Microprocessors and Microsystems 40 (2016) 27–44

Contents lists available at ScienceDirect

Microprocessors and Microsystems

journal homepage: www.elsevier.com/locate/micpro

Energy-efficient synonym data detection and consistency for virtual cache

An Hsia, Ching-Wen Chen*, Tzong-Jye Liu

Department of Information Engineering and Computer Science, Feng Chia University, Taichung City 40724, Taiwan

ARTICLE INFO

Keywords:
Virtual cache
Synonym problem
Energy saving
TLB

ABSTRACT

The cache memory consumes a large proportion of the energy used by a processor. In the on-chip cache, the translation lookaside buffer (TLB) accounts for 20–50% of energy consumption of the on-chip cache. To reduce energy consumption caused by TLB accesses, a virtual cache can be accessed by virtual addresses which are issued by a processor directly. However, a virtual cache may result in the synonym problem. In this paper, we propose low-cost synonym detection hardware and a synonym data coherence mechanism. These reduce the energy consumption incurred by TLB lookups, and maintain synonym data consistency in the virtual cache. The proposed synonym detection hardware efficiently reduces the number of blocks that must be looked up in a virtual cache for saving energy. In addition, the proposed synonym data coherence mechanism also reduces the number of invalidated blocks in the virtual cache to prevent the destruction of cache locality. The simulation results show that our proposed energy-aware virtual cache consumes 51%, 27%, and 20% less energy than the traditional physical cache, traditional virtual cache, and synonym lookaside buffer (SLB), respectively. In addition, our proposed design shows almost the same static energy consumption as SLB, and reduces static energy consumption by about 20% compared with the traditional physical cache and virtual cache.

1. Introduction

In a computer system, the memory consumes a significant proportion of energy during executing applications. In previous studies [1–3], it has been found that energy consumption of the cache memory accounts for 45–50% of the overall energy consumption of a processor. Therefore, the design of a memory system that will reduce energy consumption is an important research topic.

In a memory system, the physical memory space can be efficiently used with virtual memory. However, when a processor issues a virtual address to access a physical cache or main memory, the issued virtual address has to be translated to the physical address by a translation lookaside buffer (TLB). In previous studies [4–7], it was found that the energy consumption of TLBs accounts for about 20–50% of energy consumption of the on-chip cache. Fig. 1 illustrates the dynamic energy consumption of the TLB with the SPLASH-2 benchmark suite using different cache sizes. The TLB typically consumes 25–45% of the dynamic energy consumption of the on-chip cache. Therefore, reducing the number of TLB accesses represents an efficient method of reducing energy consumption in the memory system.

In previous studies, it was suggested that the virtual cache architecture could efficiently reduce the number of TLB accesses, and thus reduce the energy consumed when accessing TLB [8,9]. Because the virtual address issued by a processor can be used to directly fetch the desired instruction or data located in the virtual cache, the number of TLB accesses can be efficiently reduced.

However, using the virtual cache architecture may give rise to the synonym problem [8–19]. The synonym problem occurs when a data item has multiple different virtual addresses to cause multiple copies of the data item to exist simultaneously in a virtual cache. In this paper, we called the multiple copies of a data item the synonym data items. For example, multiple threads share memory space, and multiple applications use shared data or the same library. The data inconsistency problem arises when data are written to one of the multiple synonym data items in the virtual cache (read-only cache does not suffer such a problem). The processor may then obtain the wrong data from the virtual cache. Thus, to use the virtual cache architecture to reduce energy consumption, we must solve the synonym problem.

To solve the synonym problem, the synonym data items in the virtual cache have to be consistent. In general, there is no information indicating which blocks contain the synonym data items and whether they have been modified. Therefore, all virtual cache blocks that may contain the synonym data items have to be invalidated to keep the synonym data items consistent when a write or a read

* Corresponding author. +886-4-24517250X3729.
E-mail addresses: P9943324@fcu.edu.tw (A. Hsia), chingwen@fcu.edu.tw (C.-W. Chen), tjliu@fcu.edu.tw (T.-J. Liu).

http://dx.doi.org/10.1016/j.micpro.2015.11.004
0141-9331/

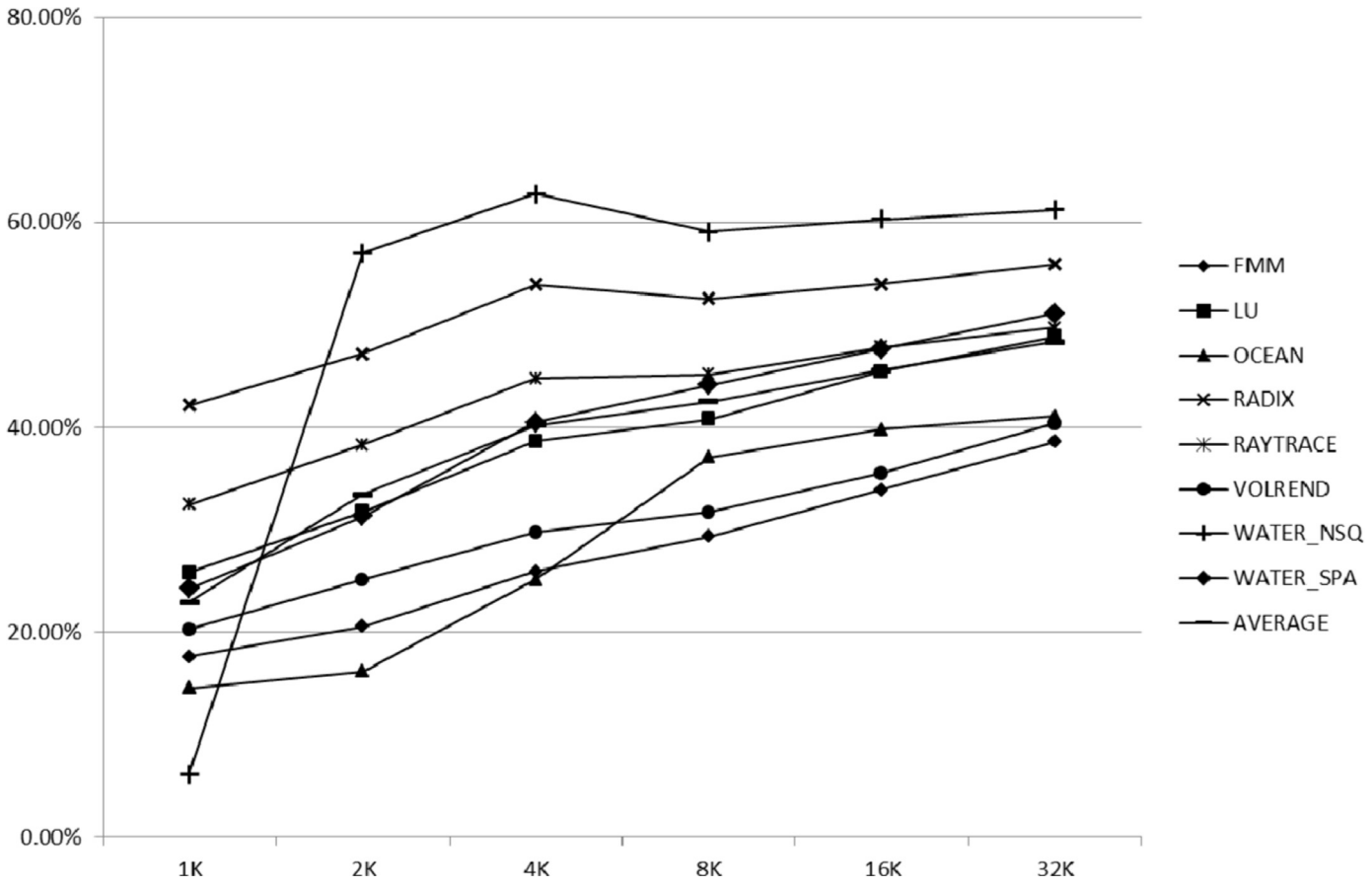

Fig. 1. Energy consumption of TLB accesses with different cache sizes as a proportion of the entire memory system.

miss to the virtual cache occurs. However, invalidating these blocks destroys cache locality, which lowers the hit rate of the virtual cache and increases execution time. For this reason, the previous studies [4,10,11,13] have used additional hardware to check whether multiple synonym data items exist when a miss occurs in the virtual cache. However, activating additional hardware for synonym data detection increases the dynamic energy consumption and execution time. Therefore, a solution to the synonym problem that decreases energy consumption and execution time must consider the added hardware cost for detecting synonym data items and the reduction in cache locality in the virtual cache.

In this paper, in order to save energy and reduce the number of invalidated blocks, we propose low cost synonym detection hardware and a synonym data consistency mechanism for the virtual cache architecture. Instead of using complicated synonym detection hardware, we use a shared bit for each virtual cache block to indicate the existence of synonym data items. That is, if the shared bit of a block is 0, it means that the block does not have another synonym data block in the virtual cache. In contrast, if the shared bit is 1, it means that the block has another synonym data block or other synonym data blocks in the virtual cache. To maintain synonym data consistency, a synonym table located behind a virtual cache is used to record the addresses of fetched data items in the virtual cache. These techniques enable the proposed mechanism to maintain synonym data consistency, reducing the number of invalidated blocks in the virtual cache and preventing the destruction of cache locality.

This paper is organized as follows. In Section 2, we review some related studies. Section 3 discusses and analyzes the synonym problem in the virtual cache, and introduces our low-cost synonym detection hardware and synonym data consistency mechanism. In Section 4, the simulation results are presented, and Section 5 concludes this paper.

2. Related work

In previous research on reducing TLB energy consumption, two related issues were introduced: the reduction of TLB energy consumption in the physical cache, and the avoidance of the synonym problem in the virtual cache. These issues are discussed in turn.

2.1. Reducing the energy consumption of TLB lookup

When a processor issues a virtual address to access the physical cache, it is translated into the physical address using the TLB. However, if a TLB miss occurs, the page table in the memory is accessed, which increases the delay time. To reduce the miss rate of the TLB, it is usually designed to have a high degree of associativity. However, previous studies [14–16] have pointed out that the energy consumption of tag comparisons is higher in hardware with a high associative degree.

Zhou [14] analyzed an application that records frequently used address translation information in a direct translation table (DTT) to replace the TLB. To reduce the energy consumption of the DTT, part of the virtual address is used to index the DTT without tag comparisons. Hsien-Hsin [20] used the semantic regions defined by software conventions and programming languages to divide a data TLB into three small sub-data translation lookaside buffers according to data types. This reduces the energy consumption of each TLB access. These mechanisms reduce the energy consumption of the TLB, but still consume energy in the TLB or additional hardware tables before accessing the physical cache.