Cross-Layer Memory Management to Achieve Power and Performance Goals

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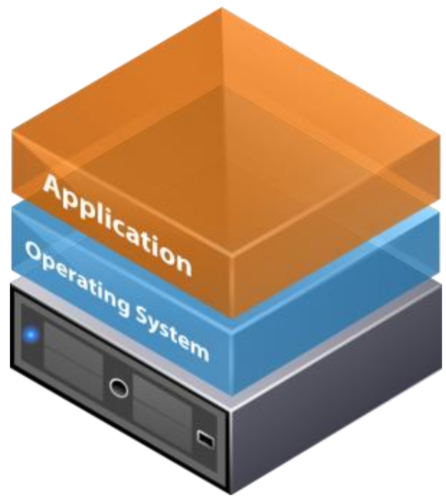
Introduction

- Assistant Professor at UT since August 2014
- Before UT
  - PhD in Computer Science at KU (July 2014)
  - Intern at Intel Corporation (2012 – 2013)
- Research interests:
  - Compilers (backend optimizations, phase ordering)
  - Operating Systems (kernel instrumentation, memory and power management)
  - Runtime Systems (dynamic compilation, program profiling, heap layout management)

Cross-Layer Memory Management



Publications: VEE ’13 [1], Linux Symposium ’14 [2], OOPSLA '15 [3]

Memory Power Management

- Memory has become a significant player in power and performance
  - Memory power is a dominant factor in servers [4,5,6,7]
- Hardware can automatically *power down* individual memory modules
- Memory power management is challenging
  - Small footprint can reside in multiple devices
  - Different memory regions can have different requirements

Example Scenario

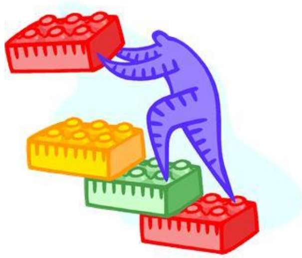
- Server system with database workload with 1TB DRAM
  - All memory in use, but only 2% of pages are accessed frequently
  - CPU utilization is low
- **How to reduce power consumption?**

A Collaborative Approach to Memory Management

- Effective memory management is difficult due to virtualization of memory
- We propose a collaborative approach:
  - Applications – communicate memory usage intent to OS
  - OS – interprets application intent and manages physical memory over hardware units
  - Hardware – communicate hardware layout to the OS to guide memory management decisions

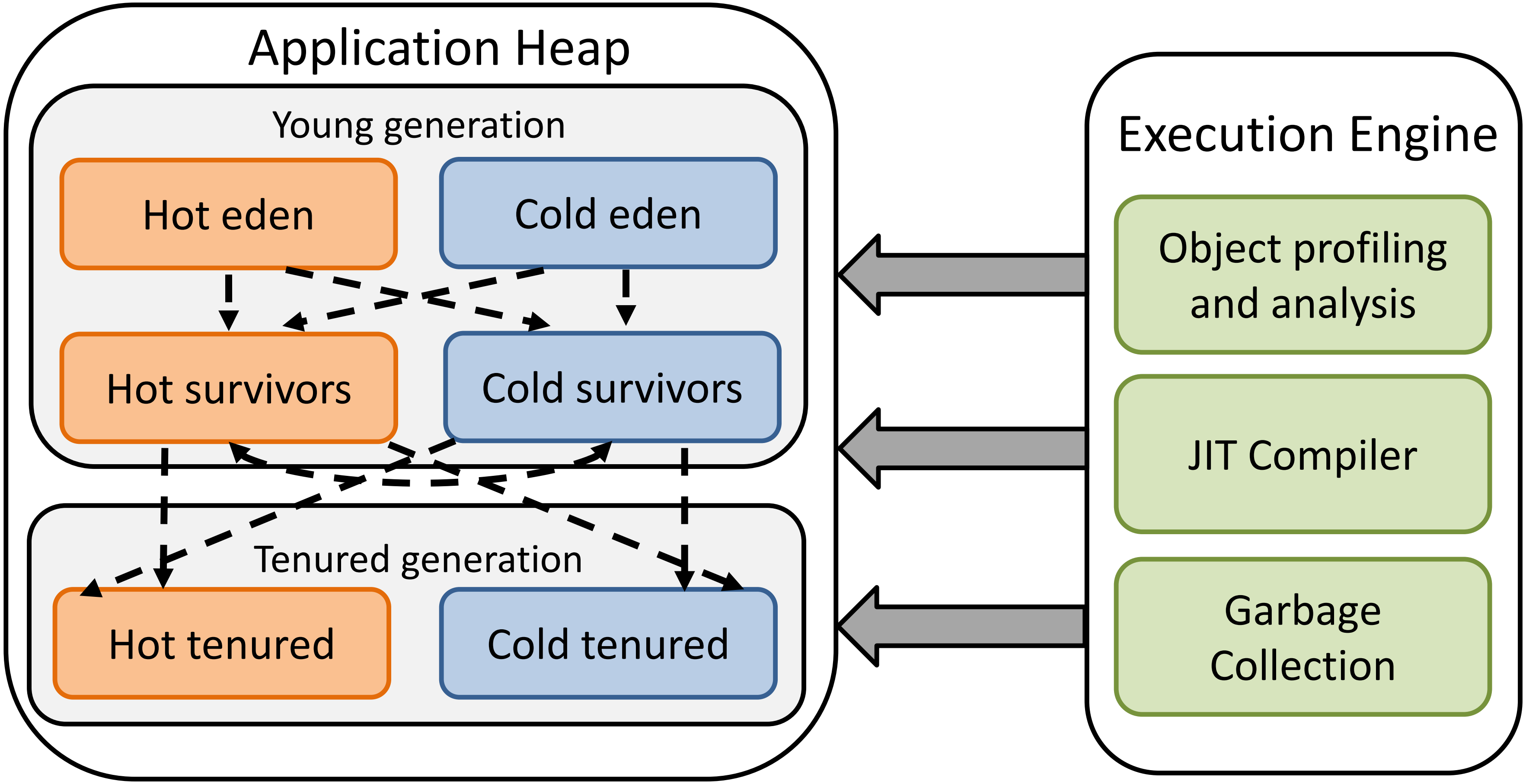
Application Guidance in the Linux Kernel

- Implemented by re-architecting a recent Linux kernel
  - Applications pass guidance to the OS by *coloring* virtual address ranges with a system call interface
  - OS organizes physical memory into software structures that correspond to hardware memory devices (*trays*)
- Limitations of our Linux kernel-based framework:
  - Little understanding of what kind of guidance will be most useful for existing workloads
  - All hints must be manually inserted into source code

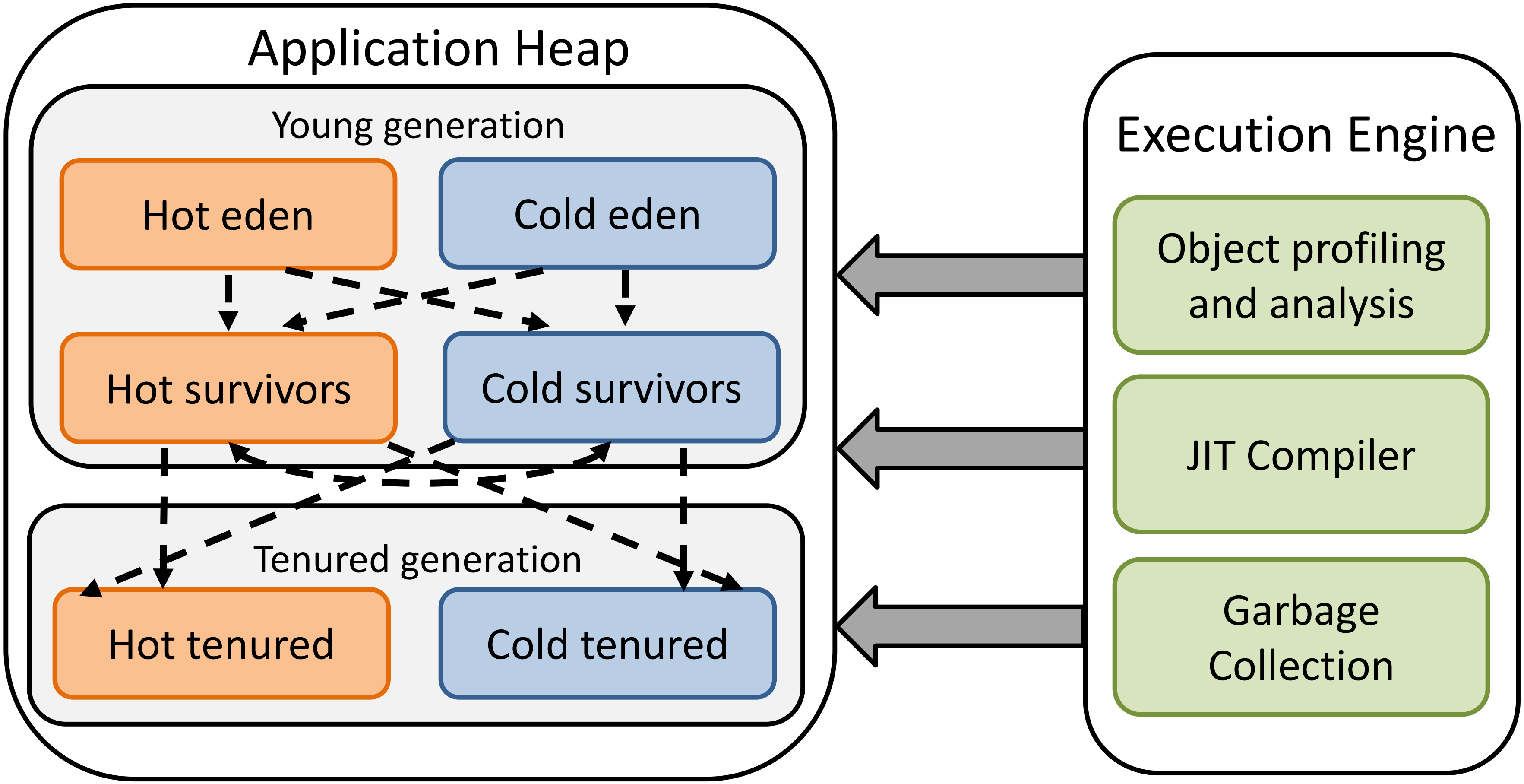


Automatic Guidance in the Application Layer

- Our approach: integrate with *automated* mechanism to generate guidance for the OS
  - No source code modifications or recompilations
- Implemented in the HotSpot JVM
  - Create separate heap regions for different usage patterns
  - Instrumentation and analysis to build memory profile
  - Partition/allocate live objects into separate regions according to partitioning strategy
  - Communicates heap region information to the OS



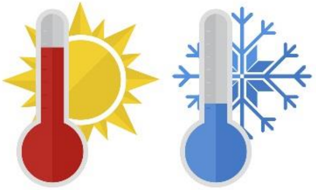
- Employ the default HotSpot config. for server-class applications
- Divide survivor / tenured spaces into spaces for hot / cold objects



- Partition allocation sites and objects into hot / cold sets
- Color spaces on creation or resize

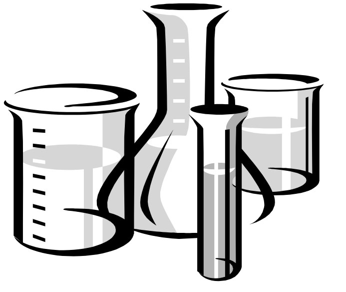
Potential of JVM Framework

- Our goal: evaluate power-saving potential when hot / cold objects are known statically
- MemBench: Java benchmark that uses different object types for hot / cold memory
- “HotObject” and “ColdObject”
  - Contain memory resources (array of integers)
  - Implement different functions for accessing mem.



Experimental Platform

- Hardware
  - Single node of 2-socket server machine
  - Processor: Intel Xeon E5-2620 (12 threads @ 2.1GHz)
  - Memory: 32GB DDR3 memory (four DIMM's, each connected to its own channel)
- Operating System
  - CentOS 6.5 with Linux 2.6.32
- HotSpot JVM
  - v. 1.6.0_24, 64-bit
  - Default configuration for server-class applications

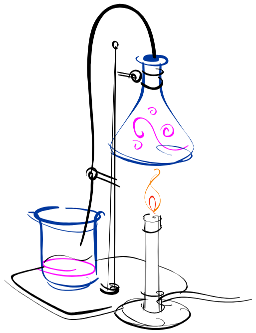


The MemBench Benchmark

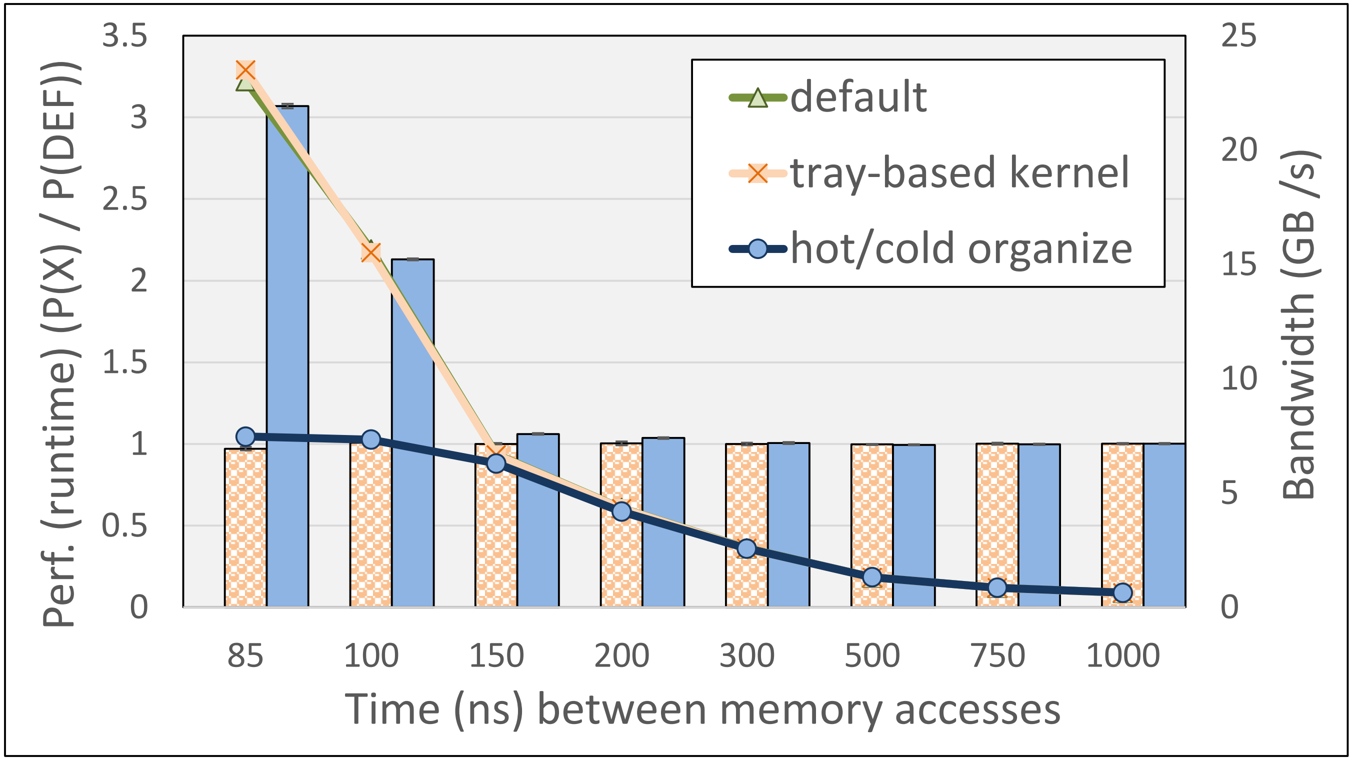
- Object allocation
  - Creates “HotObject” and “ColdObject” objects in a large in-memory array
  - # of hots < # of colds (~15% of all objects)
  - Object array occupies most (~90%) system mem.
- Multi-threaded object access
  - Object array divided into 12 separate parts, each passed to its own thread
  - Iterate over object array, only accessing hot objects
- Optional *delay* parameter

MemBench Configurations

- Three configurations
  - Default
  - Tray-based kernel (custom kernel, default HotSpot)
  - Hot/cold organize (custom kernel, custom HotSpot)
- Delay varied from "no delay" to 1000ns
  - With no delay, 85ns between memory accesses

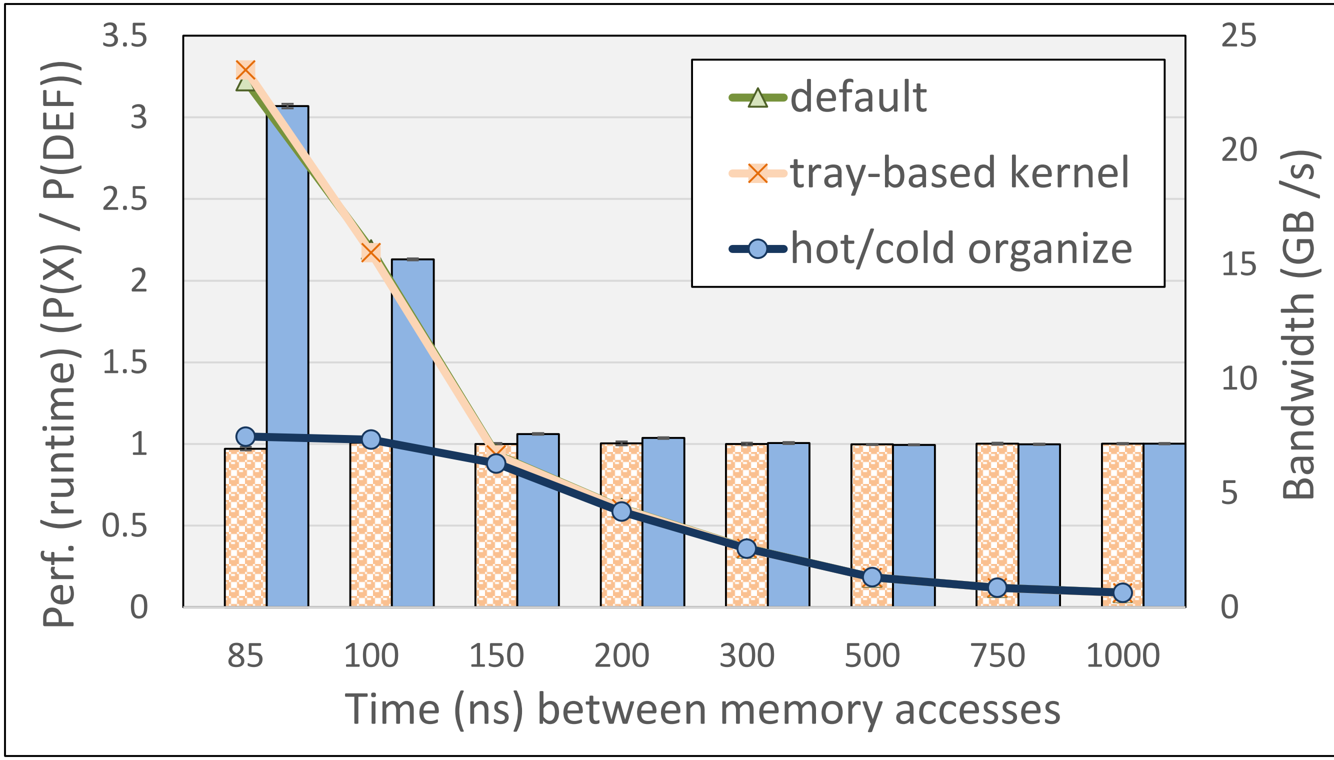


MemBench Performance



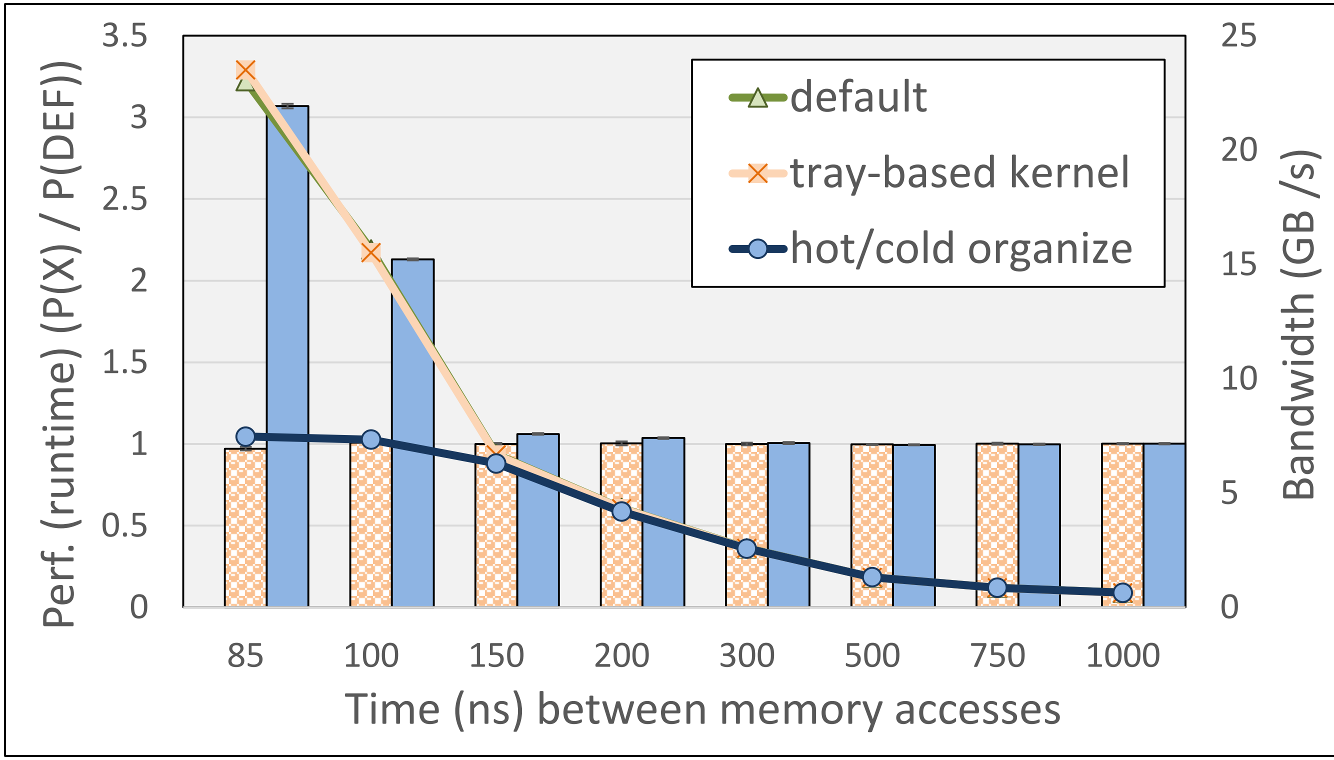
- Tray-based kernel has about same performance as default
- Hot/cold organize exhibits poor performance with low delay

MemBench Bandwidth



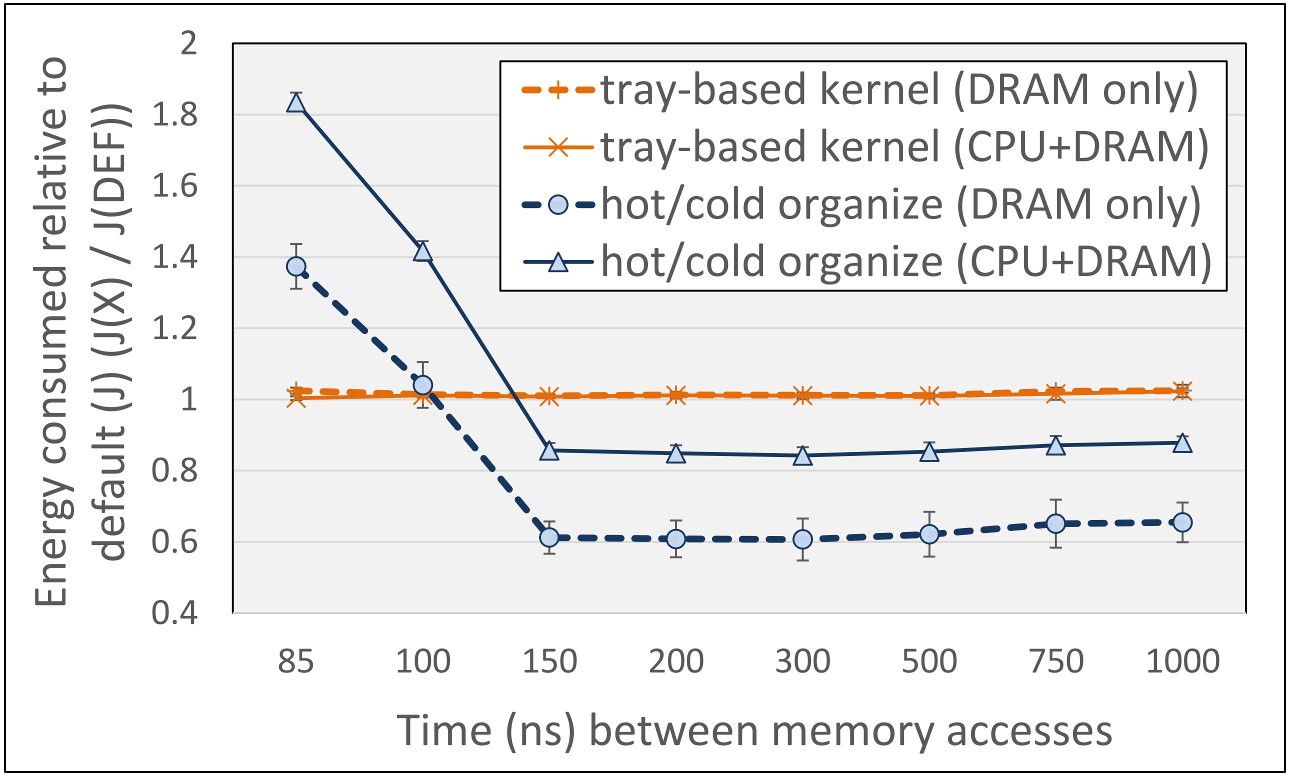
- Default and tray-based kernel produce high memory bandwidth when delay is low
- Placement of hot objects across multiple channels enables higher bandwidth

MemBench Bandwidth



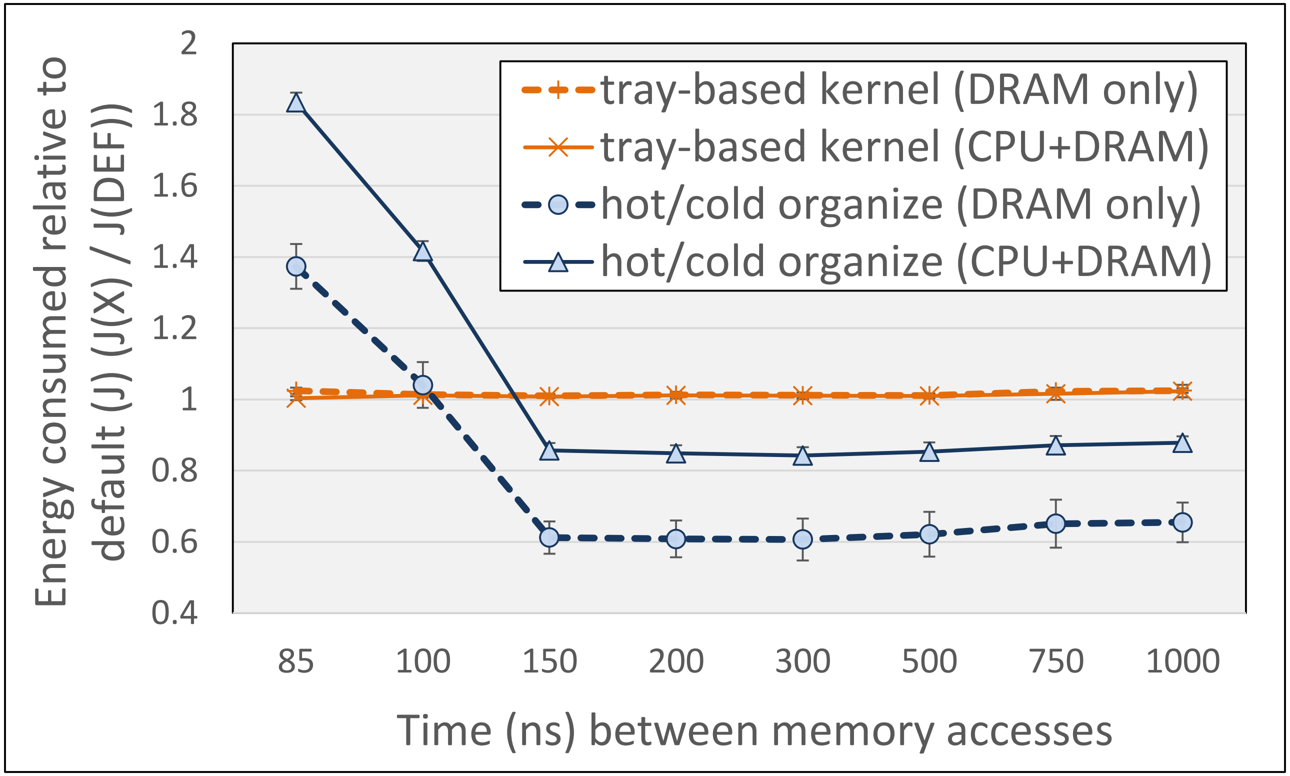
- Hot/cold organize - hot objects co-located on single channel
- Increased delays reduces bandwidth reqs. of the workload

MemBench Energy



- Hot/cold organize consumes much less power with low delay
- Even when BW reqs. are reduced, hot/cold organize consumes less power than other configurations

MemBench Energy



- Significant energy savings potential with custom JVM
- Max. DRAM energy savings of ~39%, max. CPU+DRAM energy savings of ~15%

Results Summary

- Object partitioning strategies
  - Offline approach partitions allocation points
  - Online approach uses sampling to predict object access patterns
- Evaluate with standard sets of benchmarks
  - DaCapo, SciMark
- Achieve 10% average DRAM energy savings, 2.8% CPU+DRAM reduction
- Performance overhead
  - 2.2% for offline, 5% for online

Current and Future Projects in Cross-Layer Memory Management

- Improve performance and efficiency
  - Reduce overhead of online sampling
  - Automatic bandwidth management
- Applications for heterogeneous memory architectures
- Exploit data object placement *within* each page to improve efficiency

Conclusions

- Research focuses on software systems
  - Compilers, operating systems, and runtime systems
- Cross-layer memory management
  - Achieving power/performance efficiency in memory requires a cross-layer approach
  - First framework to use usage patterns of application objects to steer low-level memory mgmt.
  - Approach shows promise for reducing DRAM energy
  - Opens several avenues for future research in collaborative memory management

Questions?

References

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