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Invent the Future

On Closed Nesting and Checkpointing in Fault-Tolerant Distributed Transactional Memory

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Software Transactional Memory

- Centralized STM
  - Simple programming model
  - Easy debugging --- deadlocks, livelocks, lock convoying, priority inversion
- Distributed STM (DTM)
  - Implementation distributed locking
  - Support for synchronization of distributed application

Nesting Models

- Flat Nesting
  - Abort causes entire transaction to restart
- Closed Nesting
  - Enclosed inside parent transaction
  - Commit of inner transaction local
  - Abort independently of parent
  - Partial rollback mechanism

Checkpointing

- Checkpointing
  - Generalization of closed nesting
  - Checkpoint saves execution state and transactional metadata
  - Rollback to previous checkpoint for abort
  - Partial rollback mechanism

Motivation with an example

- Matrix: m_1, m_2, m_3
- Result = $m_1+m_2+m_3$
- conflict on accessing m_3

- Flat Nesting will restart from **T_flat**
- Closed Nesting will restart **T_closed**

```
T_flat:
    m1 = getRemote(m1_Obj);
    m2 = getRemote(m2_Obj);
    m3 = getRemote(m3_Obj);
    intm = add(m1,m2);
T_closed:
    result = add(intm,m3);
    if commit()
        return result;
    retry T_flat;
```

Partial rollback benefits

- Do not repeat operation on m_1 and m_2
- Saved computation cost and remote calls
- Reduced abort rate as well, thus reduced transaction execution time
- Suited for replicated systems, where operations are costly

Questions?

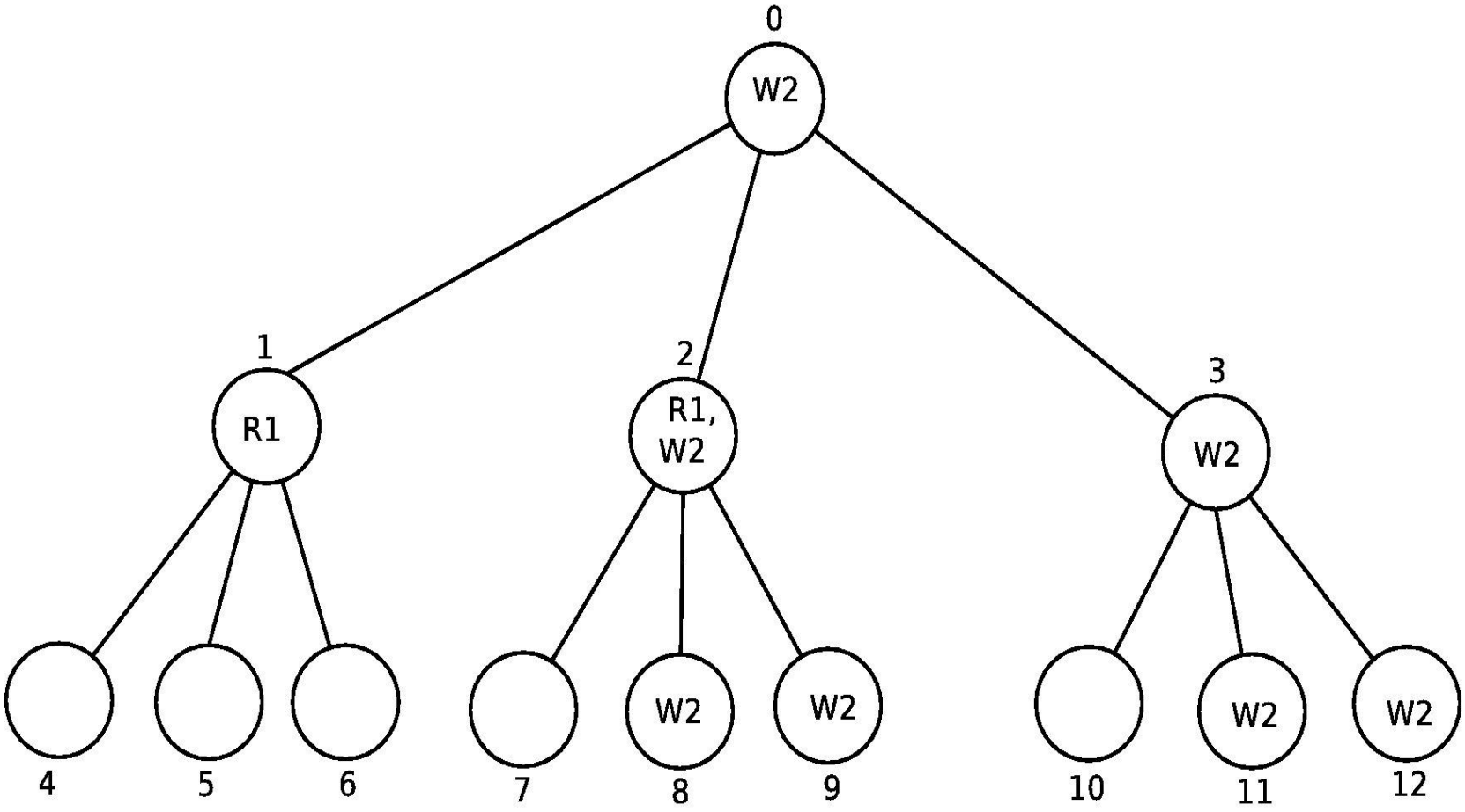
- What application/workload will benefit from partial abort, as compared to flat nesting?
- What is the potential performance improvement or degradation of partial abort?
- Which parameters of a transaction will affect the partial abort performance?

IN THE CONTEXT OF DTM

Quorum-based Replication (QR-DTM)

- Network layer:
  - Nodes form logical ternary tree
  - Read and write quorum created from tree
  - Read and write quorum always intersect
  - Reduces the number of nodes to contact
- DTM protocol (Full replication):
  - Read quorum services read and write requests
  - Selecting the highest version from read quorum gives the latest copy
  - Write quorum services commit requests

Network organization

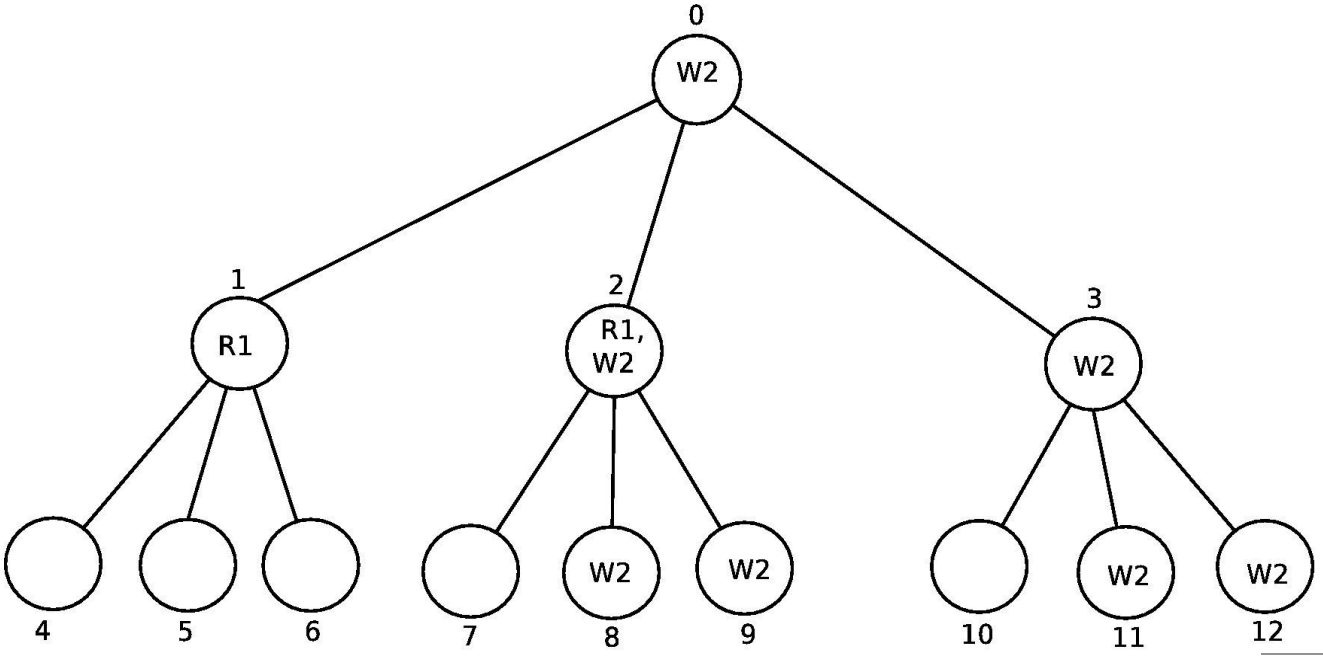


QR-DTM: Early Validation

- For every read request:
  - Validate previously read objects (piggyback read-set on read request)
  - On success, proceed to service the request
  - On failure, send abort message to the transaction

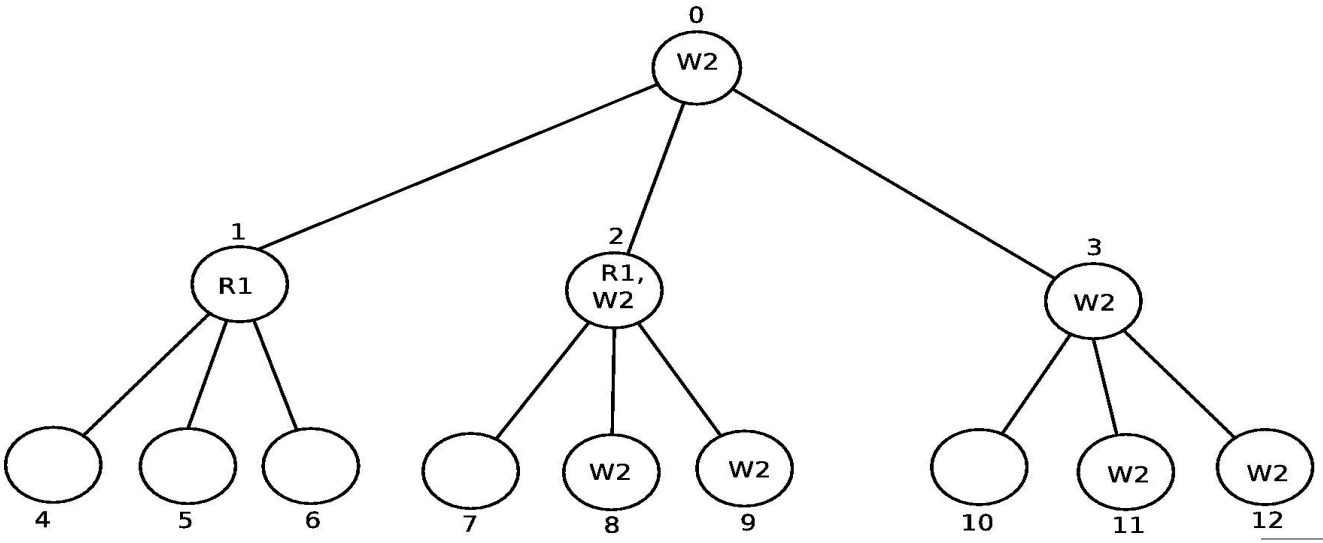
Example /1

- Read quorum R1 and Write quorum W2 intersect at n2
- T1 reads o1,o2 & o3



Example /2

- T2 commits changes to o2
- T1 requests o4 and validates all the read-set
- n1 validates T1's read-set, finds o2 is old and sends abort



QR-CN : Closed Nested Operations

- Read operation (from remote node)
  - Validate current read-set
  - If fail
    - Find the transaction with object invalidated (that needs to be aborted)
    - Send an abort message with the object not valid
  - If success
    - Responds with latest copy of requested object

QR-CN : Closed Nested Operations

- Read operation (from local node)
  - If abort response
    - Abort child or parent
  - If success
    - Select the last version from all the versions sent by remote nodes
    - Return the object
- Same behavior for write operation

QR-CN : Closed Nested Operations

- Nested transaction:
  - Commit
    - Merge read and write set with the parent
    - Read quorum validation ensures that data-set is valid at commit time
- Parent transaction:
  - Commit using write quorum

QR-CHK: Checkpointing Operations

- Transaction creates checkpoints locally
- Conflict during execution phase, can restart from appropriate checkpoint
- Checkpoint saves
  - Program counter
  - Read/write set at that point
  - Records the checkpoint ID

QR-CHK: Checkpointing Operations

- Remote nodes record the checkpoint ID for each object
- Remote node
  - For each read request, remote node validates the data-set
  - On failure
    - Finds the least checkpoint ID among the conflicting objects that has all its objects valid

QR-CHK: Checkpointing Operations

- Local Node:
  - On success, returns latest copy of requested object
  - On failure, retrieves the checkpoint ID, restores to it and resumes execution
- Checkpoints are ordered following the objects access pattern. In case of multiple conflicts, the checkpoint with minimum id is restore.

Implementation /1

- QR-CN
  - Java Exceptions for aborting transaction
  - Transaction throws exception with ID of aborted transaction
  - Transaction catching compares the ID
  - If the matching fails, throws another exception caught by parent

Implementation /2

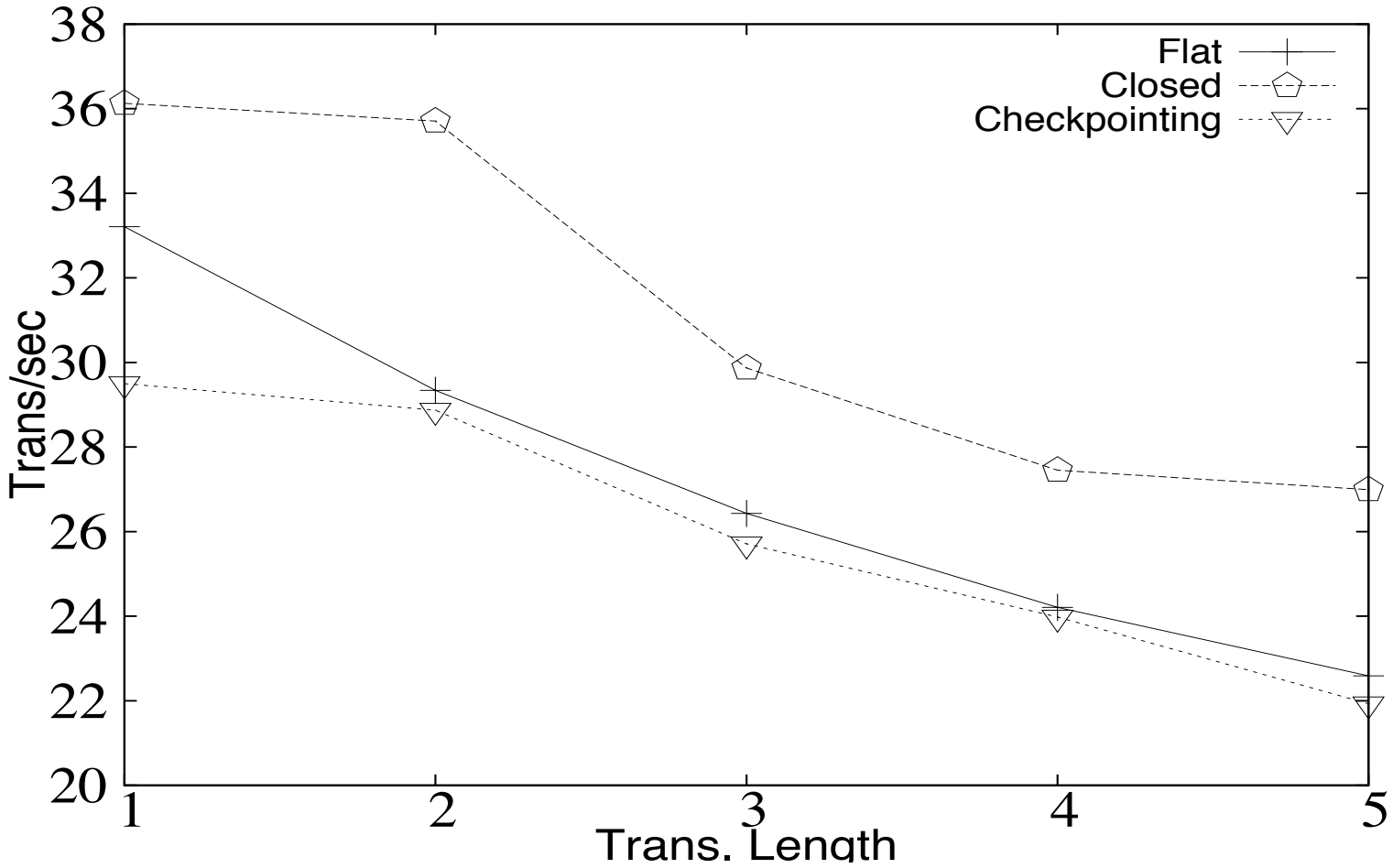
- QR-CHK
  - Java Continuations for creating checkpoints and rollback
  - Continuations save the execution state in Java object
  - Rollback retrieves this object and resumes execution

Possible bottleneck!

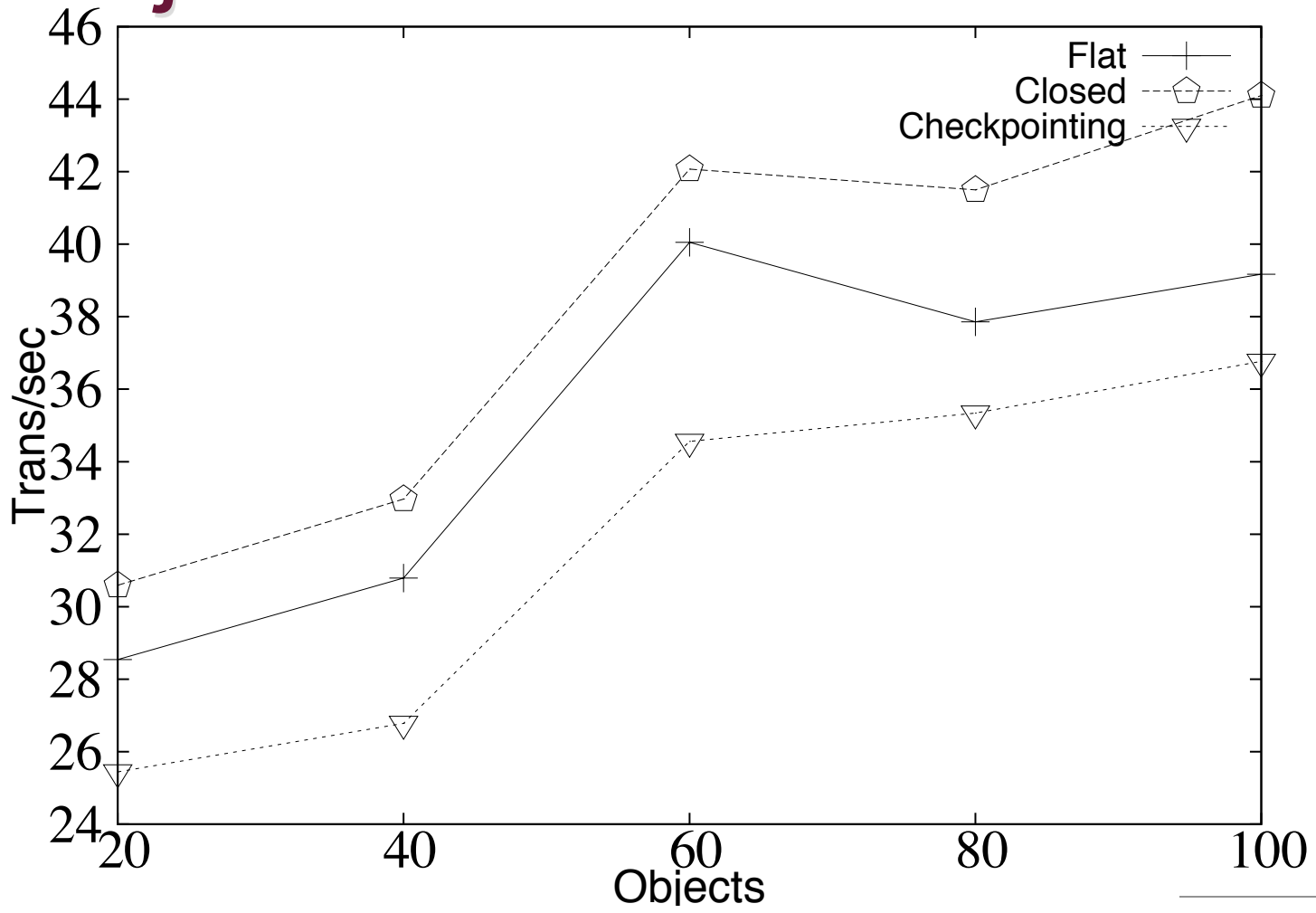
Experimental study

- For QR-CN, each operation is a closed nested transaction
- For QR-CHK, checkpoint created after reading every object
- Benchmarks
  - Bank, Hashmap, RBTree, SkipList, Vacation (STAMP)
- Test-bed: 40 nodes

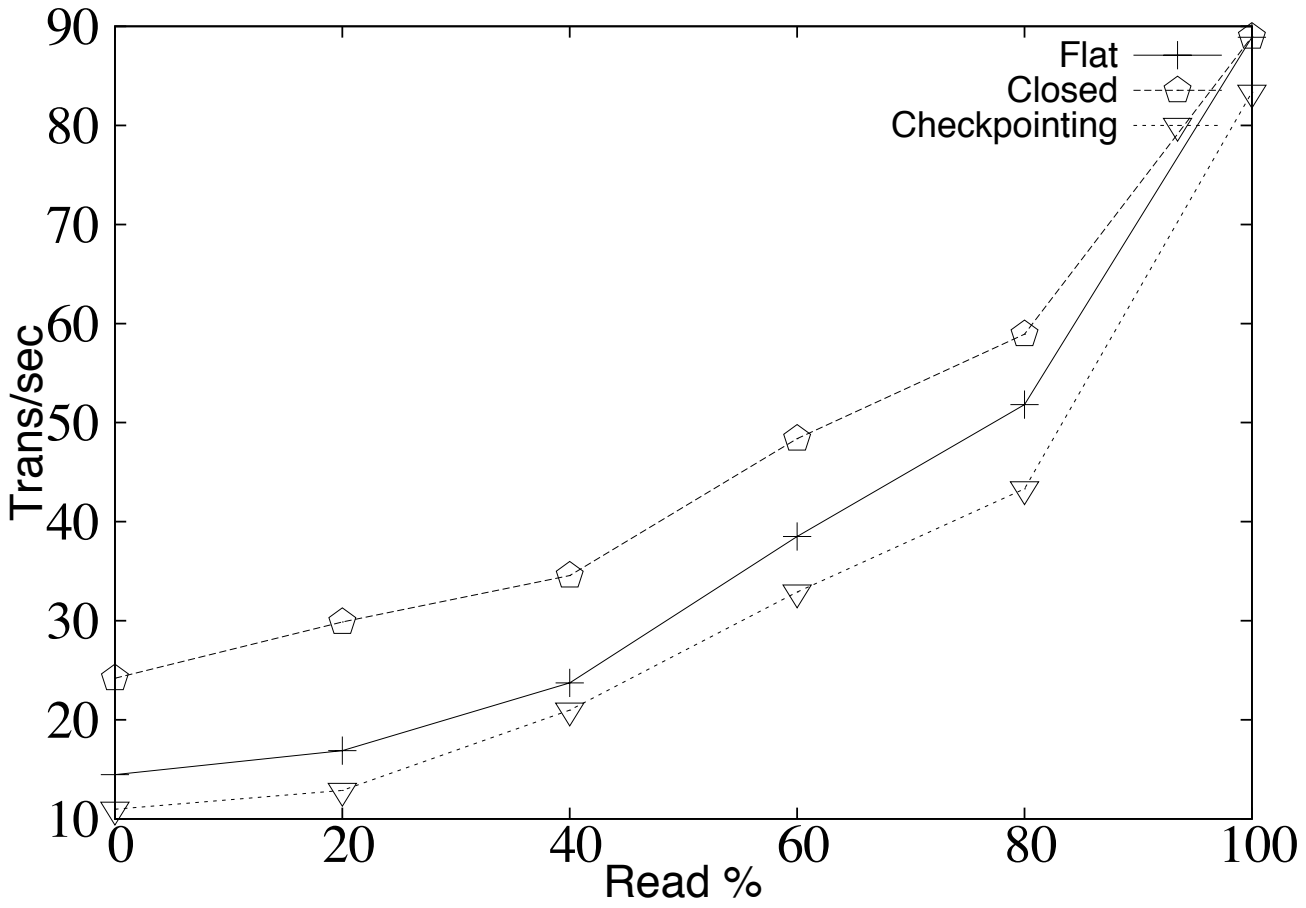
Nested Calls - Vacation



Objects accessed - Vacation



Read Workload - Vacation



Observations

- % read workload
  - Closed nesting outperforms flat nesting and checkpoints with higher margin for mostly write workload
- Transaction length
  - Increasing transactional calls, the gap between closed nesting and other increases
- Object variation
  - With a large read-set, closed nesting contention increases the gap against flat.

Conclusion

- Closed nesting has performance gain (vs flat-nesting) of 53% across all benchmarks
- 33% reduction in abort rate of closed nesting (vs flat-nesting)
- Checkpointing has 16% of performance degradation with 19% message overhead

…and the winner is…

CLOSED NESTING

Thanks

Questions?

http://www.hyflow.org/