An Asymmetric Multi-core Architecture for Accelerating Critical Sections

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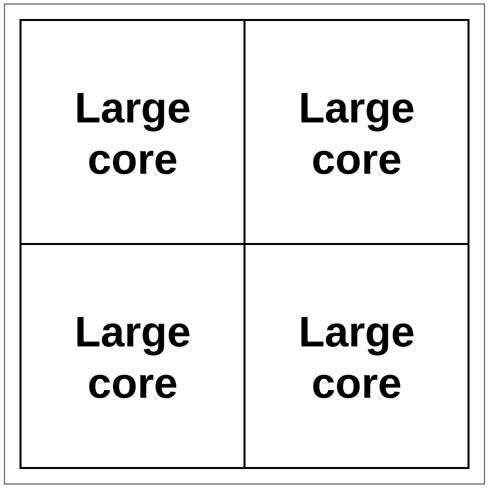
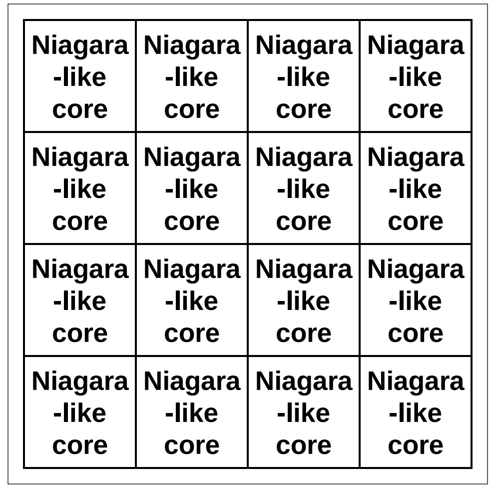
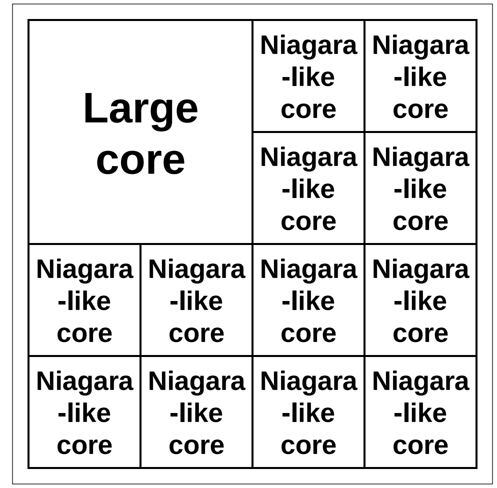
The Asymmetric Chip Multiprocessor (ACMP)



“Tile-Large” Approach



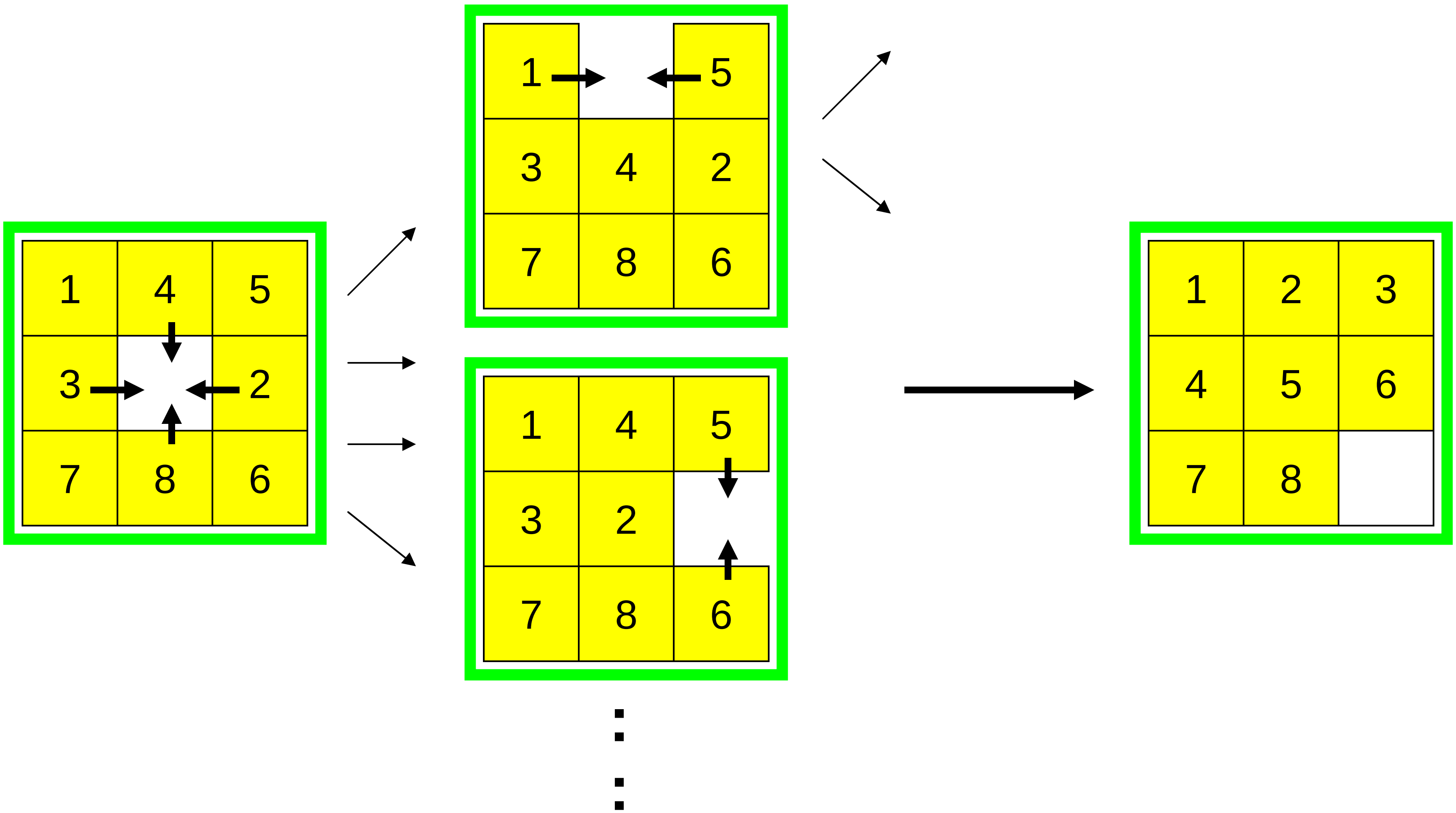
“Niagara” Approach



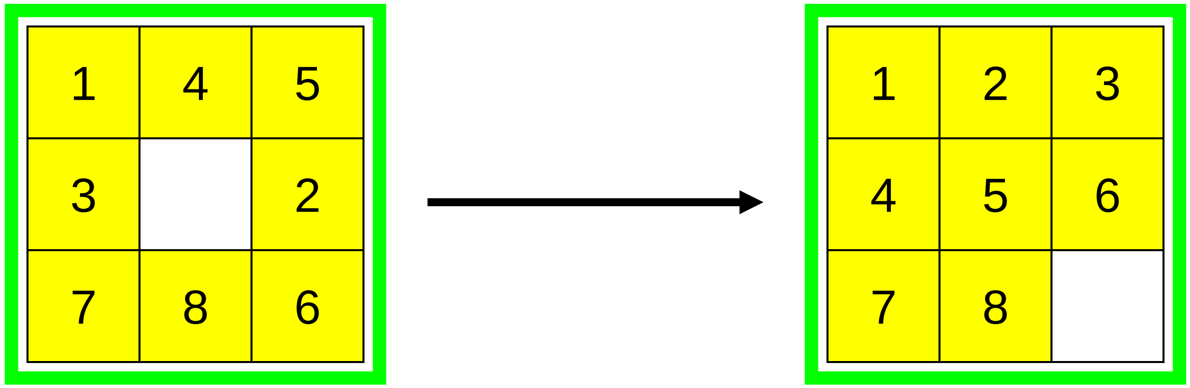
ACMP Approach

- 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



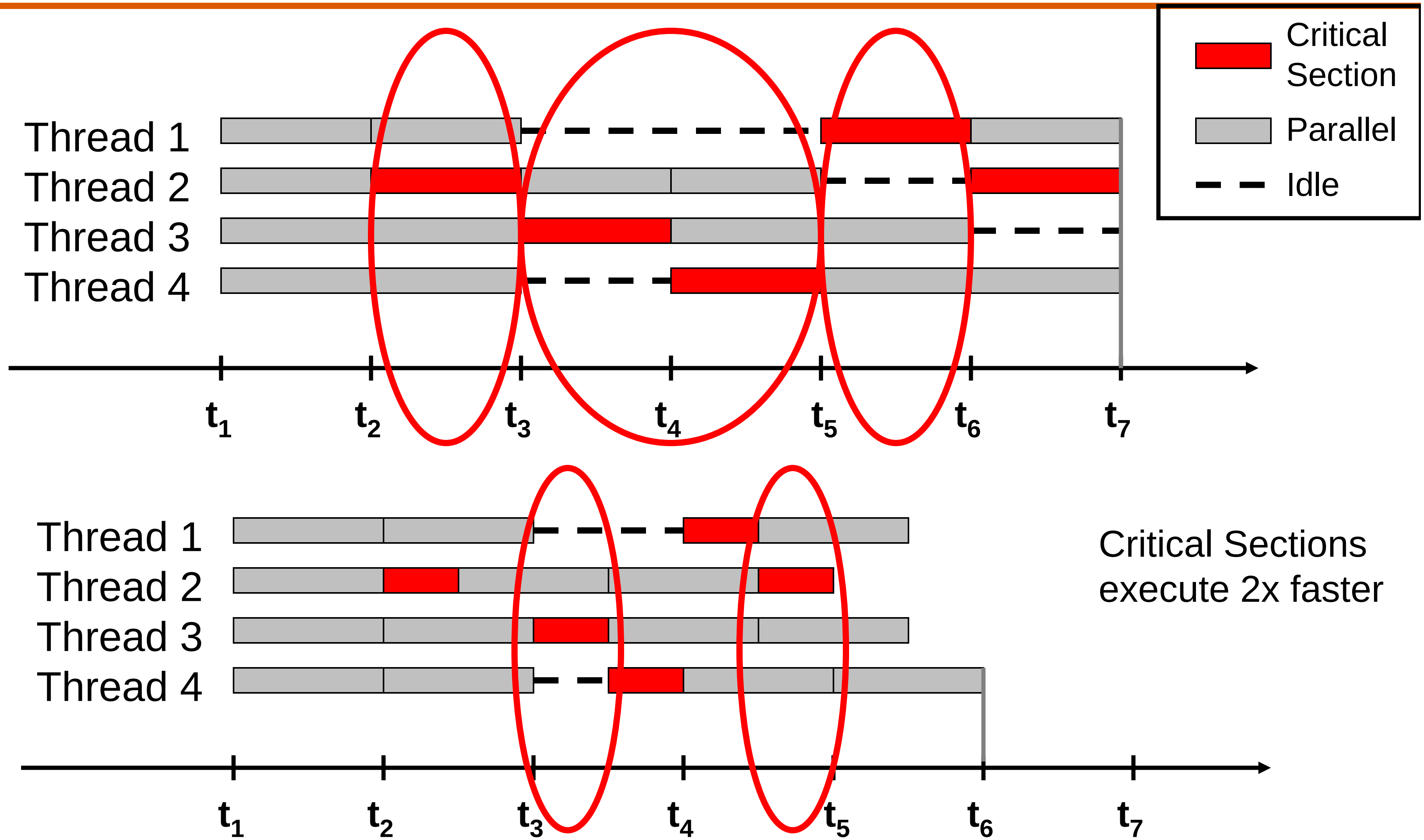
The 8-Puzzle Problem




```
while(problem not solved)

        SubProblem = PriorityQ.remove()

        Solve(SubProblem)
        if(solved)
                break
        NewSubProblems = Partition(SubProblem)

        PriorityQ.insert(NewSubProblems)
```

Critical Sections

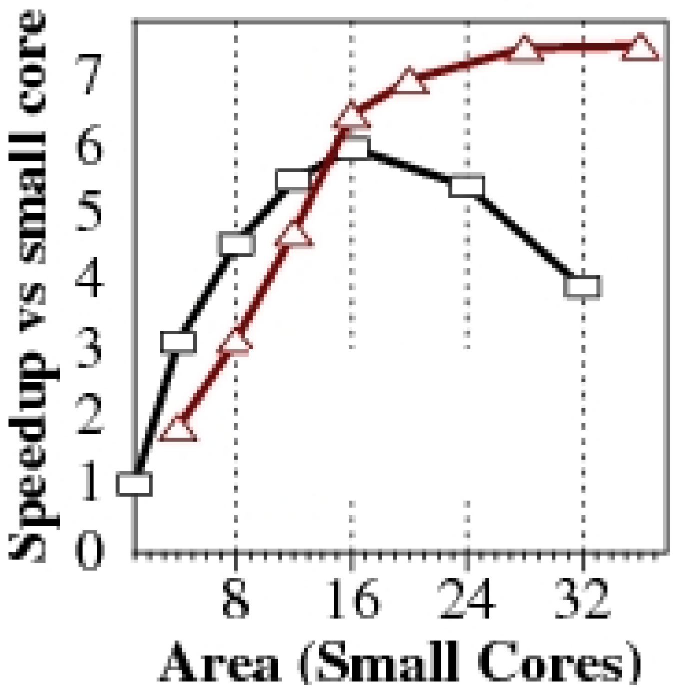
Contention for Critical Sections



Critical Sections execute 2x faster

MySQL Database

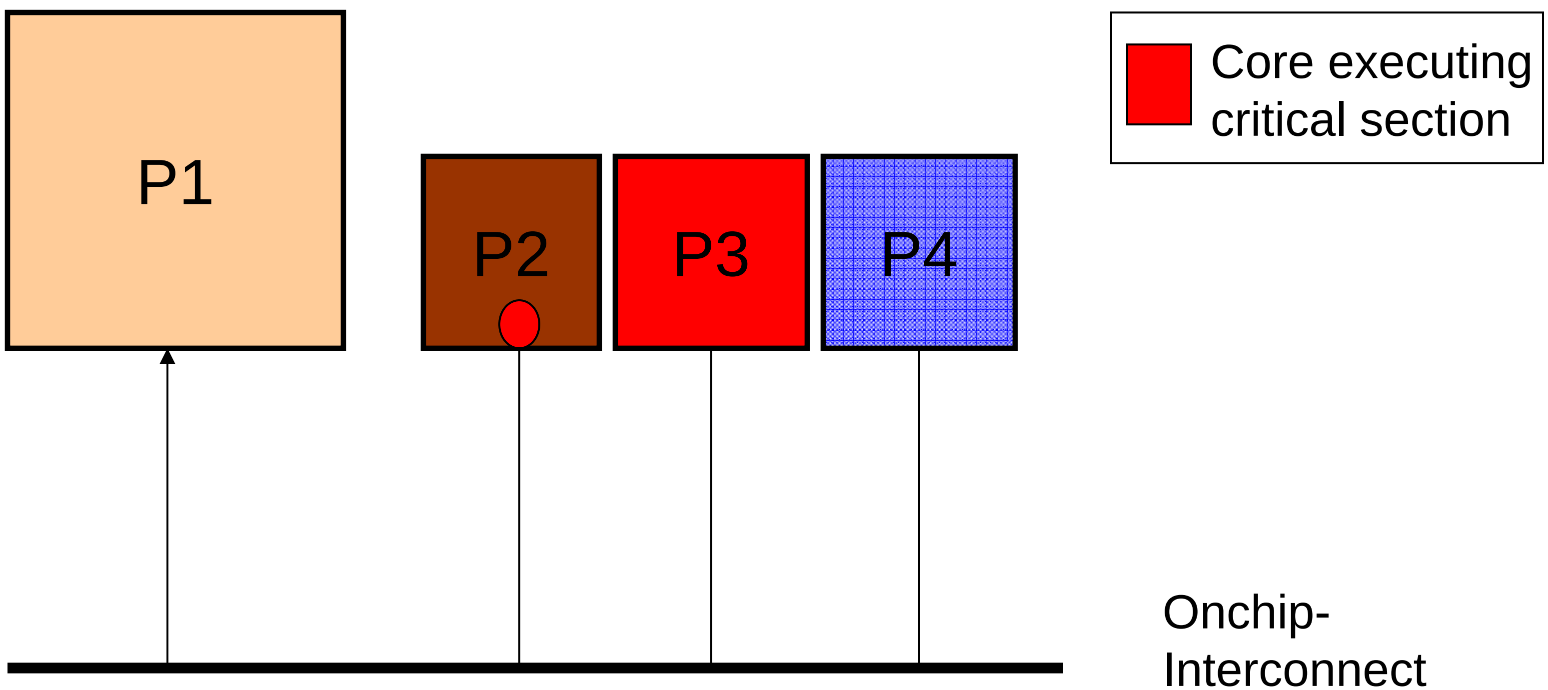
```
LOCK_open→Acquire()
foreach (table locked by thread)
        table.lock→release()
        table.file→release()
        if (table.temporary)
                table.close()
LOCK_open→Release()
```



Conventional ACMP

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

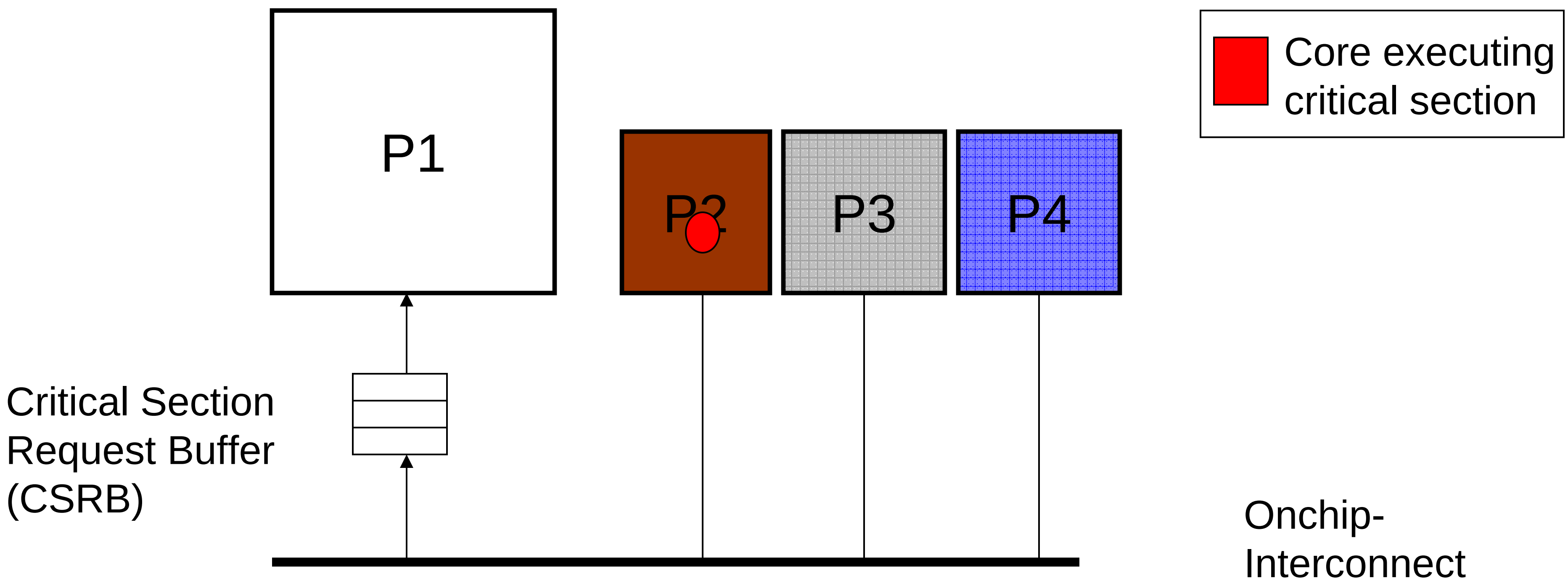
1. **P2 encounters a Critical Section**
2. **Sends a request for the lock**
3. **Acquires the lock**
4. **Executes Critical Section**
5. **Releases the lock**



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 *LOCK_ADDR*, *TARGET_PC*
  - CSRET *LOCK_ADDR*

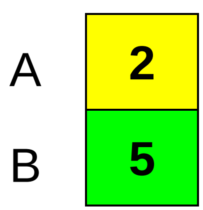
- Compiler/Library inserts CSCALL/CSRET

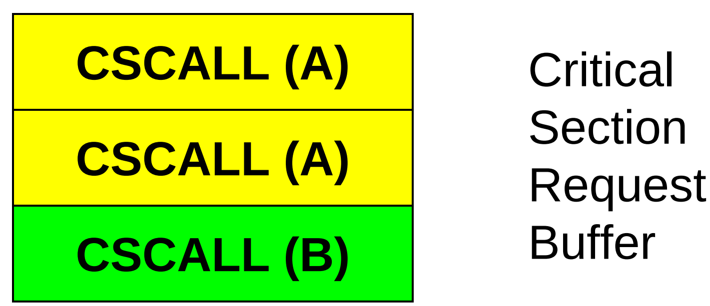
- On a CSCALL, the small core:
  - Sends a CSCALL request to the large core
    - Arguments: Lock address, Target PC, Stack Pointer, Core ID
  - Stalls and waits for CSDONE

- 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 serializes 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

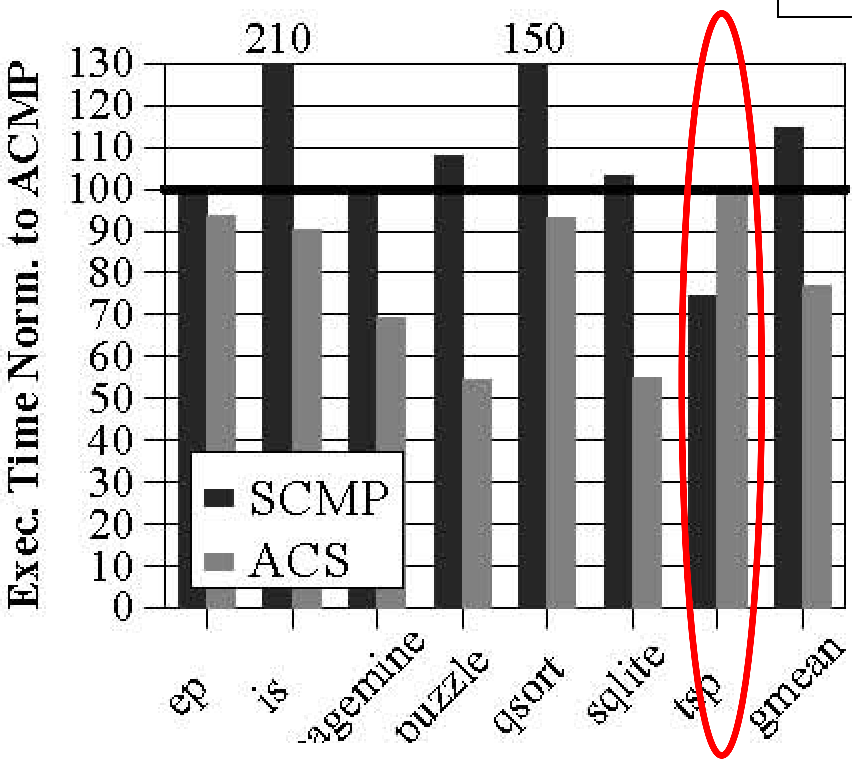
- Cache misses for private data
  - Fewer misses for shared data
    Cache misses reduce if Shared data > Private data
  - The large core can tolerate cache miss latencies better than small cores

Experimental Methodology

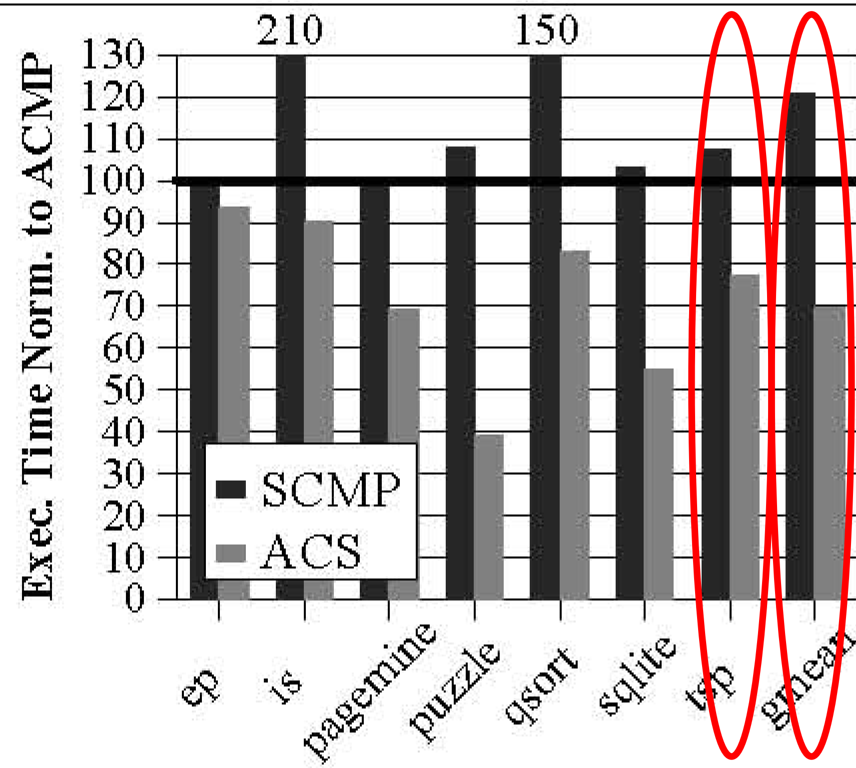
- Configurations
  - One large core is the size of 4 small cores
  - At chip area equal to N small cores
    - Symmetric CMP (SCMP): N small cores, conventional locking
    - Asymmetric CMP (ACMP): 1 large core, N – 4 small cores, conventional locking
    - ACS: 1 large core, N – 4 small cores, (N –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

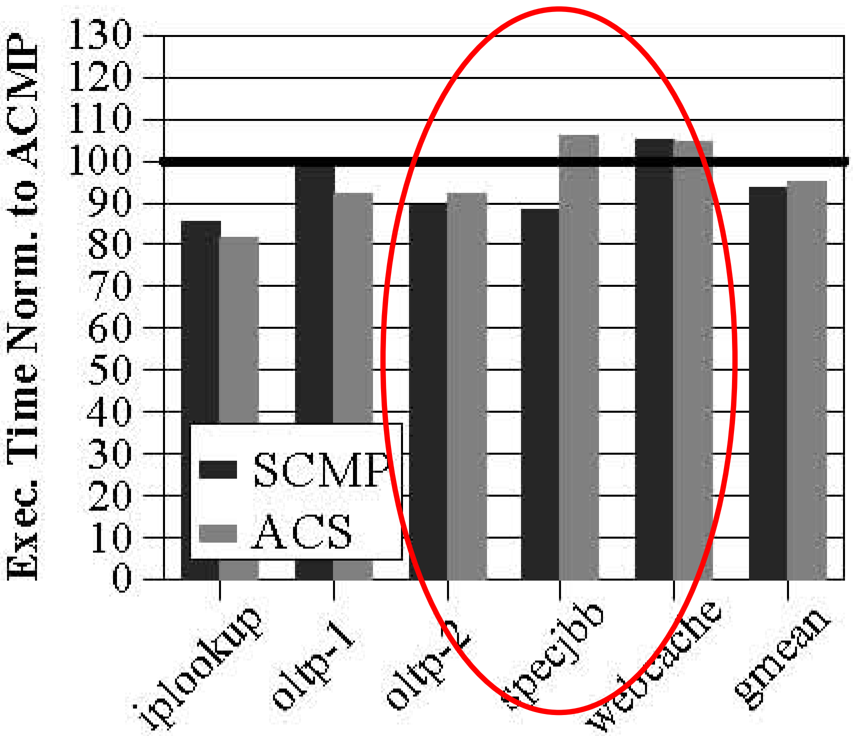


Chip Area = 16 cores
SCMP = 16 small cores
ACMP/ACS = 1 large and 12 small cores

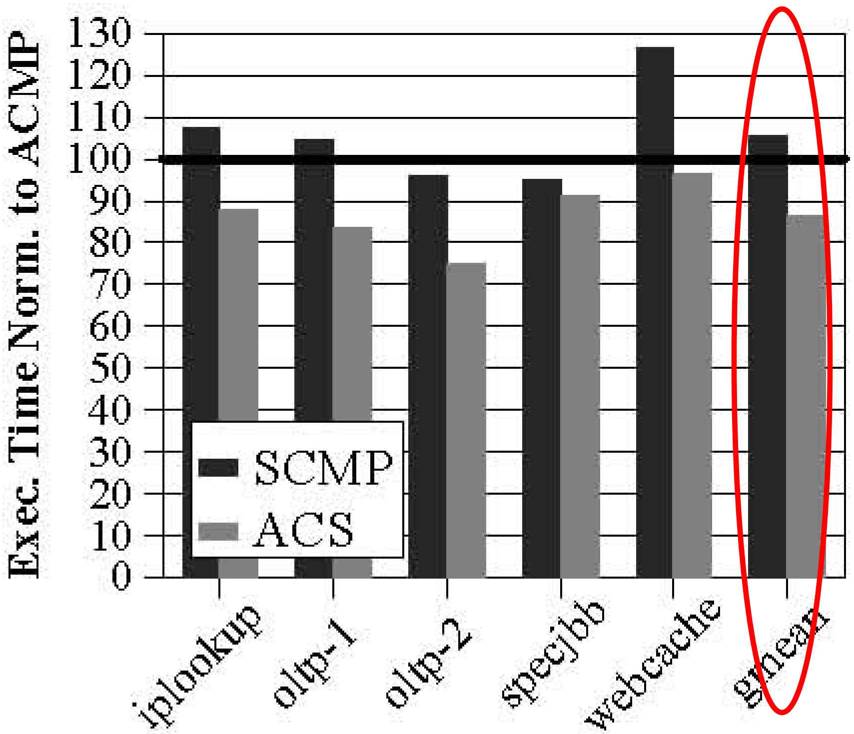


Chip Area = 32 small cores
SCMP = 32 small cores
ACMP/ACS = 1 large and 28 small cores

Workloads with Fine-Grain Locks



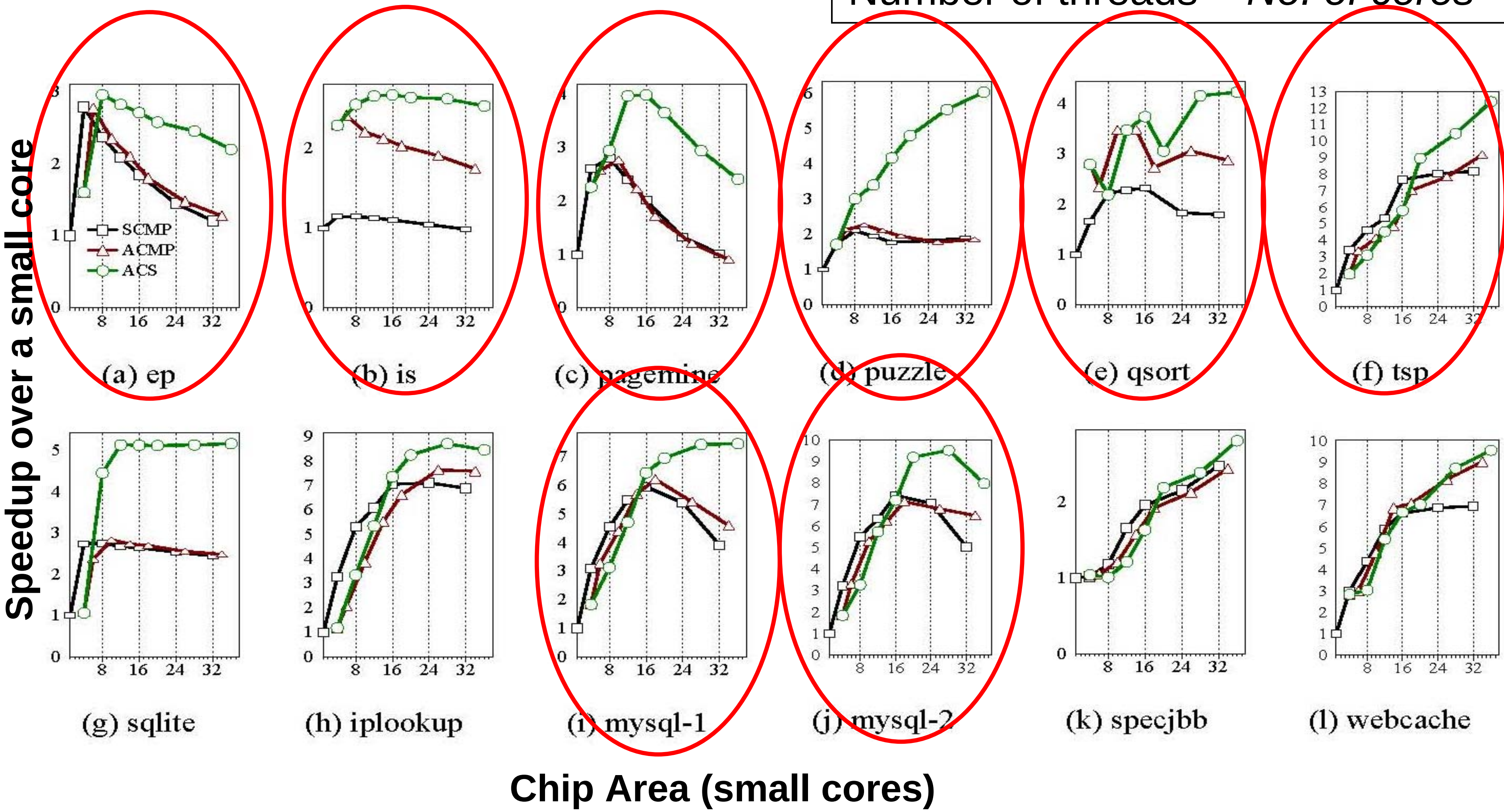
Area = 16 small cores



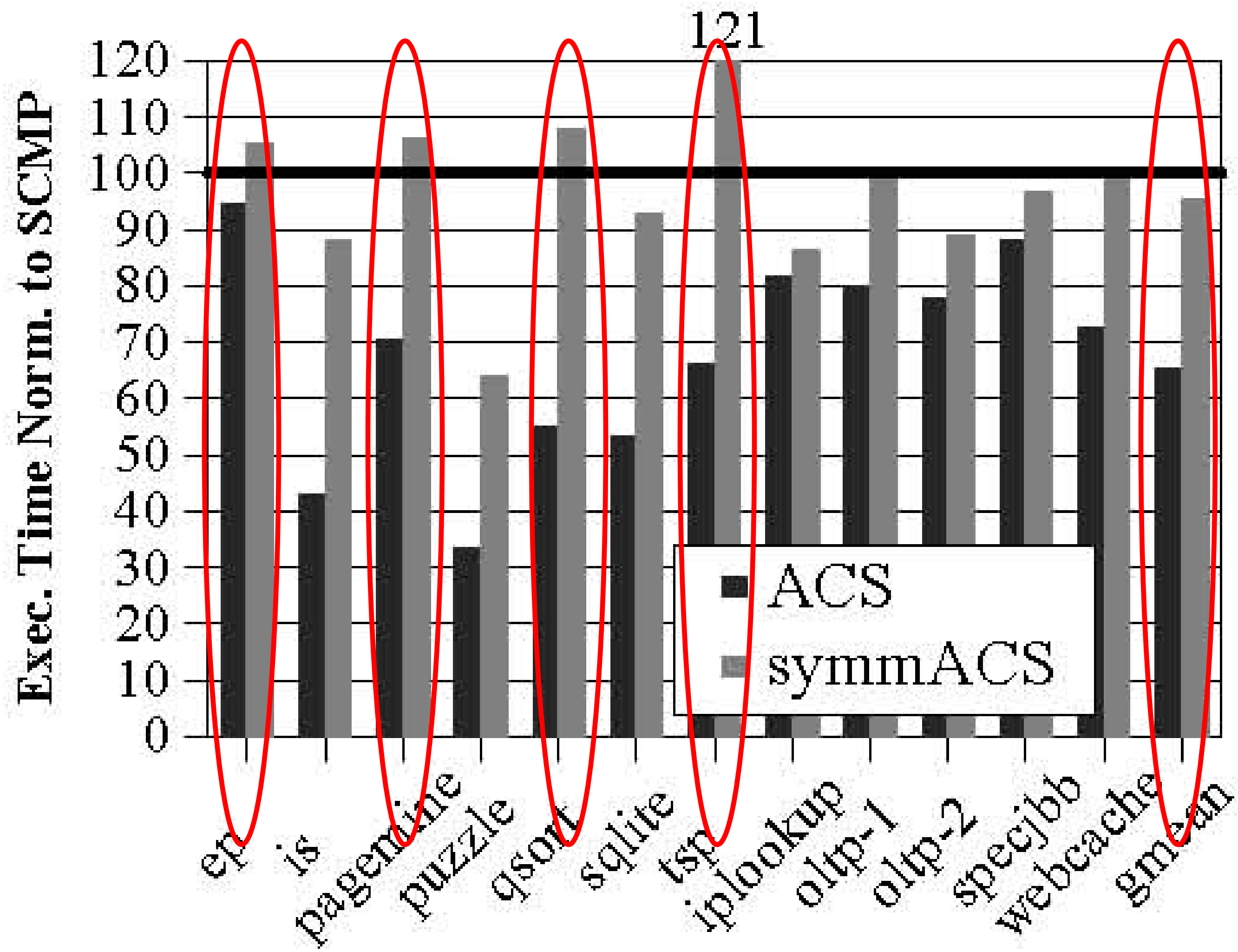
Area = 32 small cores

Equal-Area Comparisons

Number of threads = *No. of cores*



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