An Asymmetric Multi-core Architecture for Accelerating Critical Sections

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The Asymmetric Chip Multiprocessor (ACMP)

- Provide one large core and many small cores
- Accelerate serial part using the large core
- Execute parallel part on small cores for high throughput
The 8-Puzzle Problem

1 4 5
3 2 6
7 8

1 4 5
3 2 6
7 8

1 2 3
4 5 6
7 8

...
while(problem not solved)

SubProblem = PriorityQ.remove()
Solve(SubProblem)
if(solved)
    break
NewSubProblems = Partition(SubProblem)
PriorityQ.insert(NewSubProblems)
Contention for Critical Sections

Critical Sections execute 2x faster
MySQL Database

LOCK_open \rightarrow \text{Acquire()}
foreach (table locked by thread)
\hspace{1em}\text{table.lock} \rightarrow \text{release()}
\hspace{1em}\text{table.file} \rightarrow \text{release()}
if (table.temporary)
\hspace{1em}\text{table.close()}

LOCK_open \rightarrow \text{Release()}

![Diagram](Speedup vs small core)

Area (Small Cores)
Conventional ACMP

EnterCS()  
PriorityQ.insert(…)  
LeaveCS()

1. P2 encounters a Critical Section  
2. Sends a request for the lock  
3. Acquires the lock  
4. Executes Critical Section  
5. Releases the lock

Core executing critical section
Accelerated Critical Sections (ACS)

EnterCS()
PriorityQ.insert(…)
LeaveCS()

1. P2 encounters a Critical Section
2. P2 sends CSCALL Request to CSRB
3. P1 executes Critical Section
4. P1 sends CSDONE signal
Architecture Overview

- ISA extensions
  - CSCALL \texttt{LOCK_ADDR, TARGET_PC}
  - CSRET \texttt{LOCK_ADDR}

- Compiler/Library inserts CSCALL/CSRET

On a CSCALL, the small core:
  - Sends a CSCALL request to the large core
    - Arguments: Lock address, Target PC, Stack Pointer, Core ID
  - Stalls and waits for CSDONE

Large Core
  - Critical Section Request Buffer (CSRB)
  - Executes the critical section and sends CSDONE to the requesting core
“False” Serialization

- Independent critical sections are used to protect disjoint data

- Conventional systems can execute independent critical sections concurrently but ACS can artificially serialize their execution

- Selective Acceleration of Critical Sections (SEL)
  - Augment CSRB with saturating counters which track false serialization
Performance Trade-offs in ACS

• Fewer concurrent threads
  – As number of cores increase
    • Marginal loss in parallel performance decreases
    • More threads → Contention for critical sections increases which makes their acceleration more beneficial

• Overhead of CSCALL/CSDONE
  – Fewer cache misses for the lock variable

• Cache misses for private data
  – Fewer misses for shared data
    Cache misses reduce if Shared data > Private data
  – The large core can tolerate cache miss latencies better than small cores
Experimental Methodology

• Configurations
  – One large core is the size of 4 small cores
  – At chip area equal to N small cores
    • Symmetric CMP (SCMP): N small cores, conventional locking
    • Asymmetric CMP (ACMP): 1 large core, N – 4 small cores, conventional locking
    • ACS: 1 large core, N – 4 small cores, (N – 4)-entry CSRB.

• Workloads
  – 12 critical section intensive applications from various domains
  – 7 use coarse-grain locks and 5 use fine-grain locks

• Simulation parameters:
  – x86 cycle accurate processor simulator
  – Large core: Similar to Pentium-M with 2-way SMT. 2GHz, out-of-order, 128-entry, 4-wide, 12-stage
  – Small core: Similar to Pentium 1, 2GHz, in-order, 2-wide, 5-stage
  – Private 32 KB L1, private 256KB L2, 8MB shared L3
  – On-chip interconnect: Bi-directional ring
Workloads with Coarse-Grain Locks

Equal-area comparison
Number of threads = Best threads

Chip Area = 16 cores
SCMP = 16 small cores
ACMP/ACS = 1 large and 12 small cores

Chip Area = 32 small cores
SCMP = 32 small cores
ACMP/ACS = 1 large and 28 small cores
Workloads with Fine-Grain Locks

Area = 16 small cores

Area = 32 small cores
Equal-Area Comparisons

Number of threads = No. of cores

Chip Area (small cores)
ACS on Symmetric CMP
Conclusion

• ACS reduces average execution time by:
  – 34% compared to an equal-area SCMP
  – 23% compared to an equal-area ACMP

• ACS improves scalability of 7 of the 12 workloads

• Future work will examine resource allocation in ACS in presence of multiple applications