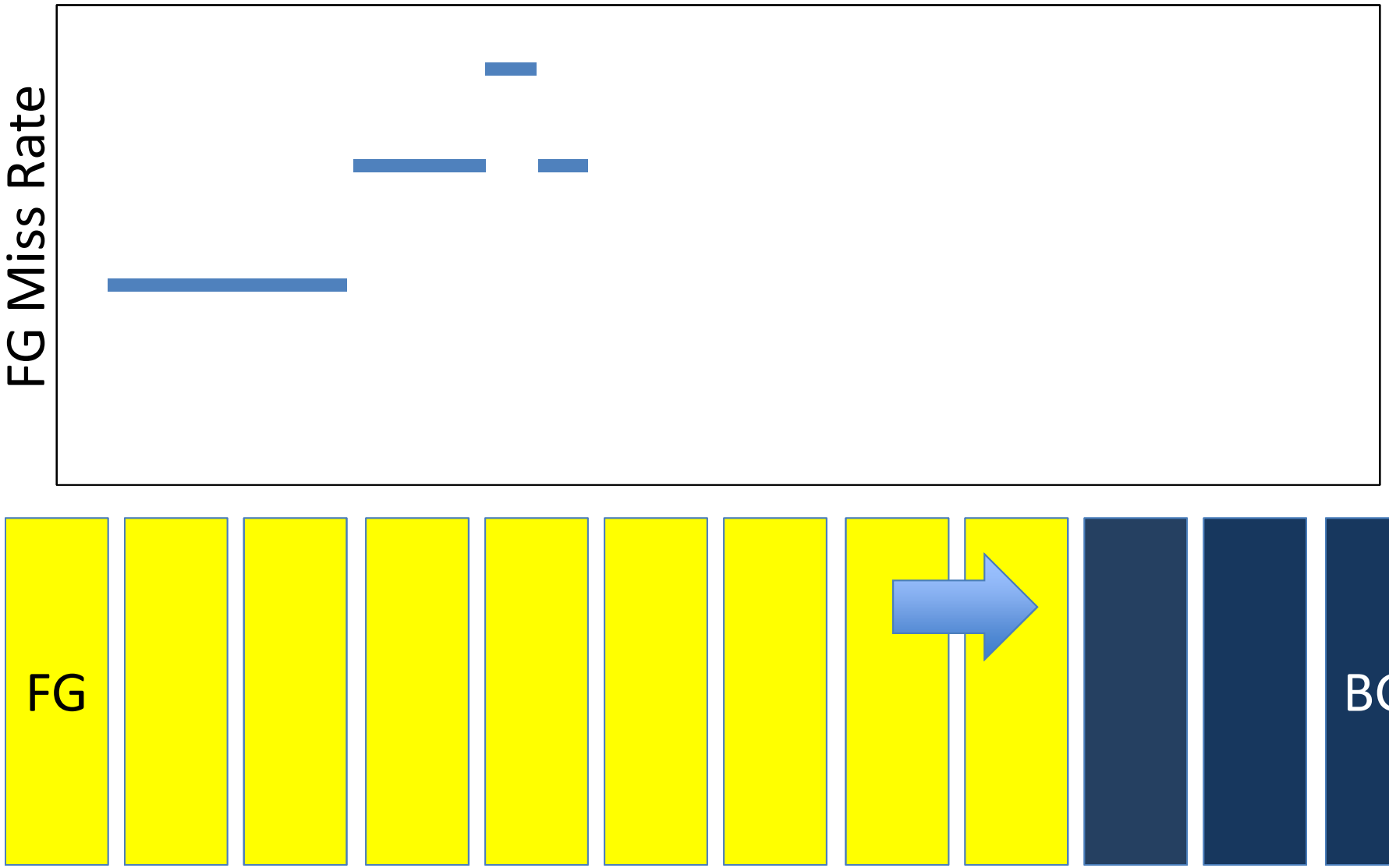
Dynamic Algorithm



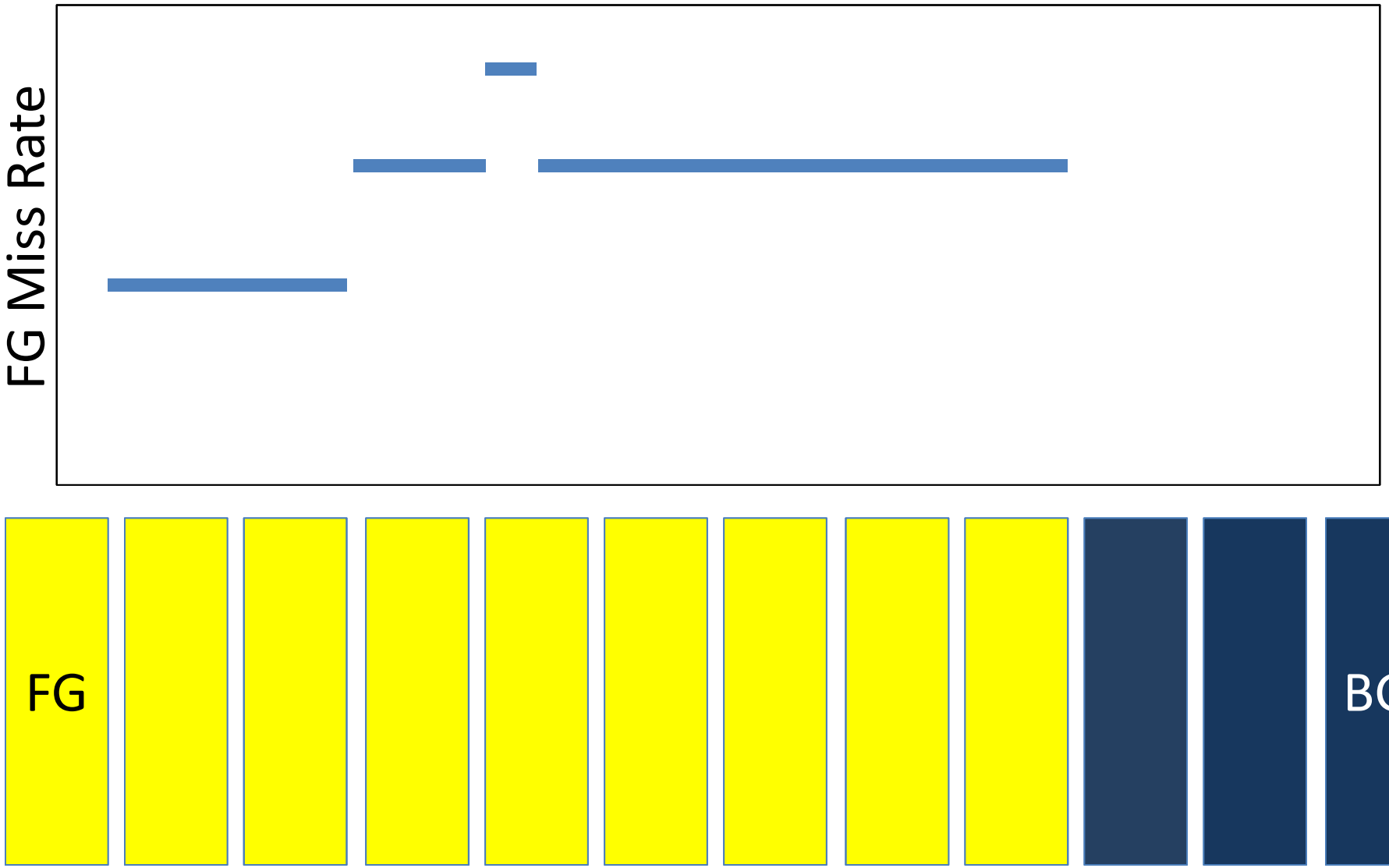
Dynamic Algorithm



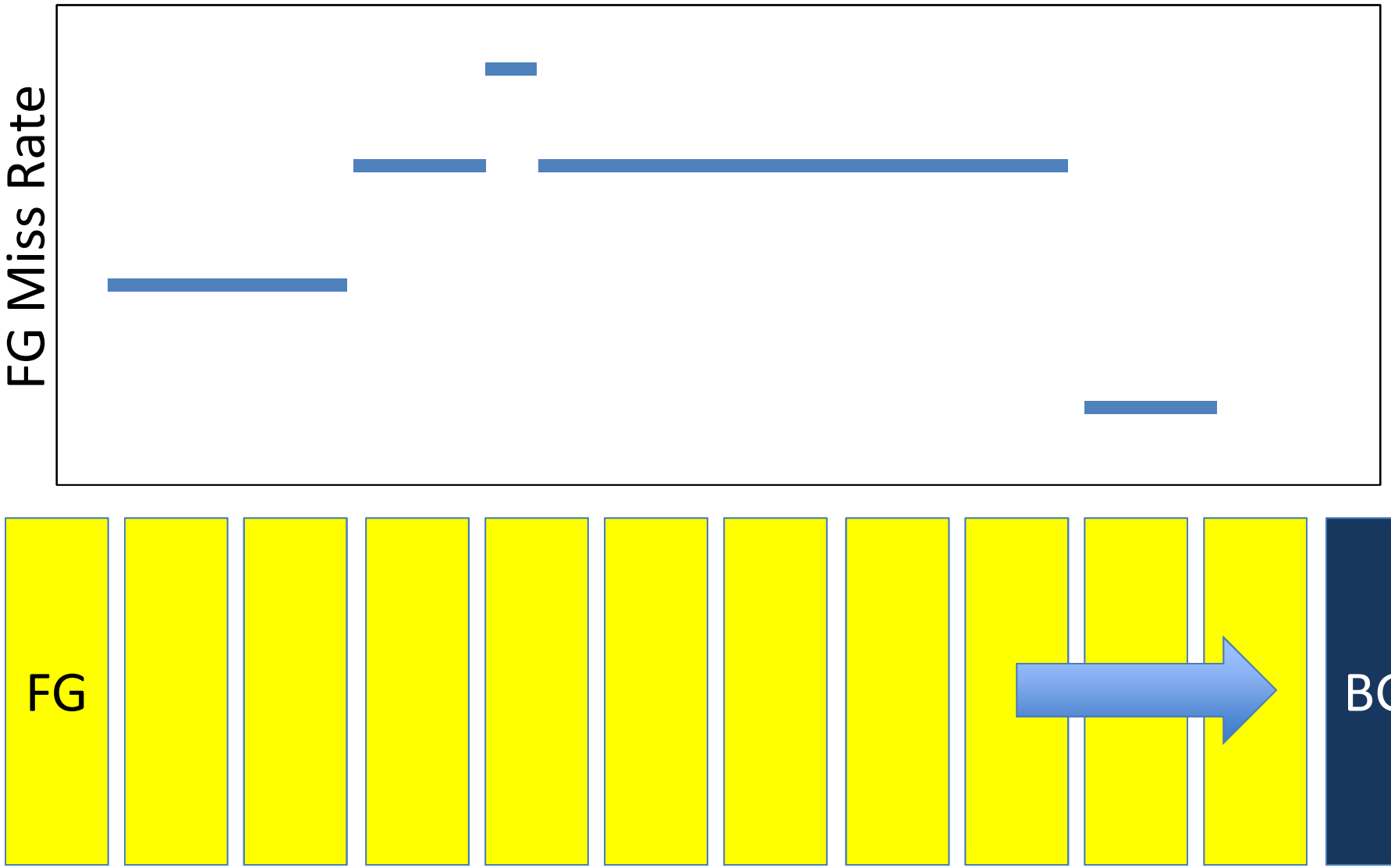
Dynamic Algorithm



Dynamic Algorithm



Dynamic algorithm



Dynamic Algorithm Results

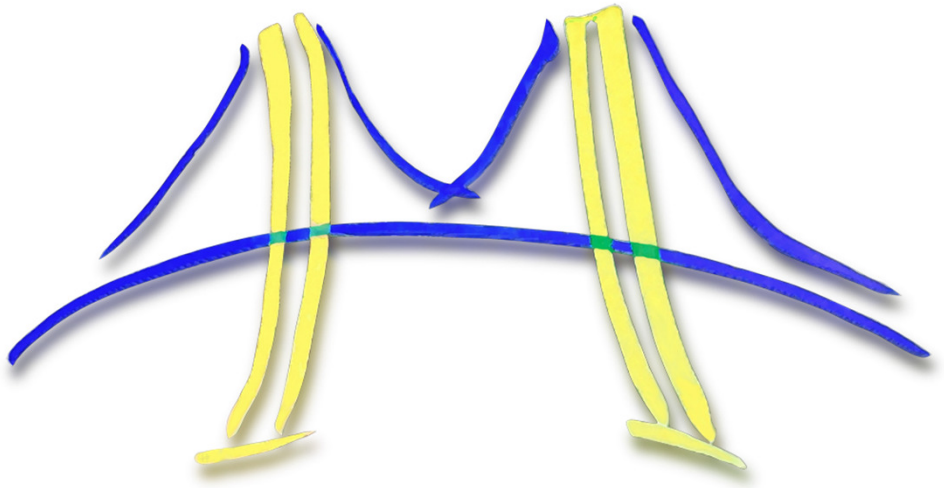
- In some cases we see significant throughput increases (up to 2.5x), resulting in a 19% throughput improvement on average
  - FG performance never worsens more than 2%
- Using a shared LLC results in a 53% throughput improvement on average
  - However, this scenario can often result in significant perf loss (up to 35%) for FG app
- Throughput correlated with energy/task

Future Work

- Explain discrepancies between real machine utilities and others' simulated results
- More big data workloads
- App-pair-specific dynamic mechanism tuning
- Mechanisms for BW partitioning
- Mechanisms to preserve prefetcher efficacy

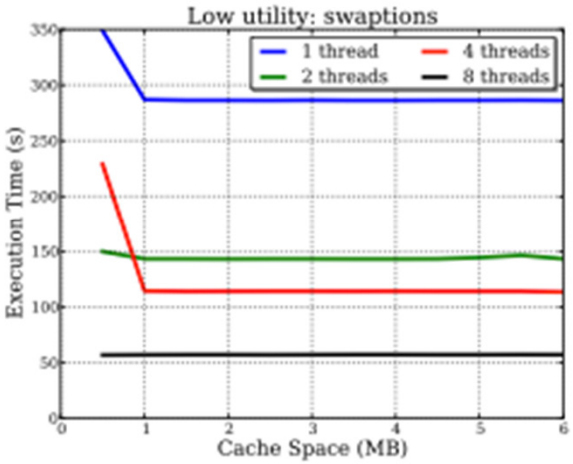
Conclusions

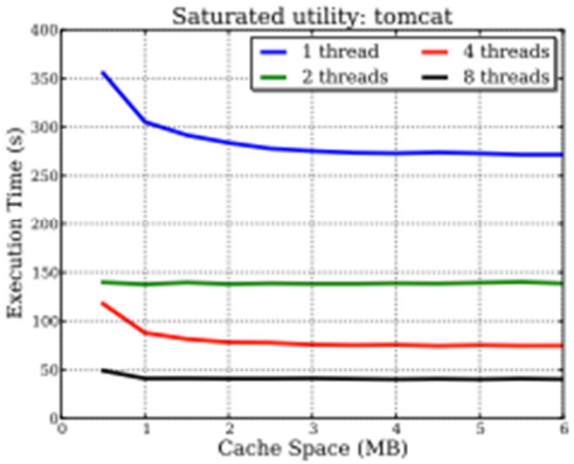
- The race-to-halt paradigm still allows for consolidation opportunities
- LLC partitioning alone is not enough to prevent degradation, but mitigates worst case
- Consolidation is very effective for saving energy, but pairing strategy >> static sharing strategy
- Dynamic LLC partitioning can be effective at reducing energy per background task while preserving FG performance

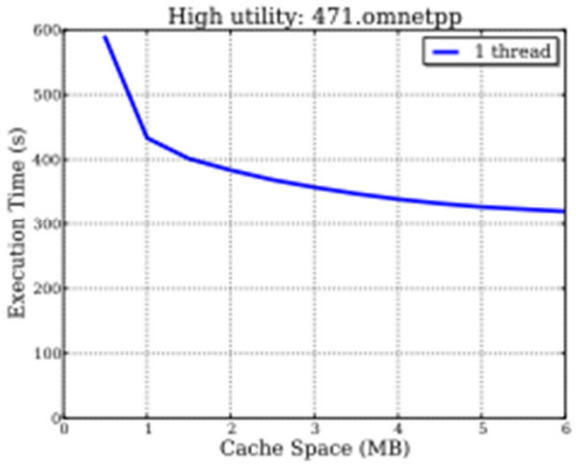


www.eecs.berkeley.edu/~hcook

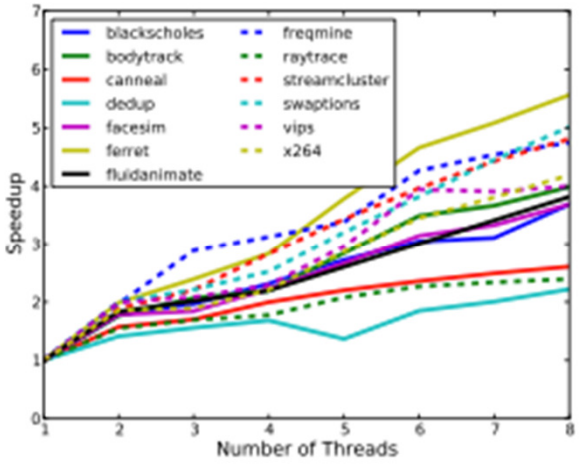
LLC sensitivity



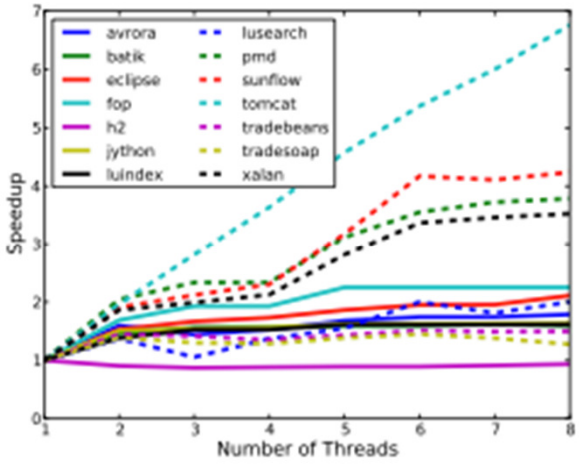




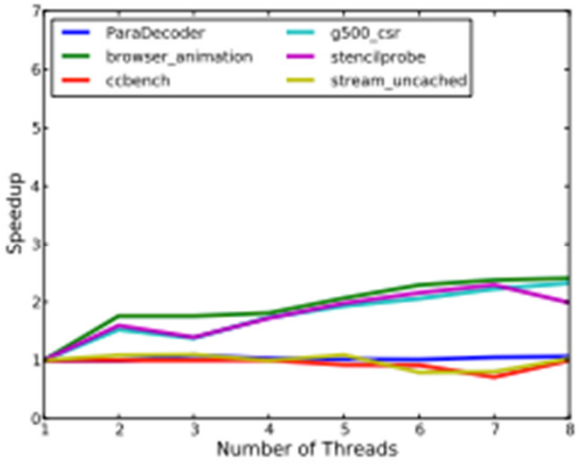
Thread scalability



(a) PARSEC applications

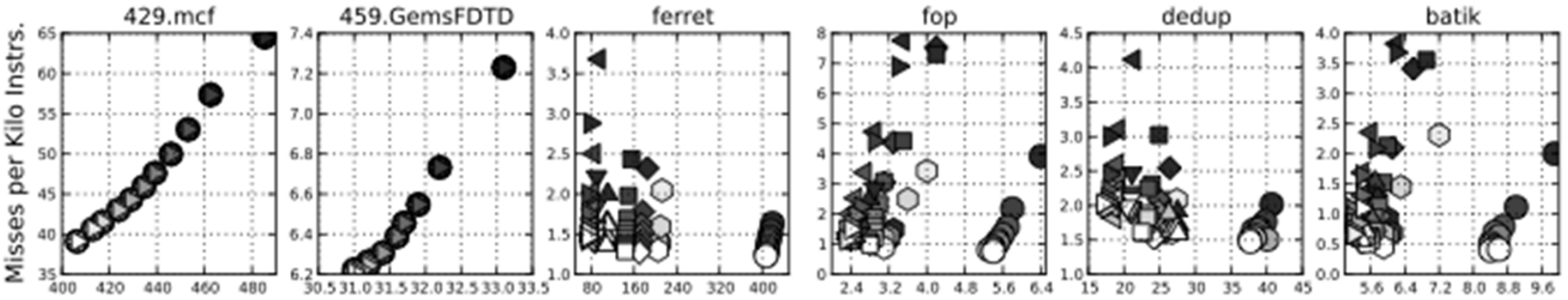


(b) DaCapo applications

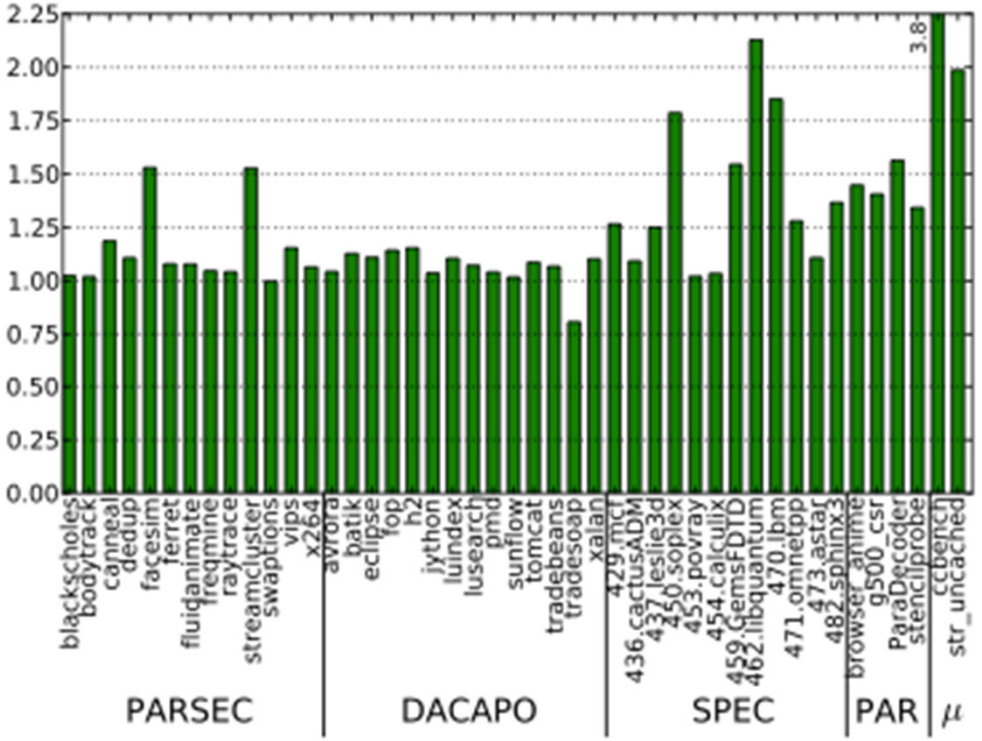


(c) Parallel applications and microbenchmarks

Utilization Diversity



BW Hog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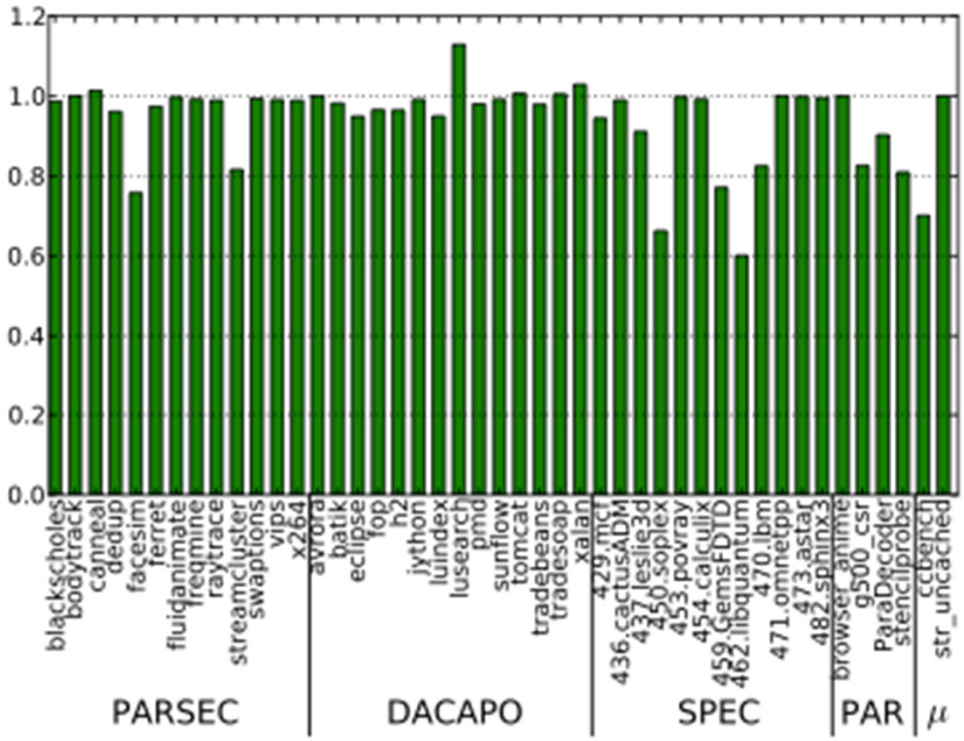
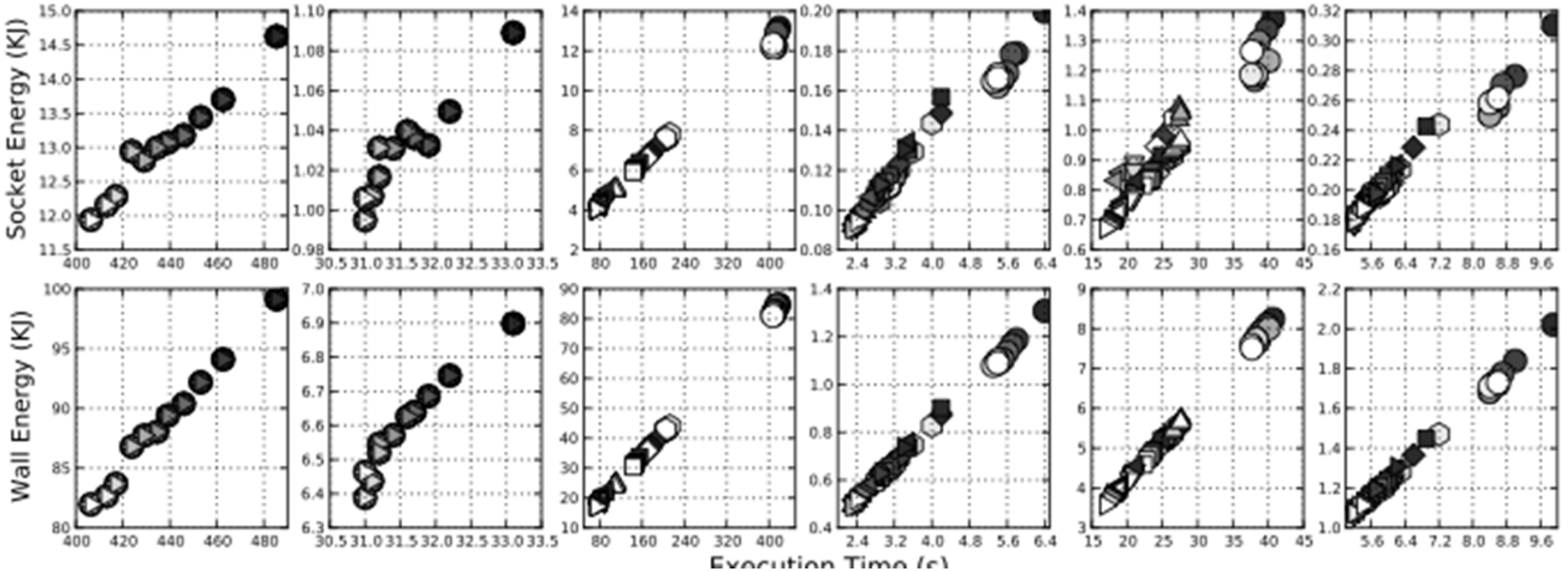
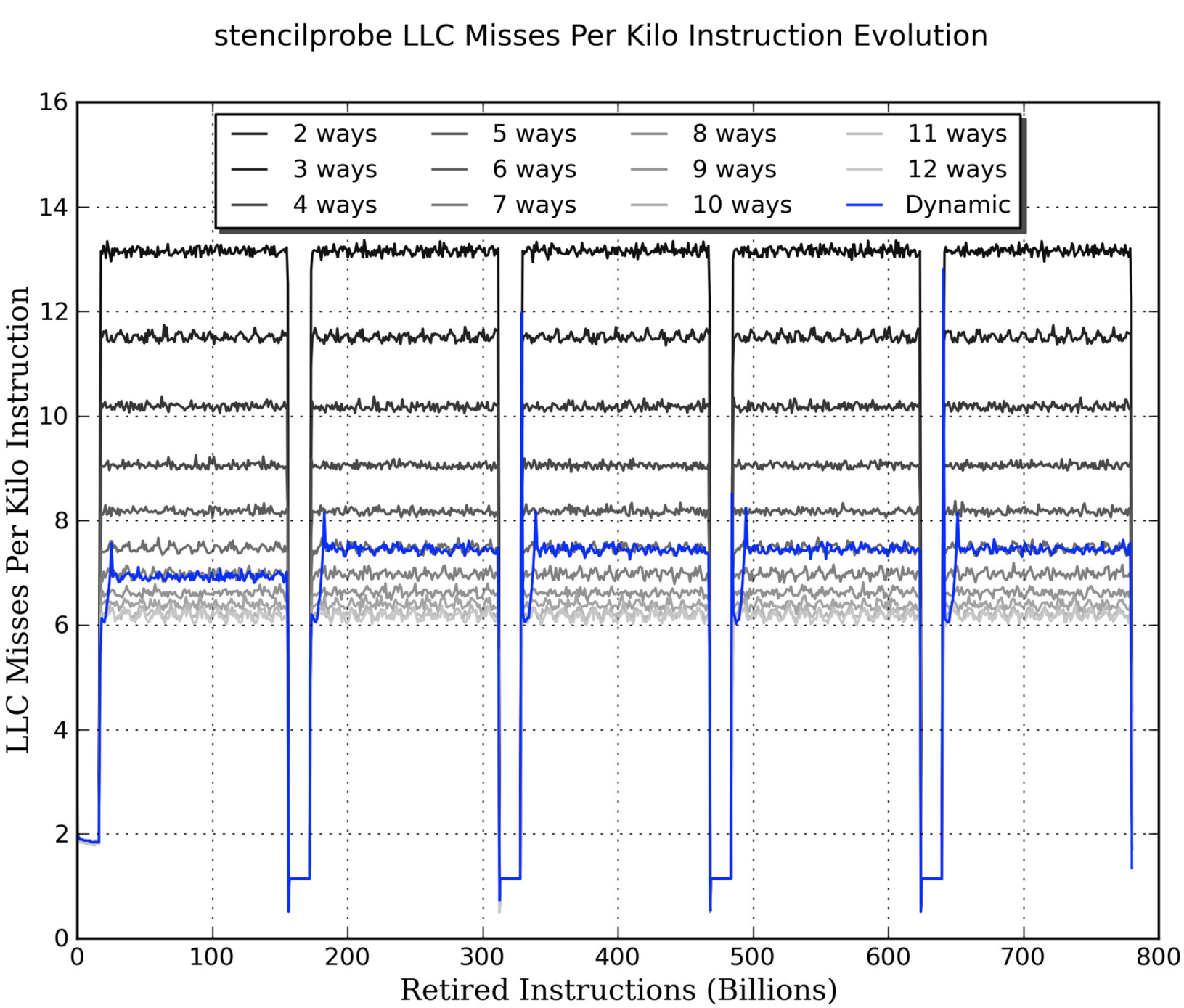
Prefetcher Sensitivity



Wall vs socket

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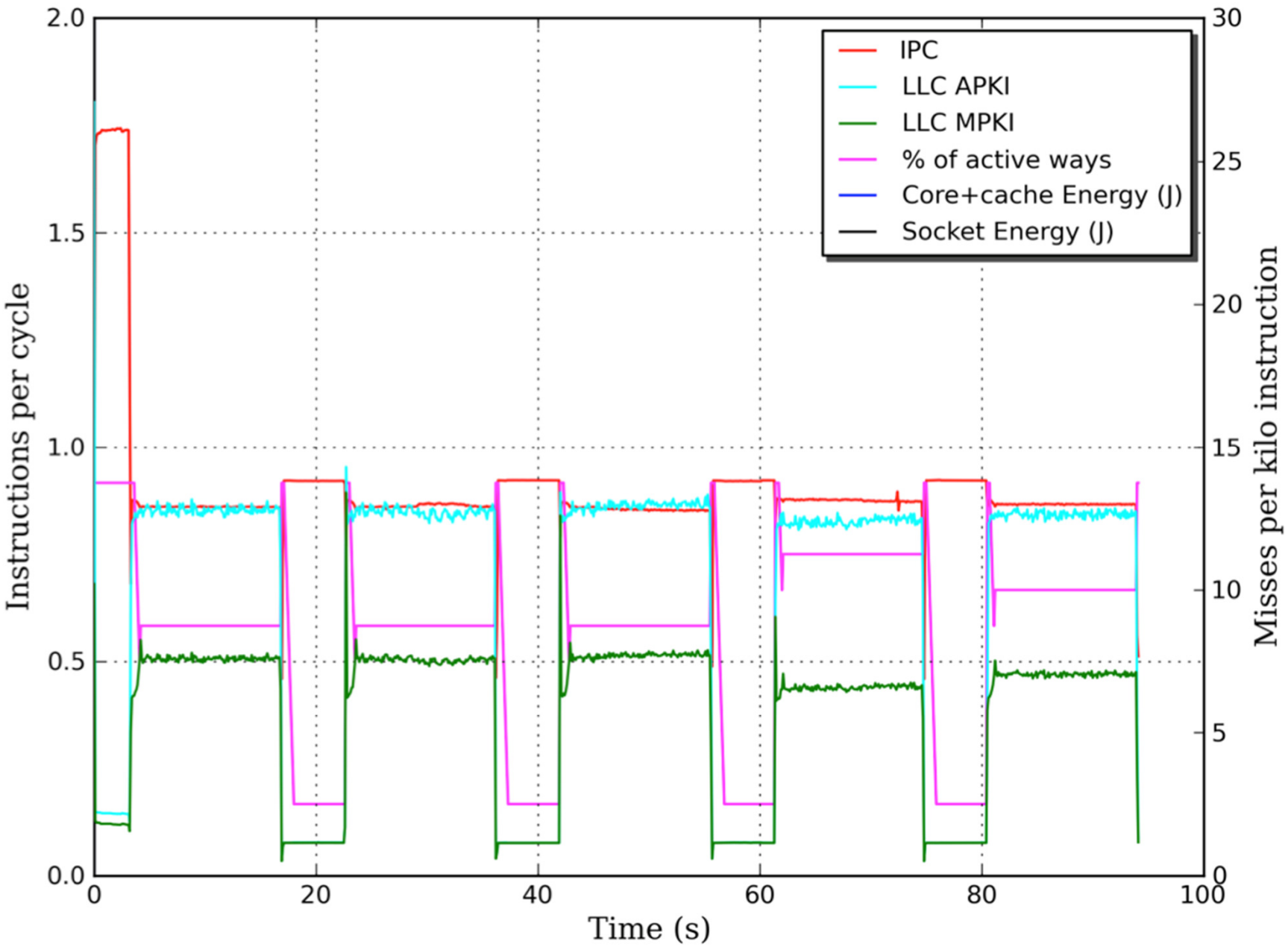
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Socket Energy (J)
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