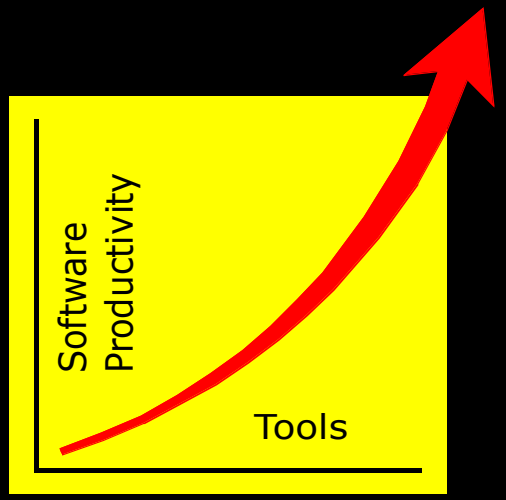
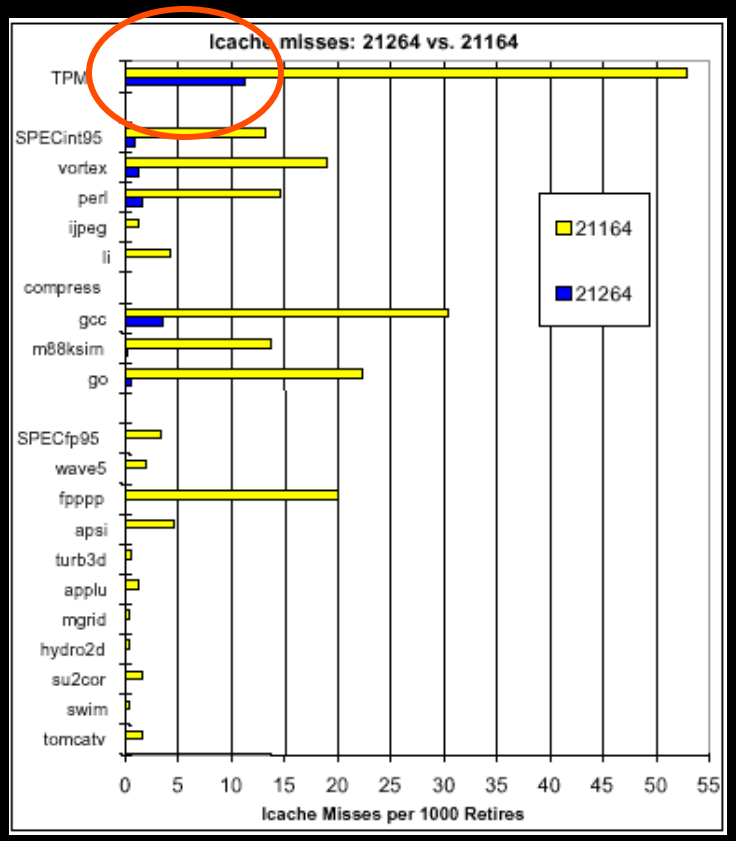
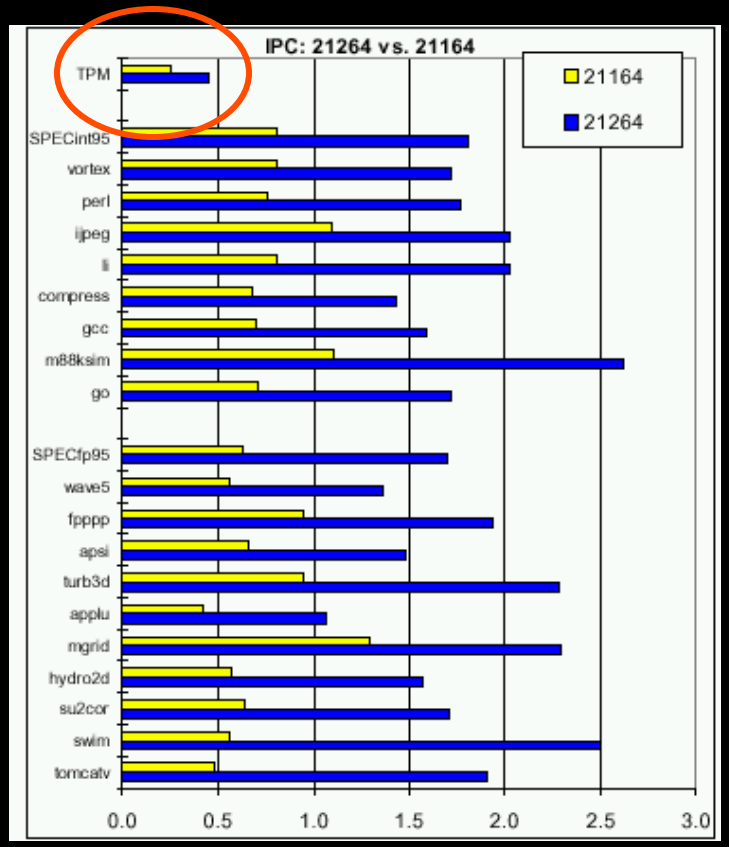
Using Cohort Scheduling to Enhance Server Performance



James Larus
Michael Parkes
Microsoft Research
June 2001

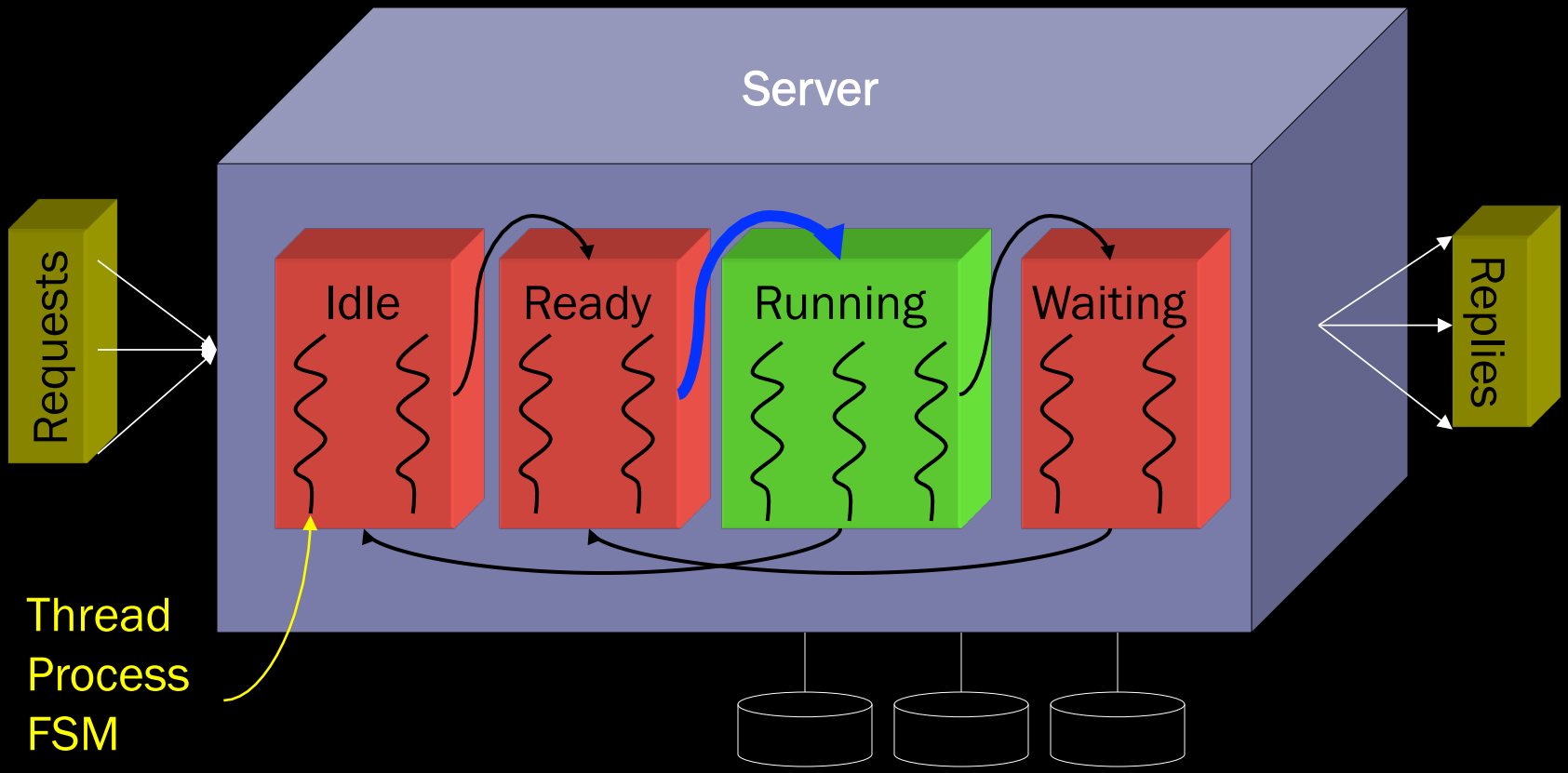
ILP of Databases



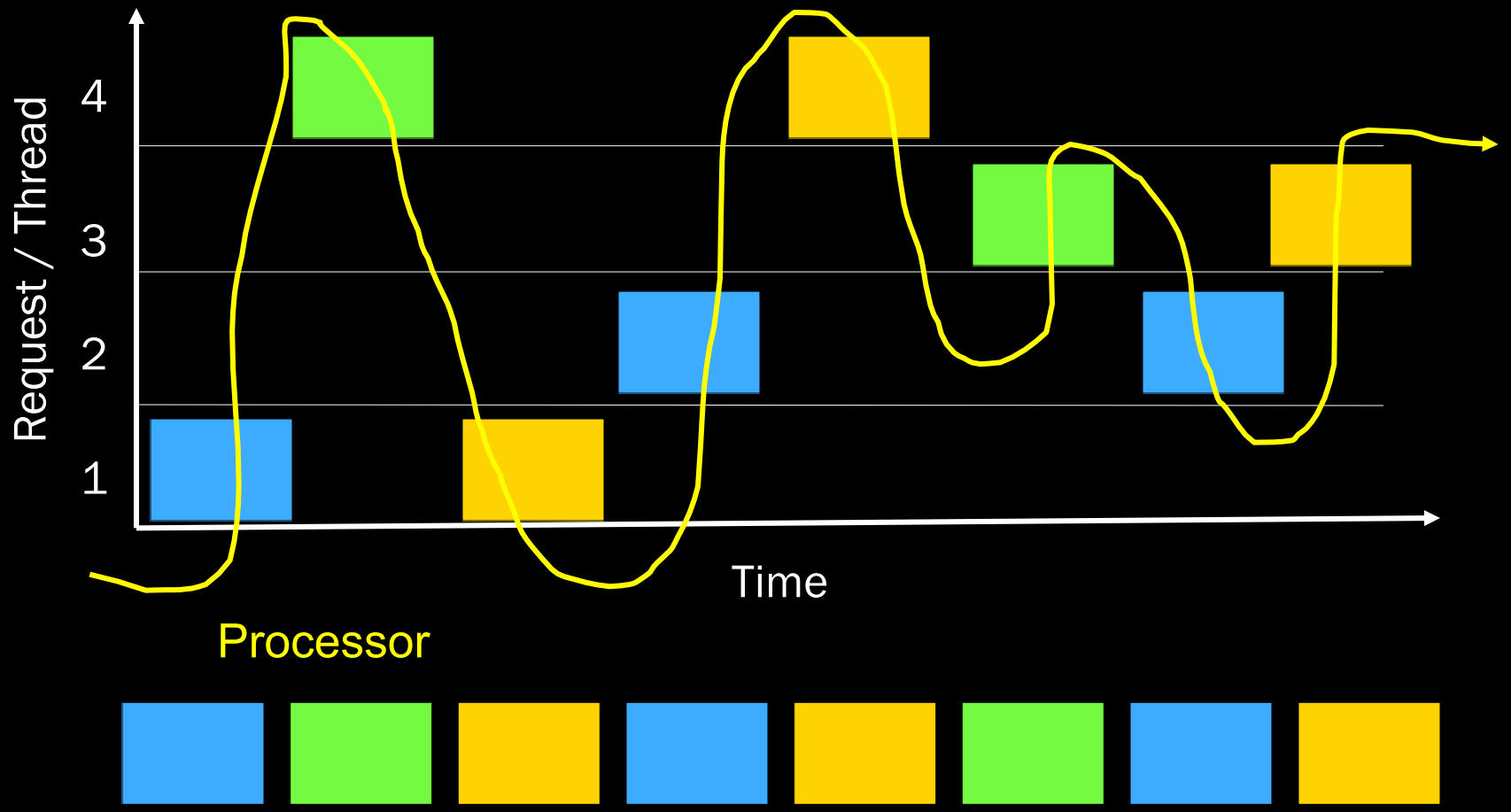


[Cvetanovic & Kessler, ISCA 2000]

Server Software Architecture



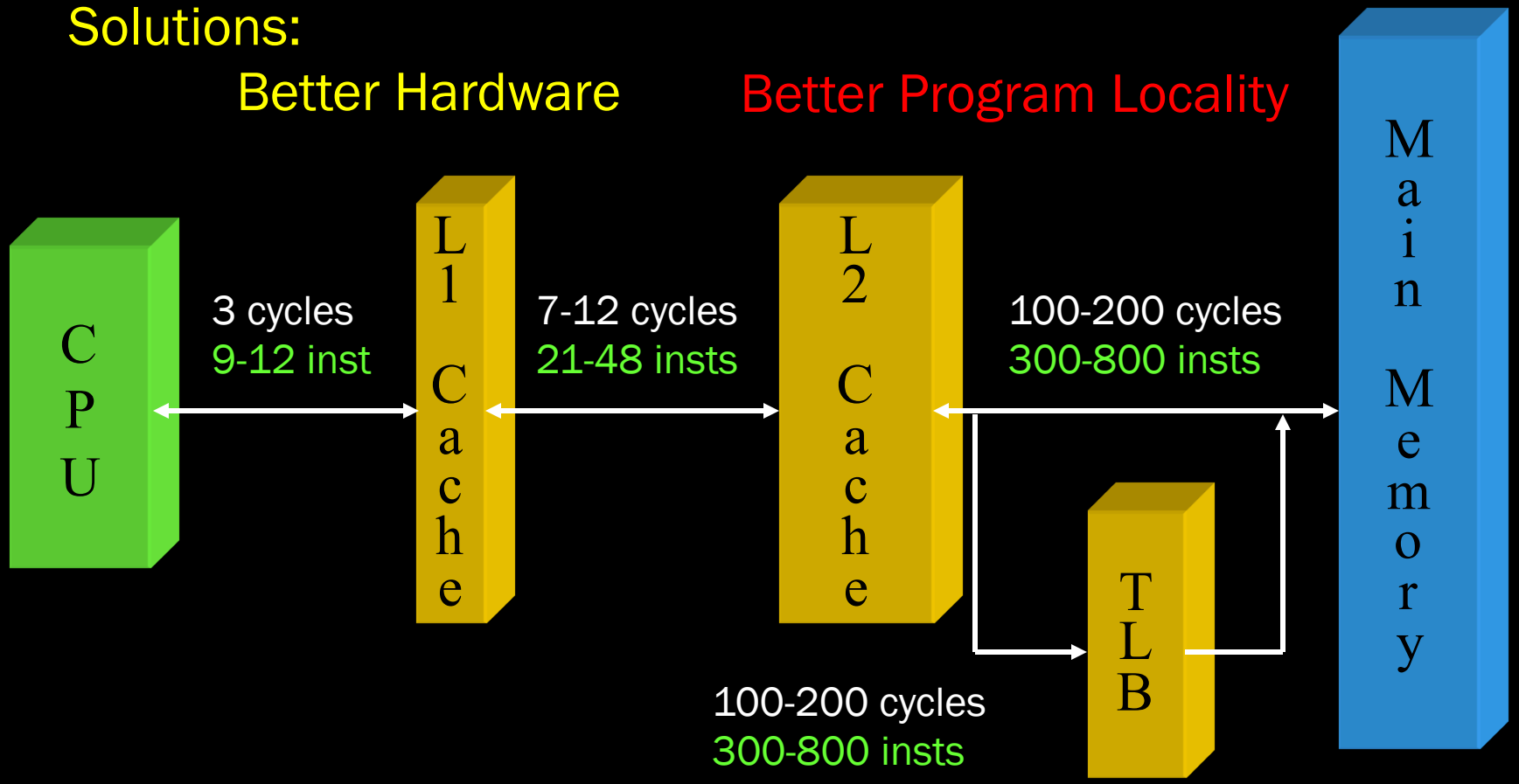
Processor Scheduling



Threads and Locality

- Short intervals have poor locality [Barroso ISCA98]
  - 25K inst (TPC-B) ⟶ 7 CPI
  - 1.7M inst (TPC-D) ⟶ 1.6 CPI
- Costly context switches [Borg, ASPLOS91]
  - 400K inst shadow (process)
- Inter-processor cache conflicts and traffic
  - 5-20% loads hit dirty data in another L2 cache [Keeton, ISCA98]

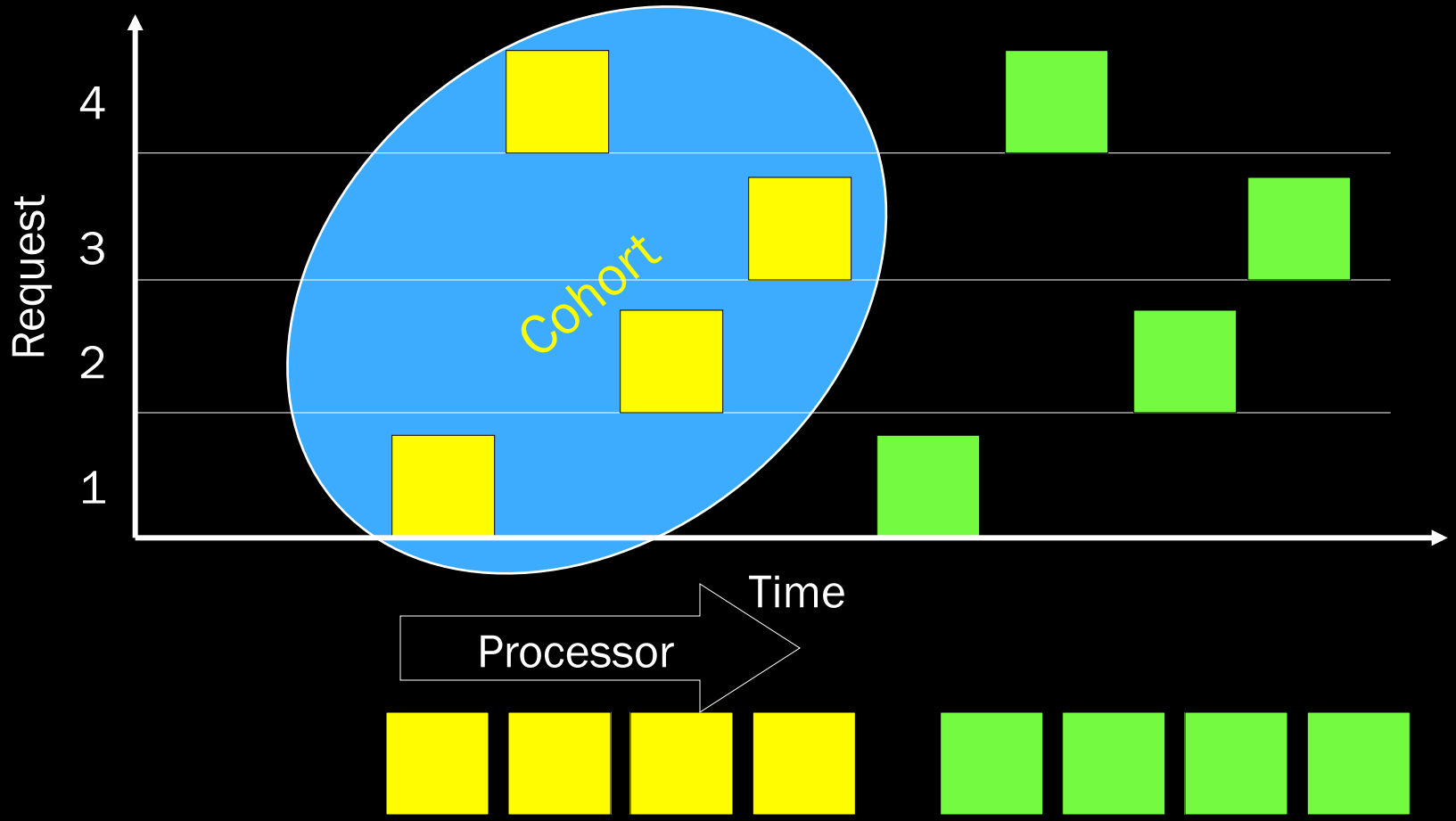
Processor-Memory Hierarchy



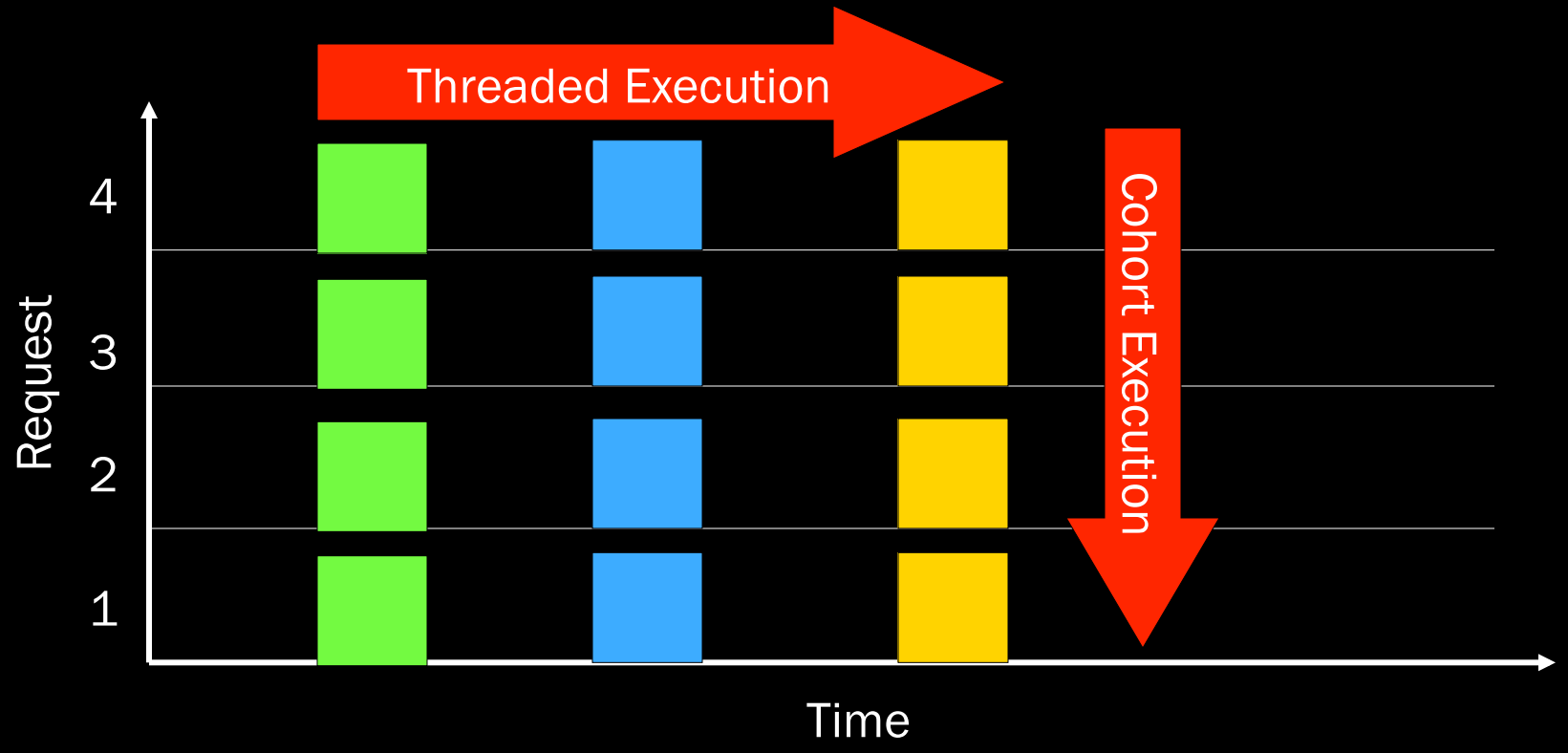
Talk Outline

- Cohort scheduling
- Staged computation
- StagedServer library
- Experiments

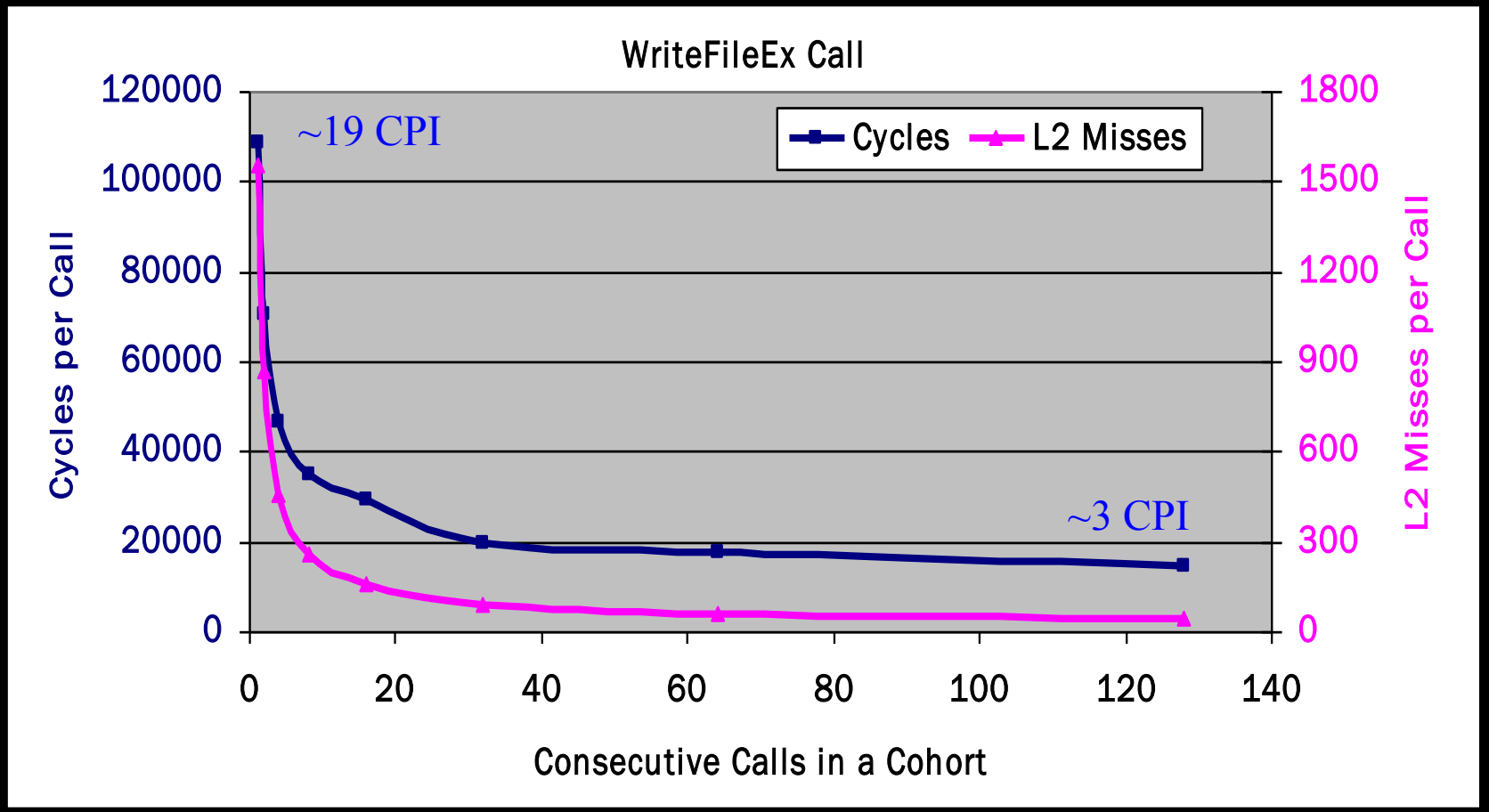
Cohort Scheduling



Another View of Cohorts



Cohort Scheduling Experiment



Aside: Cohort Schedule Thread?

- Cohort resumes execution at same PC
  - Schedule change
  - No programmer-visible changes
- Wrong boundaries
  - Cohort formed after system call
- Missed opportunities
  - Data structures accessed from many locations

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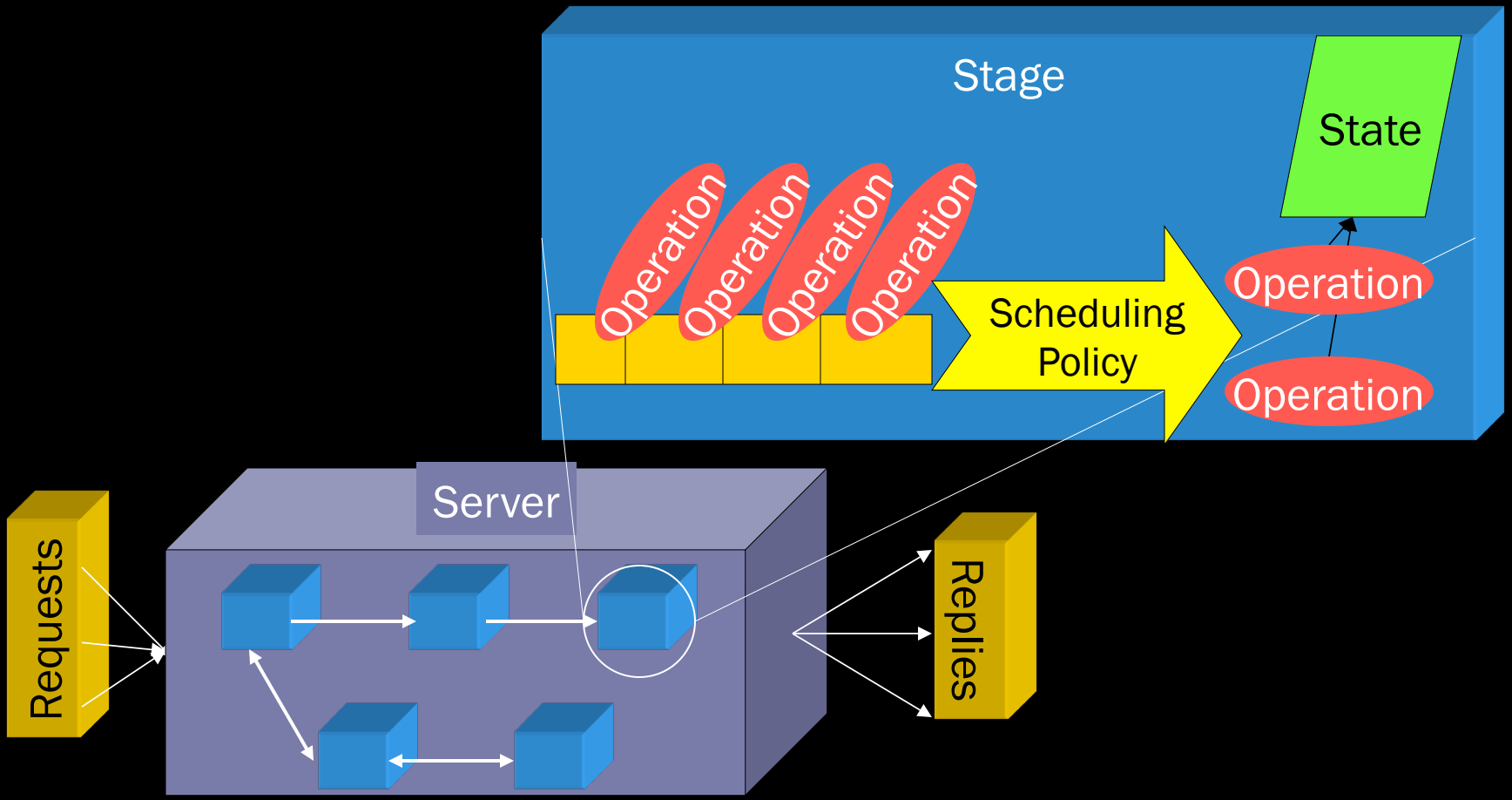
Motivation

- Programming model to support cohort scheduling
- Address shortcomings of threads
- Expensive, error-prone synchronization

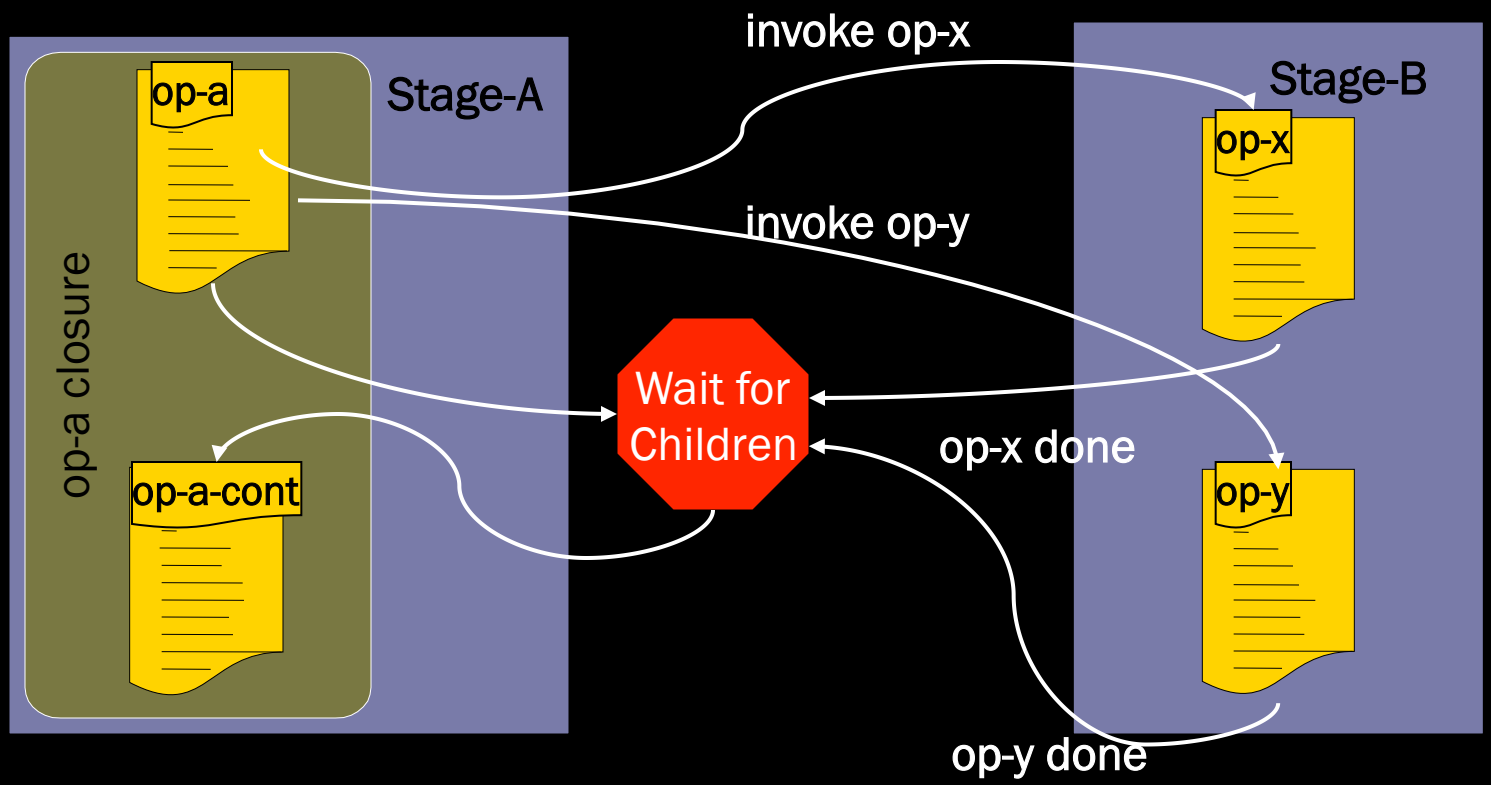
Staged Computation



Staged Programming Model

- Alternative to thread, processes, FSM
- Facilitate cohort scheduling
  - Natural abstraction for cohorts
  - Scheduling flexibility
- Reduce synchronization
- StagedServer library

Staged Computation Example



Stages

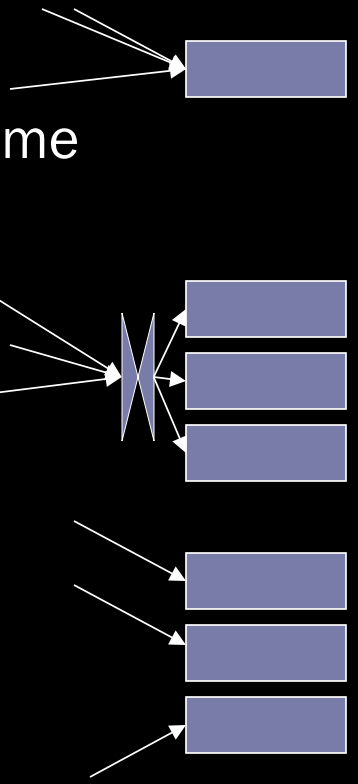
- Operations
  - Asynchronous, non-preemptible computations
- State
  - Private to stage
- Scheduling policy
  - When and how operations execute
  - Control concurrency within stage

Stages, cont'd

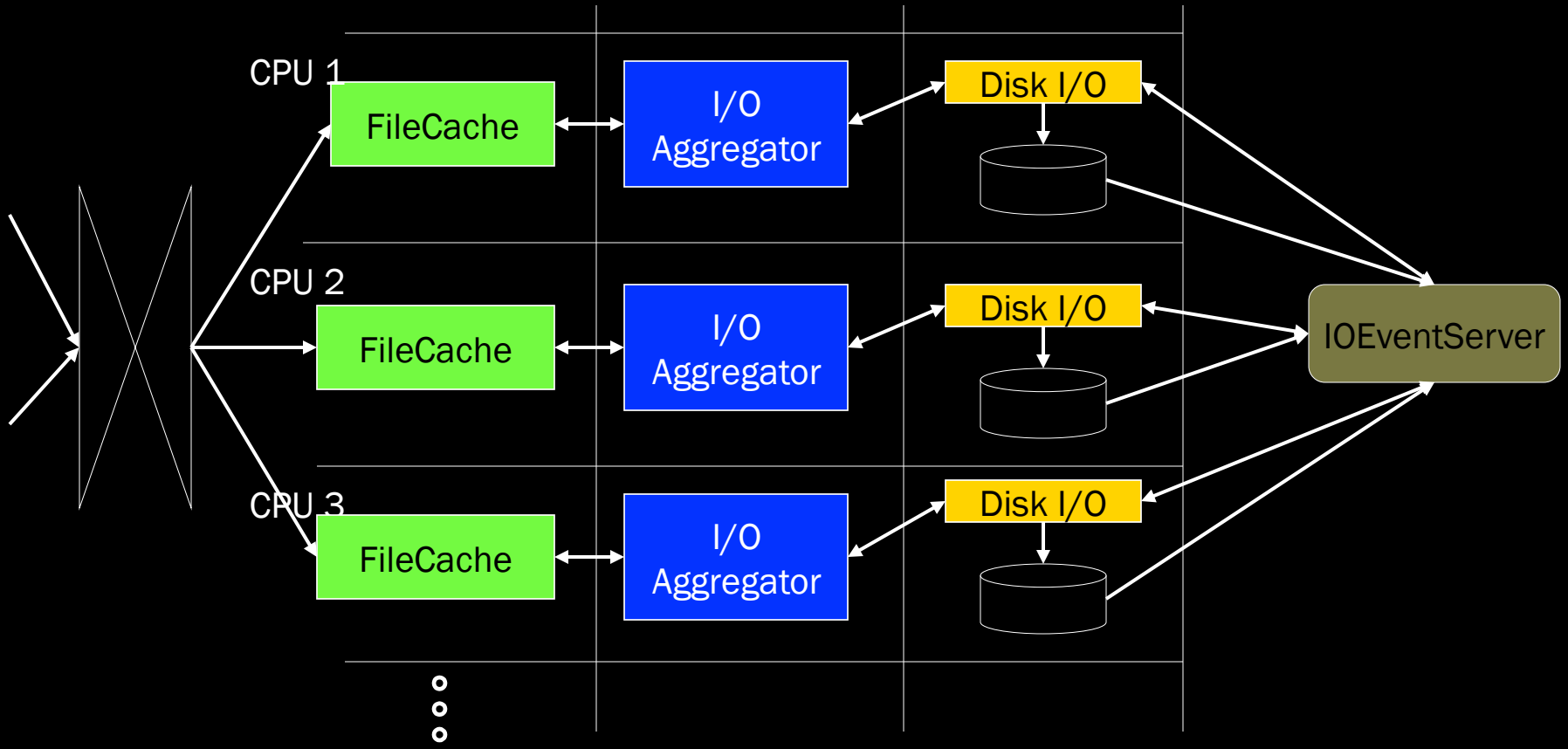
- Similar to object, but
  - Operations are asynchronous
  - Scheduling autonomy
- Natural cohort
  - Group logically related computation
  - Access share code and data

Scheduling

- Scheduling can supplant synchronization
- Exclusive stage
  - Execute one operation on one processor at a time
  - Access local data without synchronization
- Partitioned stage
  - Send operations to processor based on key
  - Processor can access local data w/o sync
- Shared stage
  - Operations run on all processors



Staged File Cache



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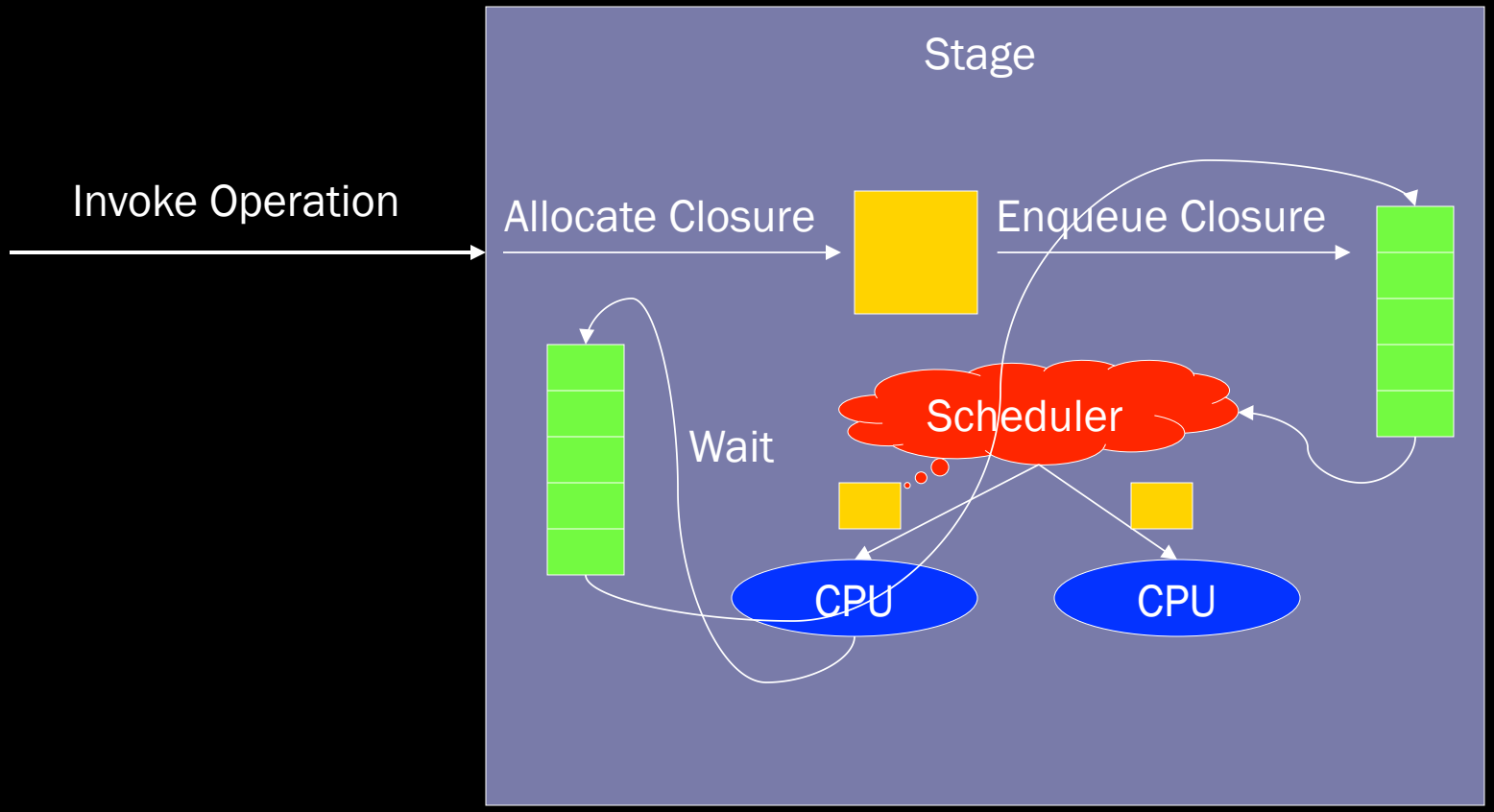
StagedServer

- C++ library
  - Uniprocessor or SMP
  - Mechanism for staged computation
  - Aggressive cohort scheduling
- Two parameterized classes
  - Stage
  - Closure

Stages and Closures



Stage Constructor

```
STAGE(const char *Name,
        STAGE_TYPE Type,
        bool BalanceLoad = false,
        int CacheSize = 0,
        int BatchThreshold = 0,
        int BatchTimer = DefaultTimer,
        bool MaintainOrder = false,
        int MaxBatchSize = StageBatchSize)
```

Operation #1

```
ACTIONS WEB_CLOSURE::EstablishConnection()
  {
   NetworkStage->CreateIncomingConnection(&NWCreateResult);

   return WaitForChildren(ReadRequest);
   }
```

Operation #2

```
ACTIONS WEB_CLOSURE::ReadRequest()
    {
    if (0 == NWCreateResult->LastError)
        {
         ConnectionNumber = NWCreateResult->ConnectionNumber;
         NetworkStage->ReadFromConnection(&NWReadWriteResult,
                                                    ConnectionNumber,
                                          StrBuffer,
                                                    sizeof(StrBuffer));
        return WaitForChildren(ParseRequest);
        }
    else
        return EstablishConnection();
    }
```

Closure

```
NETWORK_STAGE::CreateIncomingConnection(RESULT<CR> *Result)
    {
    static int roundRobin = 0;
    NETWORK_CLOSURE* x =
            new(NETWORK_CLOSURE::CreateIncomingConnection,
                this,
                Result,
                roundRobin ++)
            NETWORK_CLOSURE( );

    x->Start( );
    }
```

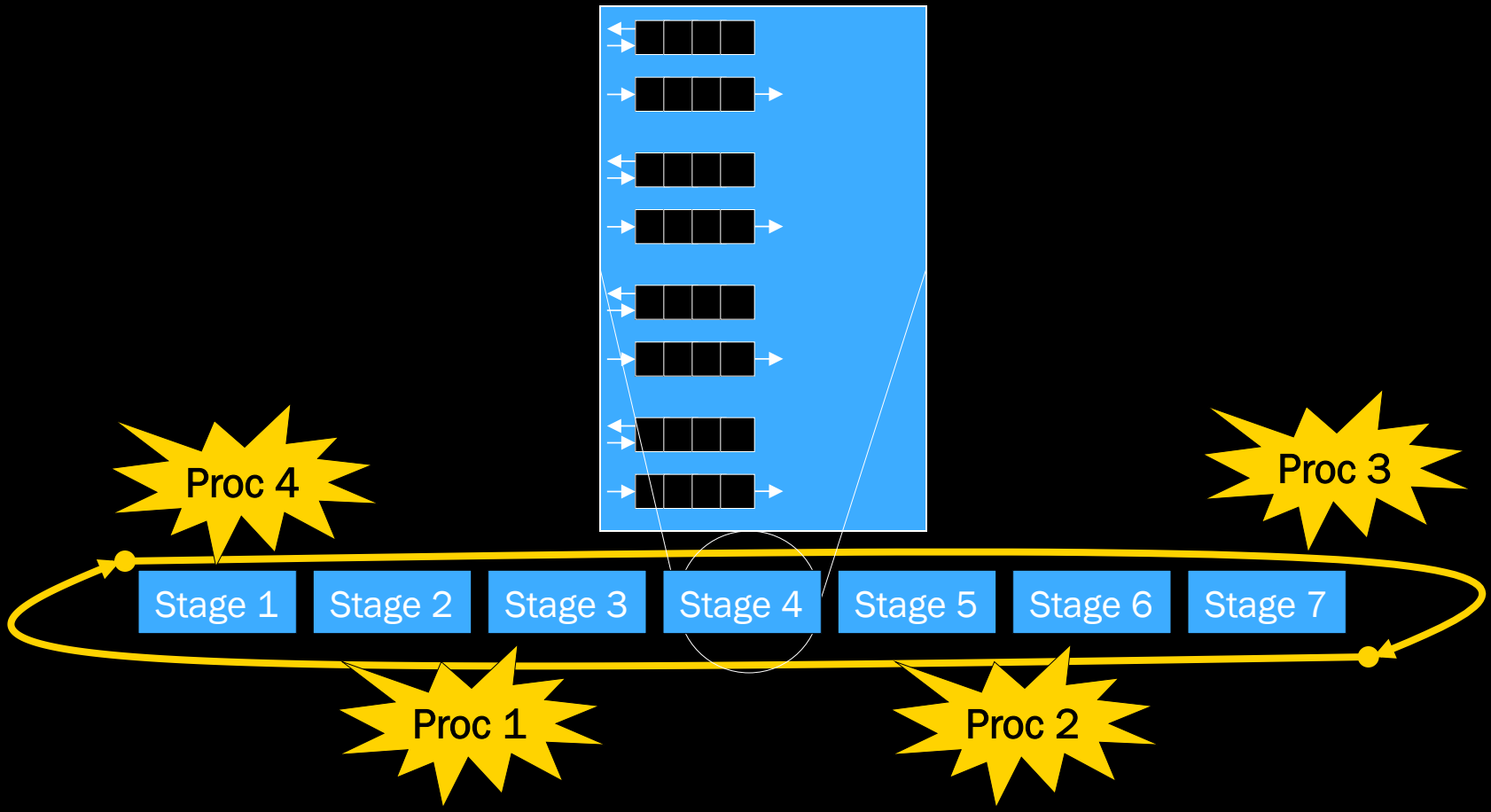
Aggressive Cohort Scheduling

- Processor affinity
  - Operation and children stay on processor
    - Ex: explicit placement, partitioning, load balancing
- Cohort scheduling
  - Per-processor, per-stage queue
  - Processor execute all operations in its queue
    - Ex: fixed cohort size

Processor Queues

- Pair of ‘queues’
  - Stack for local operations
    - No synchronization
  - Queue for remote operations
  - Process stack LIFO then queue

Wavefront Processor Scheduling



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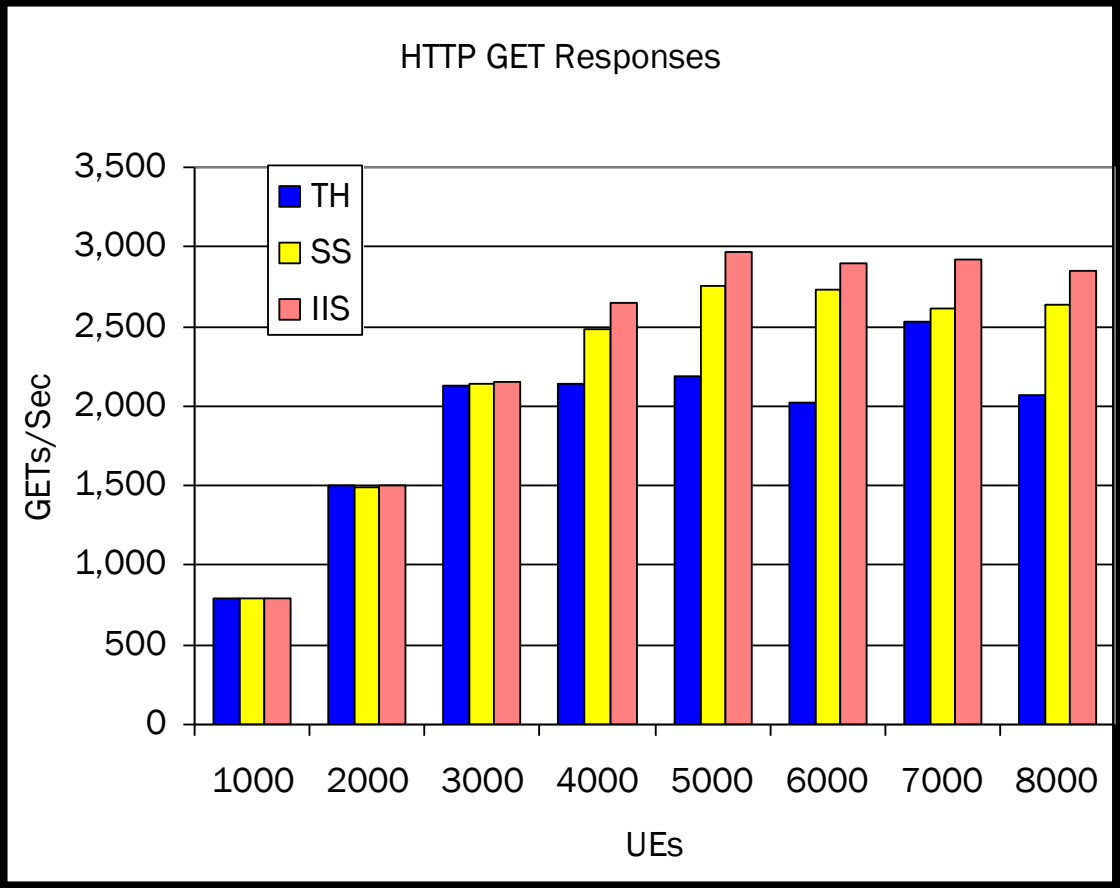
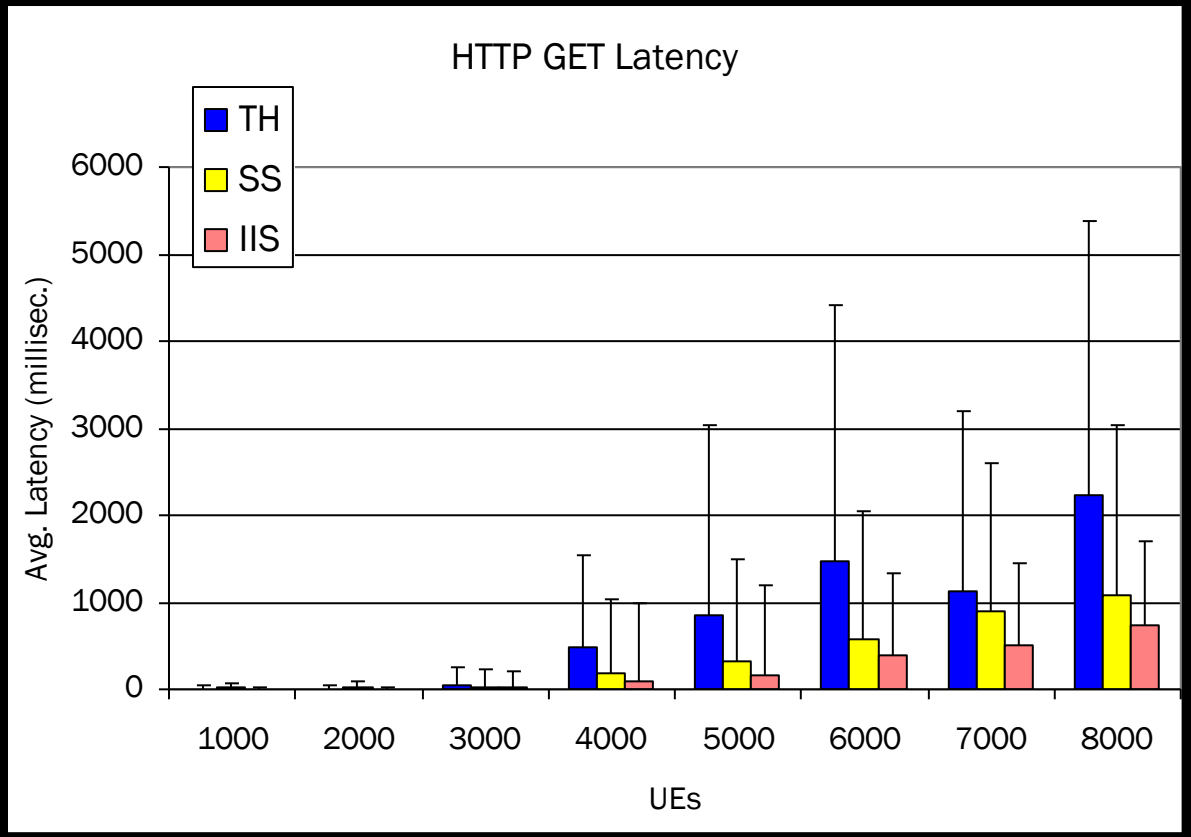
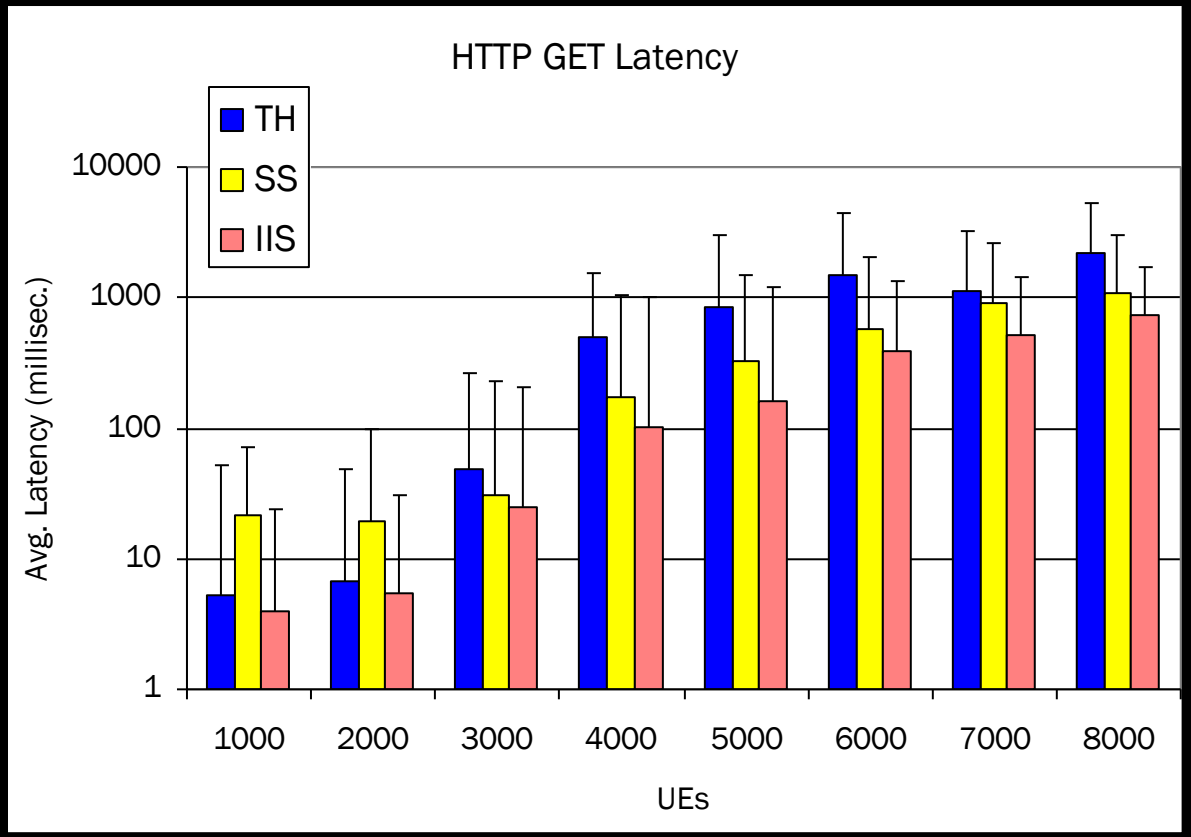
Web Server Bandwidth



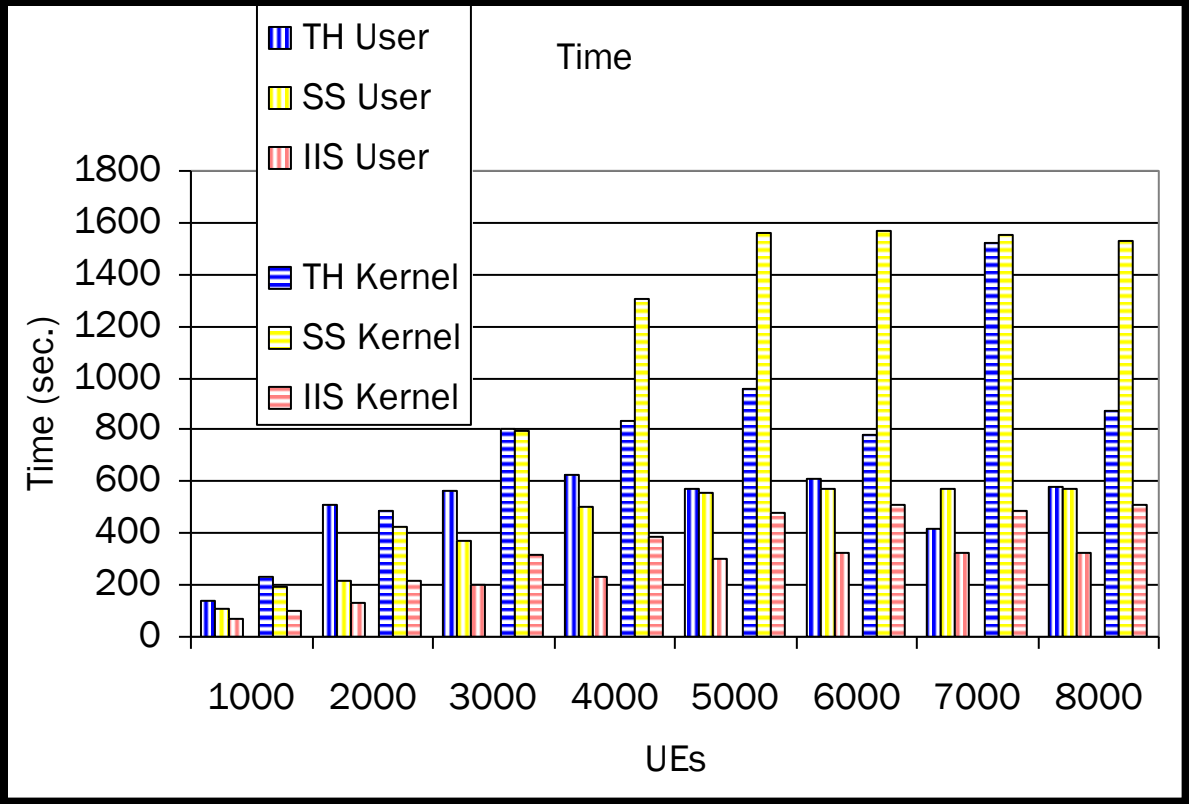
Web Server Latency



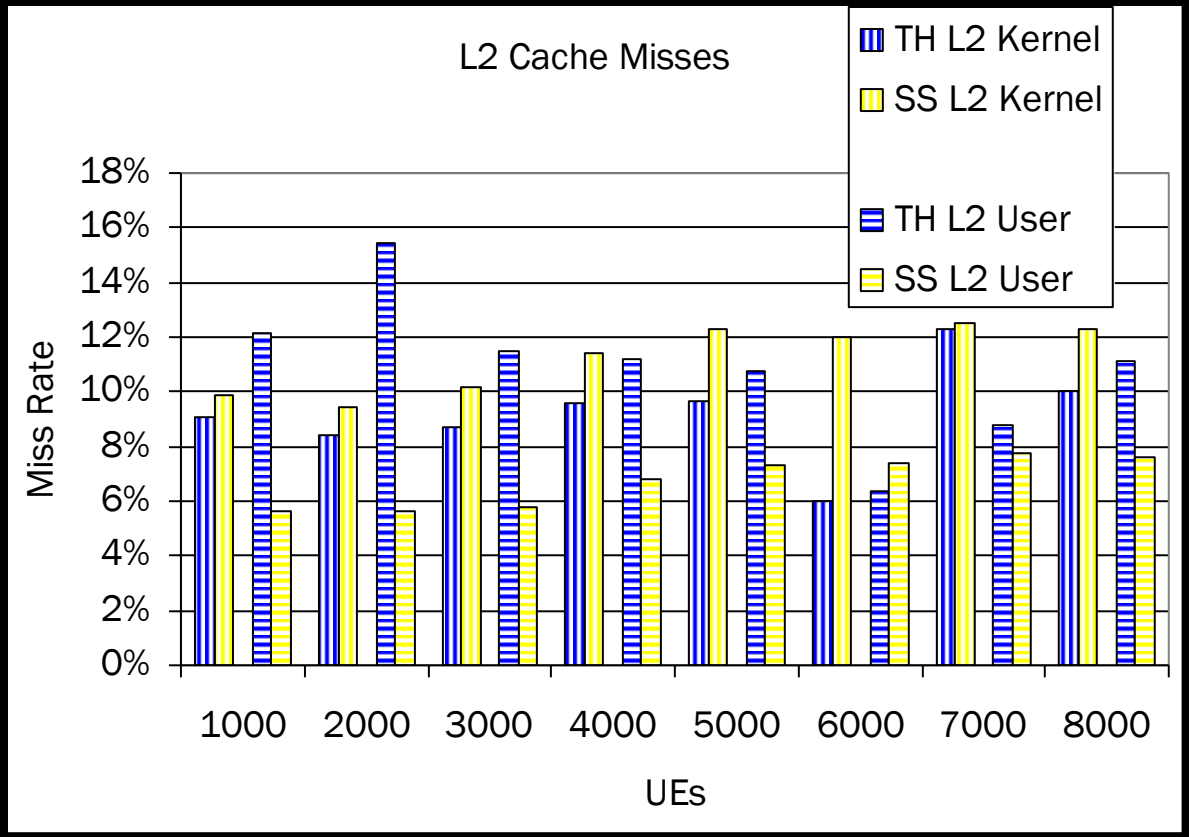
Web Server Latency (Log Scale)



Server CPU Usage



L2 Cache Misses



Future Work

- Error/fault handling
- System coordination language
  - Concise view of FSMs & communication
  - Verification of properties
    - Deadlock freedom, progress, don't lose work,...
- Extend to clusters
  - Same semantics shared/non-shared memory
  - Reconfigure without rewriting

Summary

- Good performance requires good software–not just hardware–architecture
- Threads are a weak foundation for locality

Cohort Scheduling

- Enhance locality by grouping similar operations
- Staged computation supports operation
  - Identifies cohorts
  - Supports cohort scheduling
  - Reduces synchronization

Final Thoughts

- Research must rethink fundamentals, not just refine widely used ideas
  - Internet/Middleware is enormous upheaval in SW
  - Opportunity for new ideas in programming
- Twin challenges
  - Correctness
  - Performance