Flexible Reference-Counting-Based Hardware Acceleration for Garbage Collection

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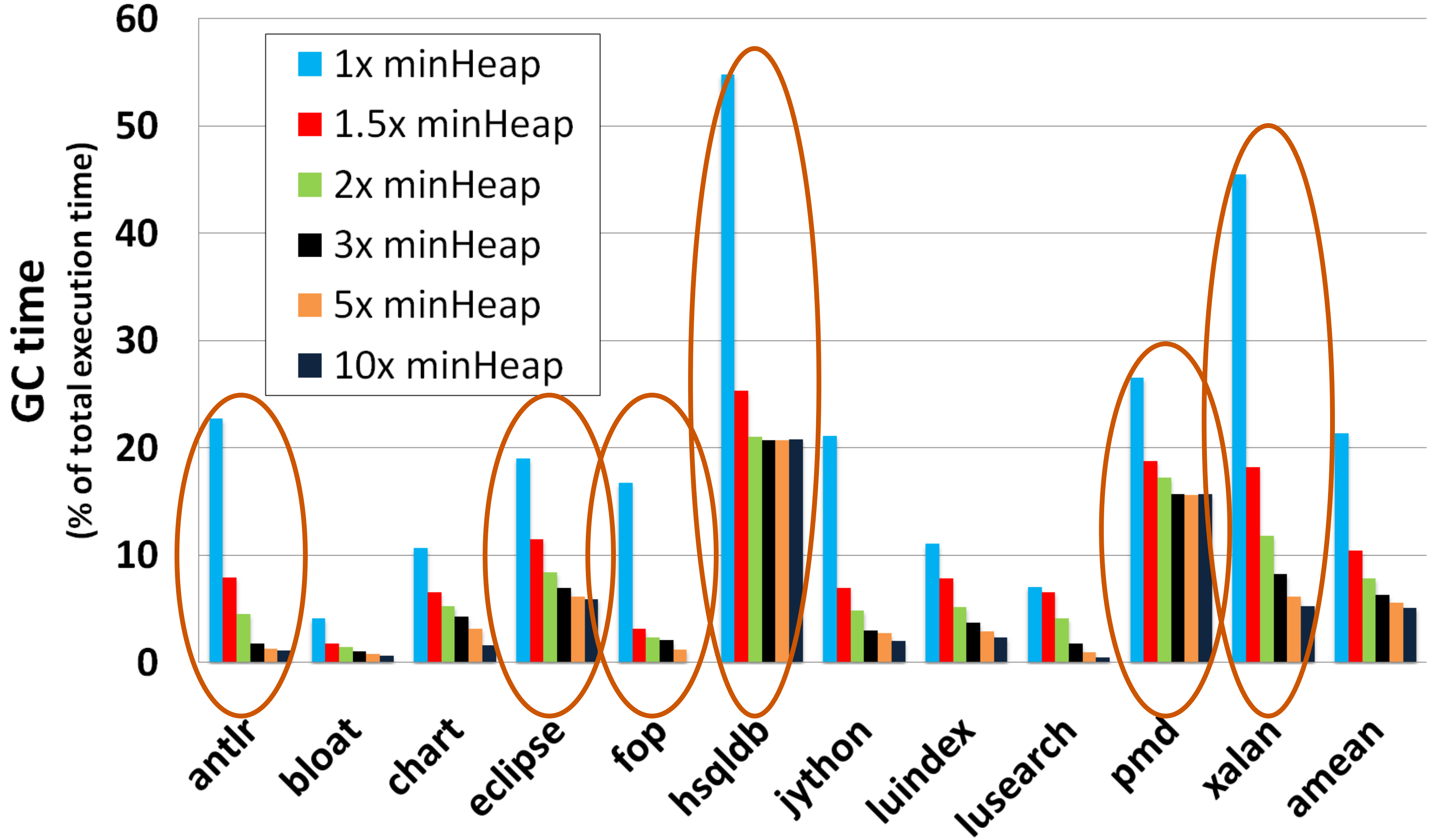
Motivation: Garbage Collection

- Garbage Collection (GC) is a key feature of Managed Languages
  - Automatically frees memory blocks that are not used anymore
  - Eliminates bugs and improves security
- GC identifies dead (unreachable) objects,
  and makes their blocks available to the memory allocator
- Significant overheads
  - Processor cycles
  - Cache pollution
  - Pauses/delays on the application

Software Garbage Collectors

- Tracing collectors
  - Recursively follow every pointer starting with global, stack and register variables, scanning each object for pointers
  - Explicit collections that visit all live objects
- Reference counting
  - Tracks the number of references to each object
  - Immediate reclamation
  - Expensive and cannot collect cyclic data structures
- State-of-the-art: generational collectors
  - Young objects are more likely to die than old objects
  - Generations: nursery (new) and mature (older) regions

Overhead of Garbage Collection



Hardware Garbage Collectors

- Hardware GC in general-purpose processors?
  - Ties one GC algorithm into the ISA and the microarchitecture
  - High cost due to major changes to processor and/or memory system
  - Miss opportunities at the software level, e.g. locality improvement
- Rigid trade-off: reduced flexibility for higher performance on specific applications
- Transistors are available
  - Build accelerators for commonly used functionality
  - How much hardware and how much software for GC?

Our Goal

- Architectural and hardware acceleration support for GC
  - Reduce the overhead of software GC
  - Keep the flexibility of software GC
  - Work with any existing software GC algorithm

Basic Idea

- Simple but incomplete hardware garbage collection until the heap is full
- Software GC runs and collects the remaining dead objects
- Overhead of GC is reduced

Hardware-assisted Automatic Memory Management (HAMM)

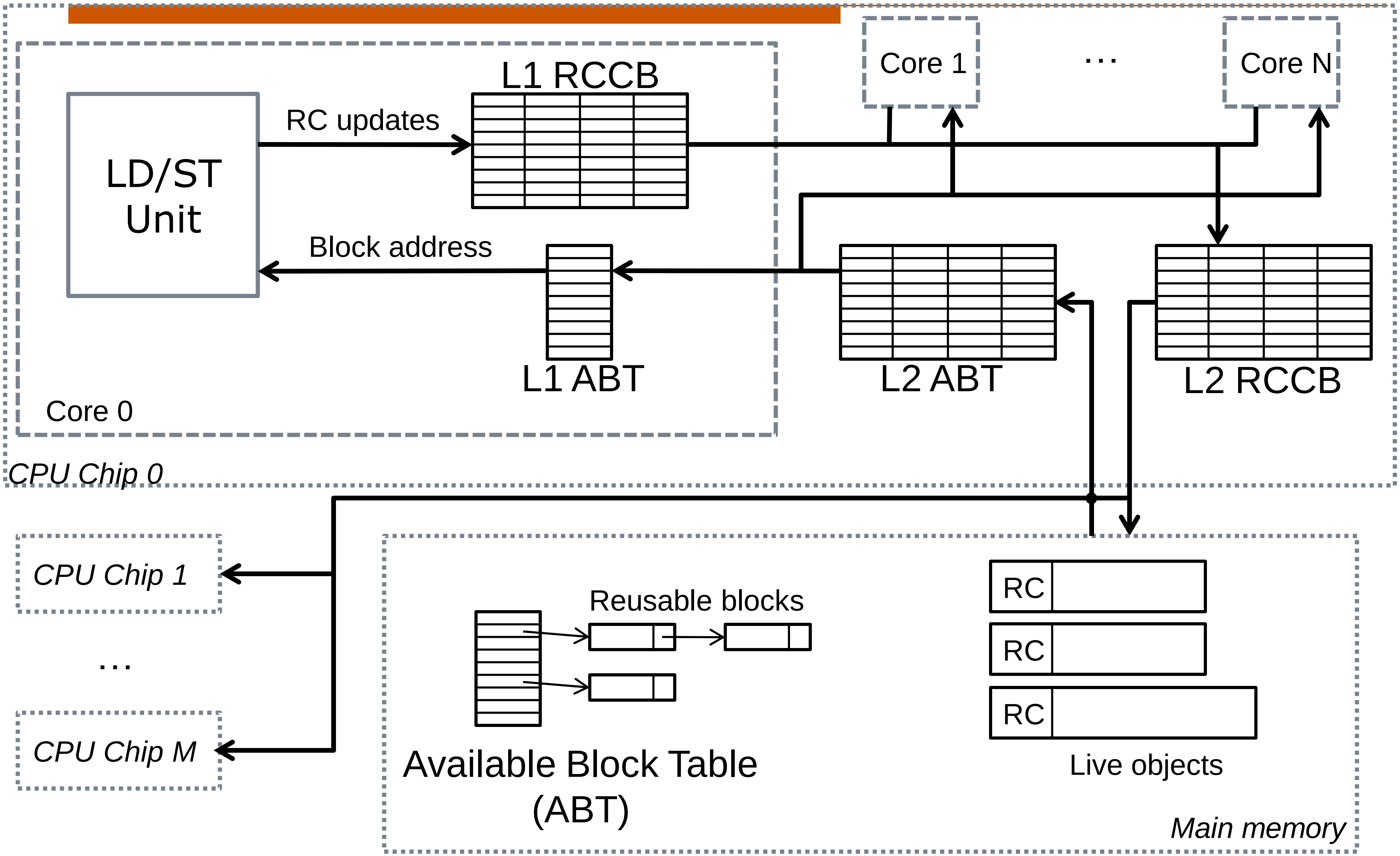
- Hardware-software cooperative acceleration for GC
  - Reference count tracking
    - To find dead objects without software GC
  - Memory block reuse handling
    - To provide available blocks to the software allocator
  - *Reduce frequency and overhead of software GC*

- Key characteristics
  - Software memory allocator is in control
  - Software GC still runs and makes high-level decisions
  - HAMM can simplify: does not have to track all objects

ISA Extensions for HAMM

- Memory allocation
  - REALLOCMEM, ALLOCMEM
- Pointer tracking (*store pointer*)
  - MOVPTR, MOVPTROVR
  - PUSHPTR, POPPTR, POPPTROVR
- Garbage collection

Overview of HAMM



Modified Allocator

addr ← REALLOCMEM *size*

if (addr == 0) then

// ABT does not have a free block → regular software allocator

addr ← *bump_pointer*

bump_pointer ← *bump_pointer* + *size*

…

else

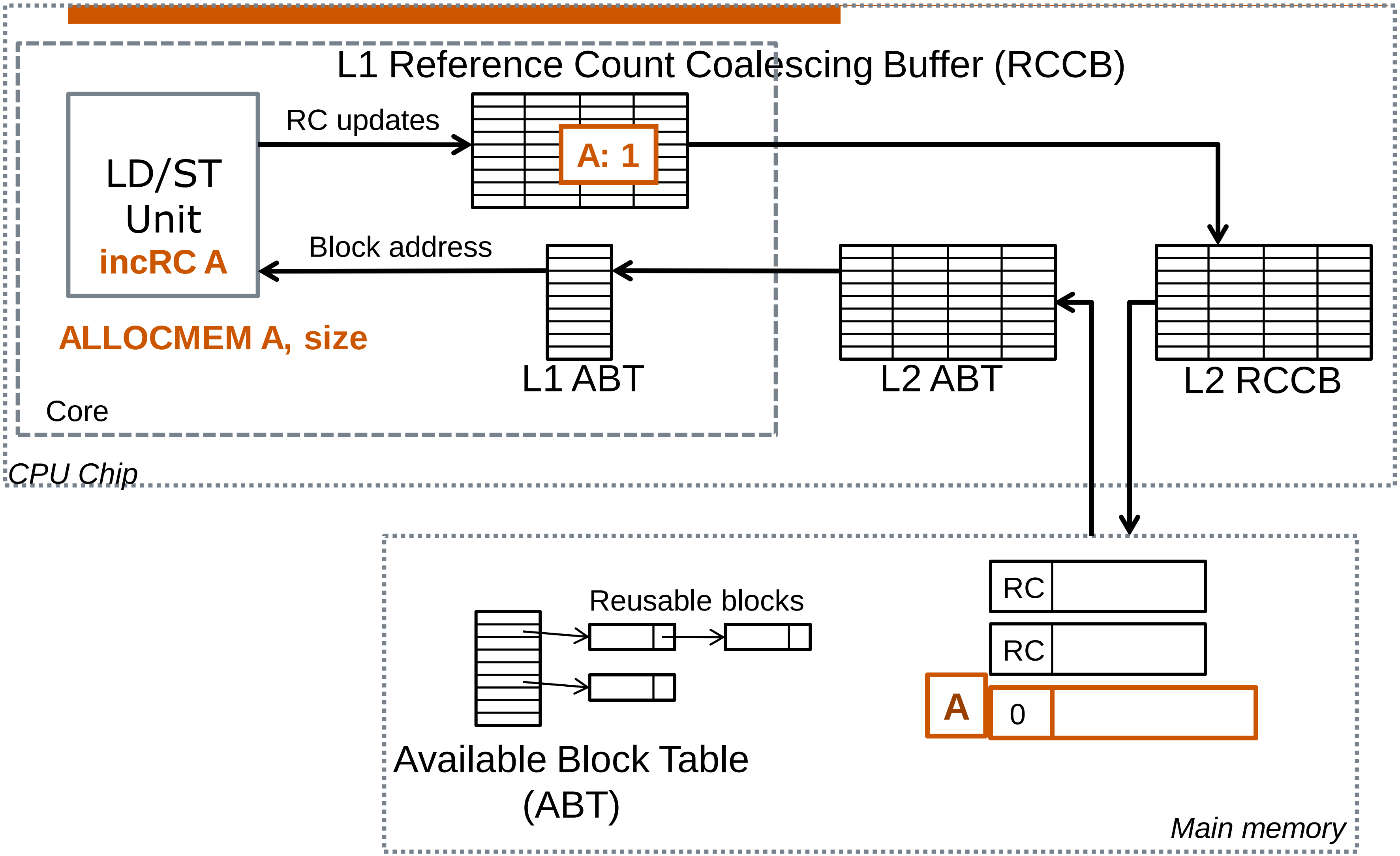
// use address provided by ABT

end if

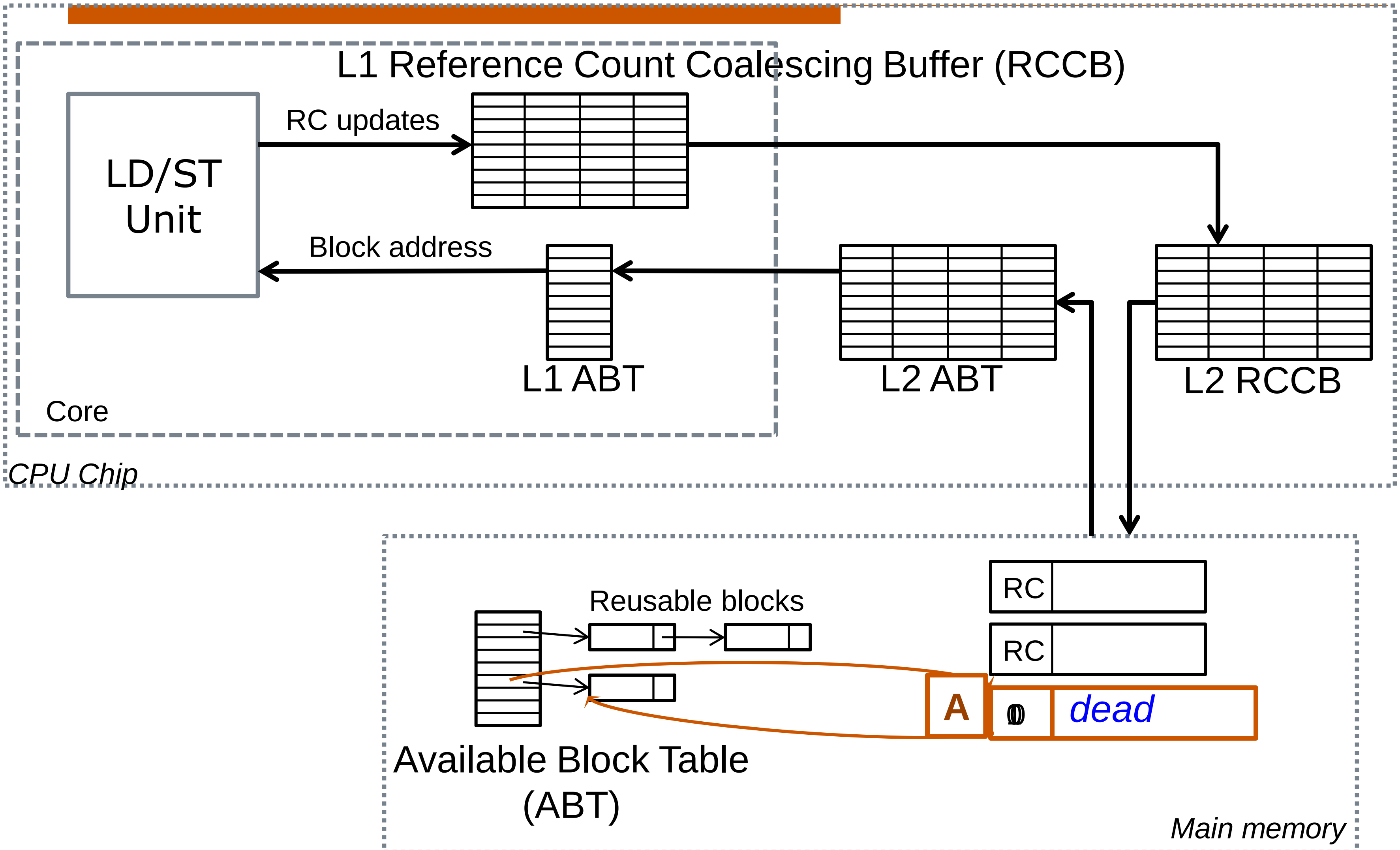
// Initialize block starting at *addr*

ALLOCMEM *object_addr*, *size*

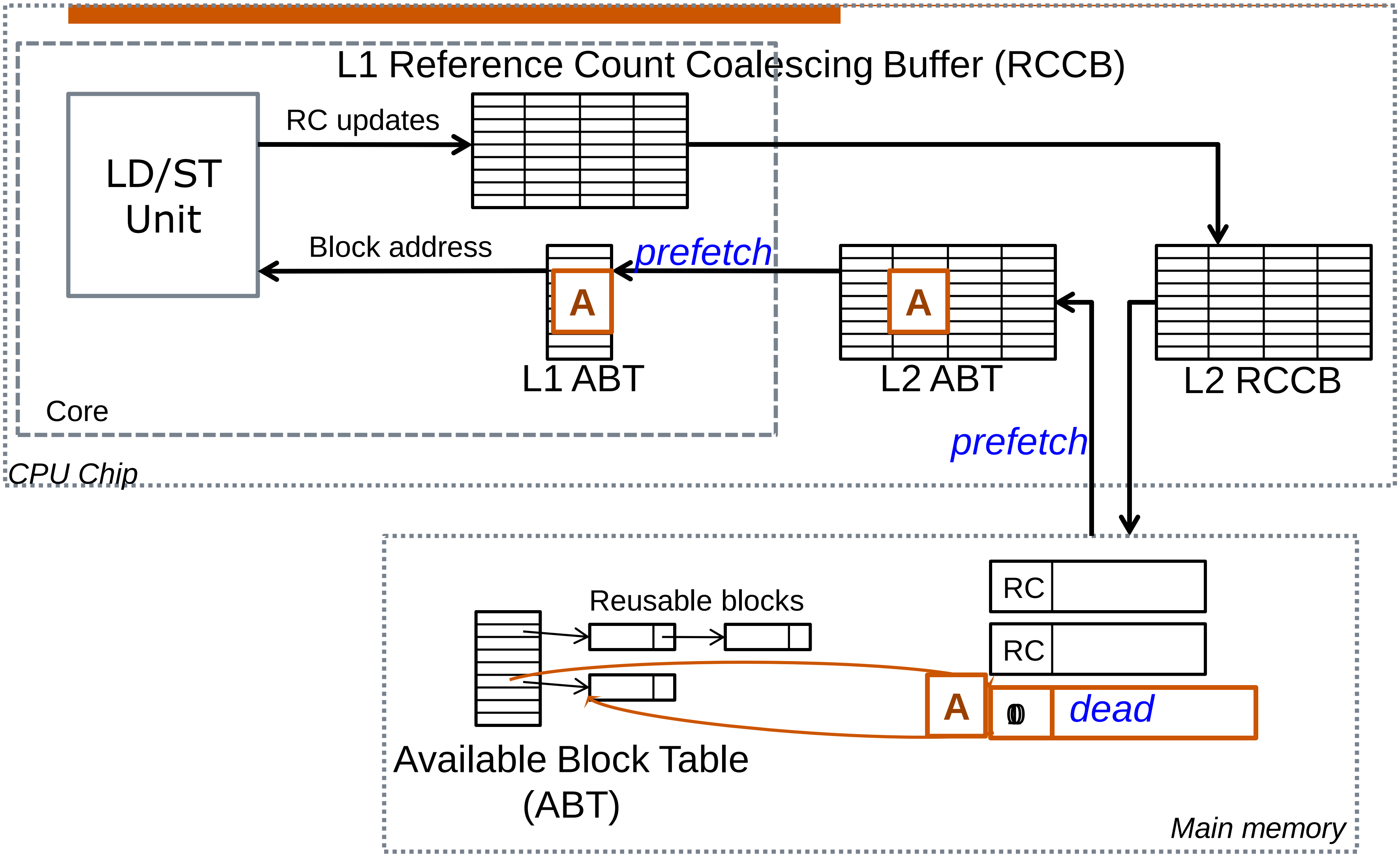
Example of HAMM



Example of HAMM



Example of HAMM



ISA Extensions for HAMM

- Memory allocation
  - ✓ REALLOCMEM, ALLOCMEM
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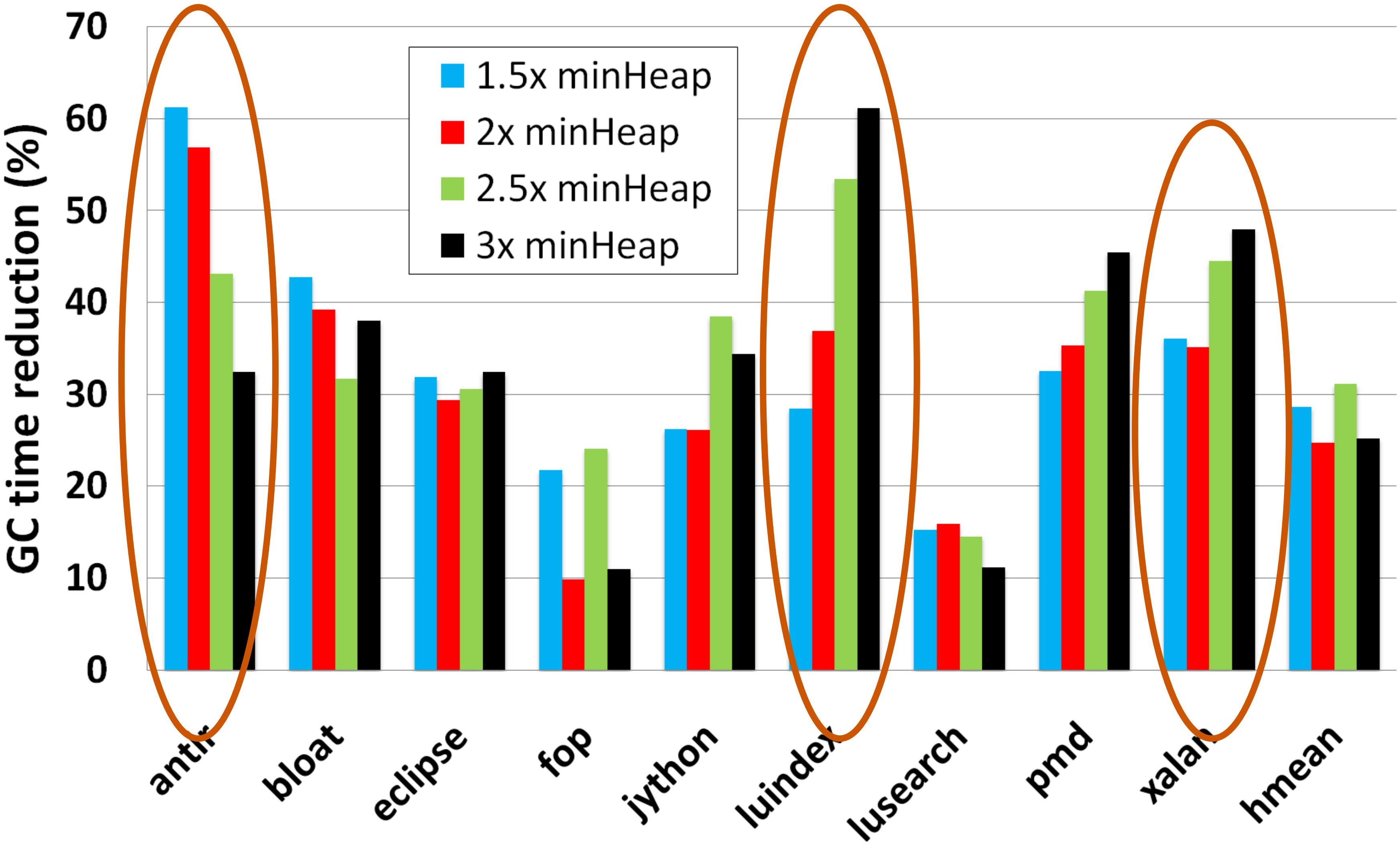
- Garbage collection
  - ❑ FLUSHRC

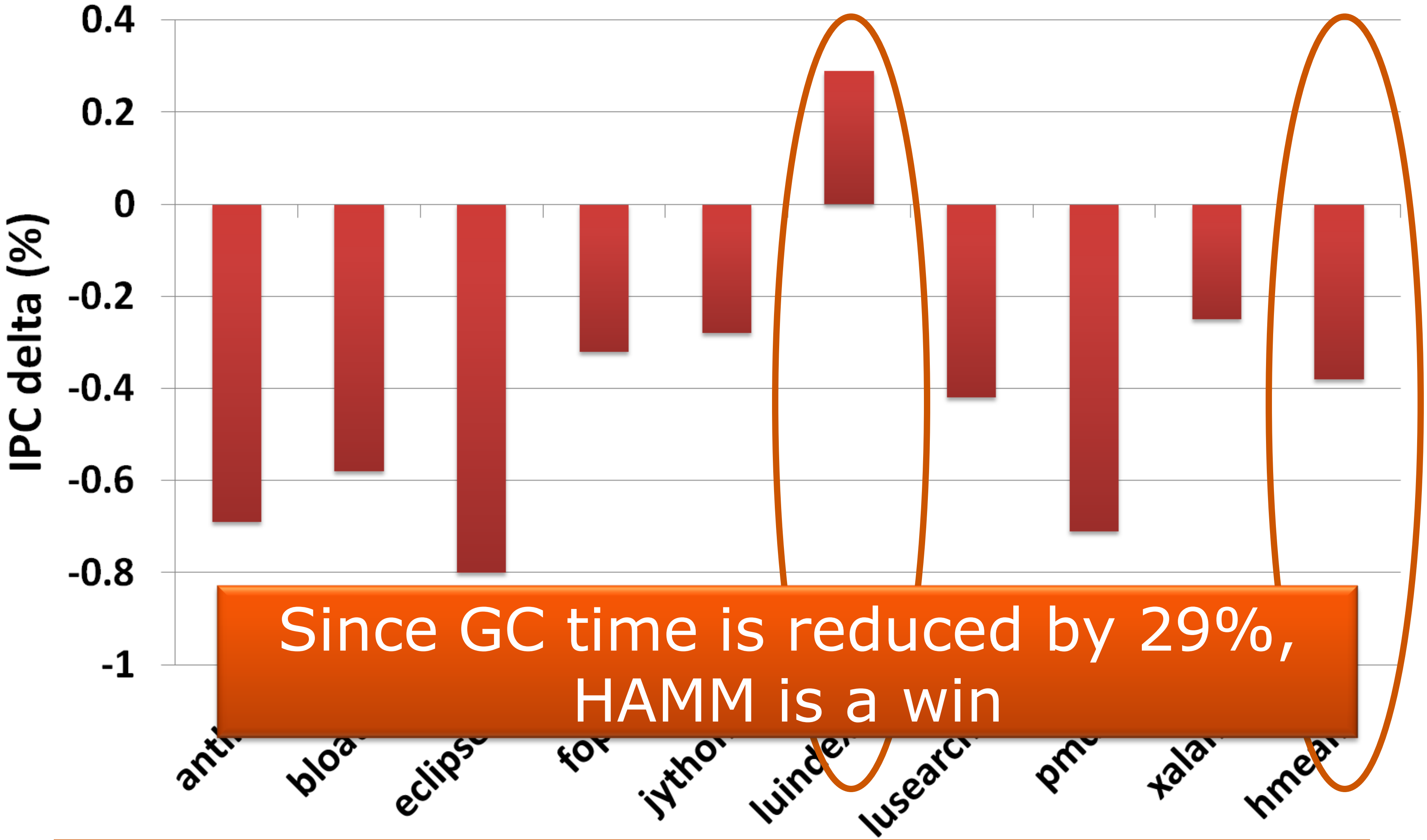
Methodology

- Benchmarks: DaCapo suite on Jikes Research Virtual Machine with its best GC, GenMS
- Simics + cycle-accurate x86 simulator
  - 64 KB, 2-way, 2-cycle I-cache
  - 16 KB perceptron predictor
  - Minimum 20-cycle branch misprediction penalty
  - 4-wide, 128-entry instruction window
  - 64 KB, 4-way, 2-cycle, 64B-line, L1 D-cache
  - 4 MB, 8-way, 16-cycle, 64B-line, unified L2 cache
  - 150-cycle minimum memory latency
- Different methodologies for two components:
  - GC time estimated based on actual garbage collection work over the whole benchmark
  - Application: cycle-accurate simulation with microarchitectural modifications on 200M-instruction slices

GC Time Reduction



Application Performance



Since GC time is reduced by 29%, HAMM is a win

Why does HAMM work?

- HAMM reduces GC time because
  - Eliminates collections: 52%/50% of nursery/full-heap
  - Enables memory block reuse for 69% of all new objects in nursery and 38% of allocations into older generation
  - Reduces GC work: 21%/49% for nursery/full-heap
- HAMM does not slow down the application significantly
  - Maximum L1 cache miss increase: 4%
    Maximum L2 cache miss increase: 3.5%
  - HAMM itself is responsible for only 1.4% of all L2 misses

Conclusion

- Garbage collection is very useful,
  but it is also a significant source of overhead
  - Improvements on pure software GC or hardware GC are limited
- We propose HAMM, a cooperative hardware-software technique
  - Simplified hardware-assisted reference counting and block reuse
  - Reduces GC time by 29%
  - Does not significantly affect application performance
  - Reasonable cost (67KB on a 4-core chip)
    for an *architectural accelerator* of an important functionality
  - HAMM can be an enabler encouraging developers
    to use managed languages

Thank You!

Questions?