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Leveraging Transactional Memory to Extract Parallelism

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Motivation

Parallel Loop

```
#pragma omp parallel for
  for (i=1; i<N; i++)
    b[i]=(a[i]+a[i-1])/2.0;

#pragma omp transfor
  for (i=0; i<N; i++)
    bin[A[i]] = bin[A[i]]+1;
```

```
#pragma omp transfor ordered
  for (i=1; i<N; i++)
    bin[A[i]] = bin[A[i]]+bin[A[i-1]];
```

Parallel Section

```
#pragma omp parallel sections
{
  #pragma omp section
    xaxis();
  #pragma omp section
    yaxis();
  #pragma omp section
    zaxis();
}
```

```
#pragma omp transsections ordered
{
  #pragma omp transsection
    xaxis();
  #pragma omp transsection
    yaxis();
  #pragma omp transsection
    zaxis();
}
```

Source: OpenMP API Ver. 3.1; OpenTM (PACT'07)

Contributions

- Leveraging TM to extract parallelism from non-analyzable codes
  - Transactions are statically numbered according to sequential ordering
  - A fully distributed commit manager decouples transaction completion from commit, and schedules commits preserving data dependences
  - A thread is allowed to execute several transactions in sequence before committing the first one
  - By scheduling commits, many aborts due to data conflicts are avoided
  - A restricted data forwarding technique, called FAC (Forwarding After Completion), reduces stall times when preserving certain flow dependences
- Initial evaluation
  - A first implementation of the above techniques is based on TinySTM
  - Some preliminary results on a simple benchmark (sparse matrix transpose)

Outline

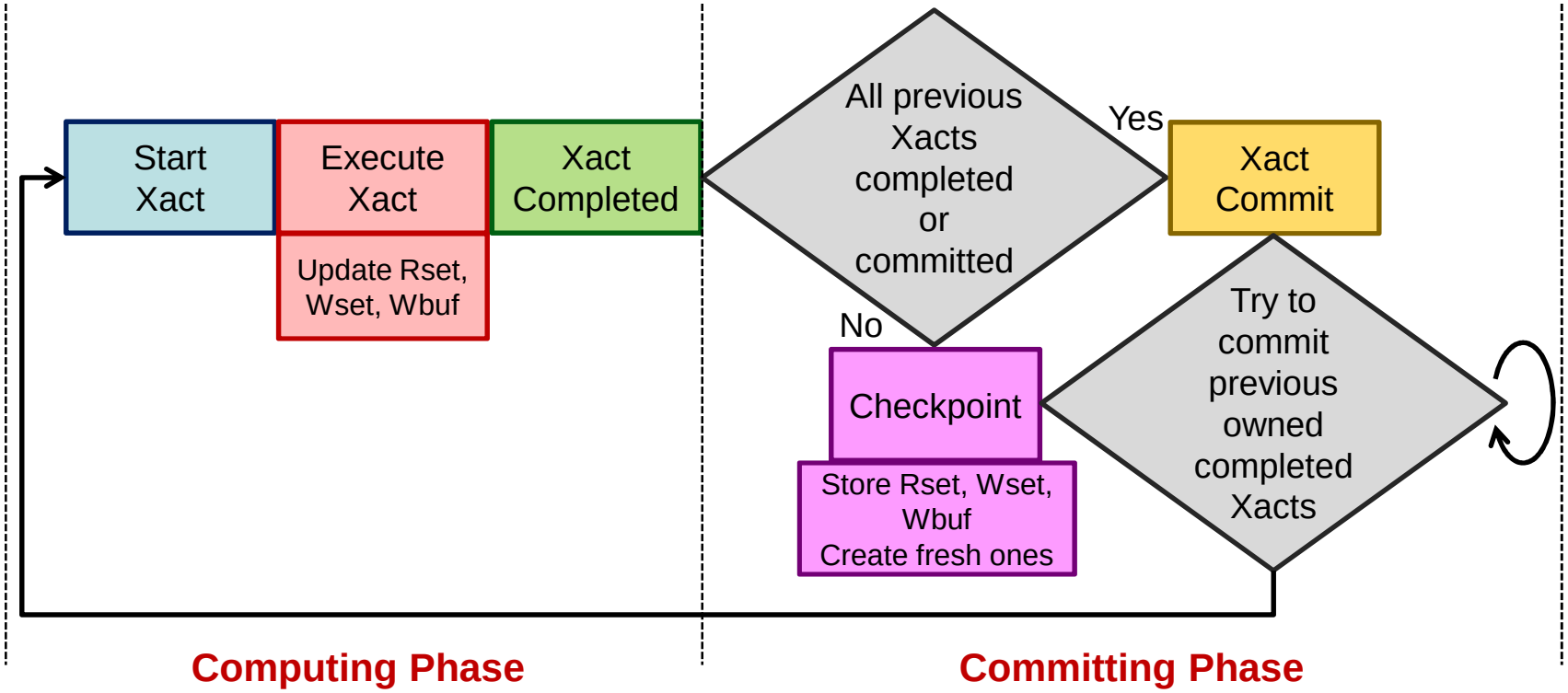
- Motivation and Contributions
- Our approach for extracting parallelism
- Evaluation

Basics of our Approach: Parallel Loops

- Programming side
  - A team of *N* threads is formed to execute in parallel transactions
  - Each **transaction** is block of iterations of size *S* that are statically assigned to the threads in a round-robin fashion in the order of the thread number (equivalent to the OpenMP clause **schedule(static,*S*)**)
  - Each transaction is assigned an **order number** (*TON*) according to the loop iteration ordering
- TM side
  - Conflict detection is eager
    - » Transaction ordering is used to filter out many conflicts avoiding aborts
    - » Completed transactions may forward written data to subsequent transactions
  - Conflict management is fully distributed:
    - » Transaction completion (execution finished) is decoupled from transaction commit
    - » When a transaction completes, the thread tries to commit all completed but still uncommitted transactions assigned to the same thread
    - » A transaction commits when all previous transactions are completed or committed (this condition allows out of order commits when safe)
  - Version management is lazy
    (although it could be eager in TM systems with strong isolation, like LogTM)

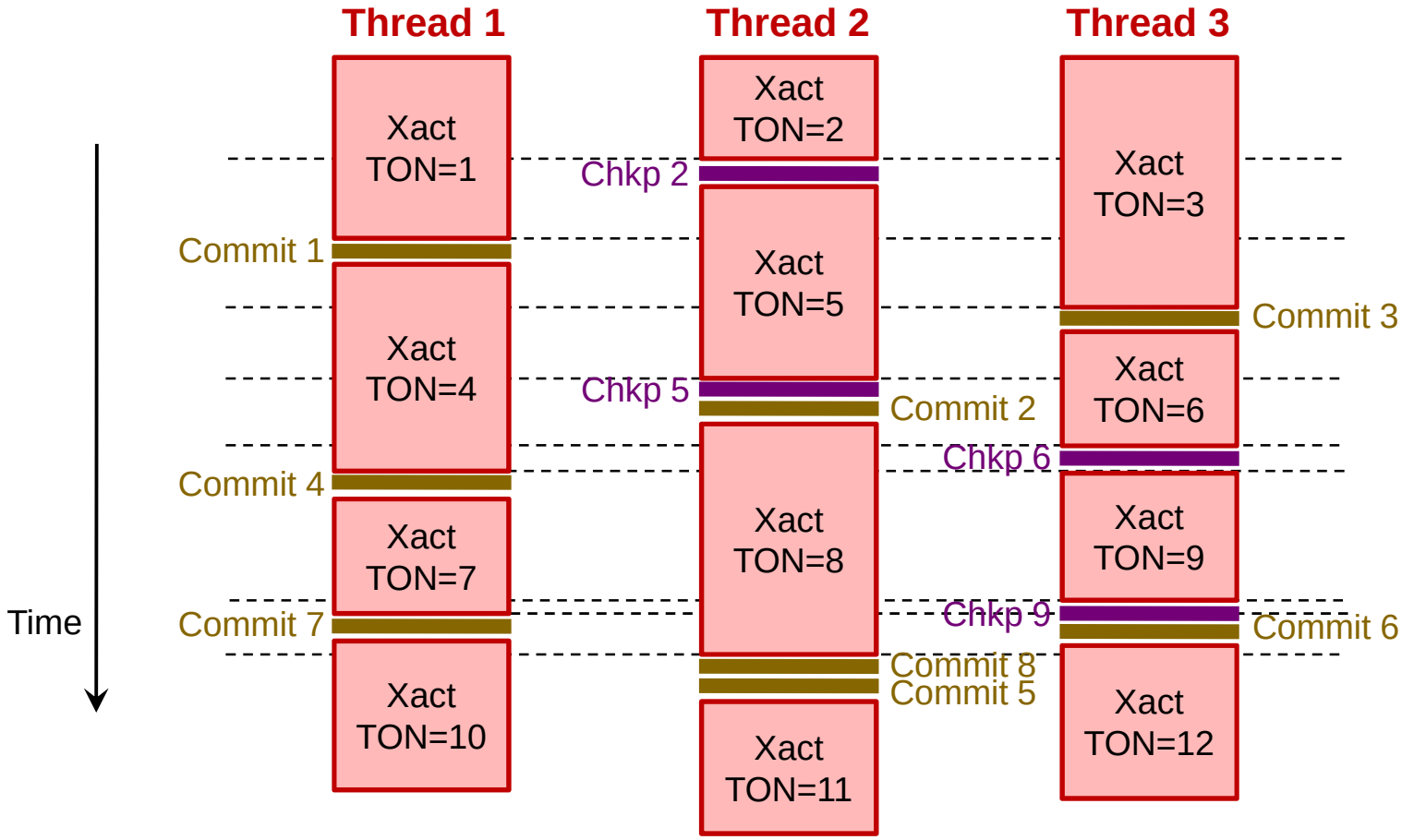
Conflict Management

- Fully distributed conflict manager
  - Each thread executes the following loop when completing a transaction
  - As committing is decoupled from completion, the thread starts a new assigned transaction instead of stalling waiting for commit
    (Stanford TCC has a similar mechanism but transactions always stall before committing)



Conflict Management: Example

- Fully distributed conflict manager
  - Transactions can **commit out of order** if it is safe (previous transactions are completed or committed and no conflicts detected)

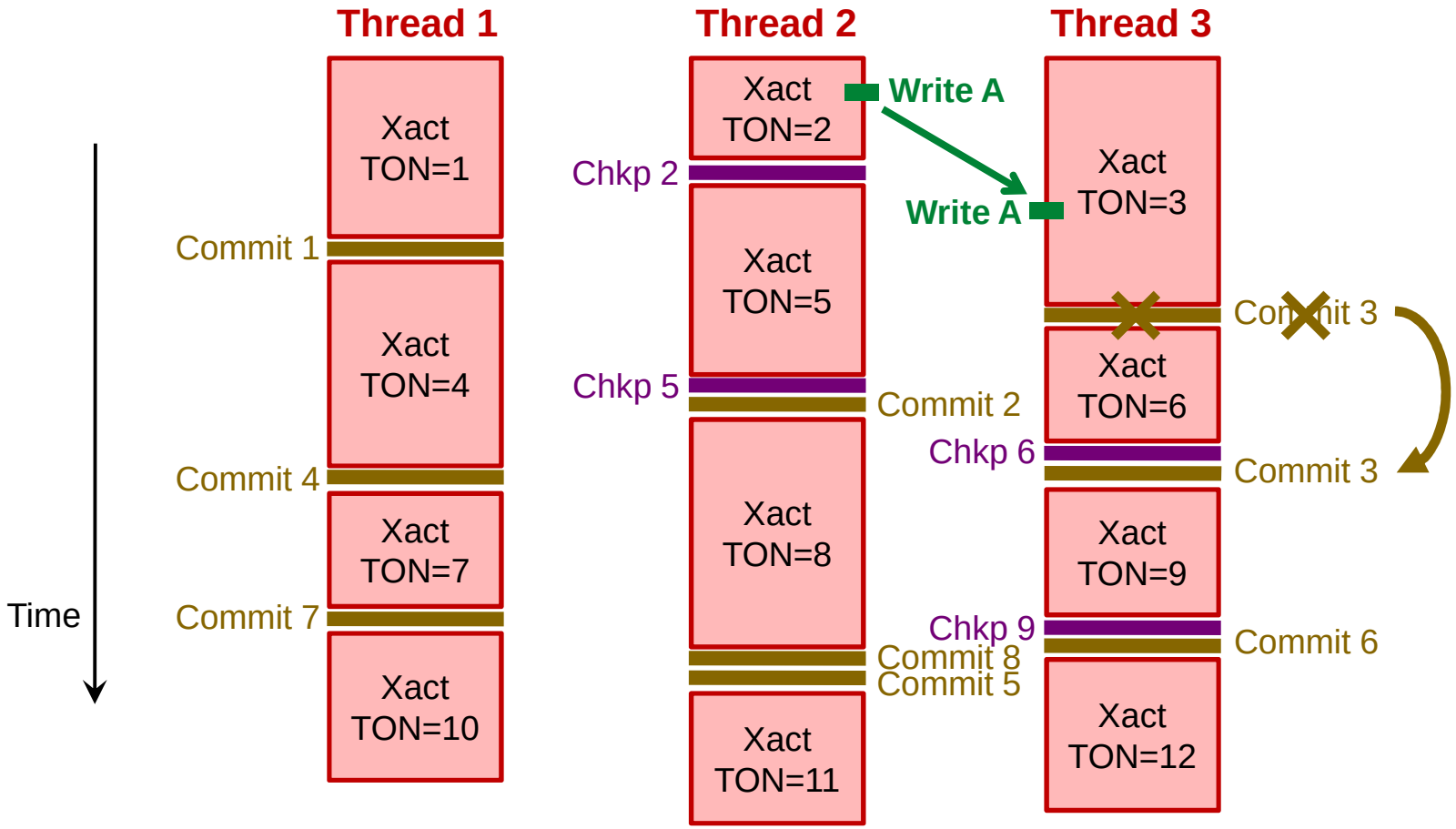


Data Dependences

- Conflict detection is eager
  - Possible data dependence violations are detected immediately
- Preservation of data dependences
  - Conflict manager preserves data dependences by scheduling transaction commits
    - » DATM (Micro'08) proposes a similar approach but without explicit transaction ordering (TON)
  - A restricted version of data forwarding, called FAC (Forwarding After Completion), is used to improve parallelism
    - » Only completed transactions can forward written values to subsequent (in TON order) transactions
    - » FAC reduces the amount of forwarded data if a transaction writes several times in the same memory location
    - » FAC avoids circular dependences between two transactions
    - » DATM, in contrast, forwards data immediately to any requester

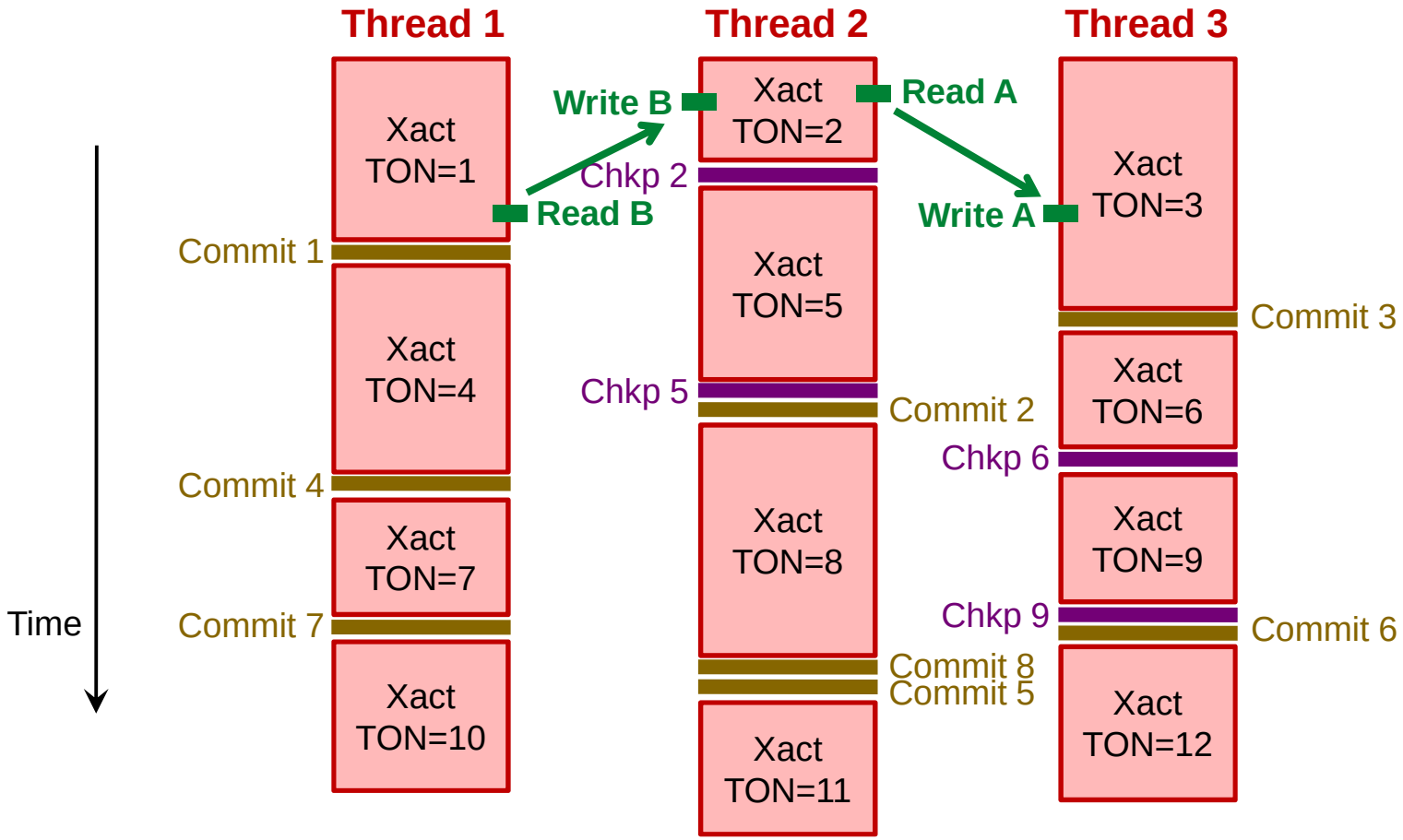
Data Dependences: Case Output-

- Output dependences
  - Transactions with a Write-Write conflict **must commit in order**
  - Both transactions run in parallel with no abort



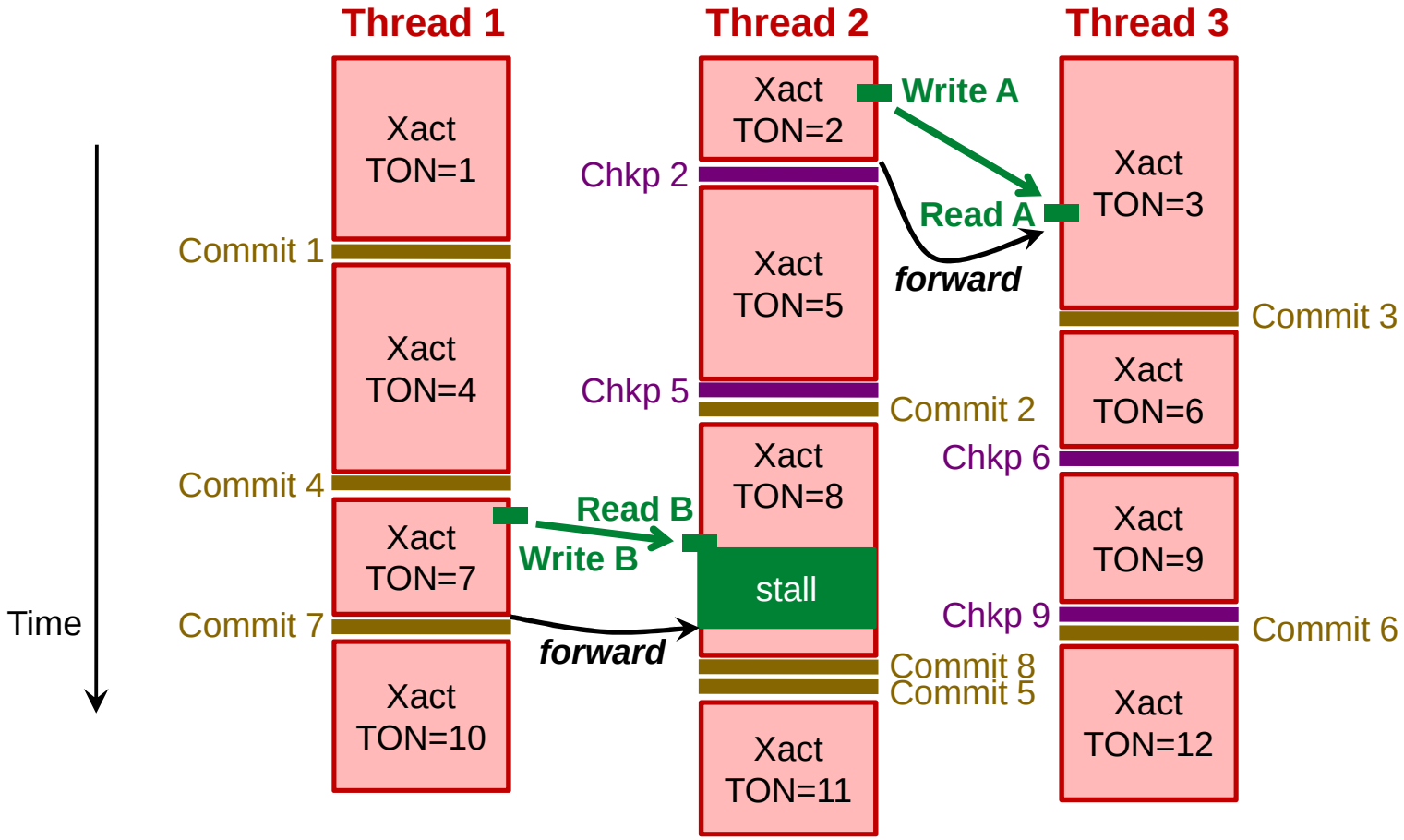
Data Dependences: Case Anti-

- Antidependences
  - Transactions with a Read-Write conflict can run safely (the baseline commit scheduling always preserve these dependences)



Data Dependences: Case Flow-

- Flow dependences
  - Transactions with a Write-Read conflict **must stall** or **abort** the reading transaction (depending on which operation executed first)
  - When stalling, the use of FAC may reduce the stall time



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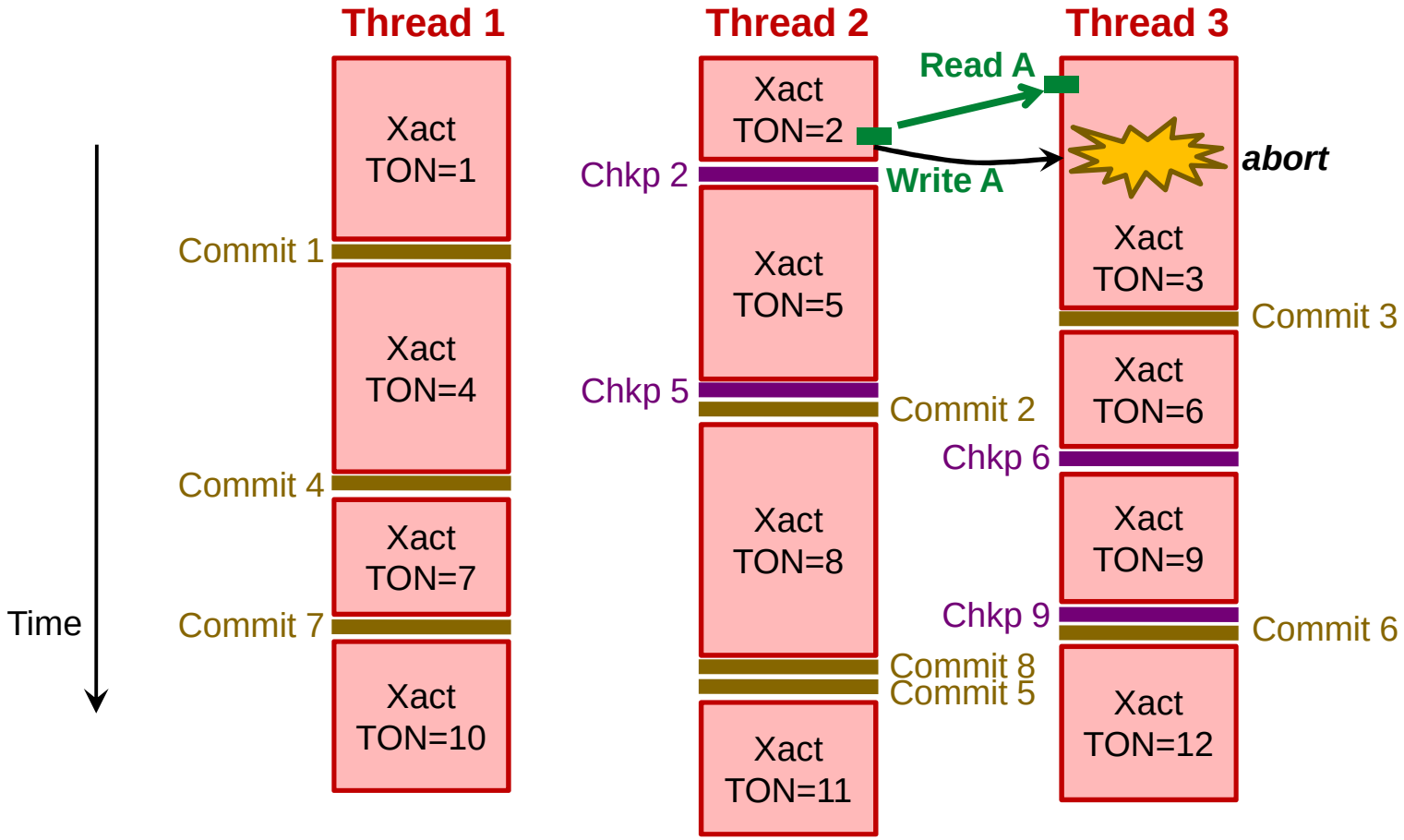

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Evaluation

- Implementation
  - The described techniques were implemented on TinySTM
  - Tested benchmark code: Sparse matrix transpose
  - All experiments were conducted on a shared-memory multiprocessor with four 8-core Intel i7 processors (32 cores in total) running Linux

Benchmark Code

- Transpose of a sparse matrix
  - Sparse matrix compressed in CRS format
  - Due to indirections through rowT(), loop-carried dependencies may exist depending on the distribution of the non-zero elements in the matrix

Initialization

```
do i = 2, Ncols+1
   rowT(i) = 0
enddo
do i = 1, row(Nrows+1)-1
   rowT(col(i)+2) = rowT(col(i)+2)+1
enddo
rowT(1) = 1
rowT(2) = 1
do i = 3, Ncols+1
   rowT(i) = rowT(i) + rowT(i-1)
enddo
```

Transpose

```
do i = 1, Nrows
   do j = row(i), row(i+1)-1
      dataT(rowT(col(j)+1)) = data(j)
      colT(rowT(col(j)+1)) = i
      rowT(col(j)+1) = rowT(col(j)+1)+1
   enddo
enddo
```

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   rowT(i) = rowT(i) + rowT(i-1)
enddo
```

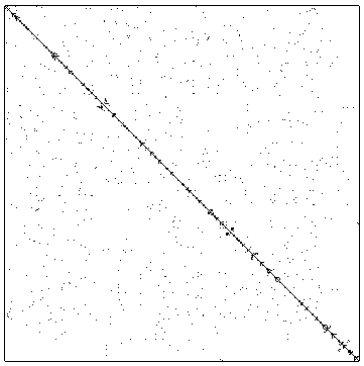
Transpose

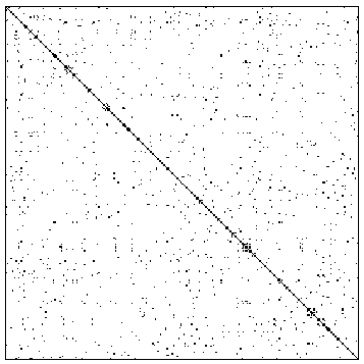
```
#pragma omp transfor schedule(static,S) ordered
do i = 1, Nrows
   do j = row(i), row(i+1)-1
      dataT(rowT(col(j)+1)) = data(j)
      colT(rowT(col(j)+1)) = i
      rowT(col(j)+1) = rowT(col(j)+1)+1
   enddo
enddo
```

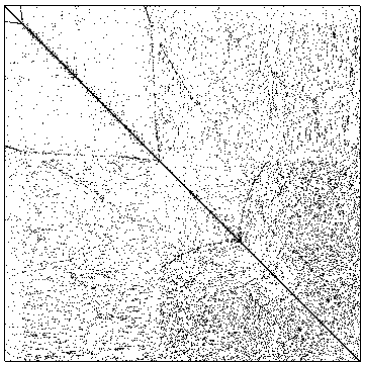
Benchmark Sparse Matrices

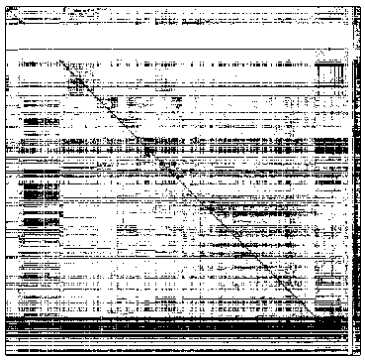
- Sparse matrices
  - Source: Matrix Market

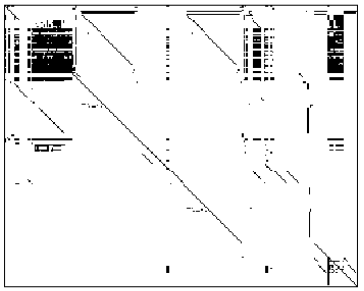
Matrix	Size	Non-zeros (Sparsity)	Symmetric
494 BUS	494 x 494	1666 (0,68%)	Yes
BCSPWR04	274 x 274	1612 (2,15%)	Yes
BCSPWR10	5300 x 5300	21842 (0,08%)	Yes
BEAUSE	497 x 506	50409 (20,04%)	No
WM3	207 x 260	2948 (5,48%)	No


494 BUS


BCSPWR04

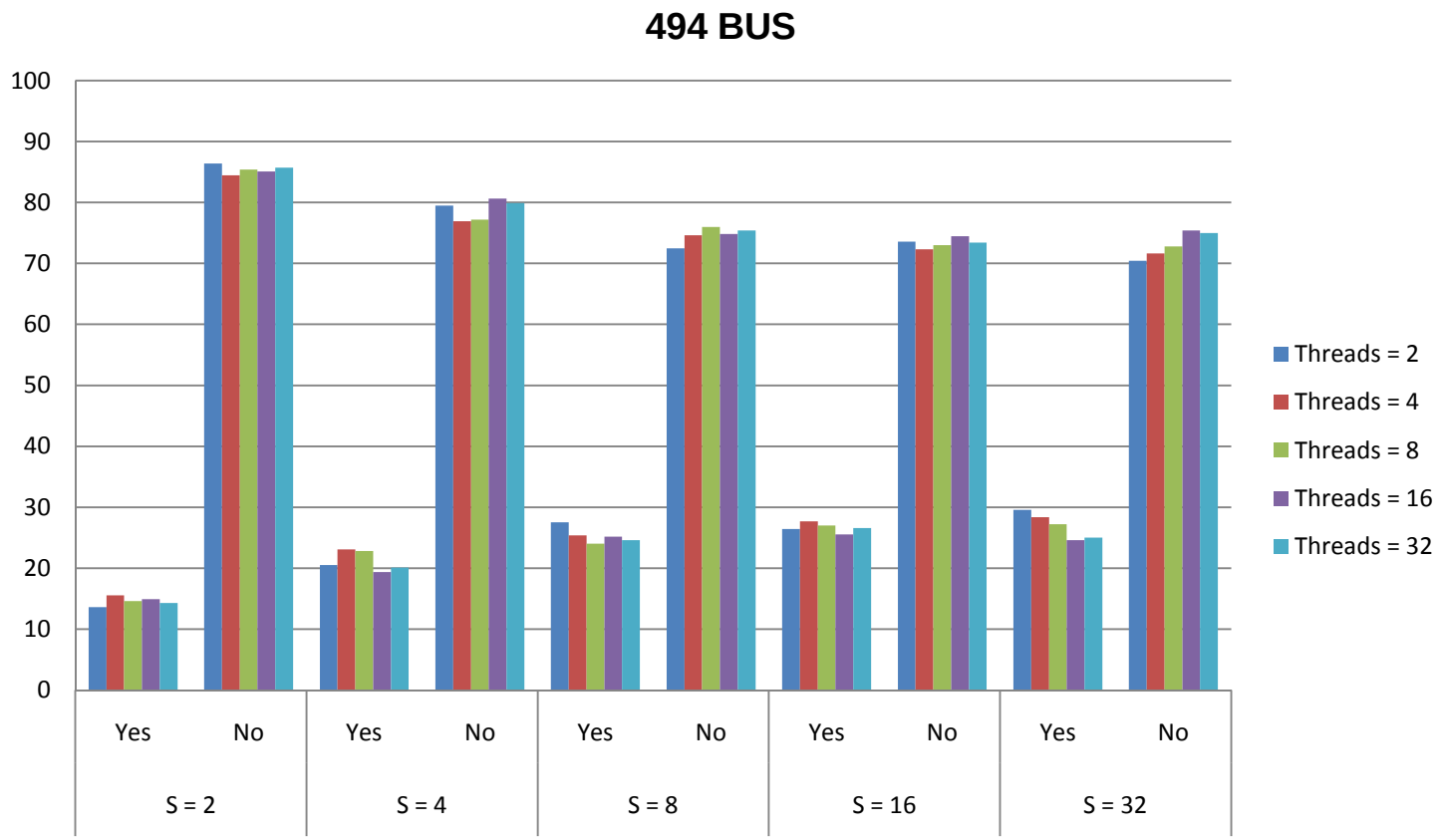

BCSPWR10


BEAUSE


WM3

Experimental Results

- Aborts avoided by the conflict manager
  - S is the size of the block of iterations executed as a transaction



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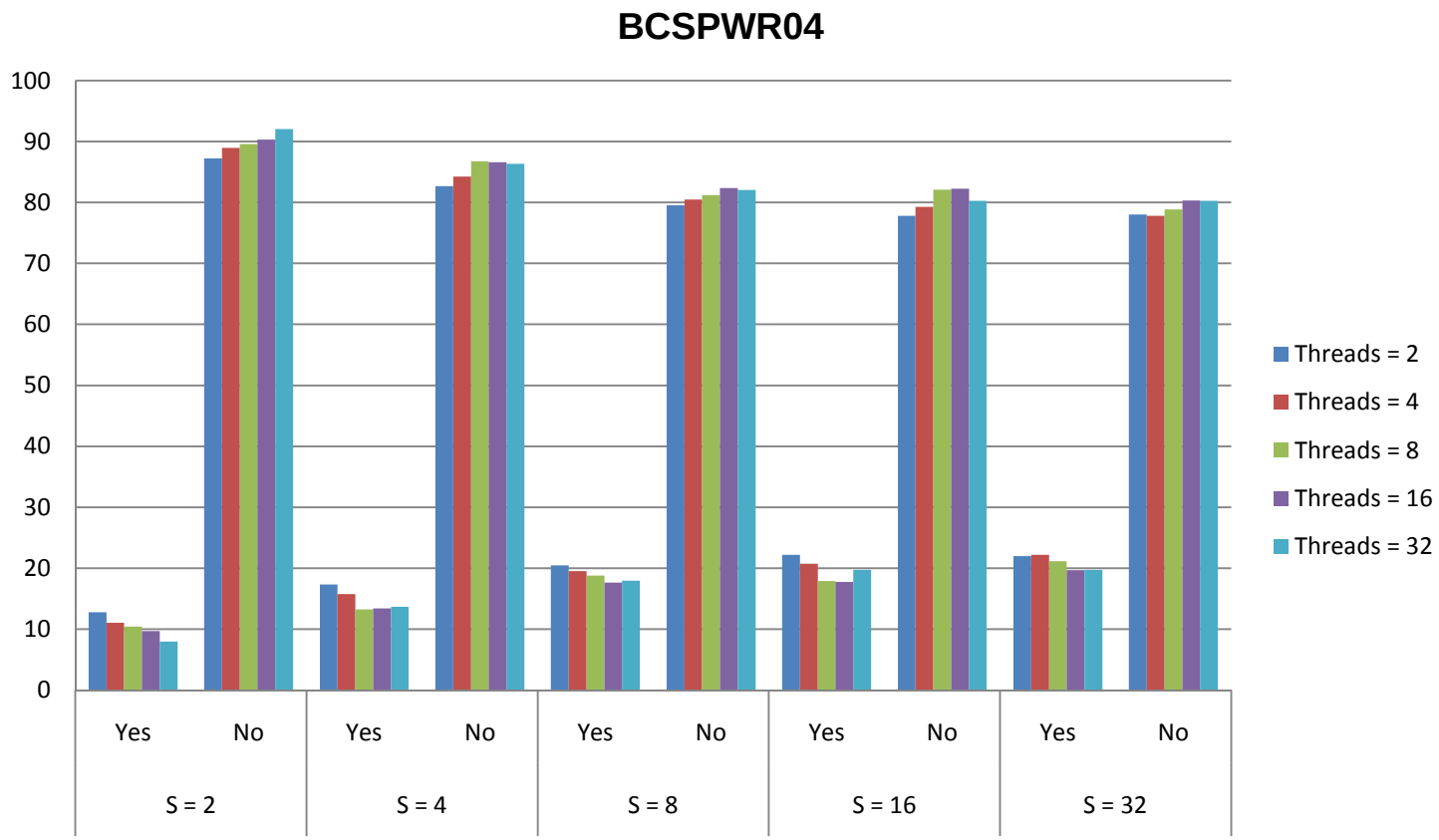

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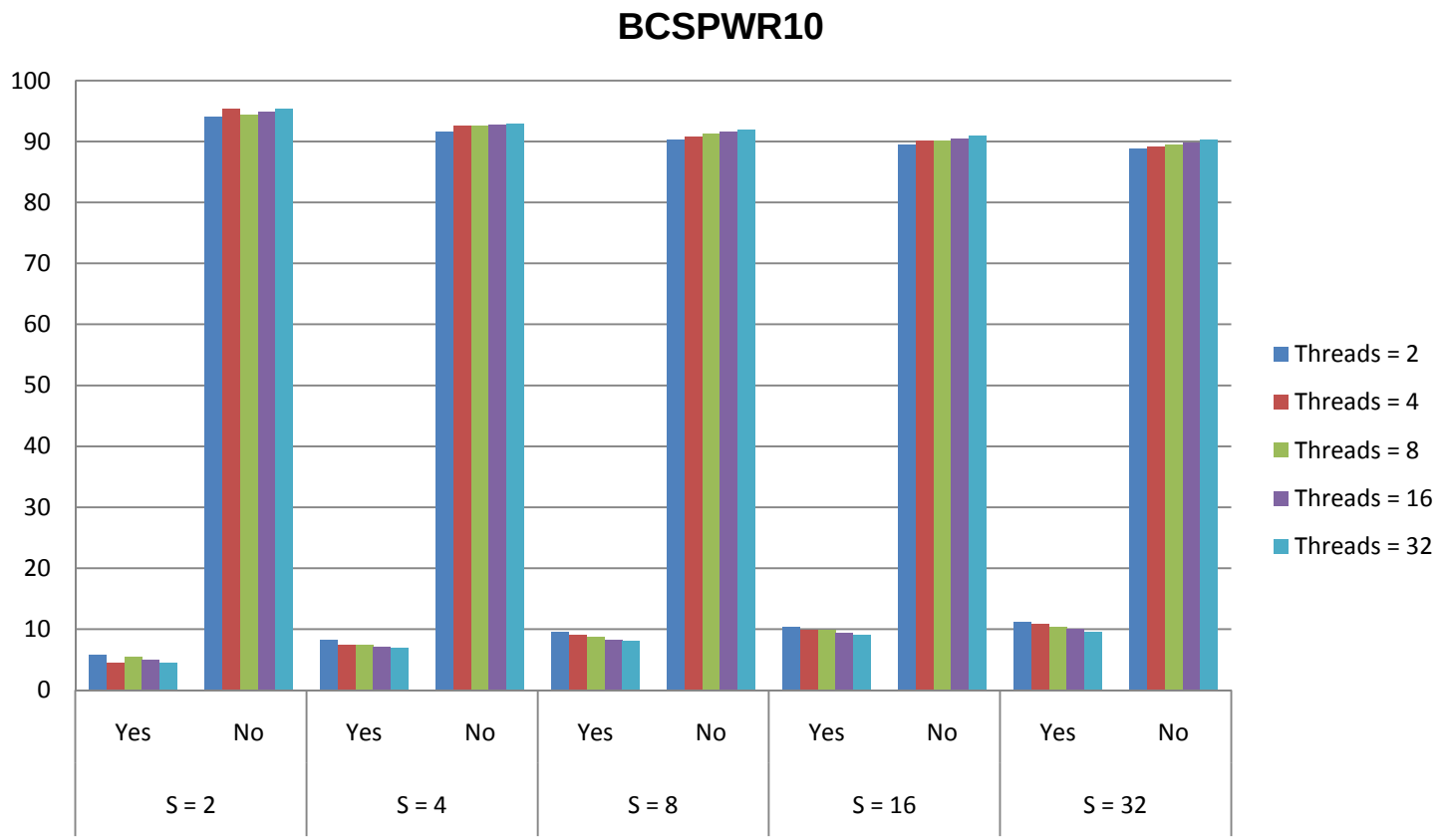

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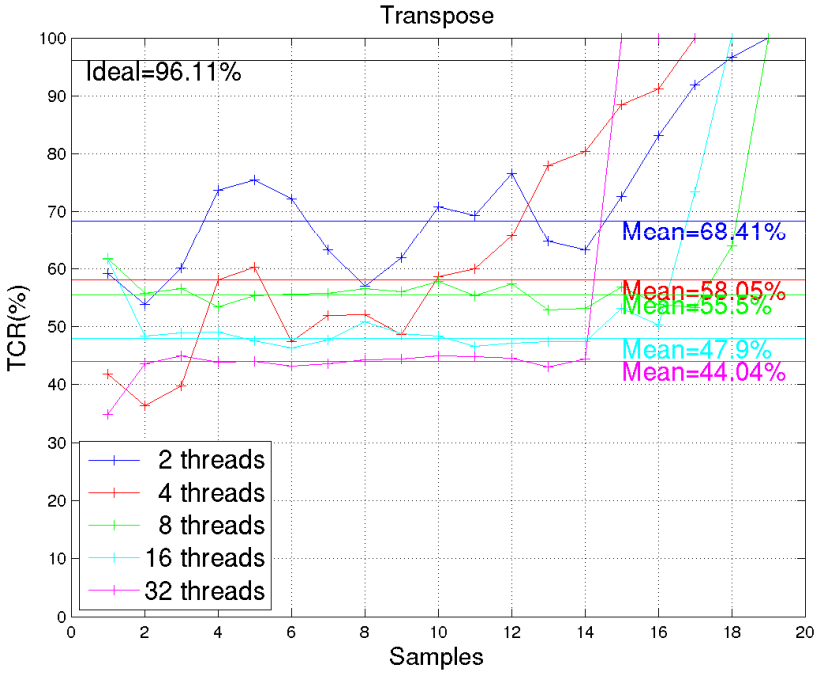
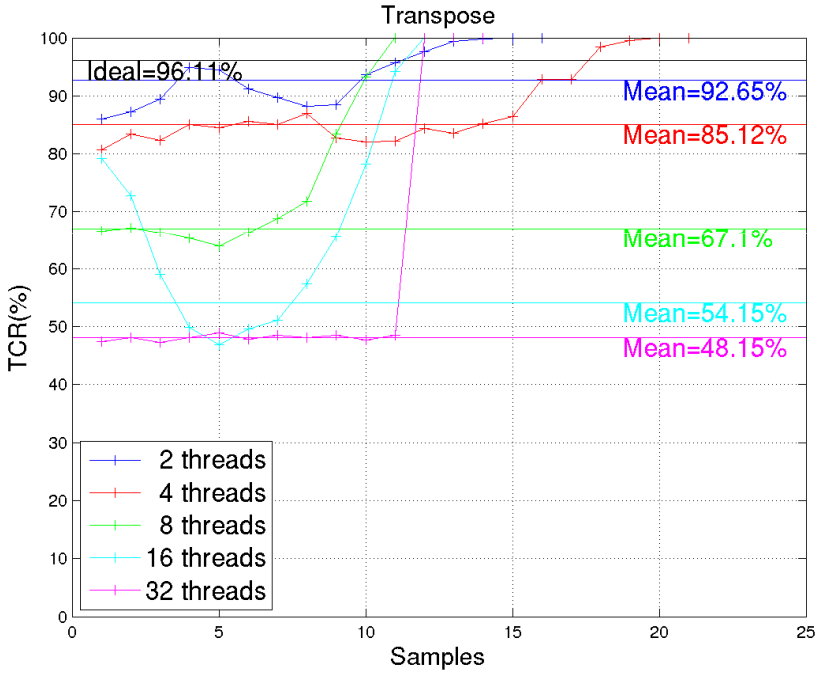
Experimental Results

- Extracted parallelism
  - TCR: Transaction Commit Rate

494 BUS



Baseline TinySTM



Our approach on TinySTM

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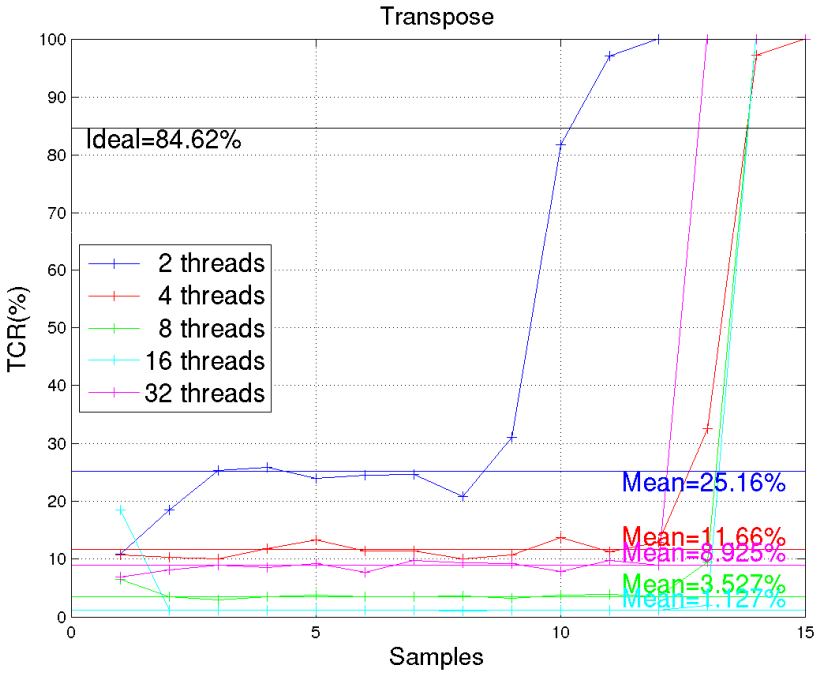

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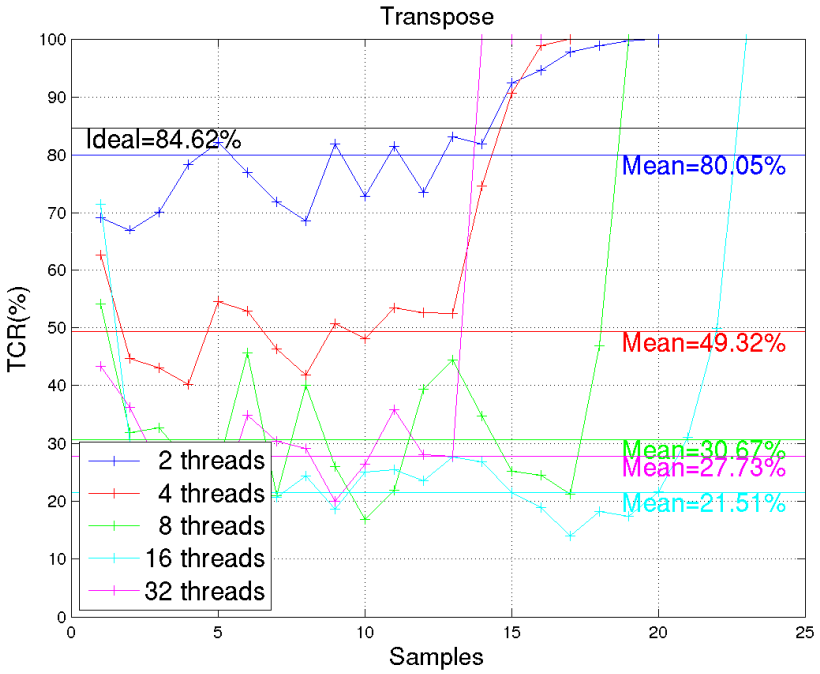

Our approach on TinySTM

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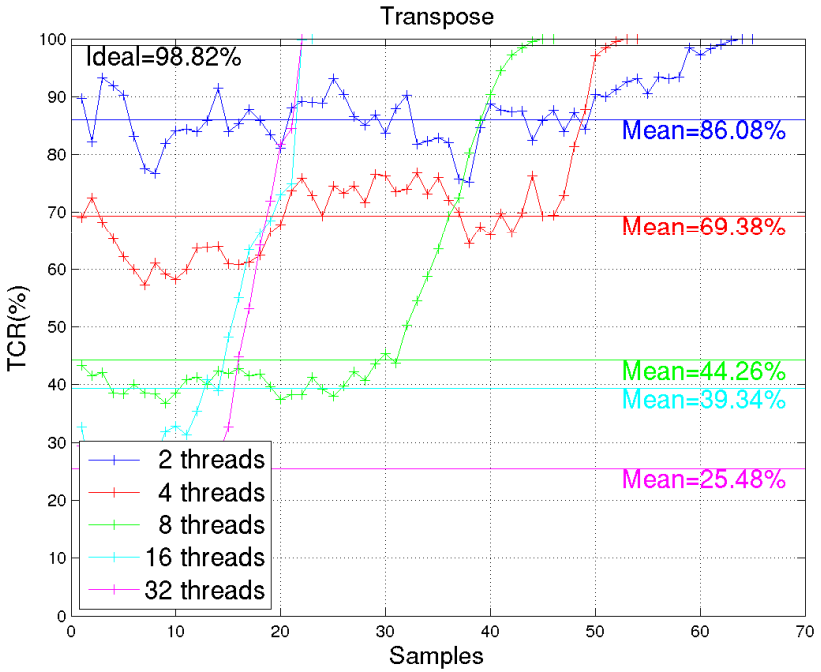
BCSPWR10



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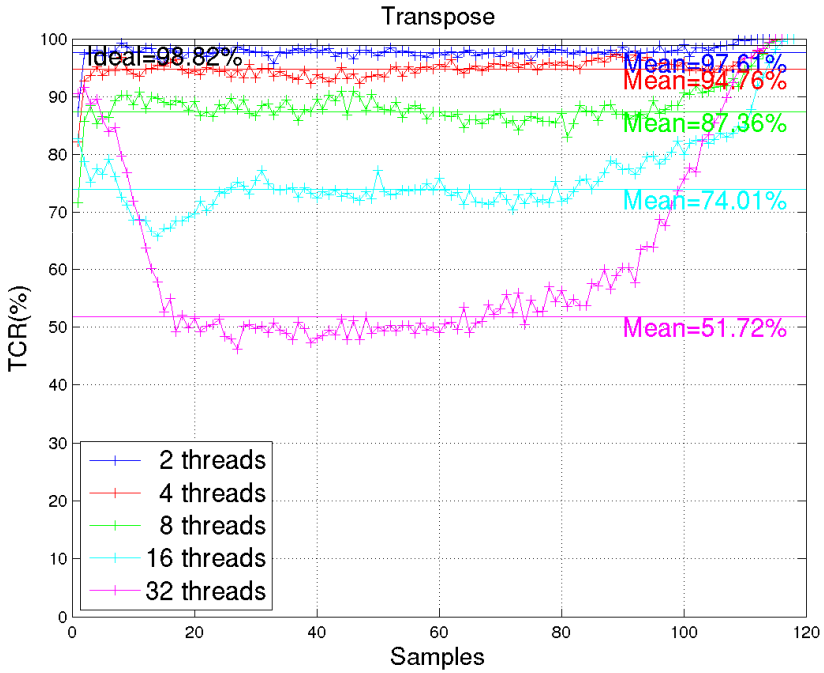

Our approach on TinySTM

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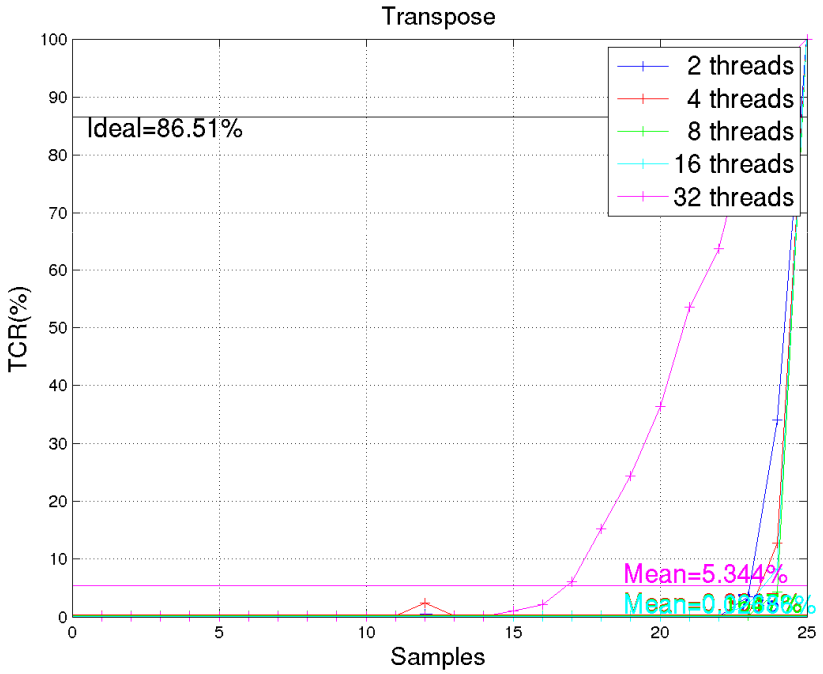
BEAUSE



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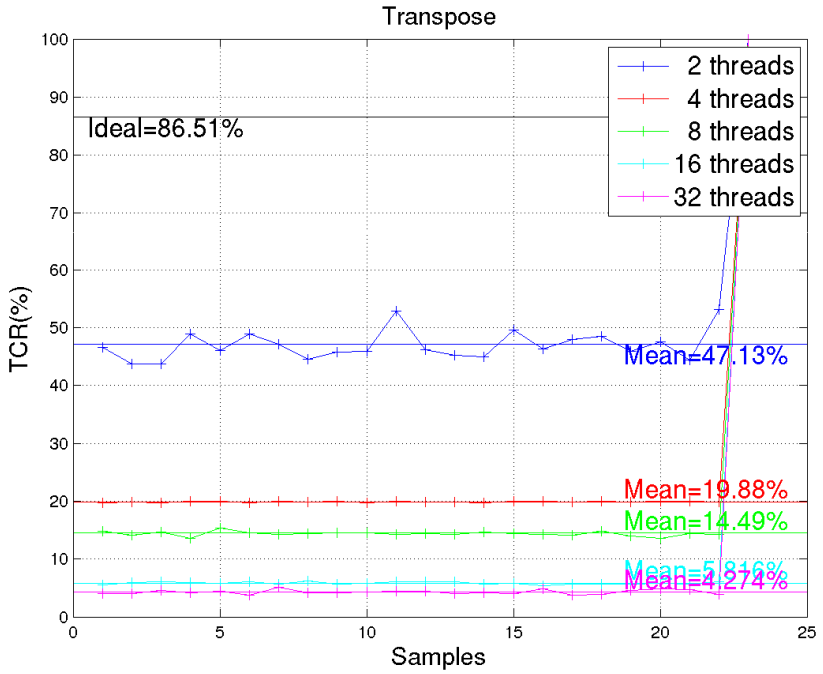

Our approach on TinySTM

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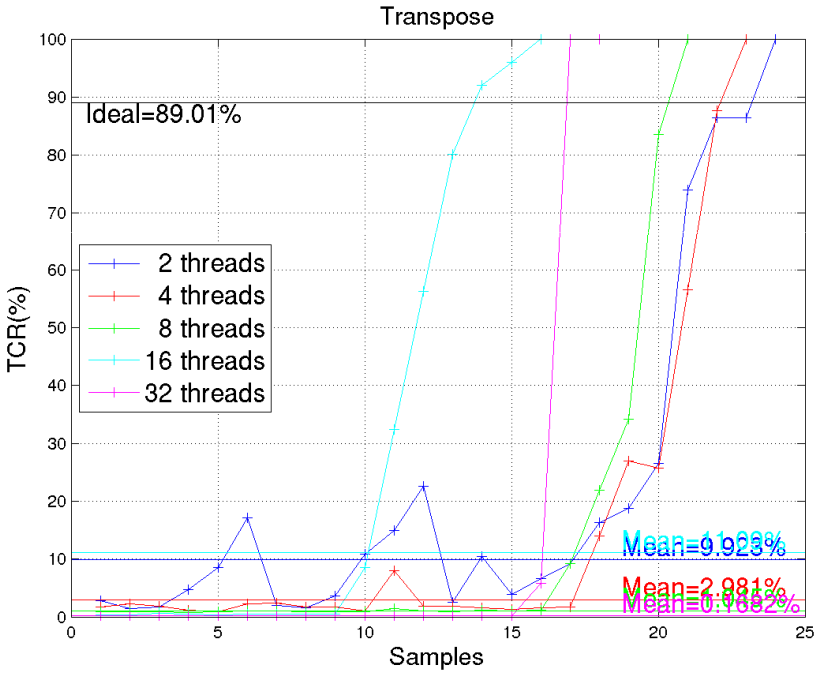

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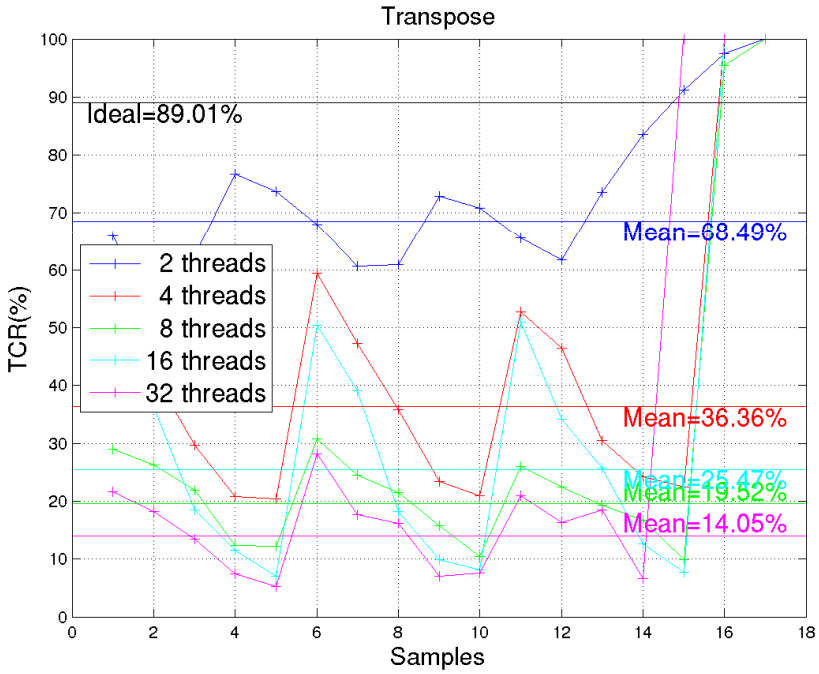

Our approach on TinySTM

Conclusions

- Leveraging TM to extract parallelism
  - Design of a fully distributed conflict manager that decouples transaction completion from commit
  - Conflict manager schedules commits in order to preserve data dependences, avoiding a great amount of aborts due to conflicts
  - Data forwarding after completion technique to reduce stall times due to flow dependences
- Future work
  - Test different options in the design space, and exploit new properties:
    - » Eager version management instead of lazy, speeding up commits
    - » Stall versus data forwarding
    - » Forwarding chains of limited length
    - » Dynamic transaction ordering instead of static
    - » Data locality