Metadata Management for Large-Scale Hybrid Memory Architectures

Introduction

Requirements for main memory

- More bandwidth and shorter latency for high performance applications
- More memory capacity for big data

Both high performance and a large capacity are required for main memory.

Hybrid memory architectures (HMAs)

Combine two types of memories to realize both high performance and large capacity

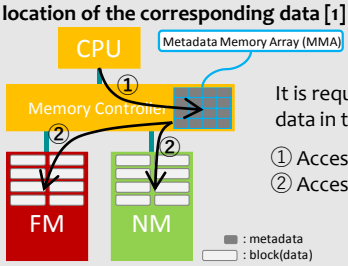
◇**Far memory (FM)**
Large capacity but **low** performance to store **infrequently**-used data

◇**Near memory (NM)**
High performance but **small** capacity to store **frequently**-used data

Management of data between NM and FM is essential to keep many frequently-used data in NM.

Metadata

Records the management of information such as location of the corresponding data [1]



It is required to access data in two steps.

① Access metadata
② Access FM or NM

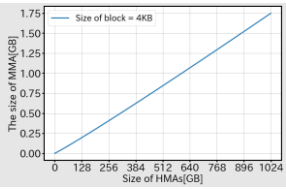
Problem : Increasing the Capacity for Metadata on an HMA

Estimation of the size of metadata memory array (MMA) in the future

$$(\textit{The size of MMA}) = \frac{(\textit{Size of HMAs})}{(\textit{Size of block})} \times \left(2 \times \frac{1}{8} log_2(\frac{(\textit{Size of HMAs})}{(\textit{Size of block})})\right) [\textit{Bytes}]$$

$\frac{(\textit{Size of HMAs})}{(\textit{Size of block})}$: *The number of metadata*

$2 \times \frac{1}{8} log_2(\frac{(\textit{Size of HMAs})}{(\textit{Size of block})})$: *Size of metadata*



- **The size of MMA increases as the size of the HMA increases.**

It is not practical to store metadata only on a chip in the future.

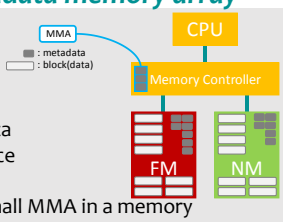
Analysis of Metadata Access Pattern

In-Memory metadata with metadata memory array

Idea
- Manage metadata by distributing them to FM/NM and memory controller

Problem
- The long access latency to the metadata in FM/NM may degrade the performance

Solution
- Stores only necessary metadata in a small MMA in a memory controller to avoid performance degradation



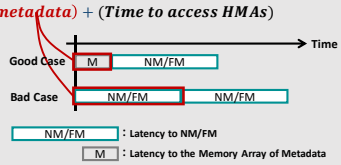
Behavior of metadata accesses

Equation of the time to access data

$$(\textit{Time to access data}) = (\textit{Time to refer metadata}) + (\textit{Time to access HMAs})$$

Good case : Access metadata in MMA
Bad case : Access metadata in NM/FM

Bad case increases the access latency to the data.



To find a way to save metadata in the MMA in advance, it is required to analyze metadata access patterns.

Experimental Results and Discussions

Purpose

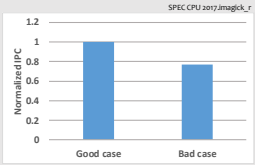
To analyze block access patterns for efficient control of metadata

Experimental environment

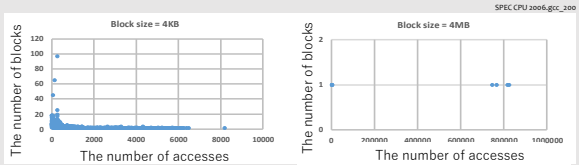
Obtain an address trace based on block address using simulators (Gem5 and NVMain) and analyze the accesses to metadata

- [Benchmark] SPEC CPU 2006, 2017
- [Cache size] L1I:64KB, L1D:64KB, L2:512KB, L3:2MB
- [Latency] M:2cycles, NM:32cycles, FM:68cycles
- If data is stored in NM/FM, NM/FM is accessed to refer metadata.

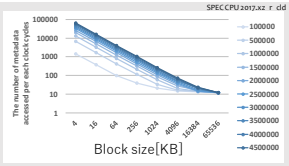
Results



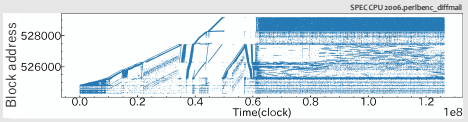
- ***The bad case decreases IPC by accessing metadata in NM and/or FM many times.***
- ***It is important for performance to predict necessary metadata and store the predicted metadata in the MMA in advance.***



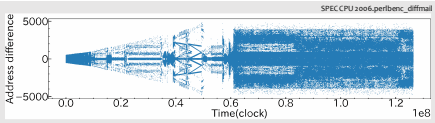
- ***When the block size is large, the number of blocks is limited.***
- ***By using the large block size, blocks can be categorized by the number of accesses.***



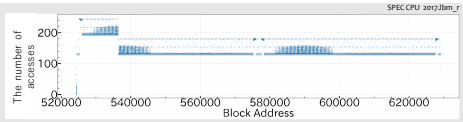
- ***By decreasing clock cycles and/or increasing the size of block, the number of metadata decreases.***



- ***Frequently accessed data or its neighbors continue to be frequently accessed.***
- ***Infrequently accessed data will not be accessed.***



- ***The address between currently accessed data and next accessed data is within a certain range.***



- ***Neighborhood of data have the similar number of accesses.***
- ***By using the block address, It is possible to predict the number of accesses.***

Conclusions & Future Work

- Large-scale HMAs need more metadata, and the capacity for metadata should be mitigated.
- This research analyzes block access pattern to realize the in-memory metadata management with metadata caching.
- The experimental results show the behavior of metadata accesses to predict metadata in the HMAs.
- In the future, it is planned to implement the metadata prediction mechanism by using the metrics.

Reference

[1] Chia Chen Chou, et al. Cameo: A two-level memory organization with capacity of main memory and flexibility of hardware-managed cache. In *Proc. of Micro*, pp. 1–12, 2014.