Practical considerations of Distributed STM systems development

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Paxos STM
probably the best DSTM in the world

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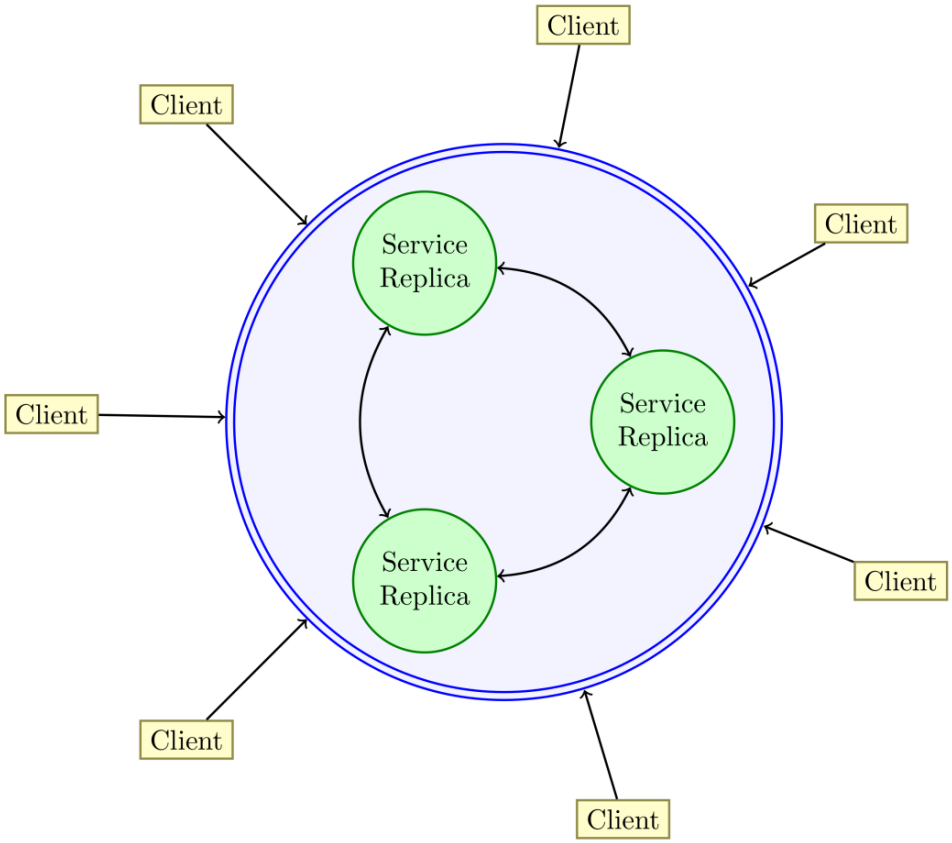
Outline

- Motivations & model
- API
- Performance
- Evaluation

Motivations

- Service Replication
  - Fault-tolerance
  - Scalability
  - Ease of development
- Transactional Replication
- Paxos STM
  - Distributed STM
  - Platform for research
  - Preliminary work



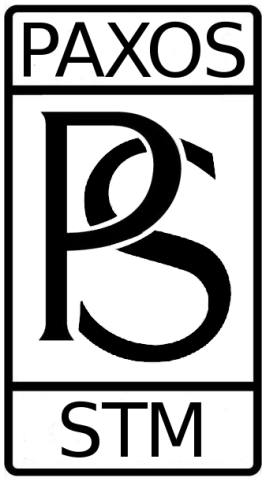
System model

- Distributed STM
  - TM on top of network
  - Support for multi-core
  - One-copy serializability
  - ACID guarantees
- Fault-tolerance
  - Crash-recovery failure model
  - $f = \left\lceil \frac{N}{2} \right\rceil - 1$

```
atomic {
   float amount = 100;
   if (accountA.balance() >= amount)
         accountA.withdraw(amount);
   else
         retry;
   accountB.deposit(amount);
}
```

Paxos STM – our system

- Distributed STM for Java
- Deferred Update
  - Objects replicated on each site
  - Optimistic concurrency control
  - Atomic Broadcast
- JPaxos as base layer
  - MultiPaxos algorithm
  - Crash-recovery failure model
  - Various recovery algorithms



API

- **No** language extensions
- **No** static code analysis

  (no pre-compilation required)
- **Automatic code instrumentation**

  (via Javassist)

API – example

```
@TransactionObject
class Account {
    private float funds;
    public float balance() { return funds; }
    public void deposit(float amount) {
        funds += amount;
    }
    public void withdraw(float amount) {
        if (amount > funds)
            throw new IllegalArgumentException();
        funds -= amount;
    }
}
```

API – behind the scene

```
@TransactionObject
class Account implements Observable, Externalizable
{
    private float funds;

    public TCID __tc_id;
    public long __tc_version;
    public volatile Account __tc_next;
    public int __tc_attr;

    public Account();
    public float balance();
    public void deposit(float f);
    public void withdraw(float f);

    public float __tc_Account_balance_internal();
    public void __tc_Account_deposit_internal(float f);
    public void __tc_Account_withdraw_internal(float f);

    public float __tc_Account_balance_noCheck();
    public void __tc_Account_deposit_noCheck(float amount);
    public void __tc_Account_withdraw_noCheck(float amount);

    public float __tc_Account_balance_wCheck();
    public void __tc_Account_deposit_wCheck(float amount);
    public void __tc_Account_withdraw_wCheck(float amount);

    public float __tc_Account_balance_sCheck();
    public void __tc_Account_deposit_sCheck(float amount);
    public void __tc_Account_withdraw_sCheck(float amount);

    public final boolean __tc_isVersion();
    public final boolean __tc_isShadowCopy();
    public final boolean __tc_isHandle();
    public final TCID __tc_getId();
    public final long __tc_getVersion();
    public final Observable __tc_getNext();
    public final void __tc_setNext(Object obj);
    public final boolean __tc_isWritten();
    public final void __tc_setWritten(boolean flag);

    public final Observable __tc_retrieve(long l);
    public final void __tc_release(long l);
    protected Account(SpecialConstructorMarker specialconstructormarker);
    public final void __tc_initHandle(TCID tcid);
    public final void __tc_initShadowCopy(TCID tcid);
    protected void __tc_copy(Account account);
    public void __tc_vcopy(Object obj);
    protected Account __tc_makeCopy();
    public Observable __tc_vmakeCopy();

    public void __tc_serializeHelper(DataOutputStream dataoutputstream) throws IOException;
    public byte[] __tc_serialize() throws IOException;
    public void __tc_deserializeHelper(DataInputStream datainputstream) throws IOException,
      ClassNotFoundException;
    public void __tc_deserialize(byte data[]) throws IOException, ClassNotFoundException;
    public void readExternal(ObjectInput objectinput) throws IOException, ClassNotFoundException;
    public void writeExternal(ObjectOutput objectoutput) throws IOException;
    public Observable __tc_addNewVersion(long l, byte data[]) throws IOException,
      ClassNotFoundException;
}
```

API – example

```
new Transaction() {
    public void atomic() {
        float amount = 100;
        if (accountA.balance() >= amount)
            accountA.withdraw(amount);
        else
            retry();
        accountB.deposit(amount);
    }
};
```

API – example

```
new Transaction() {
    public void atomic() {
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        else
            retry();
        accountB.deposit(amount);
    }
};
```

No need to manually specify RS and WS

Goodies

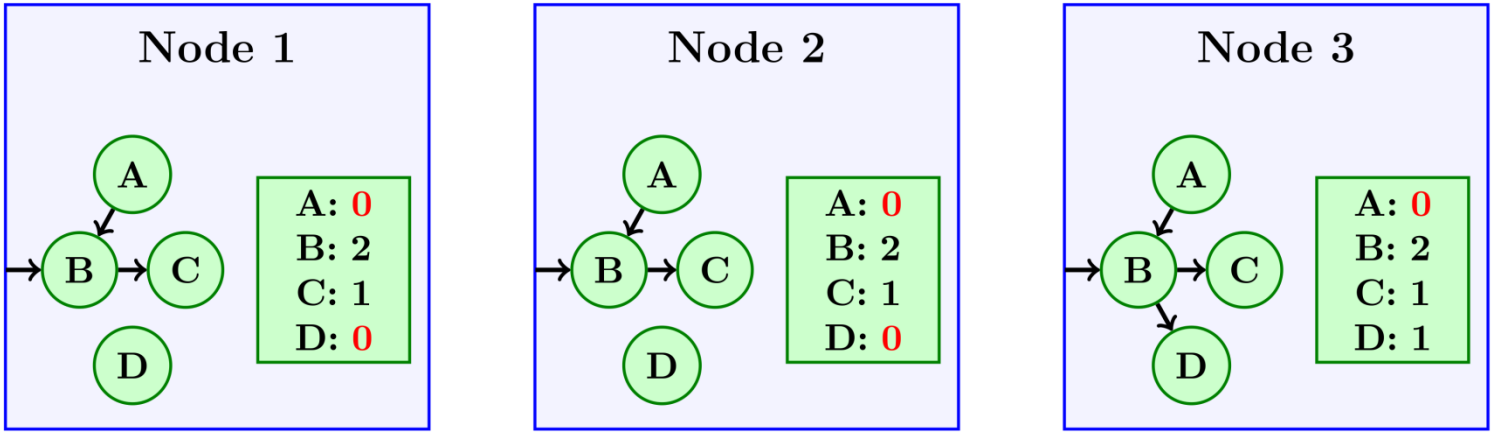
- Shared Object Registry

```
// node 1
Car car = new Car(„Rolls Royce”, „Phantom”);
PaxosSTM.addToSharedObjectRegistry(„Phantom”, car);
...
// node 2
Car car = (Car) PaxosSTM.getFromSharedObjectRegistry(„Phantom”);
```

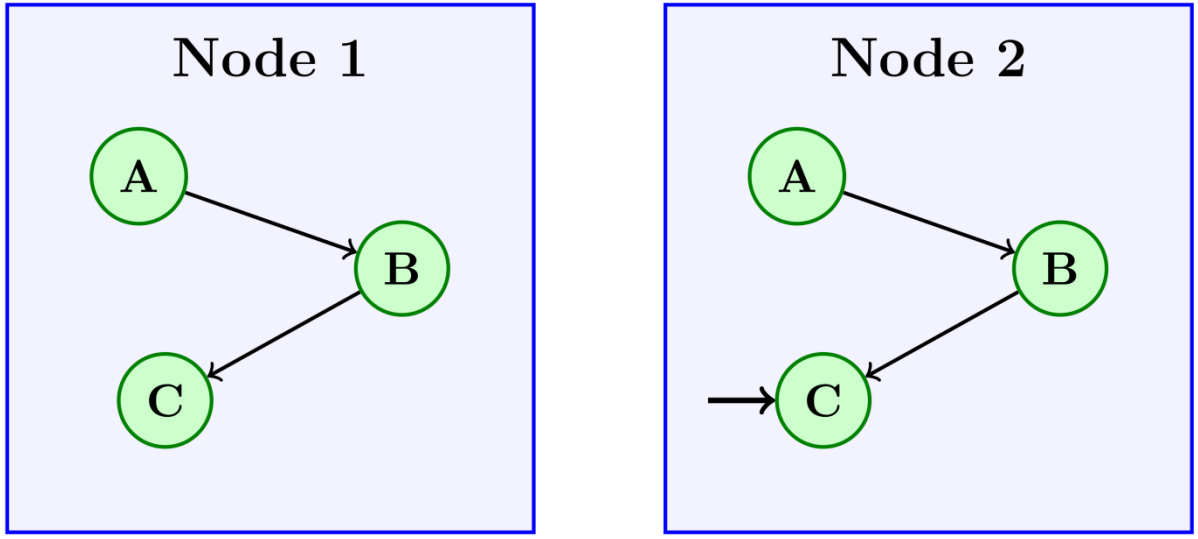
- Distributed Garbage Collector (next slide)

Distributed Garbage Collection

- Natural solution in Java
- Non-trivial solutions in distributed system
  - Counting references on different nodes
  - System-wide agreement on object removal



Distributed Garbage Collection – why Java GC is not enough?



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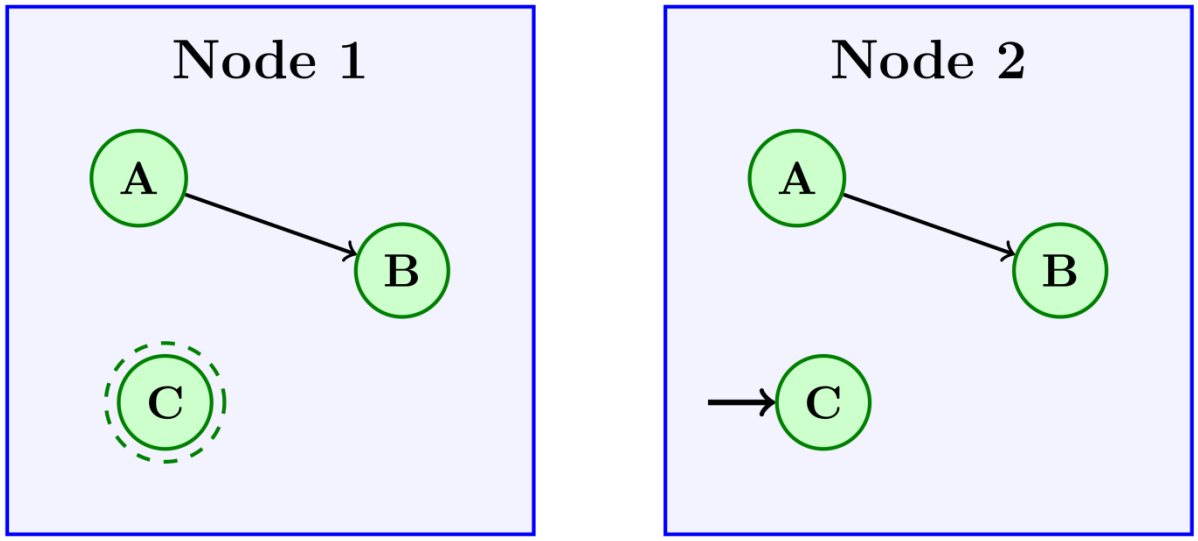

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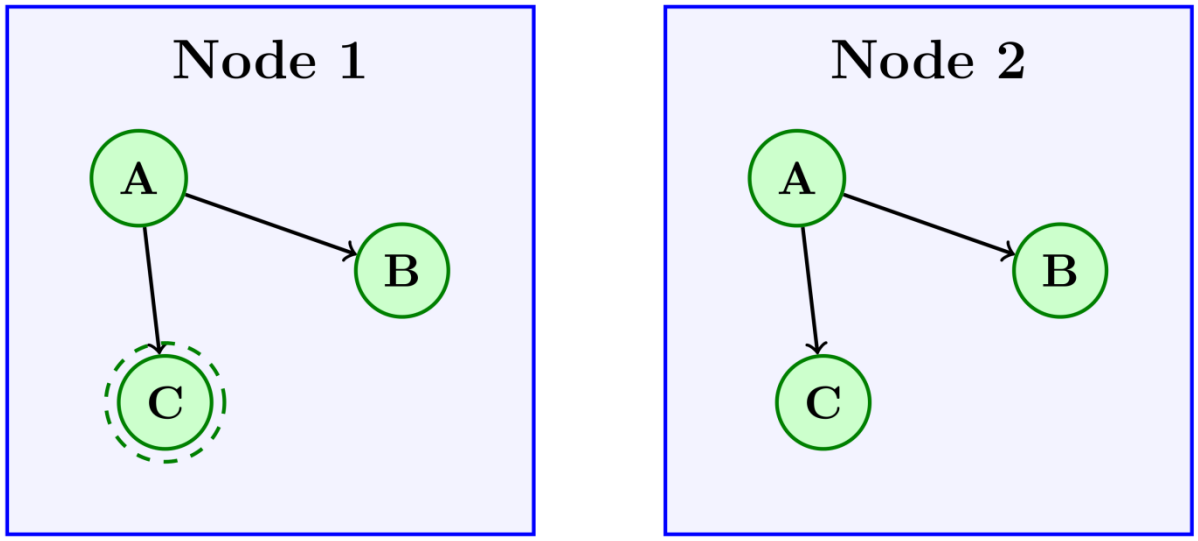

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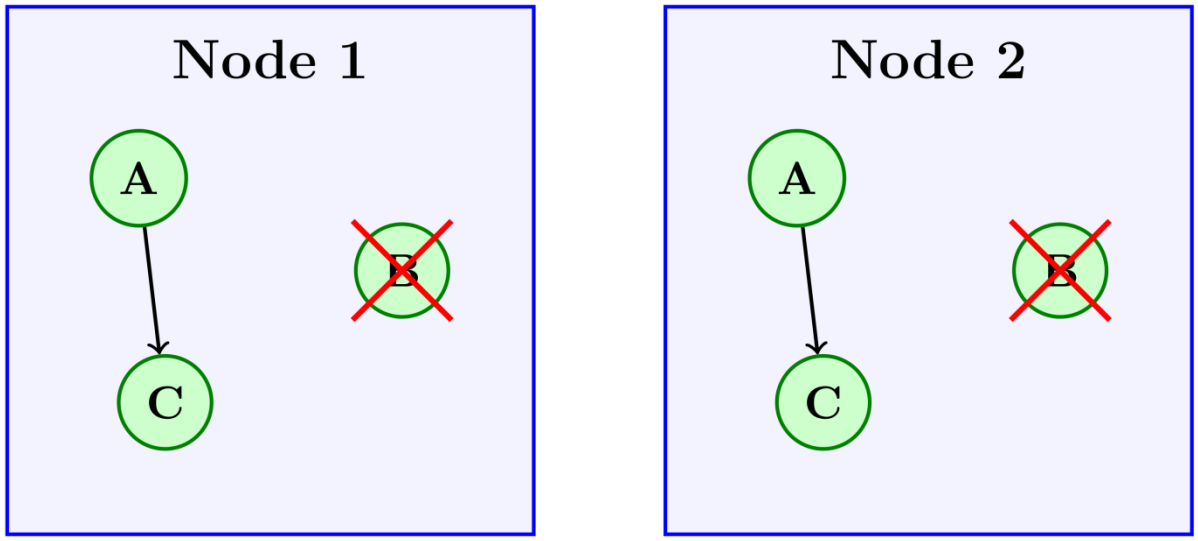

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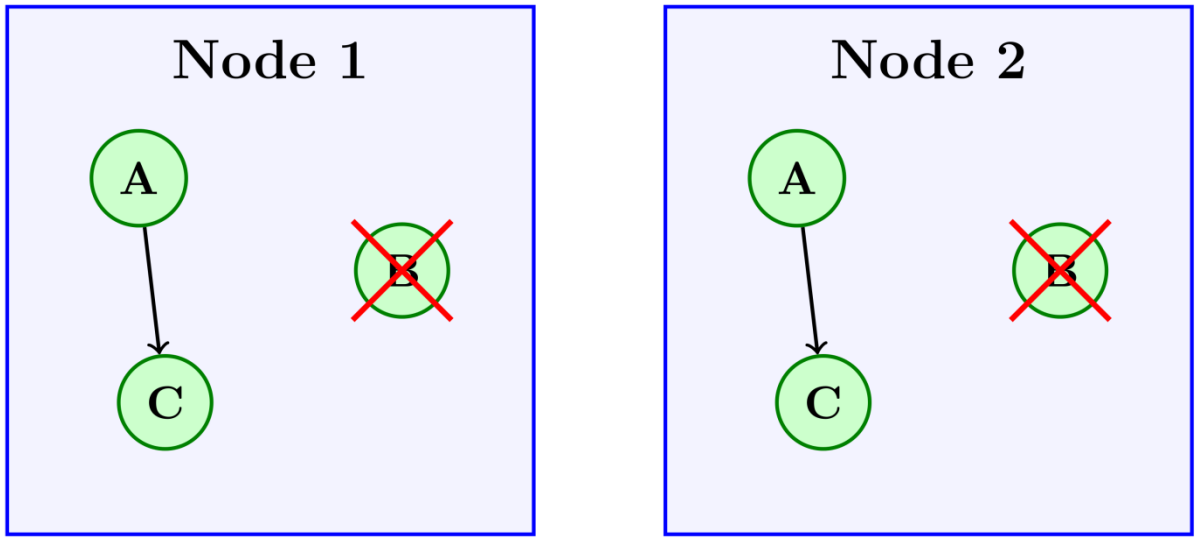


Finally no memory leaks!

Performance consideration

Implementation matters

09/2010

- 1,500 transactions/s [hash] @ 8 nodes
- One version per object
- **Internal locks** for inter-thread synchronization

02/2012

- 150,000 transactions/s [hash] @ 8 nodes
- Added multi-versioning
- **Memory barriers** inter-thread synchronization

No changes to Deferred Update

Concurrency within Paxos STM

- No explicit locks
- Synchronization on memory barriers
- Single writer principle → Cache coherency-friendliness
- **Reader threads – no synchronization overhead**

```
Class Car { ... };
volatile Car root = new Car(„Honda”);

// Thread 1
Car newCar = new Car(„Toyota”);
newCar.next = root;
root = newCar; //memory barrier
```

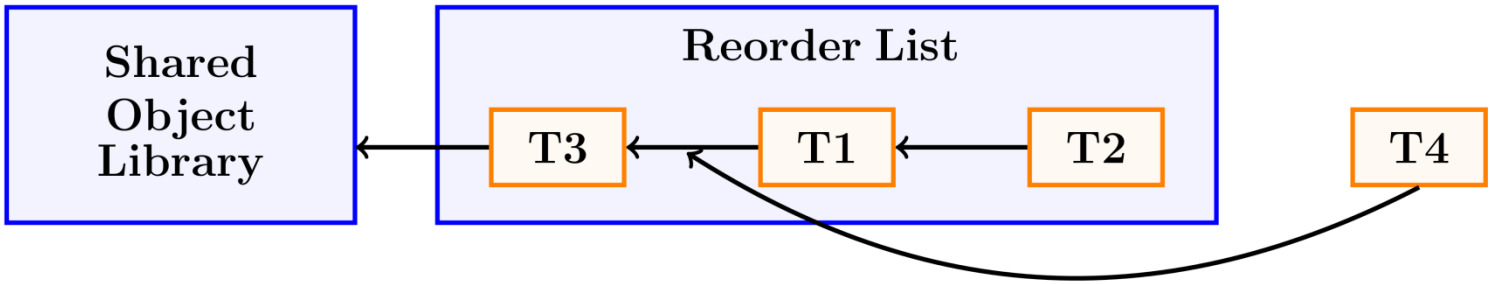
```
// Threads 2..n
Car newestCar = root;
while (newestCar != null) {
  System.out.println(newestCar);
  newestCar = newestCar.next;
}
// Toyota
// Honda
```

Other optimizations

- Abort-free execution of read-only transactions
- JPaxos – Paxos STM binding
- Custom object serialization
- Package size trim
- Heavy code profiling
  - Interface replaced by abstract class
  - Transaction exceptions' handling

Other (mis-)optimizations

- Reorder list



- Nested transactions object lookup index

```
atomic {
    x = 5;
    atomic {
        ...
        atomic {
            y = x;
        }
    }
}
```

Key observation

Performance & scalability

features of the underlying protocol

technical aspects of the implementation

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Performance & scalability

features of the underlying protocol

technical aspects of the implementation

Is the bandwidth the bottleneck?

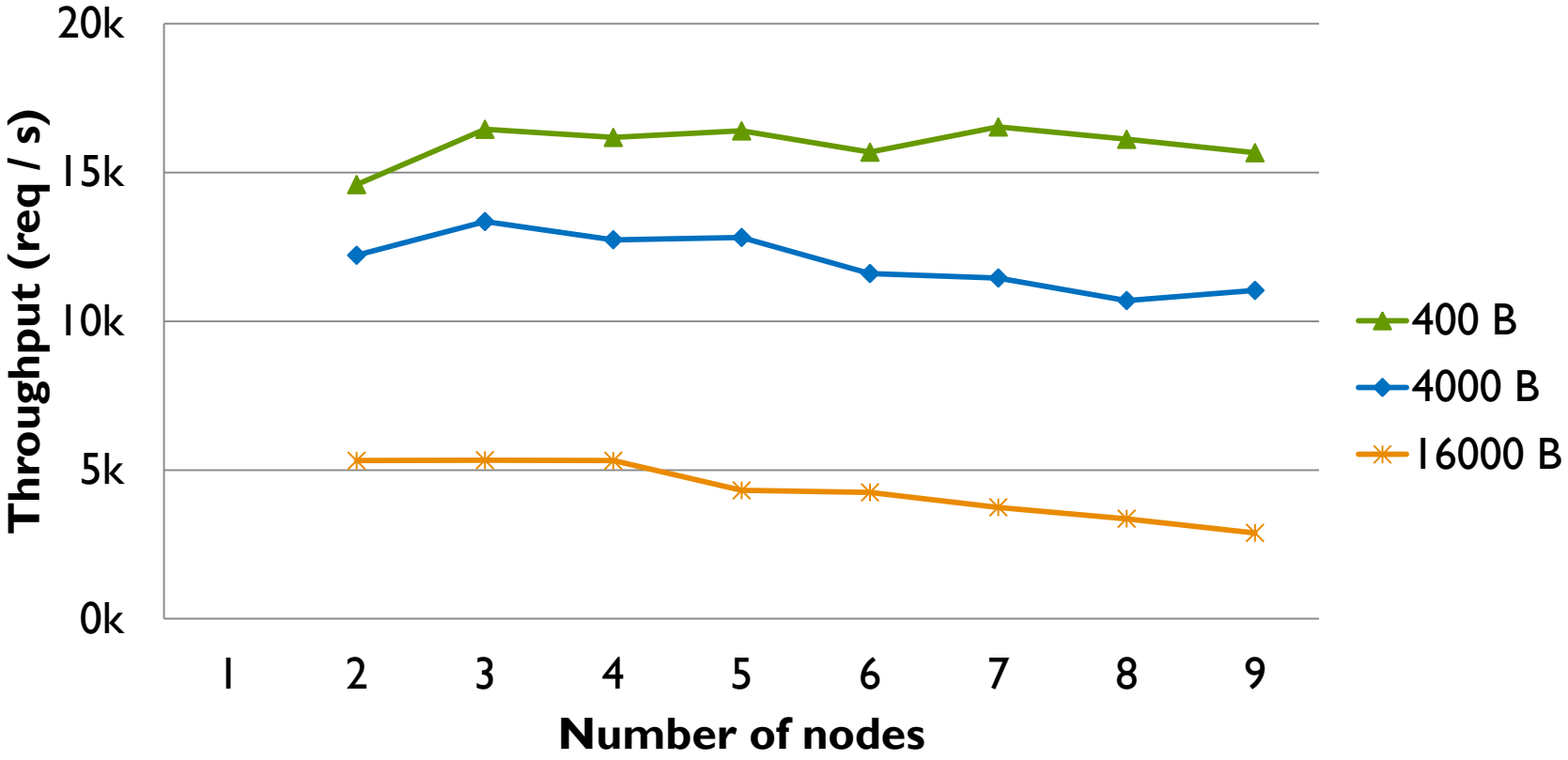
Evaluation

- Environment
  - 9 nodes x (4 x AMD Opteron 6174)
  - 4 x 12 cores @ 2.2GHz, 128KB / 512KB / 12MB cache
  - 192GB RAM
  - Infiniband QDR 32 Gbps
  - Gigabit ethernet
  - CentOS 5.6, OpenJDK 1.6

Evaluation

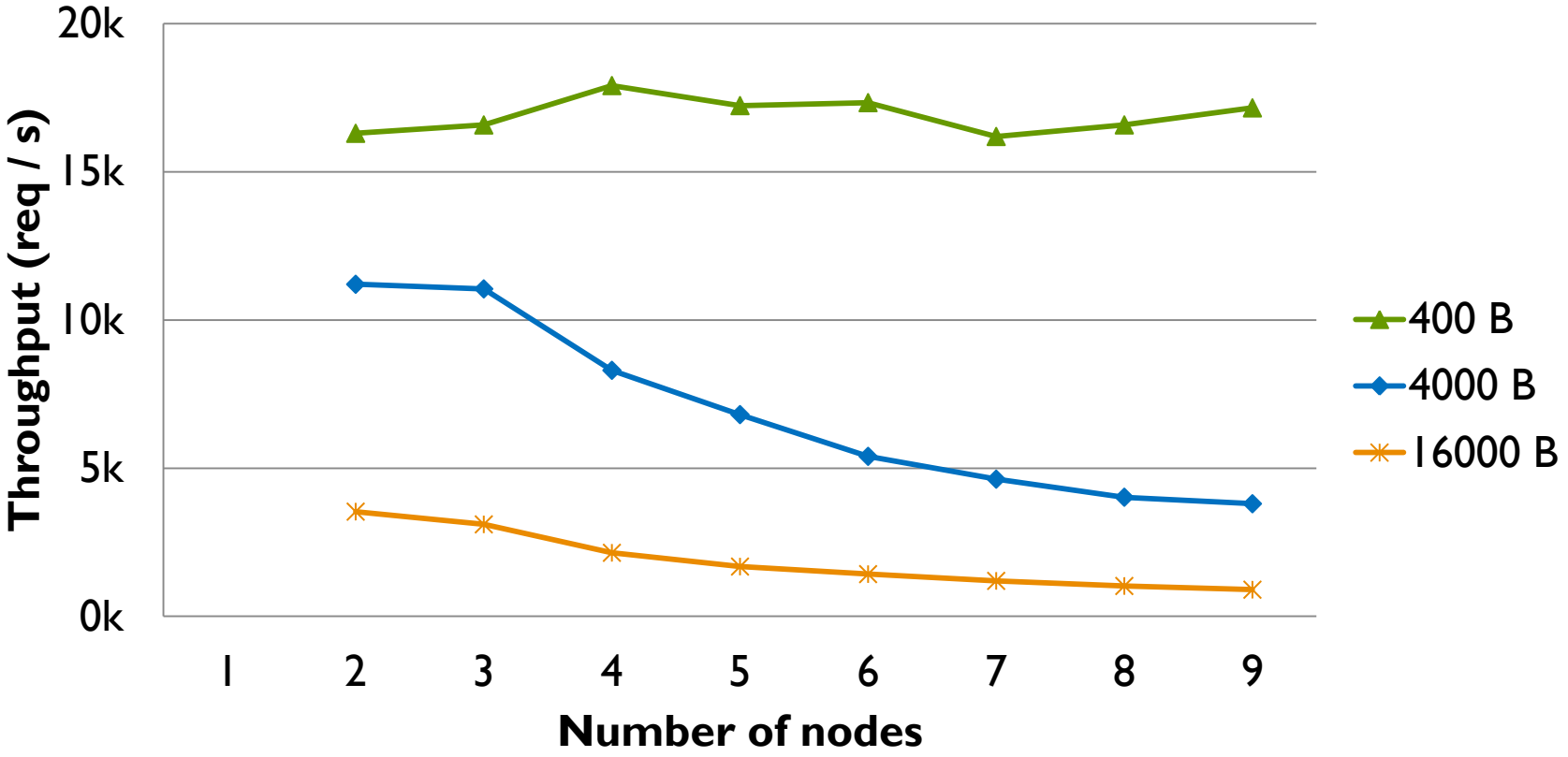
- Number of nodes: 2-9
- Number of threads/node: 48
- Scenarios RO/RW:
  - 90 / 10
  - 50 / 50
  - 10 / 90
- Microbenchmark – replicated hash table
  - Size: 10,000 elements
  - RO transaction – 100 get requests
  - RW transaction – 8 get requests + 2 put/remove request
- Bank benchmark
  - Size: 10,000 accounts
  - RO transaction – scan all the accounts
  - RW transaction – wire transfer between 2 accounts

Base layer – JPaxos (Infiniband)



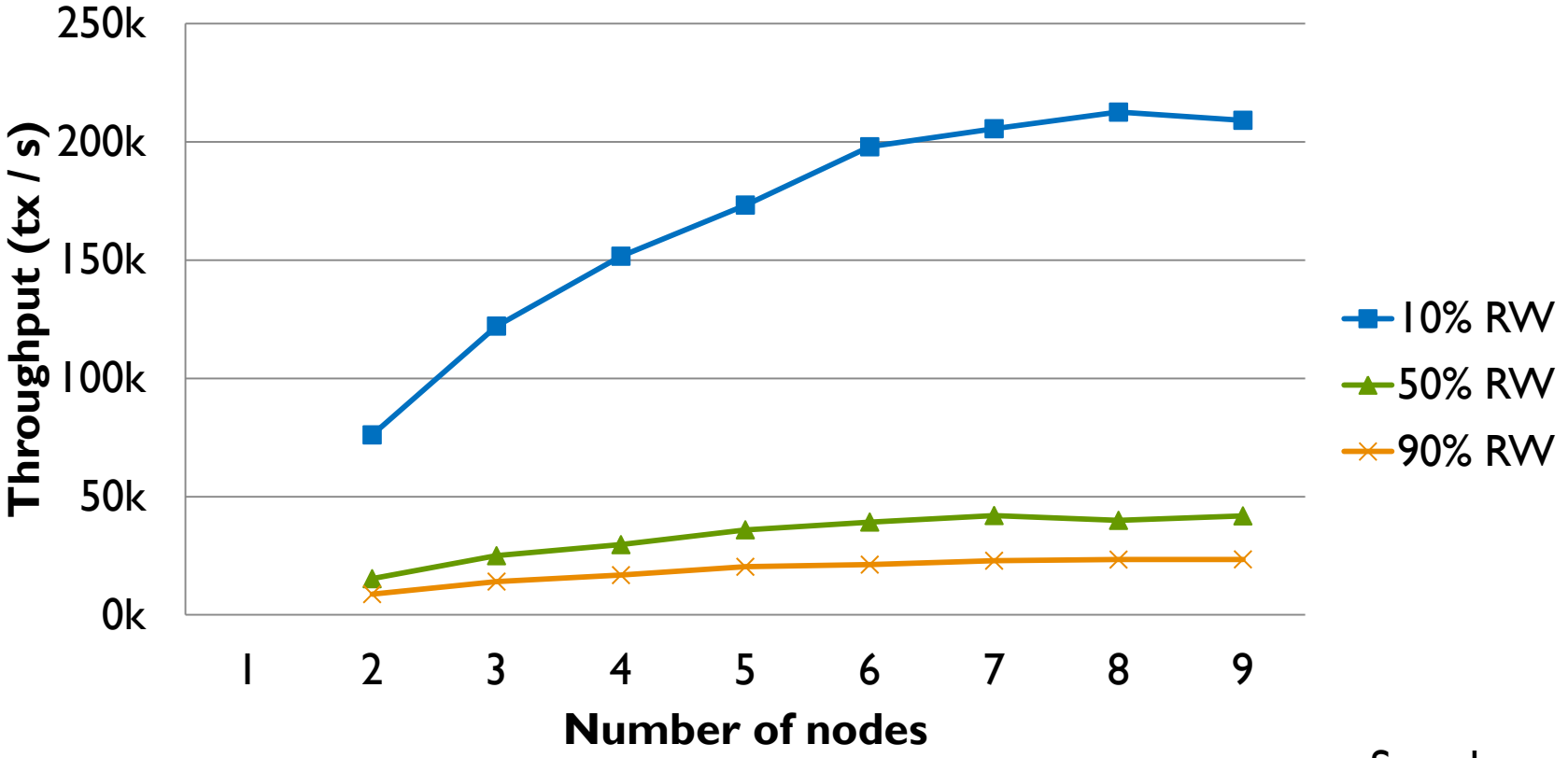
- Bigger the requests lower the throughput
- More nodes → slight performance decrease

Base layer – JPaxos (Gigabit Ethernet)



- Network gets saturated
- More nodes → dramatic performance decrease

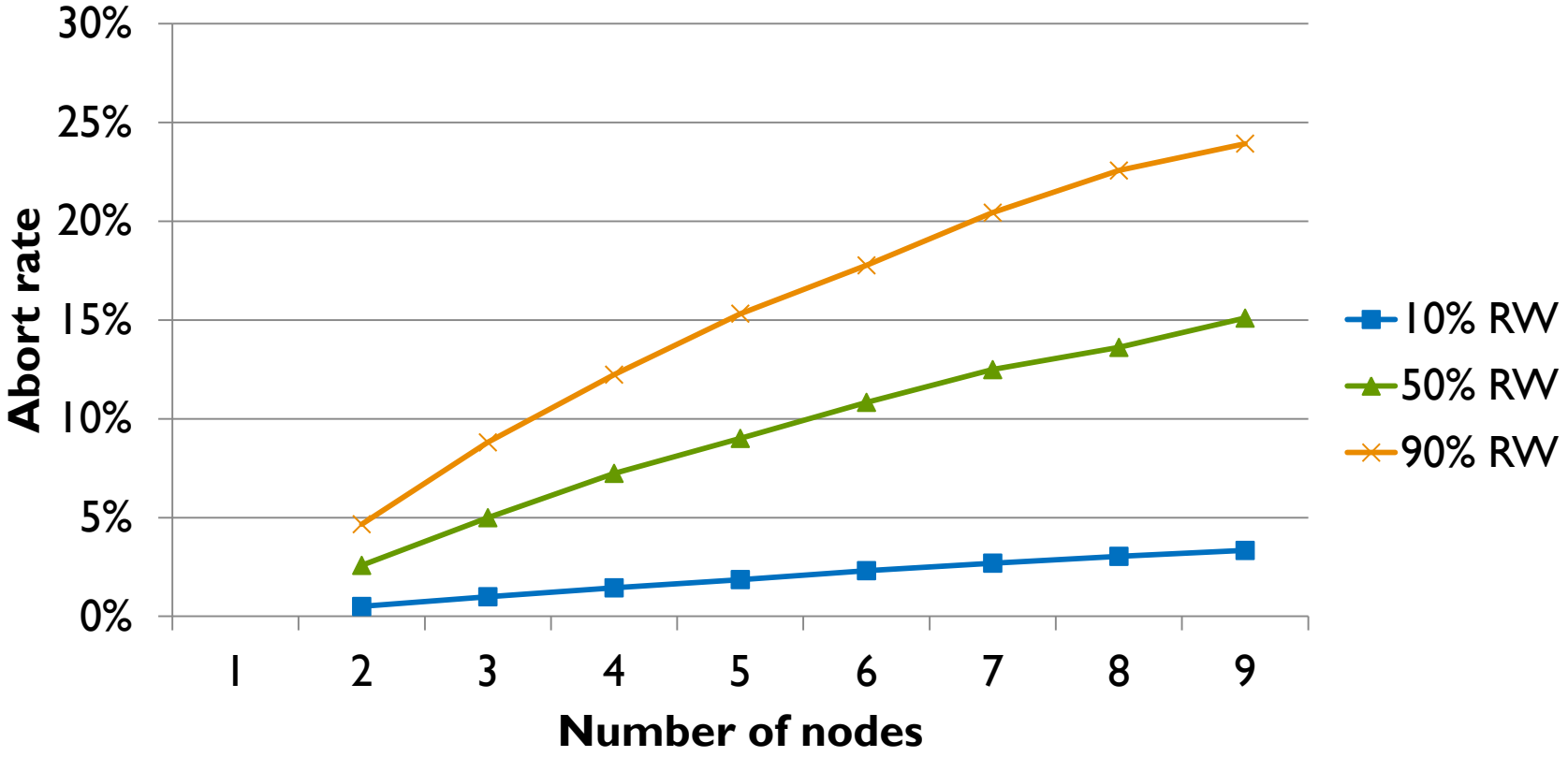
Hash table (Infiniband)



Speedup:
10% - 2.79
50% - 2.74
90% - 2.67

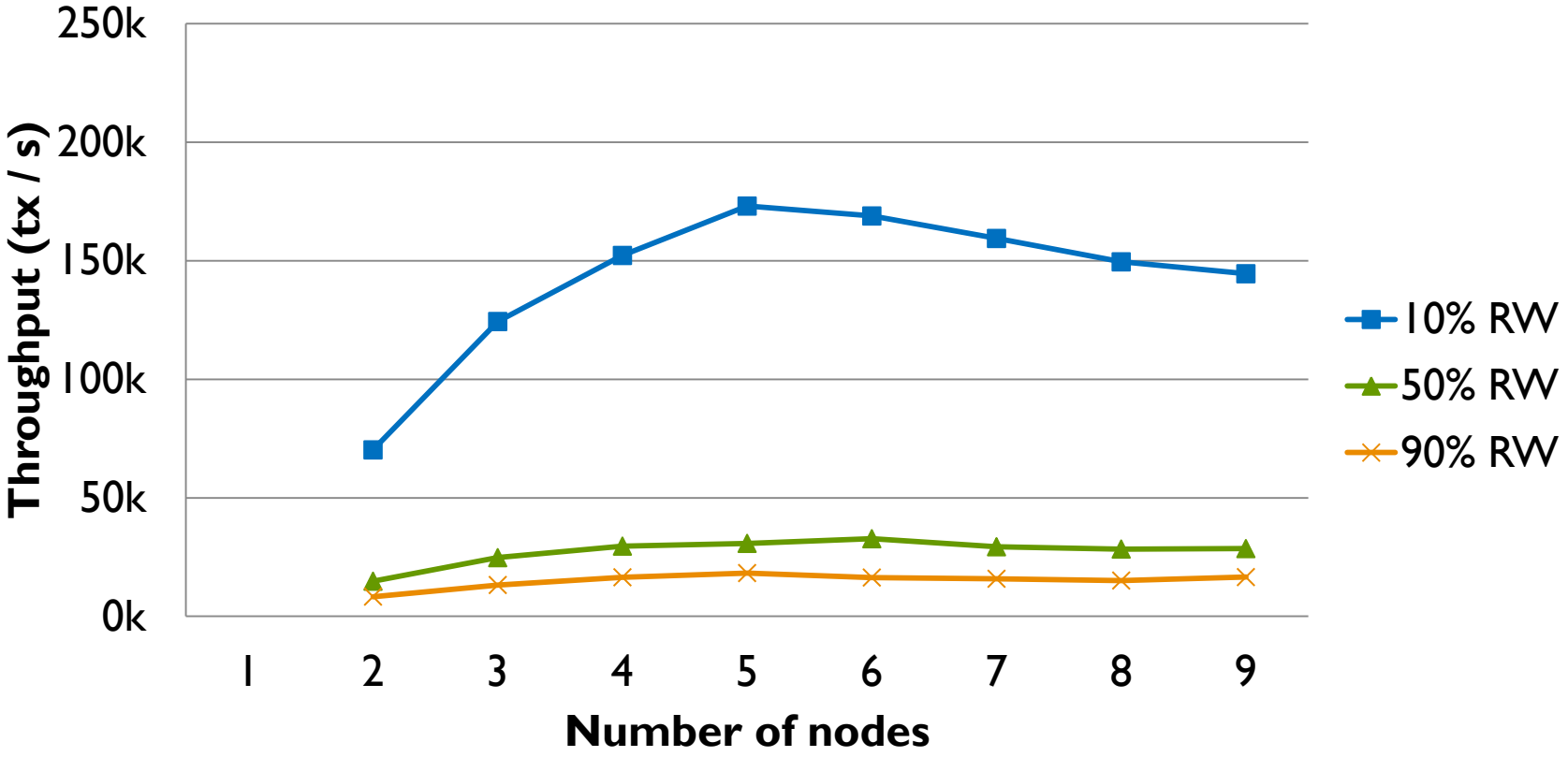
- Top result of 212k tx/s
- All the scenarios scale pretty well

Hash table (Infiniband)



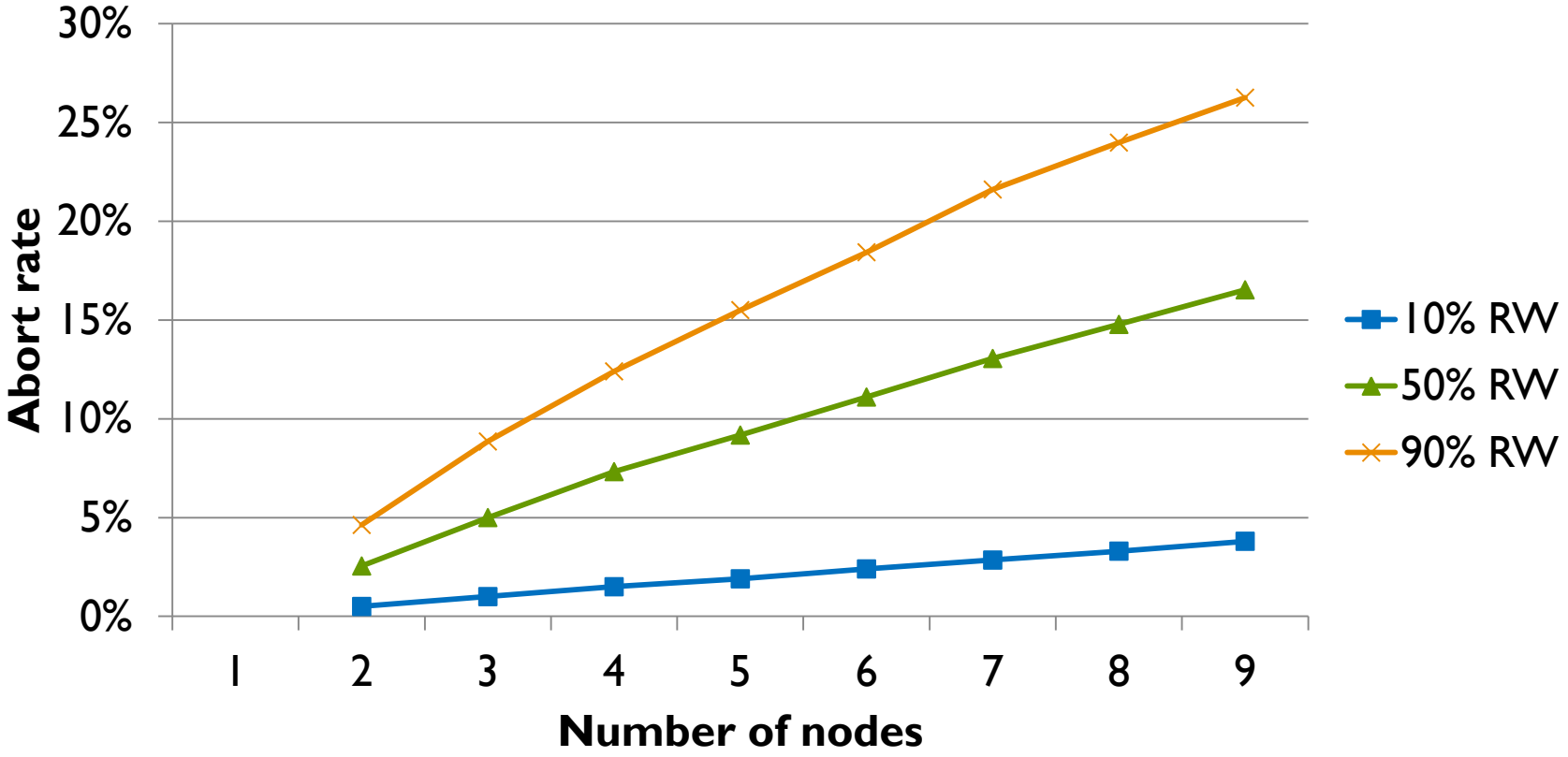
- Abort rate steadily increases with the number of nodes
- High contention (25%) limits scalability

Hash table (Gigabit Ethernet)



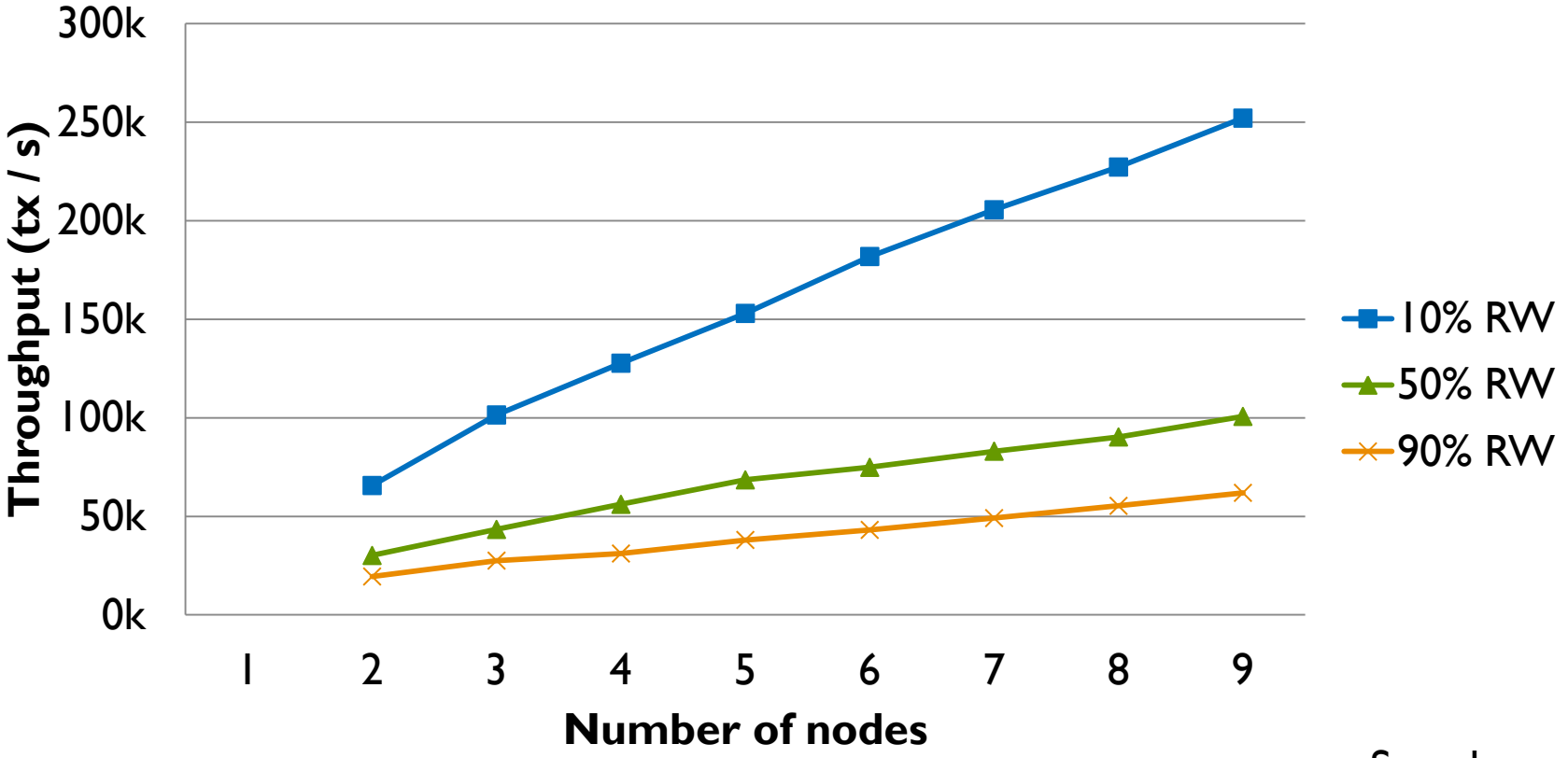
- Nearly identical throughput with up to 5 nodes
- Sudden decrease → limitation of the network interface

Hash table (Gigabit Ethernet)



- The same contention level as with Inifiniband

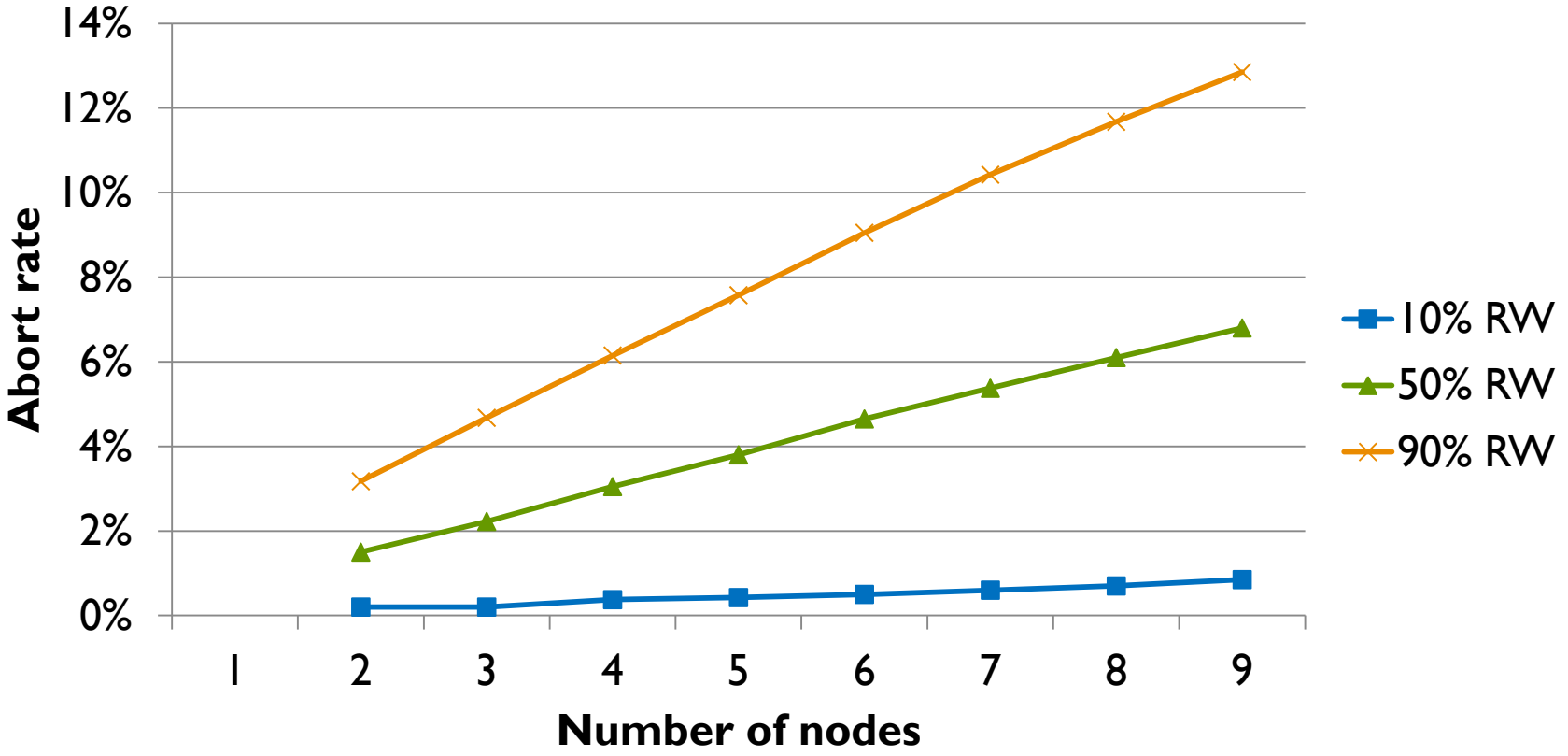
Bank (Infiniband)



- Top result of 252k tx/s
- Perfect scalability

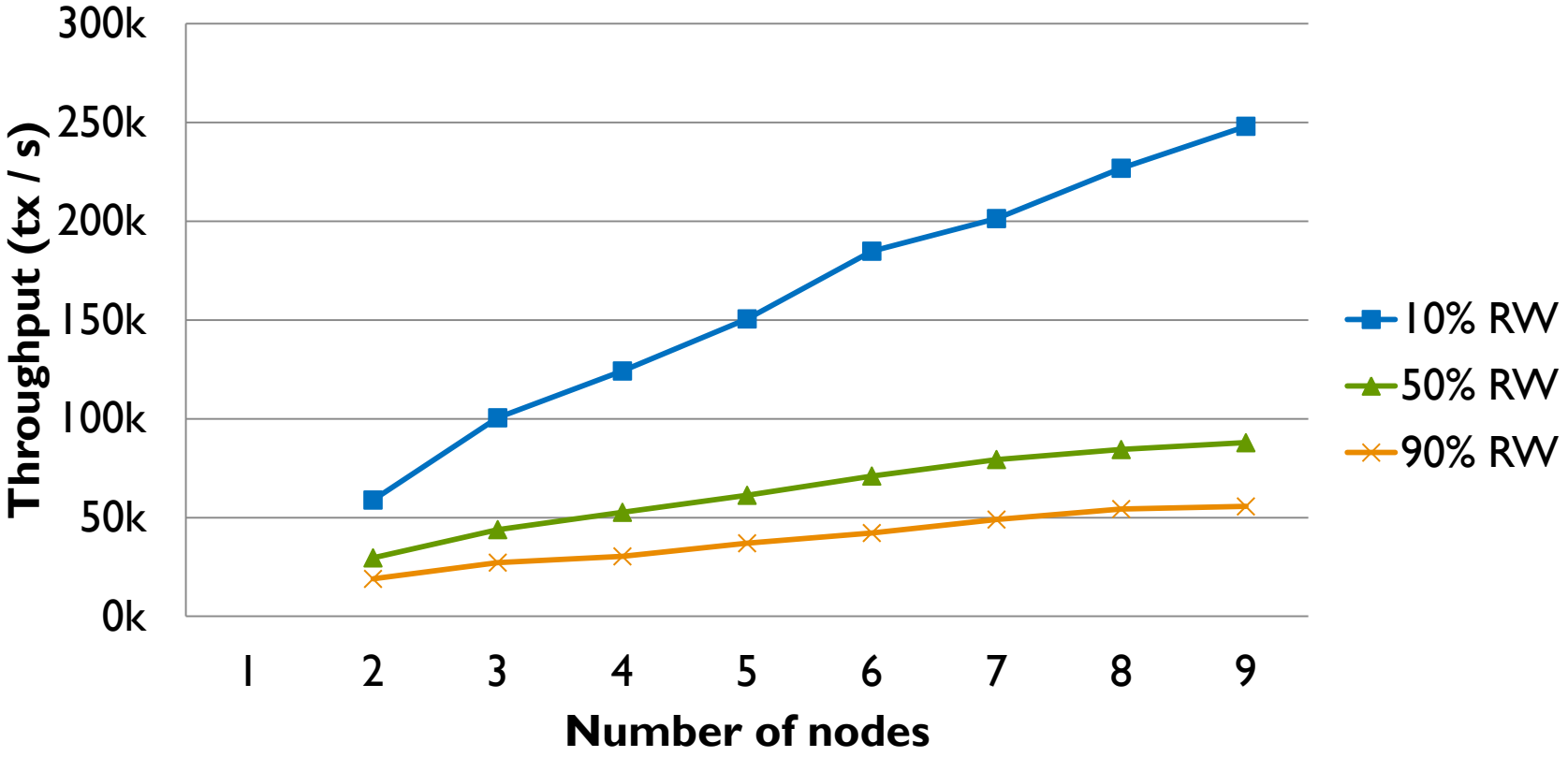
Speedup:
10% - 3.84
50% - 3.34
90% - 3.18

Bank (Infiniband)



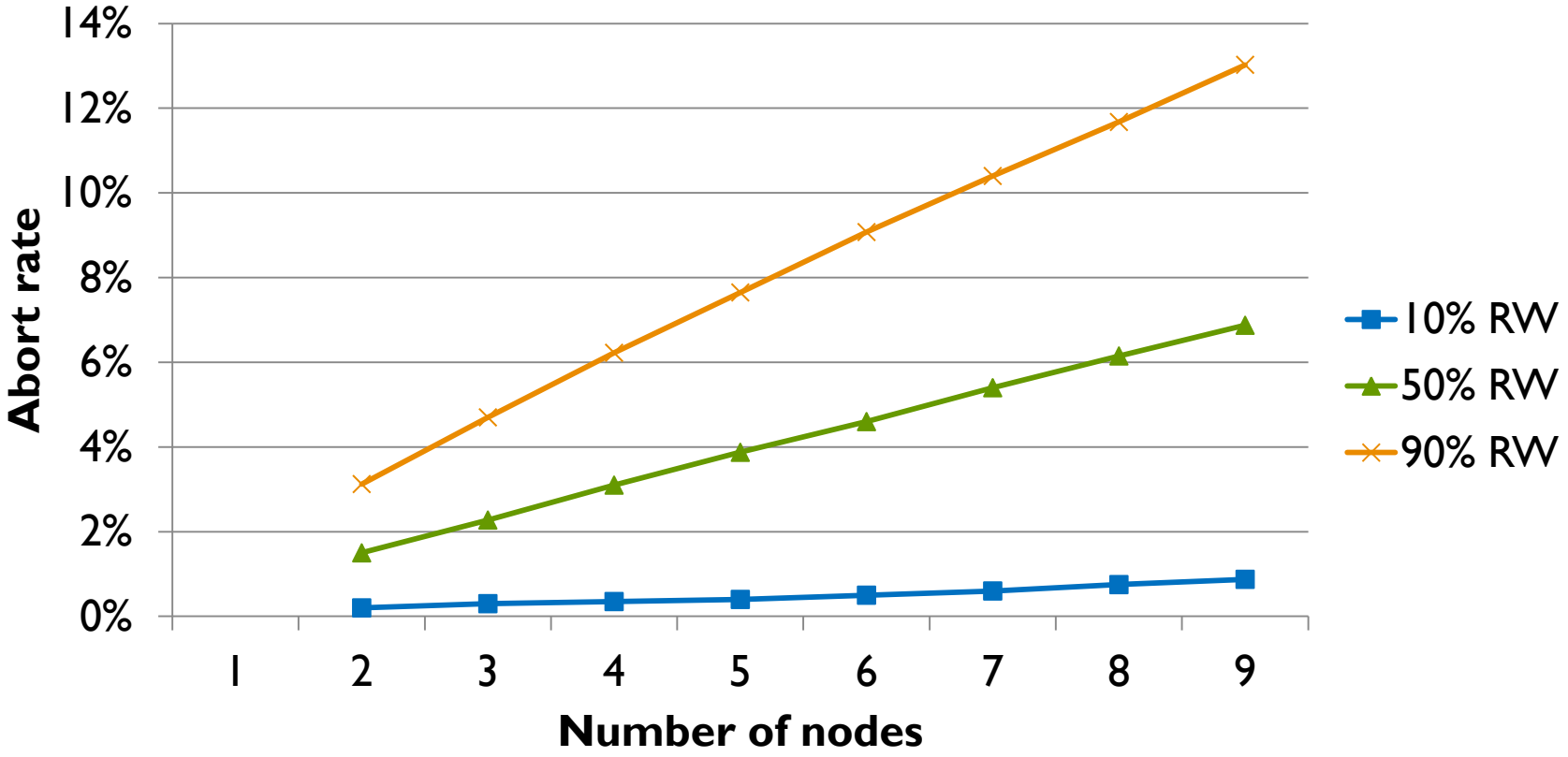
- Lower contention (14%) can be attributed to shorter tx
- No limit to scalability up to 9 nodes (what happens later?)

Bank (Gigabit Ethernet)



- No sudden decrease this time!
- Shorter tx → less data to be exchanged

Bank (Gigabit Ethernet)



- The same contention level as with Infiniband

Conclusions

- Implementation matters
  - Avoid locks!
  - Don't forget about cache
  - Profile your code
- Some techniques work only on paper
- Scalable software for scalable protocols assesment
- Network – the crucial factor

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