

Dynamic Cache Partitioning and Adaptive Cache Replacement Schemes for Chip Multiprocessors

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B.Eng.(Computer Engineering)
M.Sc.(Intelligent System)

A THESIS SUBMITTED IN FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING
THE UNIVERSITY OF ADELAIDE
AUSTRALIA

2014



THE UNIVERSITY
of ADELAIDE

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CONTENTS

List of Figures	ix
List of Tables	xiii
List of Algorithms	xv
Abstract	xvii
Declaration of Originality	xix
Acknowledgments	xxi
List of Abbreviations	xxiii
1 Introduction	1
1.1 Shared Cache of CMP Architectures and Design Challenges	2
1.2 Research Goal	6
1.3 Contributions of this Thesis	7
1.4 Thesis Overview.	9
2 Background	13
2.1 Multiprocessor System Design Space Exploration.	13
2.1.1 Multiprocessor architectures.	16
2.2 Cache Management Schemes	21
2.3 Cache Replacement Policy	28
2.4 Summary	35

3	Simulation Framework	37
3.1	The Xtensa LX4.0 Processor	37
3.2	Simulation Framework and Environment	43
3.3	SPEC2000 Benchmarks	49
3.4	Methodology	52
3.5	Summary	55
4	Cache Partitioning Schemes	57
4.1	Simple Static Allocation Scheme	58
4.1.1	Introduction	58
4.1.2	Evaluation	59
4.2	Utility-based Cache Partitioning Scheme	66
4.2.1	Overview	66
4.2.2	Evaluation	67
4.3	CPI-based Cache Partitioning Scheme	72
4.3.1	Overview	72
4.3.2	Evaluation	73
4.4	Summary	77
5	Cache Replacement Policy	81
5.1	Introduction	82
5.2	Motivation	83
5.3	Adaptive Insertion and Promotion Policy	85
5.3.1	Description	85
5.3.2	Comparing Operation of MI2PP policy to PIPP	88
5.3.3	Simulation Results	92
5.3.4	Hardware Overhead	107
5.3.5	Performance Analysis	110
5.3.5.1	Comparison with LRU, UCP, and PIPP	110
5.3.5.2	Comparison with another cache partitioning scheme.	115
5.3.5.3	Cache size sensitivity study	117
5.3.5.4	Implementation in the unpartitioned shared cache.	121
5.3.6	Conclusion	123

5.4	Partition-based Replacement Policy	124
5.4.1	Description	124
5.4.2	Evaluation	126
5.4.3	Conclusion	129
5.5	Summary	133
6	Shared Cache Partitioning Based On Performance Gain Estimations	135
6.1	Introduction	136
6.2	Motivation	138
6.3	Structure of The New Scheme	141
6.3.1	Monitoring Environment and Scheduler	143
6.3.2	Identifying the Partitioning Dependence.	145
6.4	Adaptive CPI-based Cache Partitioning Scheme	147
6.5	Experimental Evaluation.	150
6.5.1	Simulation Methodology	151
6.5.2	Simulation Results	151
6.6	Performance Analysis	155
6.6.1	Cache Scaling and Sensitivity Analysis	155
6.6.2	Effect of Dynamic Set Sampling	159
6.6.3	Comparison with Different Cache Replacement Policies	161
6.7	Complexity Management and Hardware Implementation	164
6.8	Summary	166
7	Conclusion	169
7.1	Cache Replacement Policy	170
7.2	Cache Partitioning Scheme	171
7.3	List of Contributions	173
7.4	Limitations	174
7.5	Future Work	175
7.6	Final Remarks	177
	Bibliography	179

LIST OF FIGURES

2.1	Multithreading in a multiprocessor system.	14
2.2	Basic structure of a CMP. Multiple processors with a private level 1 cache share the same physical level 2 cache [Pal et al. 2012].	17
2.3	Basic structure of a SMP. Multiple processors interconnected to their private level 1 and level 2 caches [Pal et al. 2012].	18
2.4	The basic structure of CLMP consists of multiple processors grouped into clusters (cluster size = 2) [Pal et al. 2012].	19



3.1	Xtensa LX4.0 processor architectural block diagram [Tensilica Inc. 2011].	39
3.2	Xtensa processor interfaces.	41
3.3	The baseline architecture.	44
3.4	The interconnection of the cores and cache hierarchy using the PIF in a dual-core system.	46



4.1	Total L2 cache misses improvement over standard LRU.	61
4.2	Distribution of total misses caused by each individual core in the quad-core system.	63

4.3	The speed-up of the partitioned cache with the augmented LRU policy over the standard LRU replacement policy.	65
4.4	Comparison of UCP, LRU, and EQ cache misses in a quad-core system.	68
4.5	Total L2 misses incurred by each core when the system using UCP, LRU and EQ.	70
4.6	Performance improvement of UCP over LRU and EQ for a quad-core system.	71
4.7	Reduction of total cache misses of CPI-based partitioning scheme over LRU and EQ on in a quad-core system.	74
4.8	Distribution of total L2 misses incurred by each core in the system.	75
4.9	Performance of CPI-based partitioning scheme over LRU and EQ for a quad-core system.	76



5.1	Example of insertion positions in PIPP. Consider Core 1 is allocated with 5 ways and Core 2 receives 3 ways from UCP scheme.	84
5.2	Example operation of (a) PIPP from Xie and Loh [2009], and (b) MI2PP policy for a variety of insertions and promotions activities. Assume evictions for both policies always choose the lowest-priority cache line in the set.	89
5.3	Performance result for IPC throughput of UCP, PIPP, and MI2PP policy normalised to an LRU-managed cache.	94
5.4	Performance as measured by the weighted speedups of IPC for UCP, PIPP and MI2PP policy compared to baseline LRU.	96
5.5	Comparison of UCP, PIPP and MI2PP policy over traditional LRU for the harmonic mean fairness metric.	97
5.6	L2 miss rate in MPKI of UCP, PIPP and MI2PP compared to baseline LRU policy.	98
5.7	(a) IPC throughput of the 8-core system, and (b) L2 miss rate of the 4-core and 8-core systems, using PIPP and MI2PP, relative to the baseline LRU policy.	100

5.8	(a) IPC throughput, and (b) L2 miss rate of the 16-core system, using PIPP and MI2PP, relative to the baseline LRU policy.	103
5.9	Distribution of L2 miss rate of each core in the 16-core system.	105
5.10	Distribution of L2 miss rate between MI2PP and LRU.	111
5.11	Number of cores using lower priority positions as the insertion location.	113
5.12	Distribution of L2 miss rate among UCP, PIPP and MI2PP.	114
5.13	Performance gain of MI2PP over a system using CPI-based cache partitioning scheme.	116
5.14	Total miss rate reduction normalised to the original LRU replacement policy. . .	117
5.15	Miss rate relative to the baseline LRU policy of a system with shared cache sizes of (a) 512KB, and (b) 1MB using different cache partitioning schemes and MI2PP policy.	118
5.16	Miss rate, relative to UCP, of MI2PP/UCP policy implemented in different cache sizes.	120
5.17	Miss rate reduction of MI2PP policy implemented in different sizes of unmanaged shared cache.	122
5.18	Performance improvement of PRP normalised to baseline LRU policy and UCP.	126
5.19	Performance results for the weighted speedup and fair speedup metrics.	127
5.20	L2 miss rate of PRP normalised to LRU and UCP.	129
5.21	Performance improvement of UCP, PRP and EPRP in a 512KB cache, normalized to LRU policy.	131
5.22	L2 miss rate of PRP and EPRP, relative to LRU policy.	132



6.1	Each cache line is extended to include core identification.	141
6.2	The shadow tag array and four miss counters associated with each recency position in the monitoring hardware structure of each core.	144

6.3	Miss rate improvements relative to unmanaged traditional LRU cache.	152
6.4	Performance comparison of UCP, CPI and ACCP over unmanaged LRU L2 shared cache.	153
6.5	Performance comparison using the (a) weighted speedup, and (b) harmonic mean of weighted IPC metrics.	154
6.6	Performance comparison of ACCP, UCP and CPI-based schemes on different sizes of L2 shared cache, relative to baseline LRU.	156
6.7	Miss rate reduction of ACCP over UCP and CPI-based schemes.	157
6.8	Distribution of L2 miss rate among UCP, CPI and ACCP.	158
6.9	IPC performance improvement of ACCP using (1) DSS (labelled as ACCP_S), and (2) UMON-global (labelled as ACCP) for different cache sizes, relative to baseline LRU.	160
6.10	Performance comparison of MI2PP replacement policy employed on ACCP, UCP, and CPI-based schemes, relative to baseline LRU.	162
6.11	Miss rate of MI2PP replacement policy employed on ACCP, UCP and CPI-based schemes, relative to baseline LRU.	162

LIST OF TABLES

3.1	Xtensa LX4.0 processor configuration.	44
3.2	Baseline system's configuration.	46
3.3	Classification of SPEC CPU2000 applications.	50
3.4	Workload summary.	50
3.5	List of stoppers/first applications to finish its execution in each workload mix. . .	54



5.1	Workload mixes for the 8-core system.	102
5.2	A hardware cost of an UMON circuit associated to a single processor.	108
5.3	Replacement logic complexity of the LRU, PIPP and MI2PP policies.	109



6.1	A snapshot of the information recorded during one of the execution intervals. .	146
6.2	Hardware overhead per processor.	165

LIST OF ALGORITHMS

6.1	Pseudo code for finding a line for eviction. The function returns the position of the line to be replaced.	142
6.2	Adaptive CPI-based Cache Partitioning scheme.	149

ABSTRACT

One of the dominant approaches towards implementing fast and high performance computer architectures is the Chip Multi Processor (CMP), in which the design of the memory hierarchy has a critical effect on performance. Performance can be improved by the use of a shared cache on the chip, but it is a matter of ongoing research as to how each processor can gain the greatest advantage from the cache without affecting the performance of other processors. Moreover, power is a critical issue in CMP design.

Cache replacement policies and cache partitioning schemes have been investigated and proven able to enhance shared cache management. However, it is still desirable to have an optimal replacement policy that can retain useful data as long as possible to minimise miss rate and not degrade performance in a partitioned shared cache. Many of the metrics that have led to innovations in various partitioning schemes have increased the complexity of the partitioning strategies and the hardware overhead. There is scope for more work in achieving the right balance between power consumption and performance improvement in the CMP.

This thesis investigates the effects of the cache replacement policy in a partitioned shared cache. The goal is to quantify whether a better power/performance trade-off can be achieved by using less complex replacement strategies. A Middle Insertion 2 Positions Promotion (MI2PP) policy is proposed to eliminate cache misses that could adversely affect

the access patterns and the throughput of the processors in the system. The insertion, promotion and eviction strategies of the replacement policy are investigated and modified to improve shared cache utilisation by the competing processors. The MI2PP policy employs a static predefined insertion point, near distance promotion and the concept of ownership in the eviction policy to avoid resource stealing among the processors. With these strategies, the performance of the shared cache and the overall system were enhanced and the miss rate showed significant improvement over the Least Recently Used (LRU) policy.

While existing cache partitioning schemes use a variety of performance metrics to allocate the cache for each competing processor, most of the schemes focus only on one metric in their partitioning algorithm. An Adaptive Cycles per Instruction (CPI)-based Cache Partitioning (ACCP) scheme is introduced to investigate the efficiency of using two metrics to optimise partitioning decisions and to study the trade-offs between the complexity of using more performance metrics in partition decision-making and additional hardware cost. The analysis performed on ACCP showed that the performance of the processors was improved compared to the existing CPI-based partitioning scheme introduced by Muralidhara et al. [2010], which uses only one of the performance metrics employed in ACCP. Evaluation on a more complex scheme, namely the Utility Cache Partitioning (UCP) scheme demonstrated that the ACCP on average achieved similar performance although the ACCP is simpler to implement. The low hardware overhead incurred by ACCP showed that it is superior to UCP. ACCP demonstrates that the complexity of the partitioning mechanism and hardware cost could be reduced without degrading the overall system performance.

DECLARATION OF ORIGINALITY

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Norfadila Mahrom and, to the best of my knowledge and belief, contains no material previously published written by another person, except where due reference has been made in the text.

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ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful.

All praise and thanks to Allah.

My very great appreciation and deep gratitude to my principal supervisor, Associate Professor Michael J. Liebelt for his patient guidance, assistance, encouragement and useful criticism of my research work. His willingness to allocate his time so generously to support me in many aspects and his trust in me has been very much appreciated. I also would like to express my sincere thanks to Dr. Braden J. Phillips for his valuable and constructive suggestions during the planning and development of this research work.

The generosity of the School of Electrical and Electronic Engineering, The University of Adelaide in funding extensive access to the Tensilica tools under Tensilica Inc. University Program is highly appreciated. This work would not have been possible without the support of David Bowler in all issues related to technical resources. My research candidature was sponsored by the Ministry of Higher Education, Malaysia and Universiti Malaysia Perlis, and supported by Prof. Dr. R. Badlishah Ahmad, Prof. Dr. Ali Yeon Md Shakaff and Prof. Dato' Dr. Zul Azhar Zahid Jamal.

My grateful thanks are extended for the members of CHiPTec, particularly for everyone in the Journal Club for the valuable meetings that had introduced me to the best platform in expending my knowledge and research work. Not to forget, million thanks to Noorfazila

Kamal, Dr. Puteh Saad, Deborah Coleman-George, Ivana Rebellato and Chris Andrew Haerberli for their motivation and continuous moral support.

Finally, to my family. Thank you all for being you. You know how much you have done to make me come this far.

Norfadila Mahrom

LIST OF ABBREVIATIONS

ACCP	Adaptive CPI-based Cache Partitioning
ACCP_S	ACCP with Sampled sets
API	Application Programming Interface
ART 2	Adaptive Resonance Theory 2
BIP	Bimodal Insertion Policy
CLMP	Clustered Multi Processor
CMP	Chip Multi Processor
CPI	Cycles per Instruction
CPU	Central Processing Unit
DIP	Dynamic Insertion Policy
DPP	Dynamic Promotion Policy
DSS	Dynamic Set Sampling
EQ	Equally Partitioned
FIFO	First-In First-Out
FPGA	Field-Programmable Gate Array
HU	High Utility
I/O	Input/Output
ID	Identification
IPC	Instructions per Cycle
ISA	Instruction Set Architecture

ISS	Instruction Set Simulator
ISSCC	IEEE international Solid-State Circuits Conference
L1	Level one
L2	Level two
L3	Level three
LFU	Least Frequently Used
LIP	LRU Insertion Policy
LLC	Last Level Cache
LRU	Least Recently Used
LU	Low Utility
MI2PP	Middle Insertion 2 Positions Promotion
MMU	Memory Management Unit
MPKI	Misses per 1000 Instructions
MPP	MRU Promotion Policy
MRU	Most Recently Used
MU	Marginal Utility
PIF	Processor Interface
PIPP	Promotion/Insertion Pseudo-Partitioning
PRP	Partition-based Replacement Policy
PSEL	Policy Selector
RAM	Random Access Memory
RISC	Reduced Instruction Set Computer
ROM	Read Only Memory
SIPP	Single-step Incremental Promotion Policy
SMP	Symmetric Multi Processor

SPEC	Standard Performance Evaluation Corporation
SU	Saturating Utility
TADIP	Thread-Aware Dynamic Insertion Policy
TADPP	Thread-Aware Dynamic Promotion Policy
TIE	Tensilica Instruction Extension
UCP	Utility-Cache Partitioning
UMON	Utility Monitor
UMON_DSS	Utility Monitor with Dynamic Set Sampling
VPR	Versatile Place and Route
XCC	Xtensa C/C++ Compiler
XPG	Xtensa Processor Generator
XTMP	Xtensa Modeling Protocol