KPart: A Hybrid Cache Sharing-Partitioning Technique for Commodity Multicores

Nosayba El-Sayed

Anurag Mukkara

Po-An Tsai

Harshad Kasture

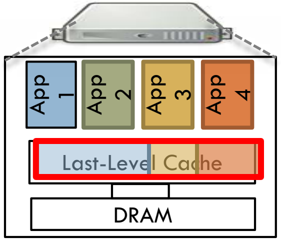
Xiaosong Ma

Daniel Sanchez


QCRI
معهد قطر لبحوث الحوسبة
Qatar Computing Research Institute
جامعة حمد بن خليفة
HAMAD BIN KHALIFA UNIVERSITY

MIT CSAIL

Cache partitioning in commodity multicores



- Partitioning the last-level cache among co-running apps can reduce interference → improve system performance

✔ Recent processors offer hardware cache-partitioning support!

✖ Two key challenges limit its usability

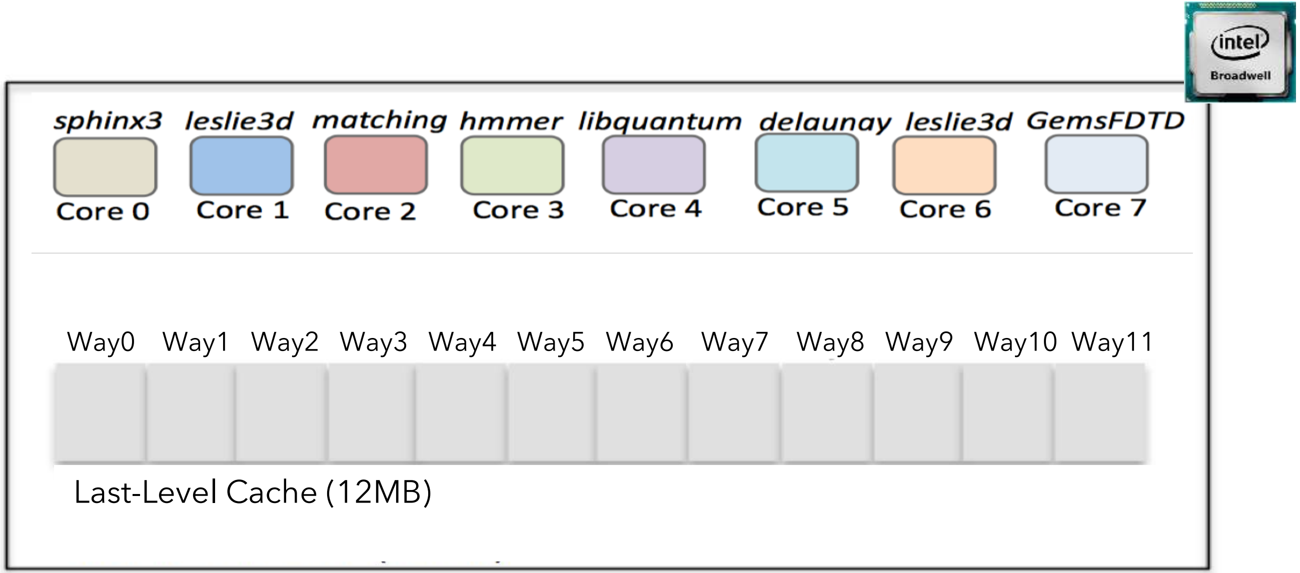
1. Current hardware implements coarse-grained way-partitioning → hurts system performance!
2. Lacks hardware monitoring units to collect cache-profiling data

KPart tackles these limitations, unlocking significant performance on real hardware (avg gain: 24%, max: 79%), and is publicly available

Limitations of hardware cache partitioning

1. Implements coarse-grained way-partitioning ➔ hurts system performance

- Real-system example (benchmarks: SPEC-CPU2006, PBBS)



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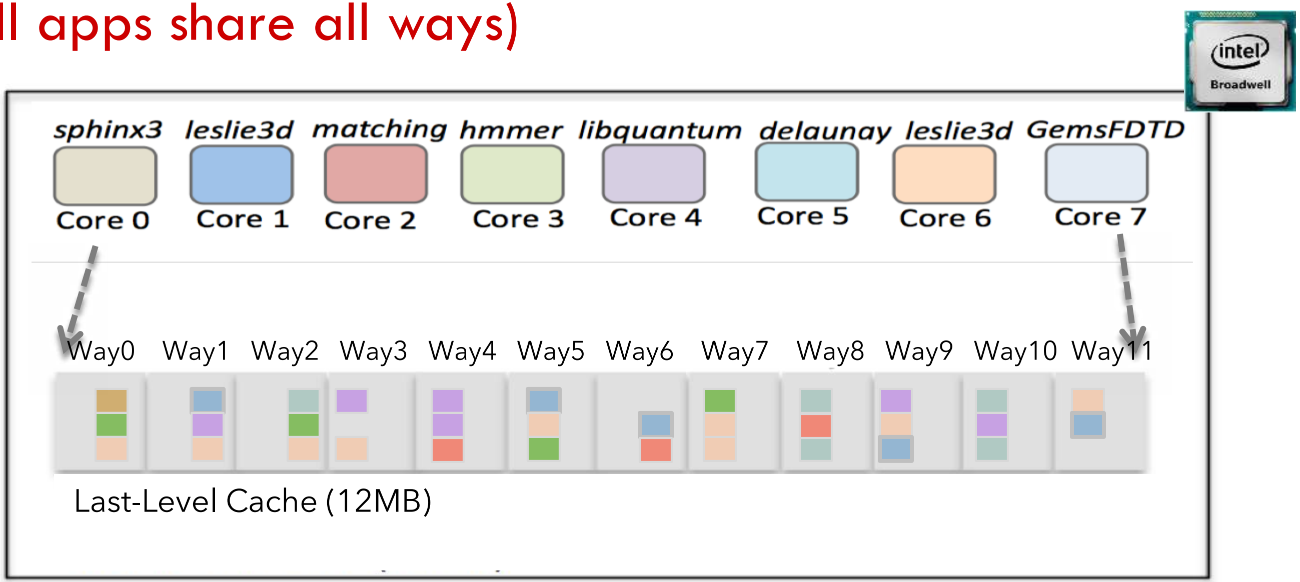
- Real-system example (benchmarks: SPEC-CPU2006, PBBS)
- Baseline: NoPart (All apps share all ways)



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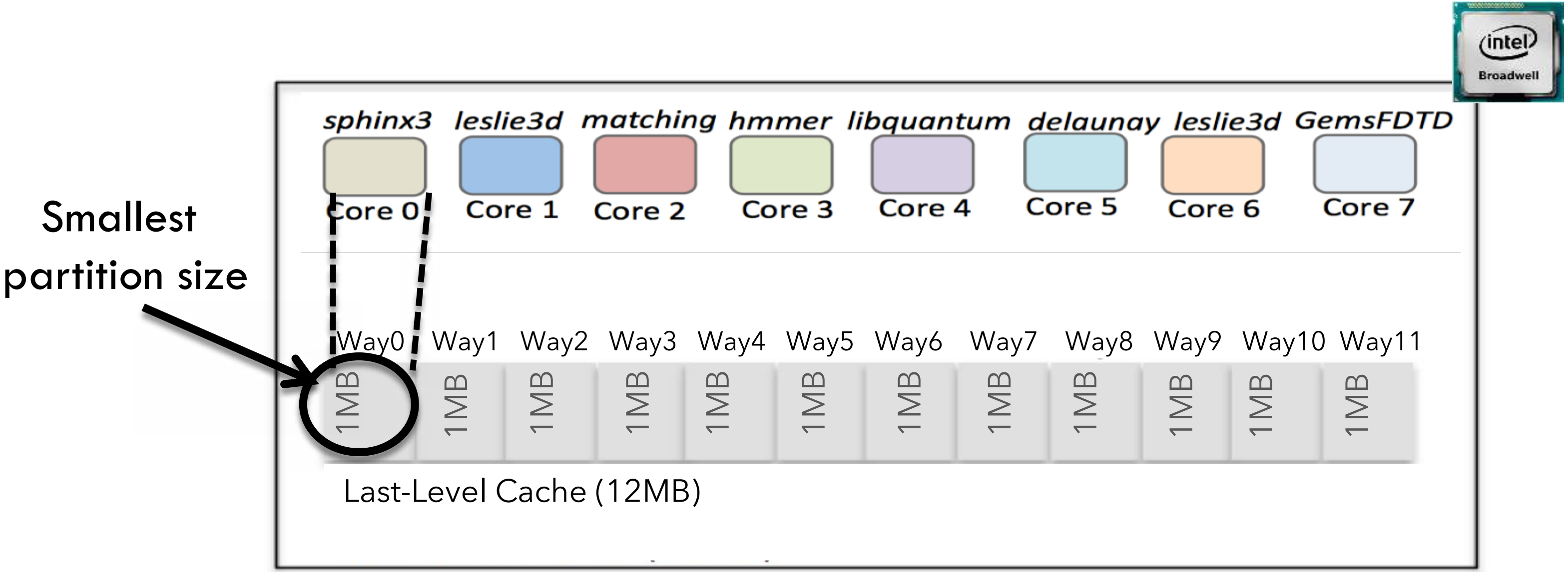

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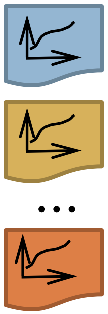
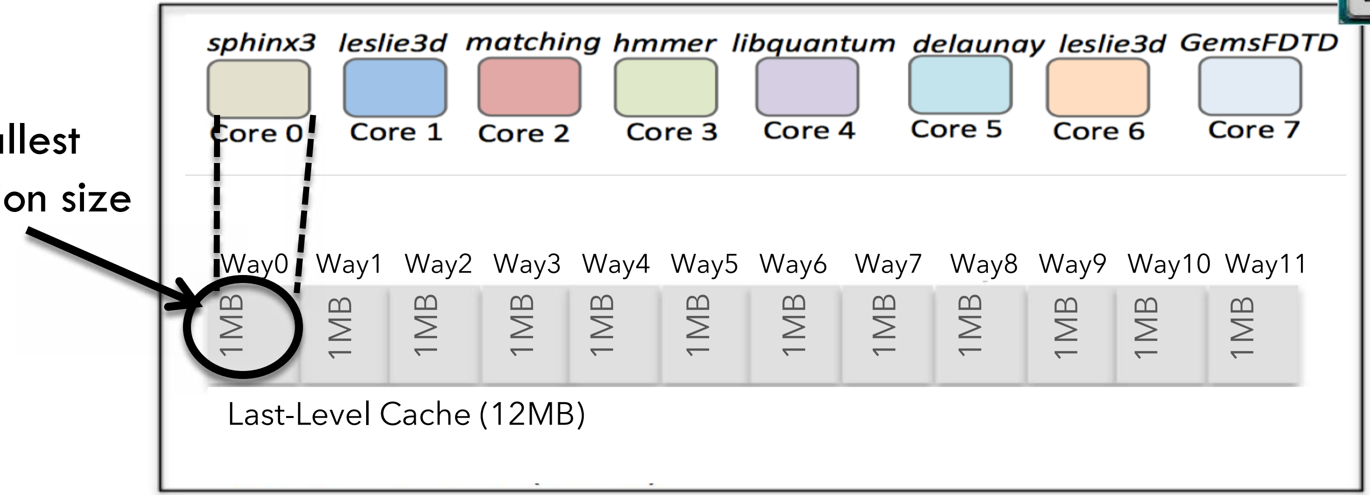
- Real-system example (benchmarks: SPEC-CPU2006, PBBS)
- Conventional policy: Per-app, utility-based cache part (UCP)

Application Cache-Profiles



Smallest partition size



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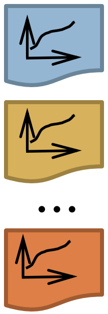

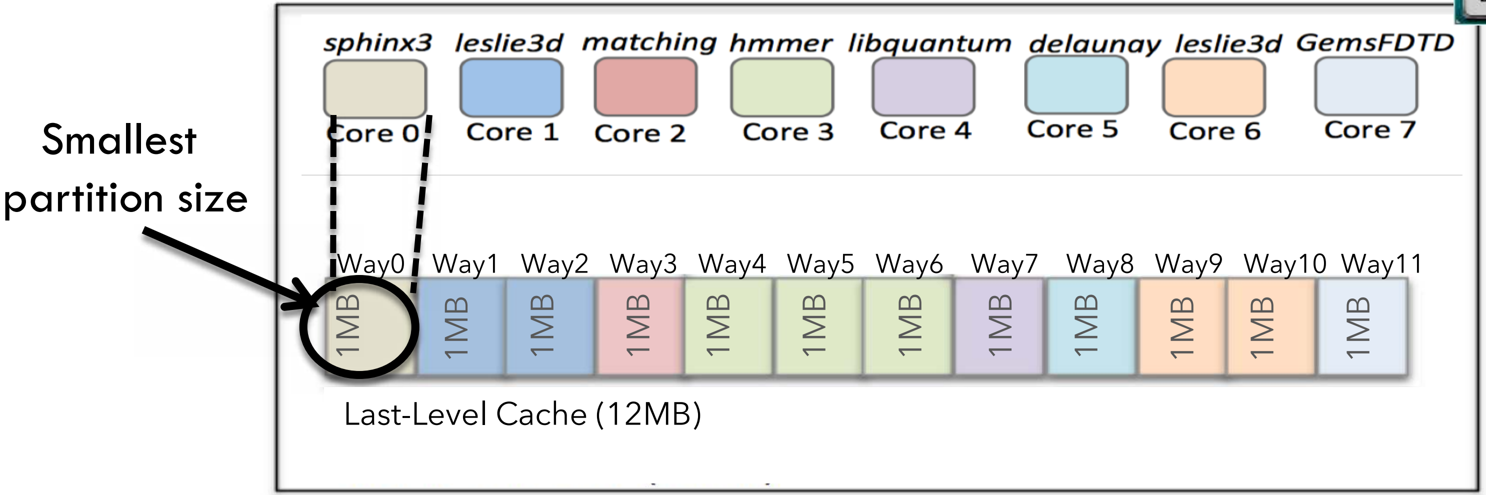

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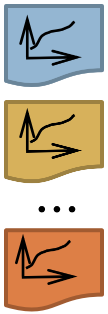

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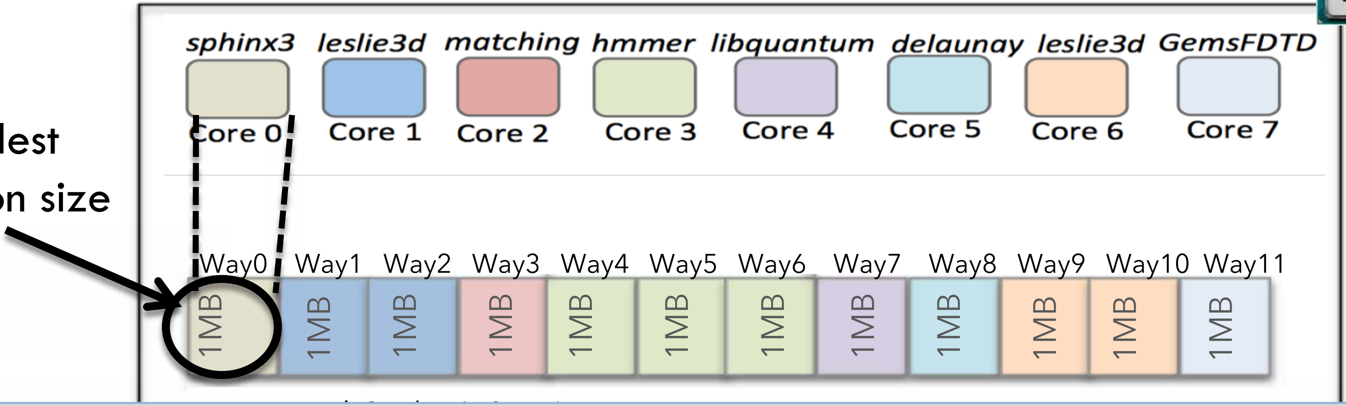

Conventional policies yield small partitions with few ways:
low associativity ➔ more misses
This example: throughput degrades by 3.8%

Prior work on cache partitioning

- **Hardware way-partitioning: restrict insertions into subsets of ways**
  - Available in commodity hardware
  - Small number of coarsely-grained partitions!
- **Page coloring**
  - No hardware support required
  - Not compatible with superpages; costly repartitioning due to recoloring; heavy OS modifications
- **High-performance, fine-grained hardware partitioners (e.g. Vantage** [ISCA'11]**, Futility Scaling** [MICRO'14]**)**
  - Support hundreds of partitions
  - Not available in existing hardware
- **Hybrid technique: Set and WAy Partitioning (SWAP)** [HPCA'17]
  - Combines page coloring and way-partitioning → fine-grained partitions
  - Inherits page coloring limitations

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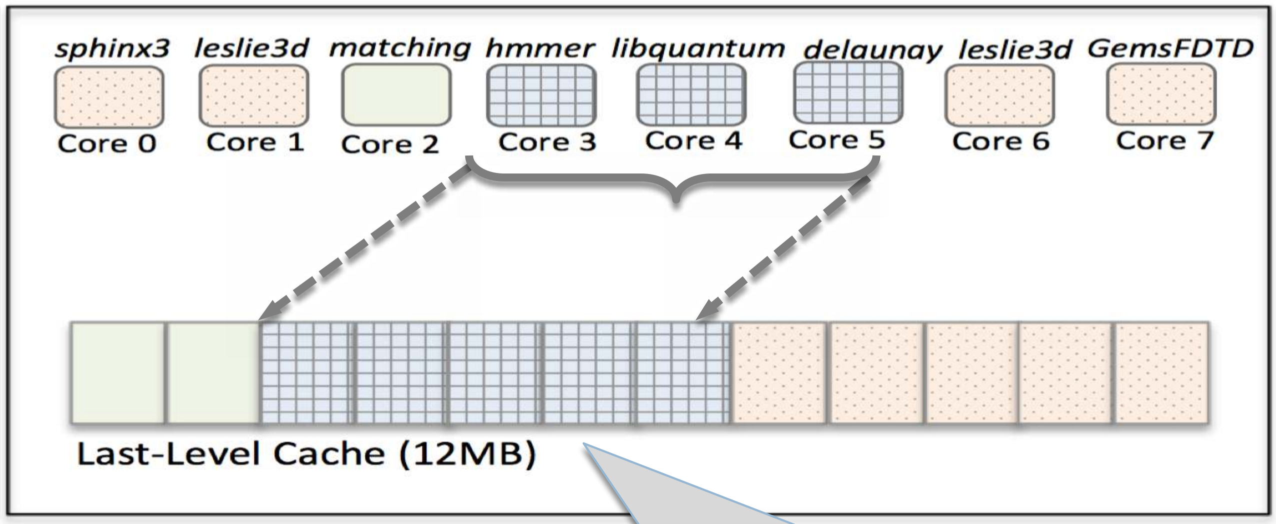
KPart performs hybrid cache sharing-partitioning to make use of coarse-grained partitions

Cache-Aware App Grouping

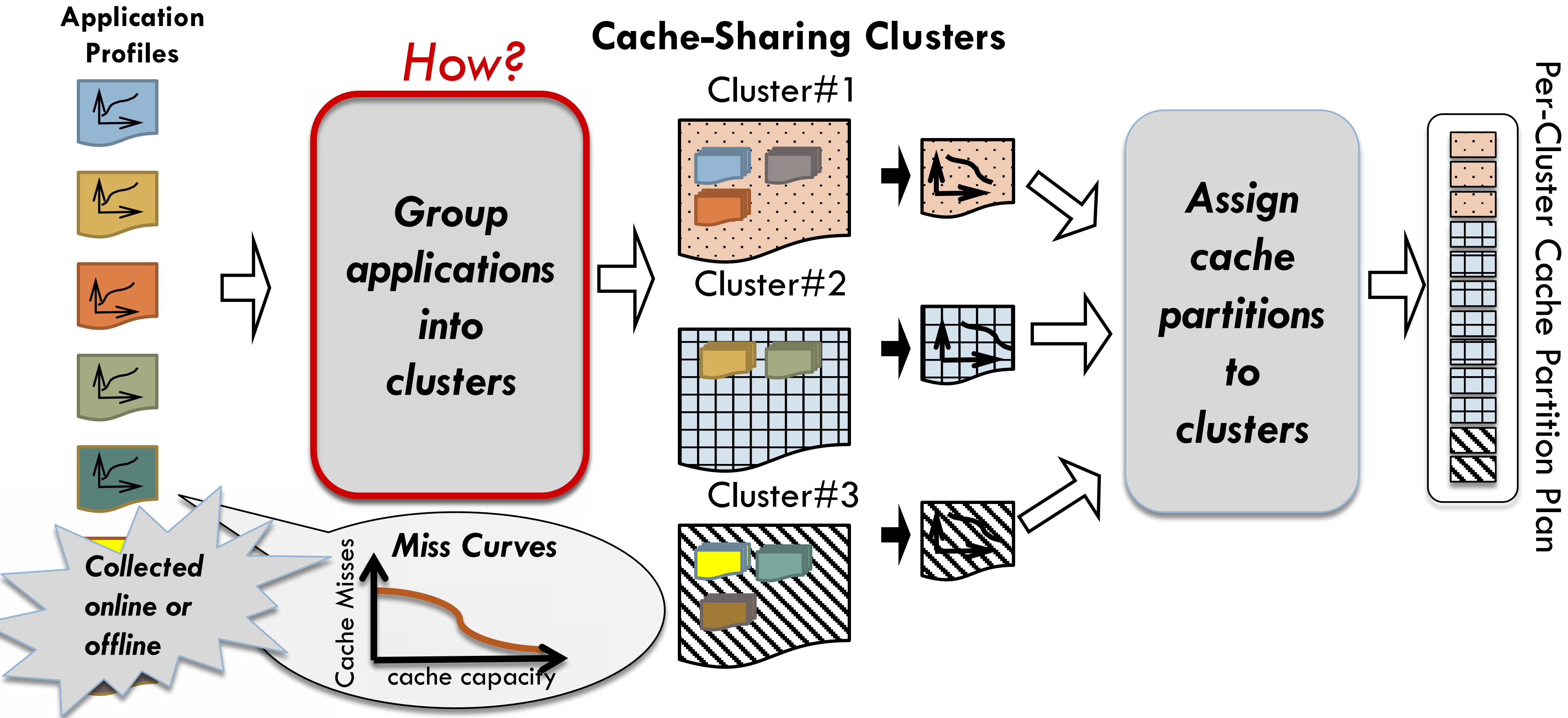
group 1
group 2
group 3



Grouping must be done carefully!

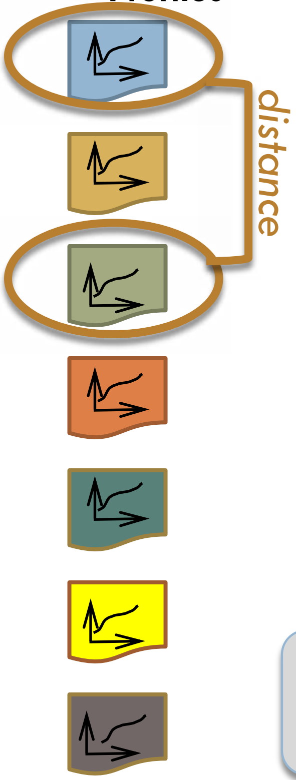
Avoids significant reduction in cache associativity
➔ throughput **improves** by **17%**

KPart overview: Hybrid cache sharing-partitioning

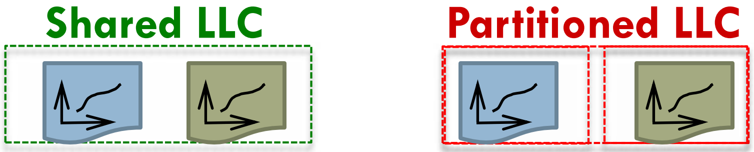


Clustering apps based on cache-compatibility: Distance metric

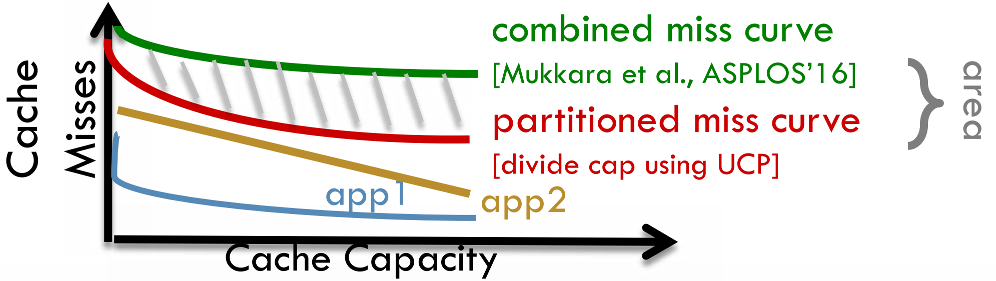
Application Profiles



- How many additional cache misses are expected when two apps share cache capacity vs. when it's partitioned?



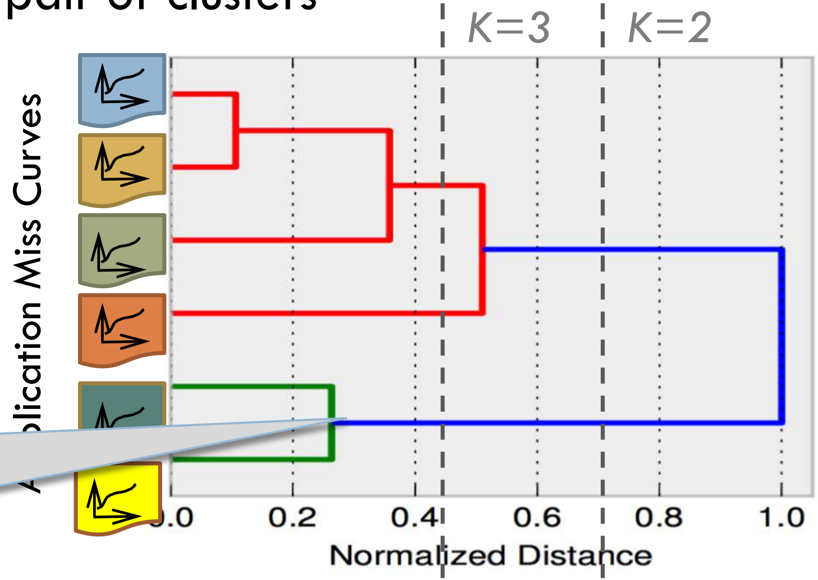
- Use cache miss curves to estimate:



Area ➔ expected performance degradation when apps share cache capacity (due to additional misses)

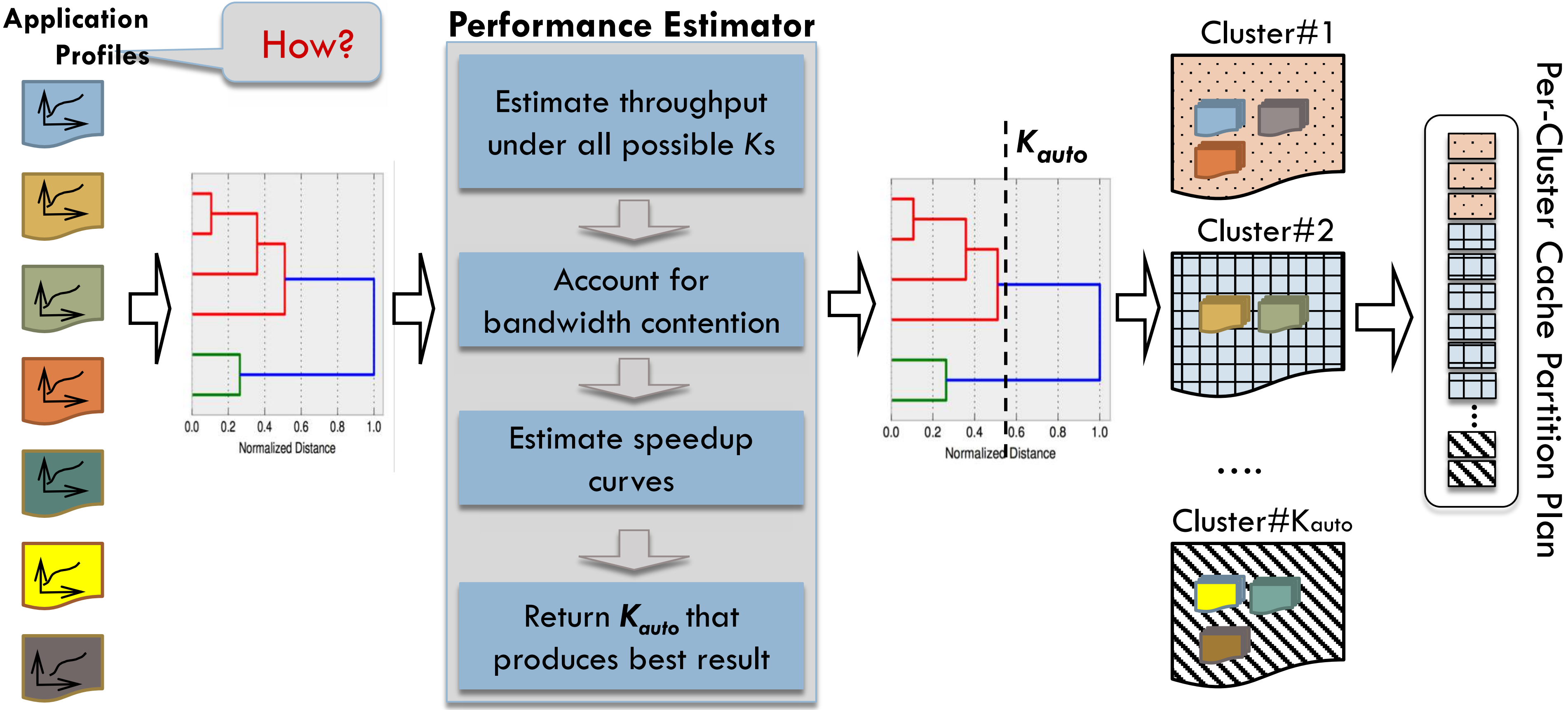
Grouping applications into clusters

- **Hierarchical clustering:**
  - Start with the applications as individual clusters
  - At each step, merge the **closest** pair of clusters until only one cluster is left..



How do we find the best ***K*** without running the mix?

Automatic selection of *K* in KPart



Cache-partitioning in commodity multicores

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✔ Recent processors offer hardware cache-partitioning support!

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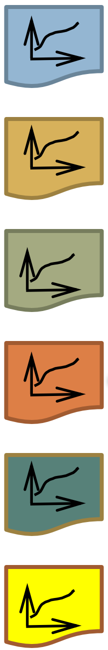
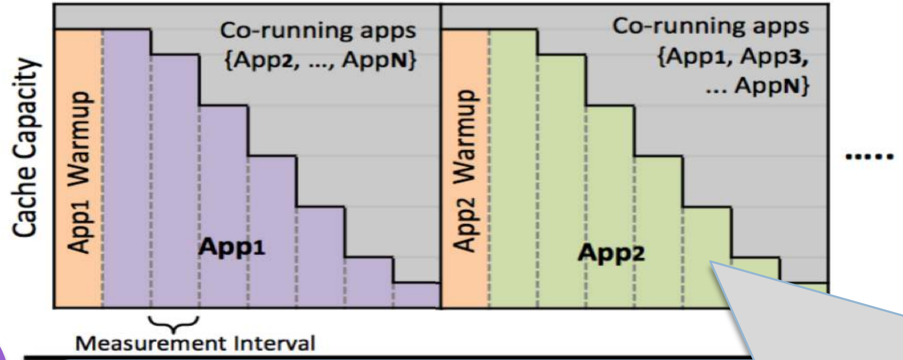
How do we profile applications online at low overhead and high accuracy?

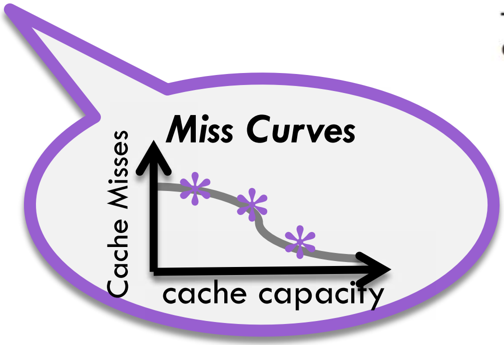
Application Profiles



- Prior work mostly simulated hardware monitors that don't exist in real systems, or used expensive software-based mem address sampling

DynaWay exploits hardware partitioning support to adjust partition sizes periodically ➔ measure performance *(misses, IPC, bandwidth)*

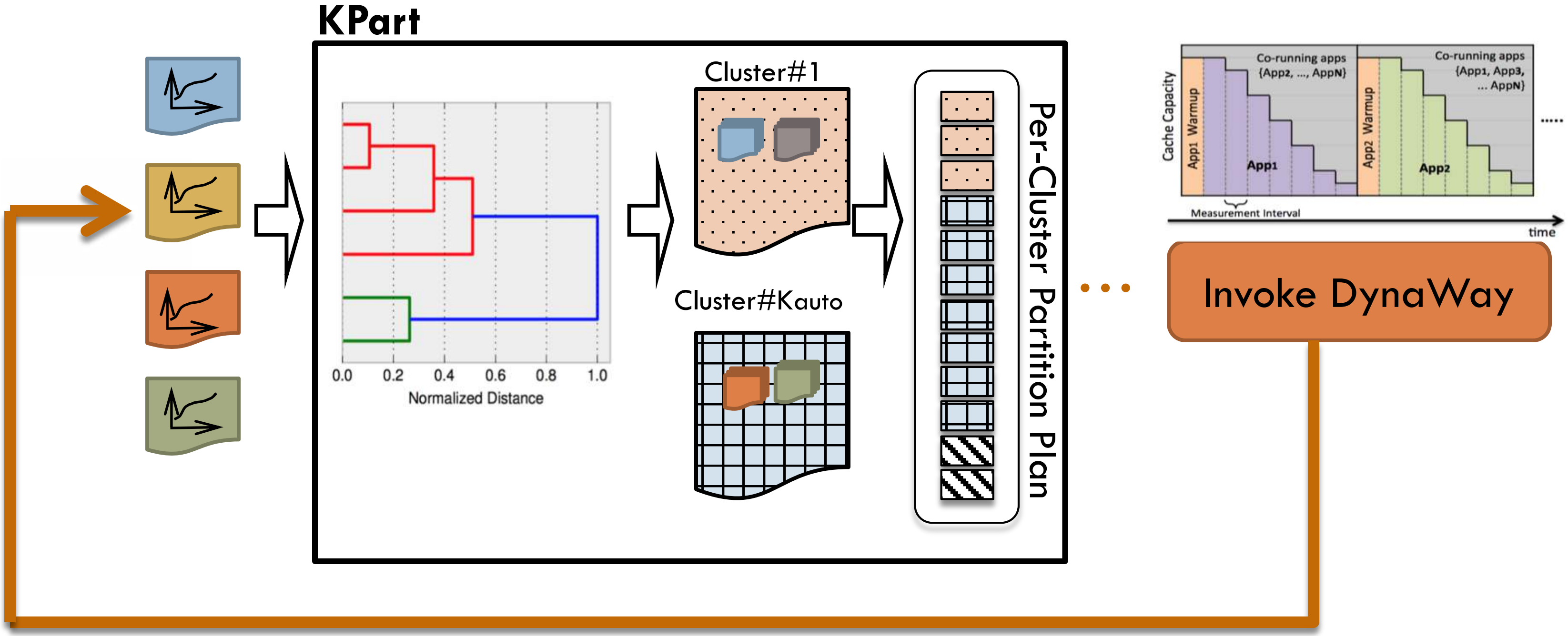




We applied optimizations to reduce measurement points and interval length (see paper)

➔ less than 1% profiling overhead (8-app workloads)

KPart+DynaWay profiles applications online, partitions the cache dynamically



Generate online profiles + update periodically

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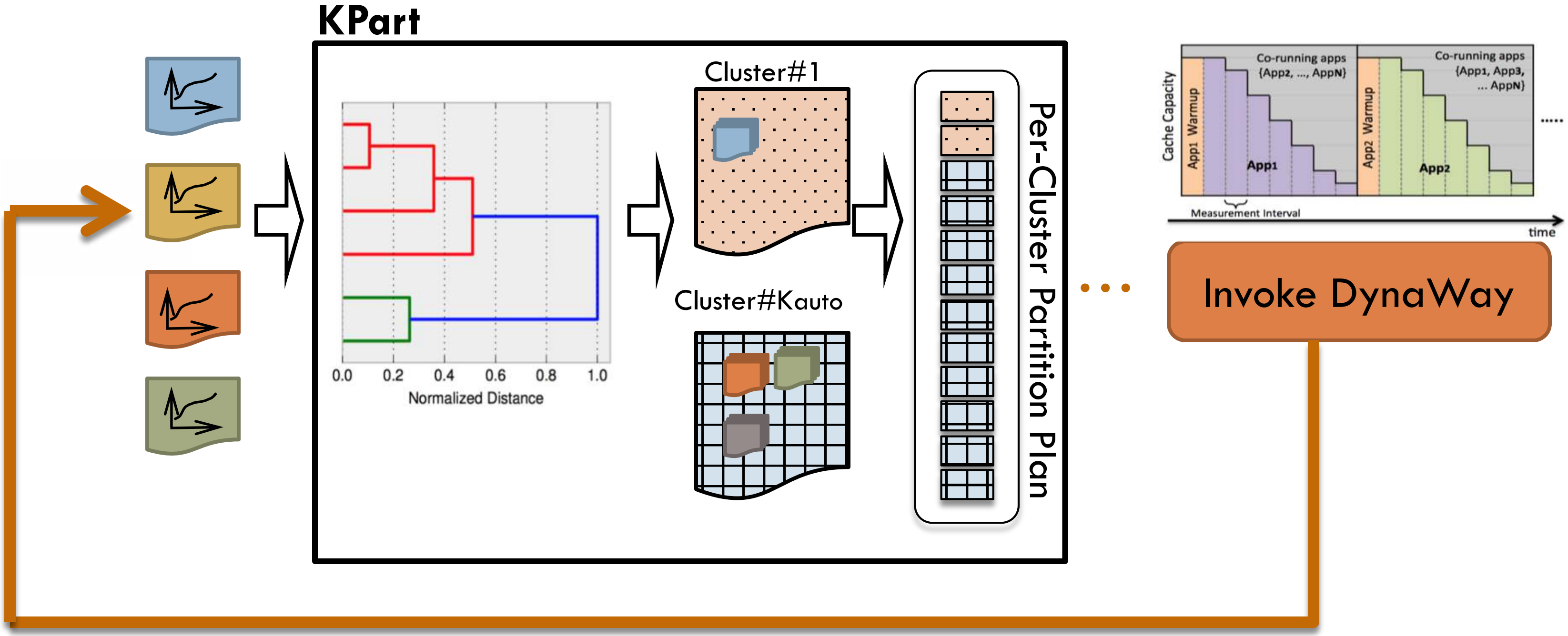

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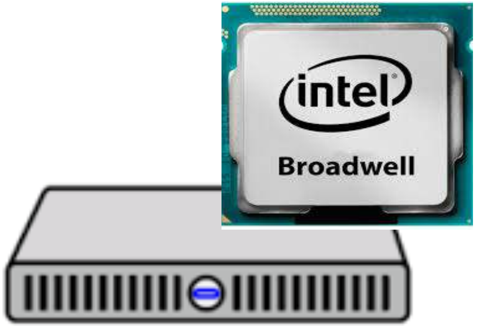
KPart Evaluation



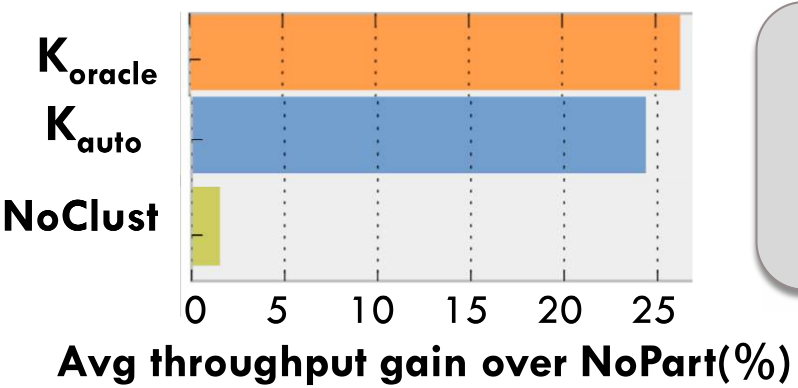
Evaluation methodology

- **Platform:** 8-core Intel Broadwell D-1540 processor (12MB LLC)
- **Benchmarks**: SPEC-CPU2006, PBBS
- **Mixes:** 30 different mixes of 8 apps (randomly selected), each app running at least 10B instr.
- **Experiments:**

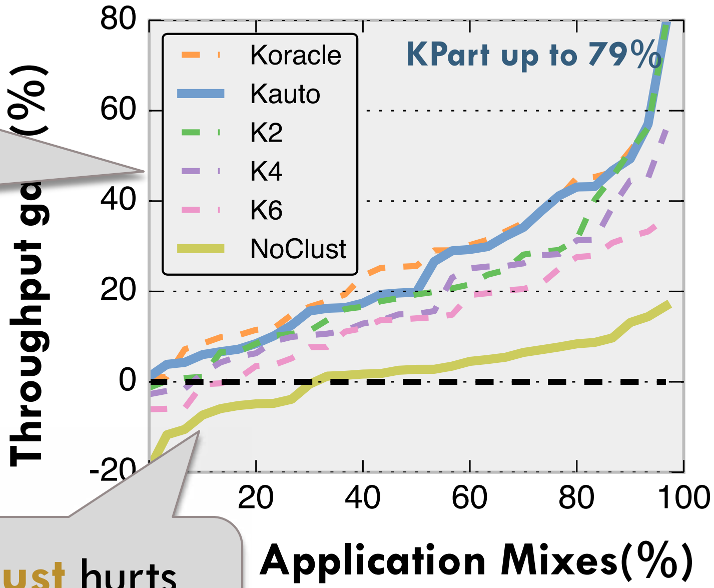
KPart on real system with offline profiling	KPart on real system with online profiling (using DynaWay)	KPart in simulation compared against high-performance techniques	KPart with mix of batch and latency-critical applications

KPart unlocks significant performance on real hardware

- Evaluation results on a real system with offline profiling



Important to use K_{auto} instead of fixed K

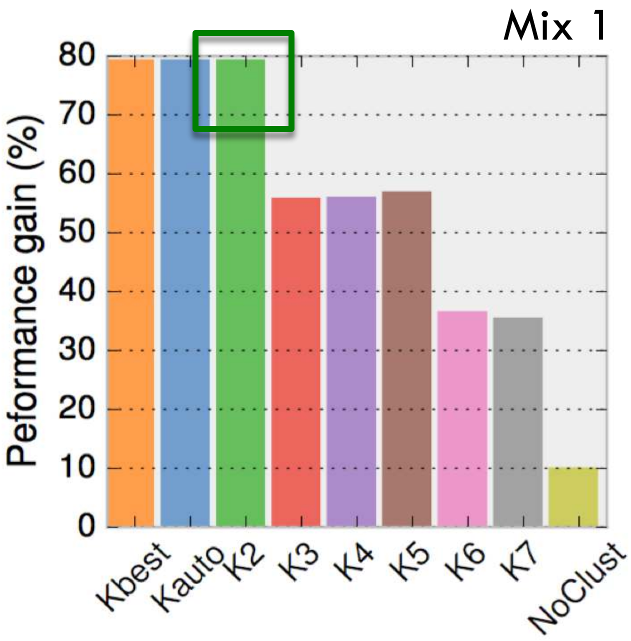


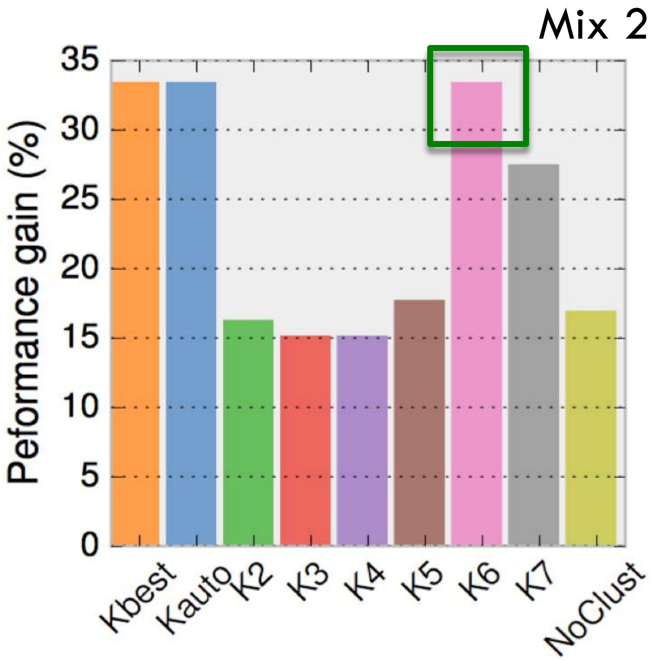
KPart improves system performance by **24%** on average!

NoClust hurts ~30% of mixes

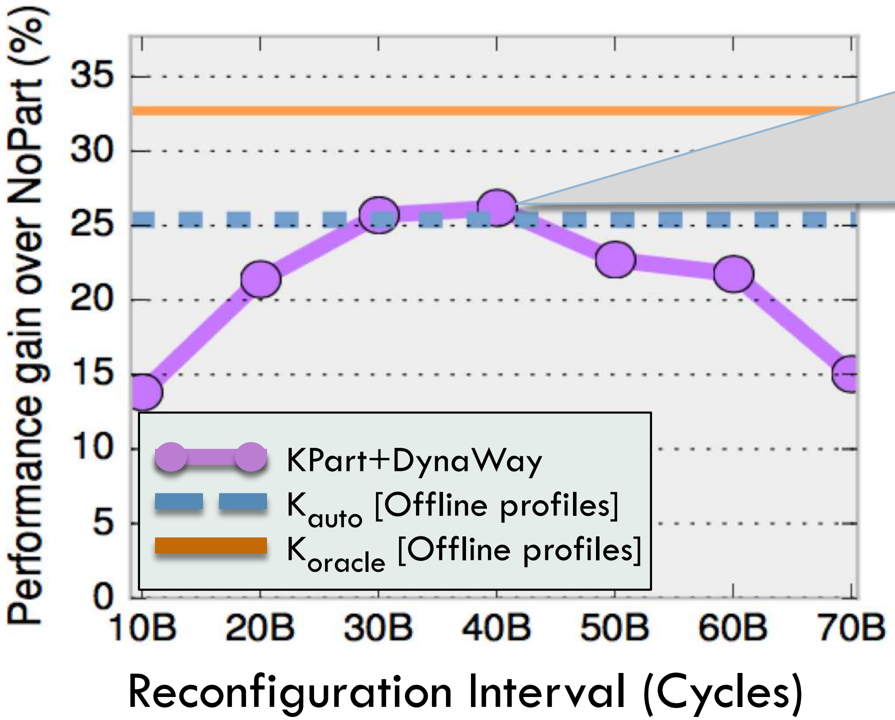
KPart unlocks significant performance on real hardware

- Evaluation results on a real system with offline profiling
- Case studies of individual mixes:





KPart evaluation with DynaWay's online profiles



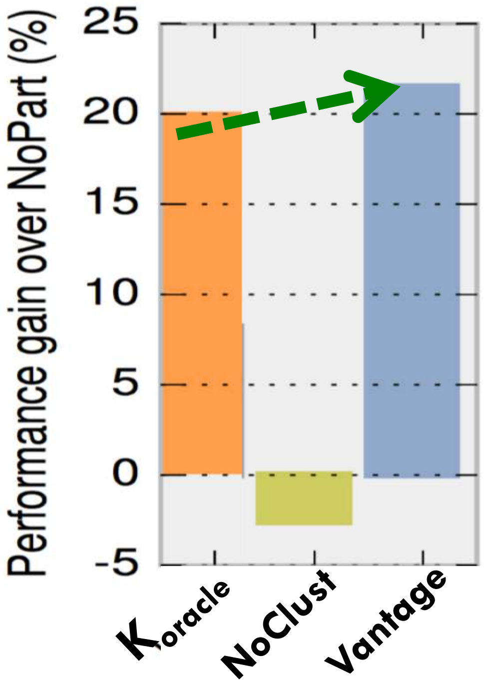
KPart+DynaWay can even outperform static KPart with offline profiling

(adapts to application phase changes!)

KPart bridges the gap between current and future hardware partitioners

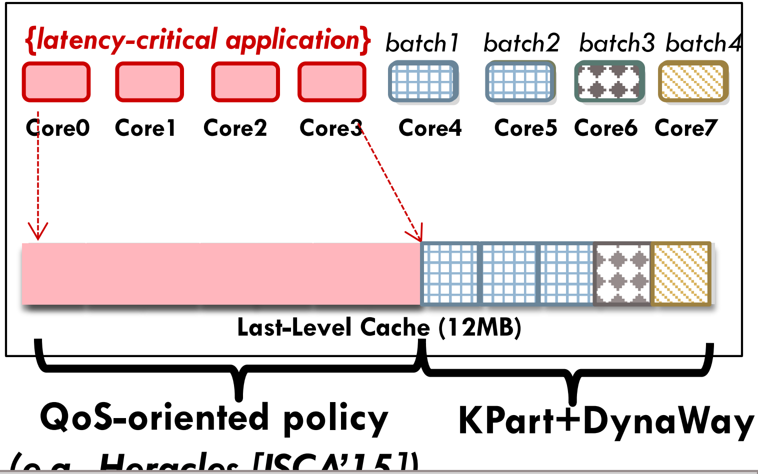
- In simulation: we compared KPart to a high-performance fine-grained hardware partitioner, Vantage [ISCA'11]

KPart achieves most of the gains obtained by fine-grained partitioning!



KPart helps LC apps when combined with QoS-oriented techniques

- KPart focuses on batch apps, but data centers colocate latency-critical (LC) and batch
- Prior work uses cache partitioning to provide QoS guarantees for LC apps
  - but does not improve batch apps throughput



Combining KPart with QoS-oriented technique can improve both batch throughput and LC latency:

- Kpart improves batch throughput which leads to reduced memory traffic
- LC apps benefit from more bandwidth and cache

Evaluation: On same 8-core system running both LC and batch apps, up to 28% improvement in batch throughput and up to 7% improvement in LC tail latency

KPart summary

- ✓ KPart unlocks the potential of hardware way-partitioning using a **hybrid sharing-partitioning** approach
- ✓ KPart improves **throughput significantly** (avg: **24%**) & bridges the gap between current and future partitioning techniques
- ✓ **DynaWay** exploits existing way-partitioning support to perform lightweight & accurate cache-profiling
- ✓ **KPart+DynaWay** can be combined with QoS-oriented policies to colocate **latency-critical apps** and batch apps effectively

KPart is open-sourced and publicly available at http://kpart.csail.mit.edu

Thank you! Questions?

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