Boost + Software Transactional Memory

Boost Library Conference (BoostCon)

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Outline

Purpose

Problem

- The Multicore Revolution
- Mutual Exclusion

Using TM

- **Five Interfaces + Beyond**

Under the Hood

Roadmap to boost::stm

Toward

boost STM

Collaborators

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The Multicore Revolution

And Our Free Lunch

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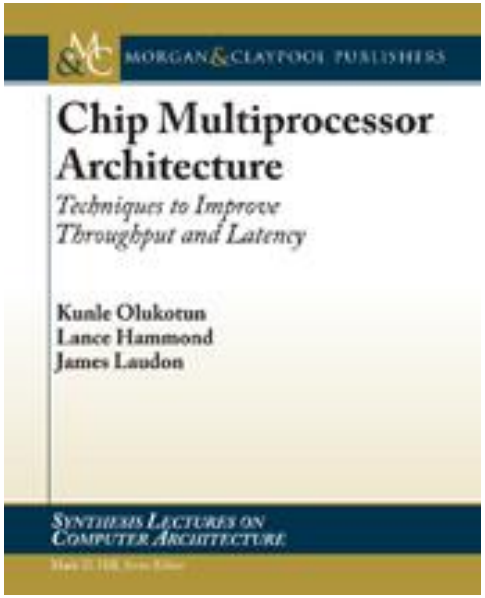
Why Multicore Computers?

Manufacturers could not make uniprocessors faster

Heat dissipation a problem

"Large uniprocessors are no longer scaling in performance ..."



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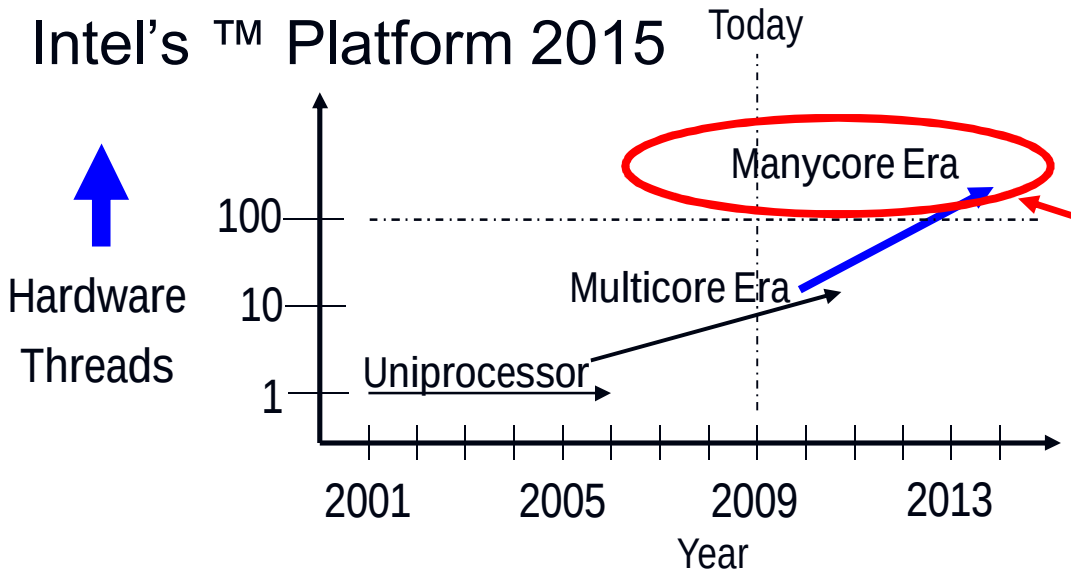
“The Free (Performance) Lunch Is Over”



Going to become more visible

Disadvantages:

- No universal performance benefit like unicore
- ***Only parallel software benefits***

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Parallelizing Code

How do we make software parallel?

- Rewrite code w/ parallel libraries
  - boost::thread, boost::mutex, boost::mpi

So what ***is*** the problem?

- **Conventional parallel programming is very difficult**

Bank Account Problem

Checking account

- Global int **C**
- Controlled by lock **LC**

Savings account

- Global int **S**
- Controlled by lock **LS**

Goal:

- Move $$ checking to savings
- Don't bounce checks!
- ***Atomic Operation?***

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Library Approach: Inconsistent Data

```
void setC(int c)
{
   lock(LC);
   C = c;
   unlock(LC);
}
```

```
void getC(int &c)
{
   lock(LC);
   c = C;
   unlock(LC);
}
```

```
void setS(int s)
{
   lock(LS);
   S = s;
   unlock(LS);
}
```

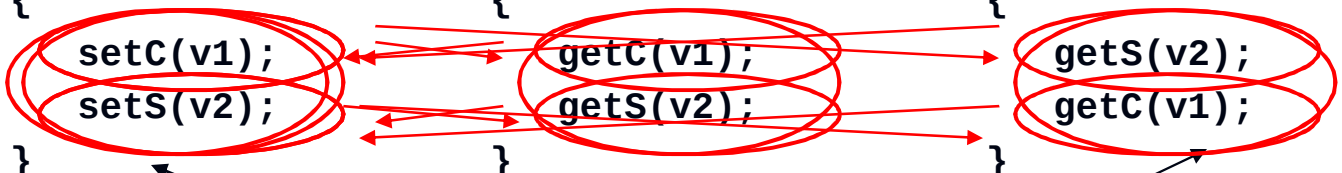
```
void getS(int &s)
{
   lock(LS);
   s = S;
   unlock(LS);
}
```

library interface boundary

```
void setCandS
(int v1, int v2)
{
   setC(v1);
   setS(v2);
}
```

```
void getCandS
(int &v1, int &v2)
{
   getC(v1);
   getS(v2);
}
```

```
void getSandC
(int &v2, int &v1)
{
   getS(v2);
   getC(v1);
}
```



can lead to inconsistent data

Hacker's Approach: Deadlock

```
void setCandS
(int c, int s)
{
  lock(LC);
  lock(LS);
  C = c;
  S = s;
  unlock(LC);
  unlock(LS);
}
```

```
void getCandS
(int &c, int &s)
{
  lock(LC);
  lock(LS);
  c = C;
  s = S;
  unlock(LC);
  unlock(LS);
}
```

```
void getSandC
(int &s, int &c)
{
  lock(LS);
  lock(LC);
  s = S;
  c = C;
  unlock(LS);
  unlock(LC);
}
```

can deadlock

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Composing Parallel Libraries

```
void setC(int c)
{
  atomic(t) {
   t.w(C) = c;
  } end_atom
}
```

```
void getC(int &c)
{
  atomic(t) {
   c = t.r(C);
  } end_atom
}
```

```
void setS(int s)
{
  atomic(t) {
   t.w(S) = s;
  } end_atom
}
```

```
void getS(int &s)
{
  atomic(t) {
   s = t.r(S);
  } end_atom
}
```

Real TBoost.STM Code

```
void setCandS
(int c, int s)
{
  atomic(t) {
    setC(c);
    setS(s);
  } end_atom
}
```

```
void getCandS
(int &c, int &s)
{
  atomic(t) {
    getC(c);
    getS(s);
  } end_atom
}
```

```
void getSandC
(int &s, int &c)
{
  atomic(t) {
    getS(s);
    getC(c);
  } end_atom
}
```

Toward boost STM

Brief Overview of TM

Transactional Memory (TM)

- Optimistic concurrency
- Synchronization: ***transaction***
- Transactions compose
- Generally retried until commit

Transaction (tx): finite set of operations

- Requires **ACI**
  - **Atomic**: all or nothing
  - **Consistent**: only legal memory states
  - **Isolated**: other txes cannot see until committed

Contention Management (CM)

- Mechanism for tx forward progress

Example Transaction and ACI

```
native_trans<int> x = 0, y = 0;

Thread 1                          Thread 2
atomic(t) {                       atomic(t) {
  ++t.w(x);                         --t.w(y);
  --t.w(y);                       ++t.w(x);
} end_atom                        } end_atom
```

Transaction terminated

```
// CM: Thread 1's tx commits, Thread 2's tx aborts

// end state, x = 1, y = -1, atomic all or nothing
// abort if x or y change, ensure consistent
// mid-state, x = 1, y = 0 is isolated
```

TBoost.STM

In Five Interfaces

(And Two Class Templates)

TBoost.STM's native_trans

`native_trans<>`

- Used for all native types
- Arrays ok, not pointers

Examples:

- `native_trans<bool> txBool;`
- `native_trans<float> txFloat;`
- `native_trans<int> txIntArr[100];`

TBoost.STM in Five Interfaces

```
void transaction::initialize()
```

- Initializes STM, always first call

```
void transaction::initialize_thread()
```

- Initializes thread, call per thread before using tx

```
atomic(<transaction name>)
{ <compound> } end_atom
```

- Constructs a transaction object
- Executes <compound> until successful

```
template <typename T> T&
transaction::w(T&)
```

- Perform tx write; returns ref of object to write

```
template <typename T> T const&
transaction::r(T const&)
```

- Perform tx read; returns const ref of object to read

<> = user supplied

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Using native_trans<int>

```
native_trans<int> C = 1000;

int deposit_and_balance()
{
  int c = 100, bal = -1;
  atomic (t)
  {
    t.w(C) += c;
    bal = t.r(C);
  } end_
  return bal;
}
```

Isolated State Captured

Starting State:

- C = 1000
- bal = -1

Ending State:

- C = 1100
- bal = 1100

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Using native_trans<int> []

```
native_trans<int> arr[100];

void read_arr(int out[])
{
  atomic(t) {
    for (int i = 0; i < 100; ++i)
      out[i] = t.r(arr[i]);
  } end_atom
}
void write_arr()
{
  atomic(t) {
    for (int i = 0; i < 100; ++i)
      t.w(arr[i]) = i;
  } end_atom
}
```

Starting State:

- arr = 0, 0, 0, ...

Ending State:

- arr = 0, 1, 2, ...

Note: read_arr()

- Never sees:
  - 0, 1, 2, 0, 0, ...
- Only: 0, 0, 0, ...
- Or: 0, 1, 2, 3, ...

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TBoost.STM's transaction_object

`transaction_object`

- Used for all user-defined types
- Must be default and copy constructable
- Must have callable operator=
- Uses curiously recurring template

Building transaction_object (char*)

```
class str_trans : public transaction_object <str_trans>
{
  char *b_;
public:
   str_trans() : b_(0) {}
   str_trans(str_trans const &rhs) : b_(0) { cp(rhs.b_); }
   str_trans& operator=(str_trans const &rhs)
   { cp(rhs.b_); return *this; }
   void cp(char const *buf)
   {
      delete [] b_; b_ = 0;
      if (0 == buf) return;
      b_ = new char [strlen(buf)+1]; strcpy(b_, buf);
   }
   char const * buf() const { return b_ ? b_ : ""; }
   ~str_trans() { delete [] b_; }
};
```

Toward boost STM

Building transaction_object (char*)

```
using namespace std;
str_trans str;

void read_str(string &s)
{
   atomic(t) {
      s = t.r(str).buf();
   } end_atom
}

void write_str(string const &s)
{
   atomic(t) {
     t.w(str).cp(s.c_str());
   } end_atom
}
```

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Beyond Five Interfaces

How Do We Perform I/O (or Any Irreversible Operation)?

`transaction::make_irrevocable()`

- If fails, throws exception
- Otherwise, ***guaranteed*** to commit

```
void hello_world() {
  atomic(t) {
    write_str((string)
       "hello concurrent world");
    string s; read_str(s);
    t.make_irrevocable();
    cout << s.c_str();
  } end_atom
}
```

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Building lists

```
template <typename T> class list_node :
  public transaction_object< list_node<T> >
{
  list_node *next_;
  T value_;
};

template <typename T> class linked_list
{
public:
  bool lookup(T const &val) const; //assume coded
  bool insert(list_node<T> const &rhs); // new
  bool remove(list_node<T> const &rhs); // del
private:
  list_node<T> head_;
};
```

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new and delete

Do not use **`new`** and **`delete`** for txes!

To create memory

- **`T* new_memory()`**
- **`T* new_memory_copy(T const &rhs)`**

To destroy memory

- **`delete_memory(T &rhs)`**

Building list::insert

```
bool insert(list_node<T> const &rhs) {
   atomic(t) {
      list_node<T> const *headP = &t.r(head_);
      if (NULL != headP->next()) {
         // find location to insert
         list_node<T> *newN = t.new_memory_copy(rhs);
         // set prev, new and next
      } else {
         list_node<T> *newN = t.new_memory_copy(rhs);
         // set head
      }
   } end_atom
   return true;
}
```

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Building list::remove

```
bool remove(list_node<T> const &rhs) {
  atomic(t) {
    // find the item to remove
    if (cur->value() == rhs.value()) {
      // reset pointers
      t.delete_memory(*cur);
      t.end(); return true;
    }
  } end_atom
 return false;
}
```

what does this do?

before_retry

```
atomic(<tx>) { <compound> }
before_retry { <compound> }
```

- before_retry executes before tx is retried
- useful for cleanup
- changing tx priority, CM strategy, etc.

Building algo::move

```
template <typename C> bool algo::move
(C &l1, C &l2, C::node_type const &v)
{
  bool r = false;
  atomic(t) {
    if (l1.lookup(v) && !l2.lookup(v))
    {
      l1.remove(v); l2.insert(v); r = true;
    }
  } before_retry { r = false; }
  return r;
}
```

References and Smart Pointers

Generally, don't do this:

- **`native_trans<int> &x = t.w(X);`**
  - a bad idea
- **`native_trans<int> &x = t.r(X);`**
  - an even worse idea!

Instead, use:

- **`boost::stm::read_ptr(transaction &t, T)`**
- **`boost::stm::write_ptr(transaction &t, T)`**

Problems With Holding References

```
native_trans<int> txInt = 0;

void test_parent() {
  atomic(t) {
    native_trans<int> &tx = t.r(txInt);
    if (0 == tx) test_nested();
    cout << tx << endl;
  } end_atom
}

void test_nested() {
  atomic(t) { ++t.w(txInt); } end_atom
}
```

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Use read_ptr

```
native_trans<int> txInt = 0;

void test_parent() {
  atomic(t) {
    read_ptr< native_trans<int> >
      tx(t, txInt);
    if (0 == *tx) test_nested();
    cout << *tx << endl;
  } end_atom
}
void test_nested() {
  atomic(t) { ++t.w(txInt); } end_atom
}
```

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Use write_ptr

```
native_trans<int> txInt = 0;

void test_parent() {
  atomic(t) {
    write_ptr< native_trans<int> >
      tx(t, txInt);
    if (0 == *tx) test_nested();
    cout << ++*tx << endl;
  } end_atom
}
void test_nested() {
  atomic(t) { ++t.w(txInt); } end_atom
}
```


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Under the Hood:

Fast Synrchonization

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Optimistic Concurrency

Pessimistic concurrency (locks)

- Critical section limited to single thread

Optimistic concurrency (transactions)

- Unlimited threads can execute critical section
- Truly optimistic concurrency
  - Simultaneously ***conflicting*** critical section execution
  - ***Not supported by all TMs***

Important aspects

- Consistency checking
- Updating policies

Consistency Checking

Consistency checking

- Process to verify state of transaction is consistent
- ***Inconsistency:*** $C_w \cap (I_w \cup I_R) \neq \emptyset$

Validation

- Each memory location has version #
- When committing
  - tx verifies version # is same
  - increments version for writes

Invalidation

- No version #s used
- When committing
  - abort txes reading/writing mem its writing

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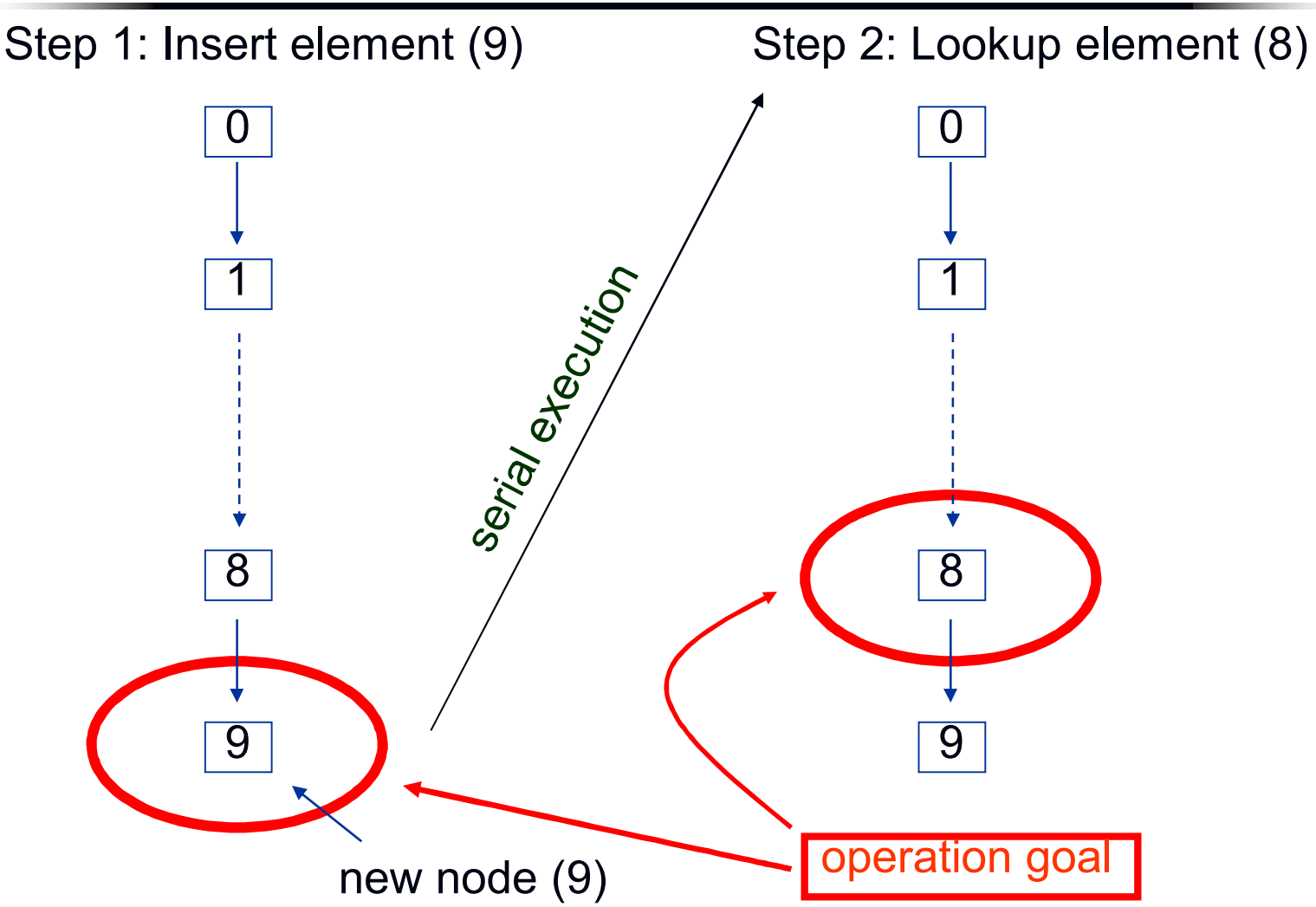
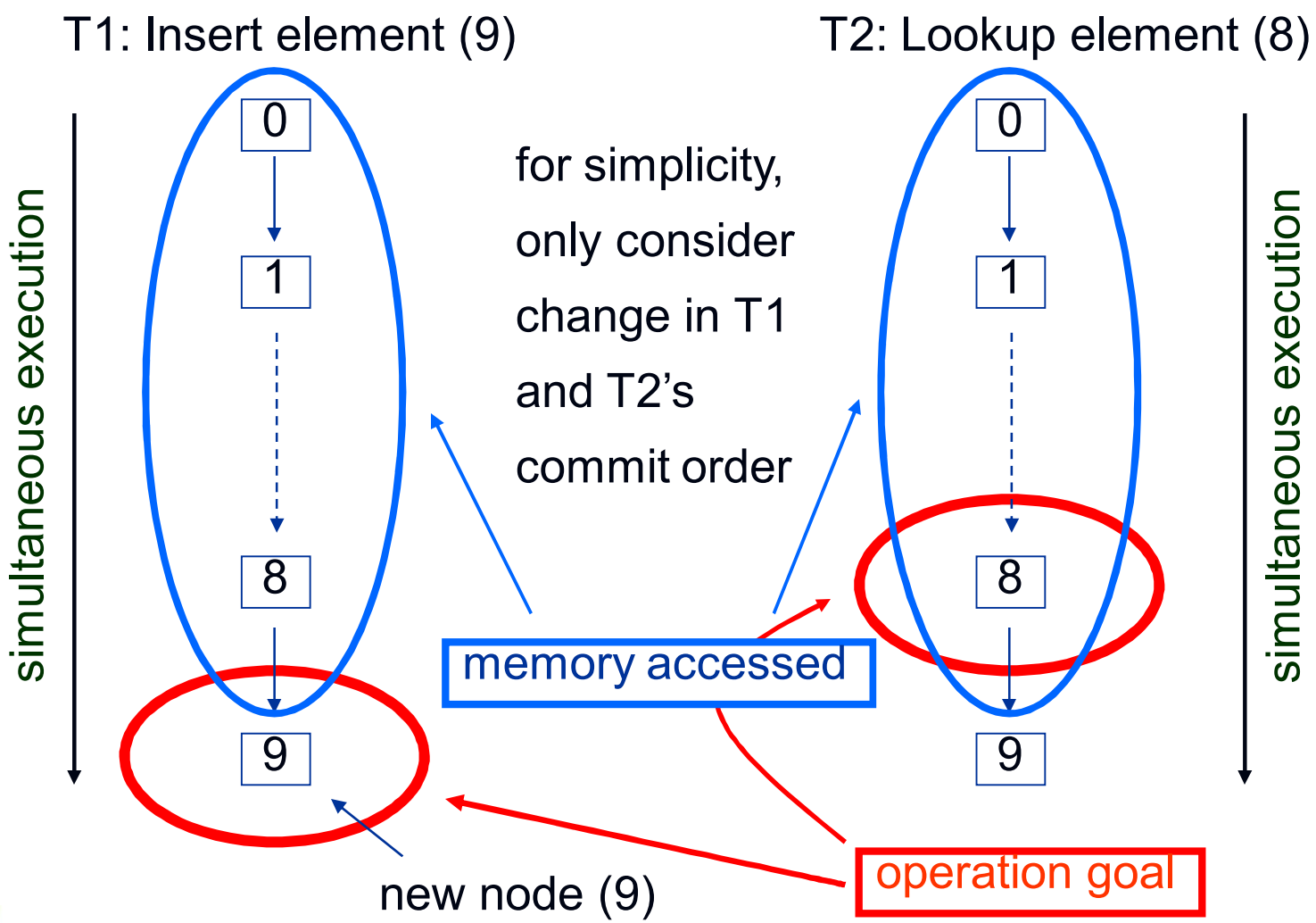
Linked List (Pessimistic)



Linked List (Optimistic)



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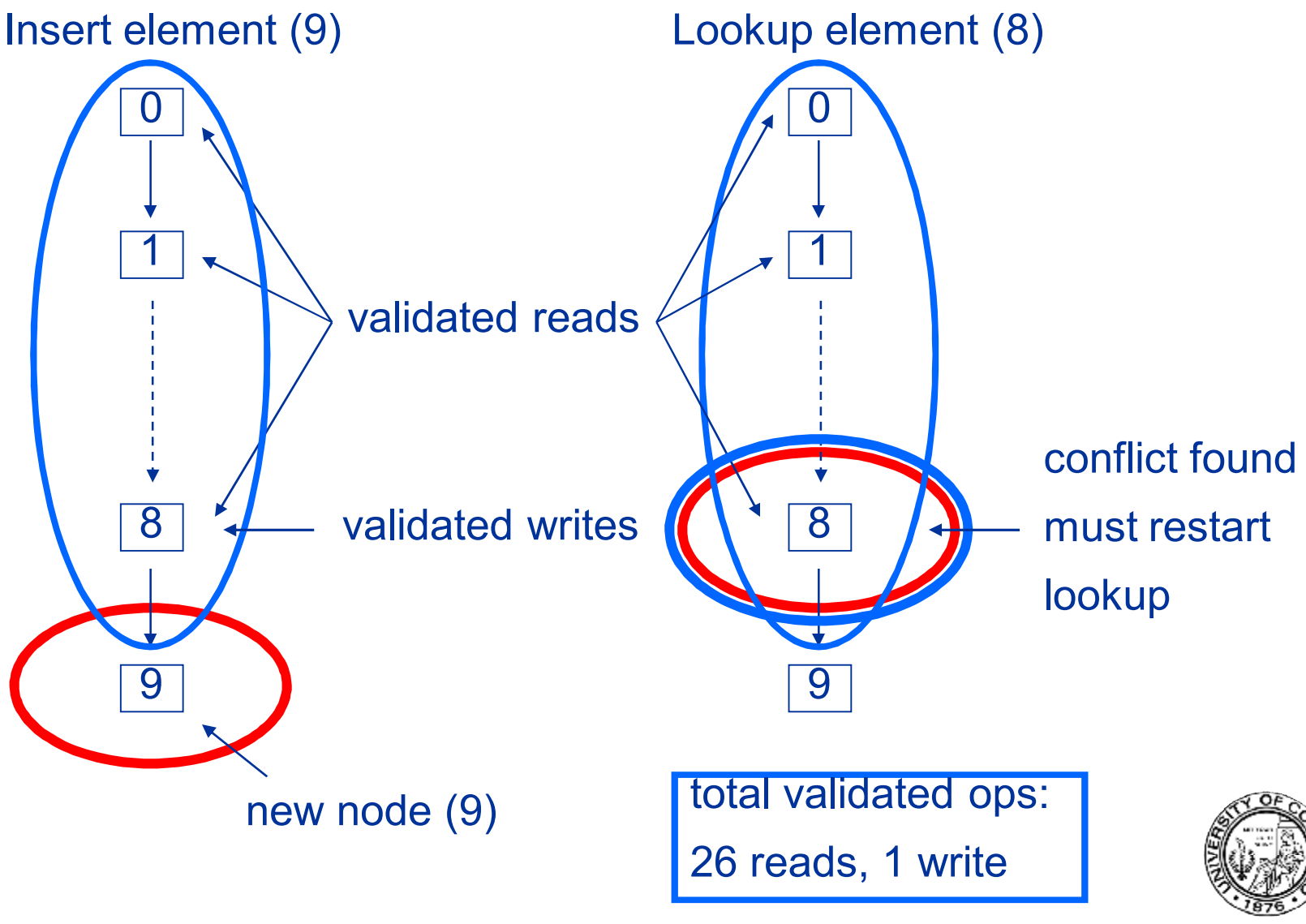
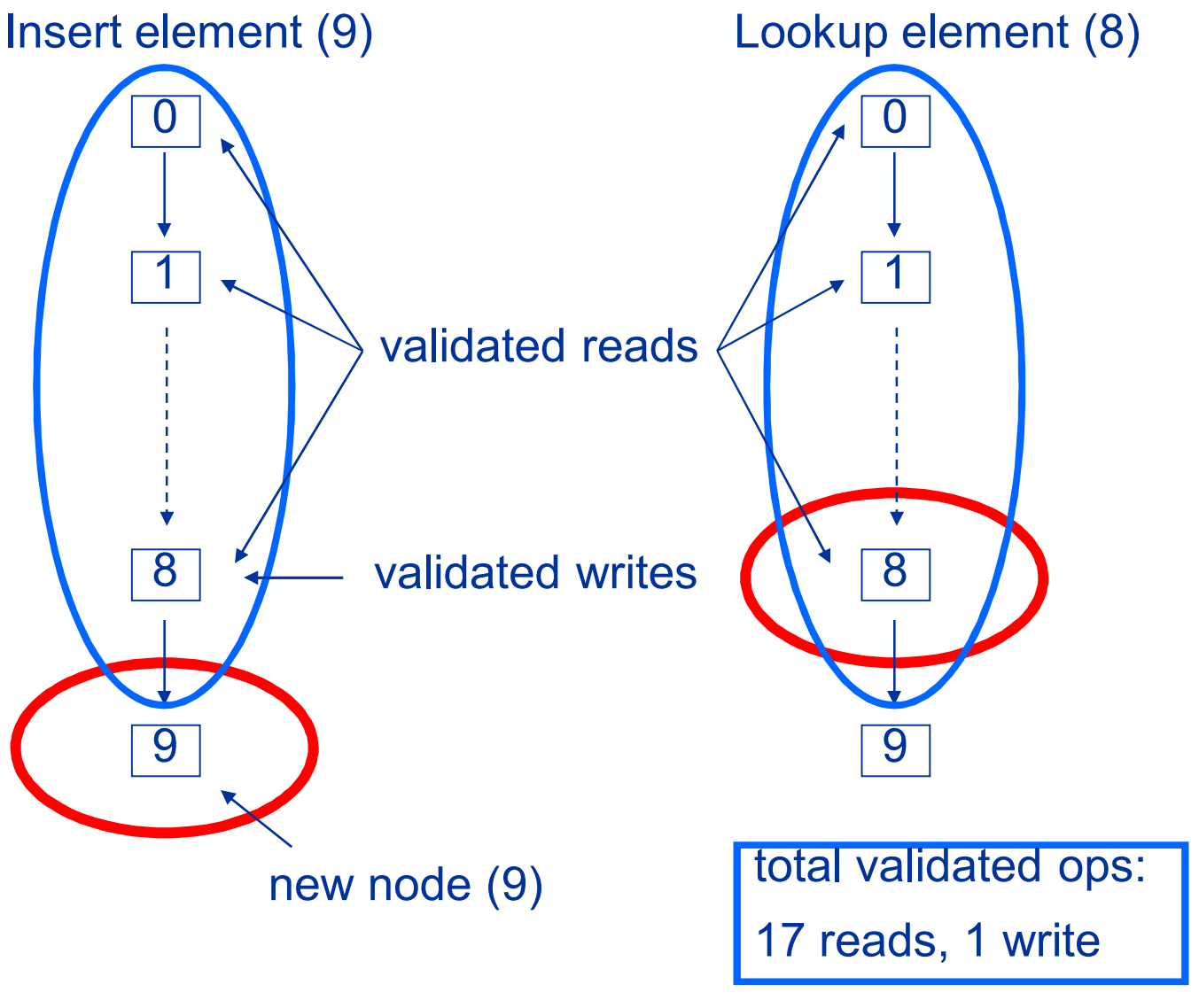
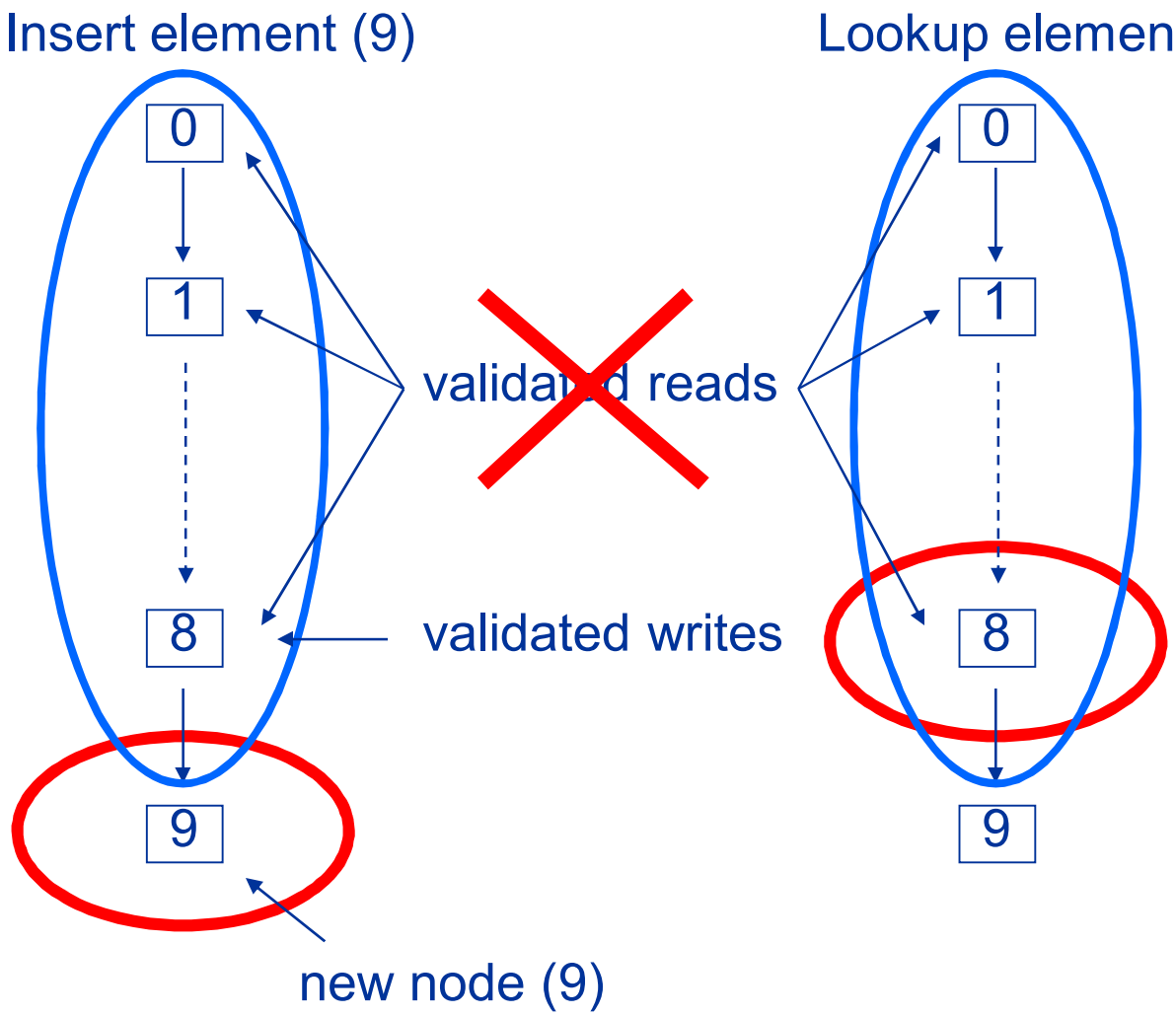
Validation – Insert, Lookup



Validation – Lookup, Insert



Invalidating Linked List



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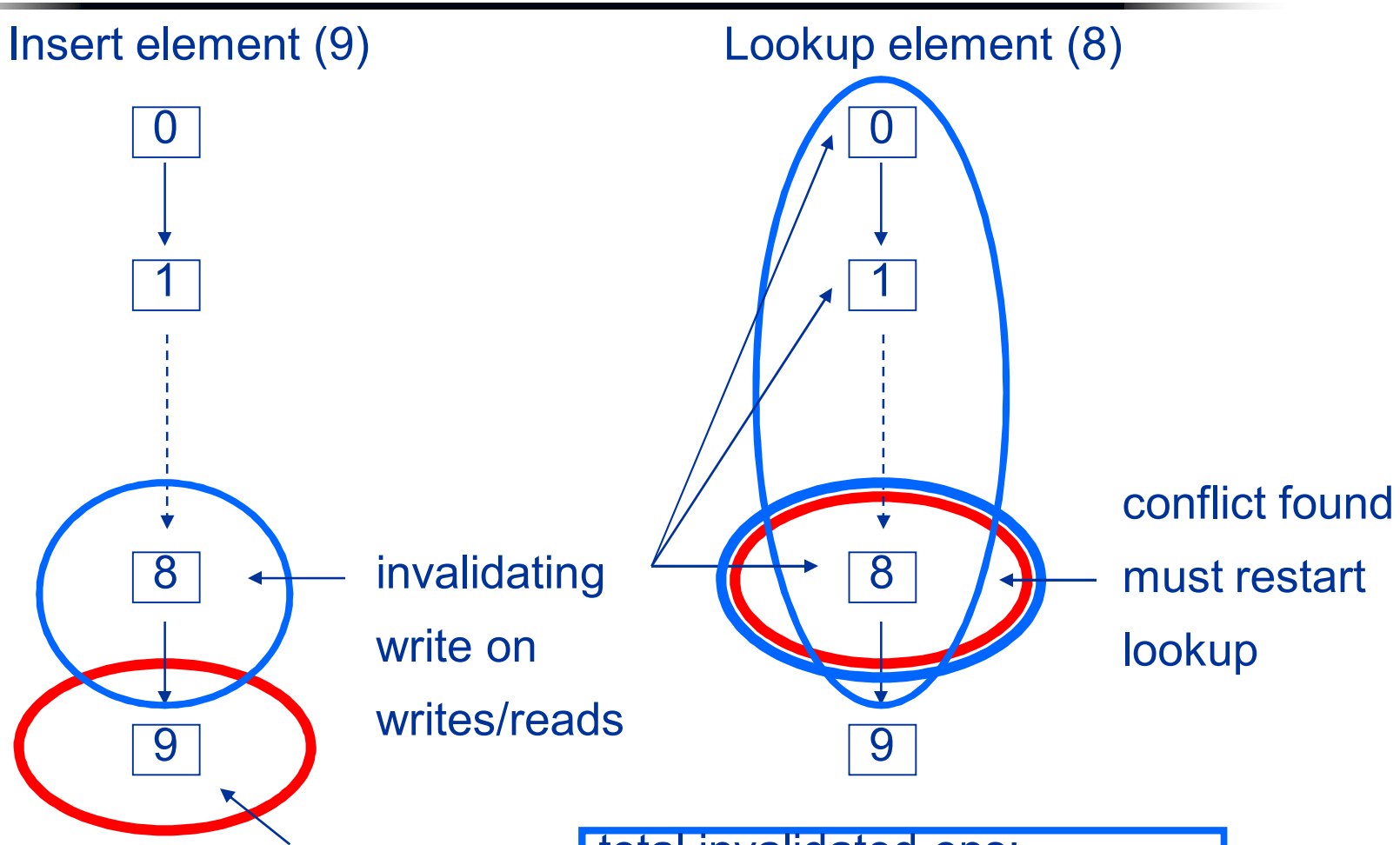
Invalidation – Insert, Lookup



total invalidated ops:
9 reads unopti, 3 reads opti

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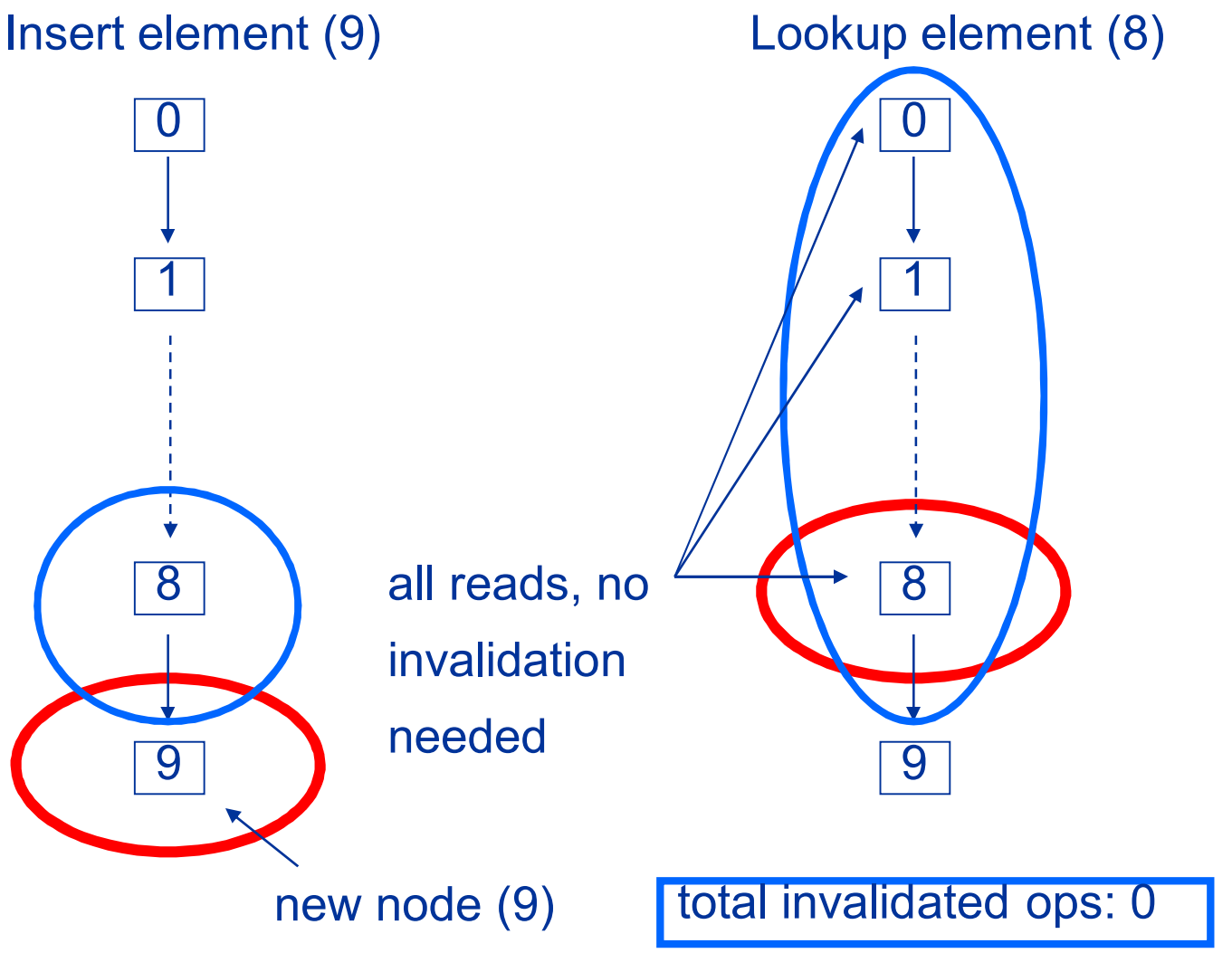
Invalidation – Lookup, Insert



Consistency Checking

Validation

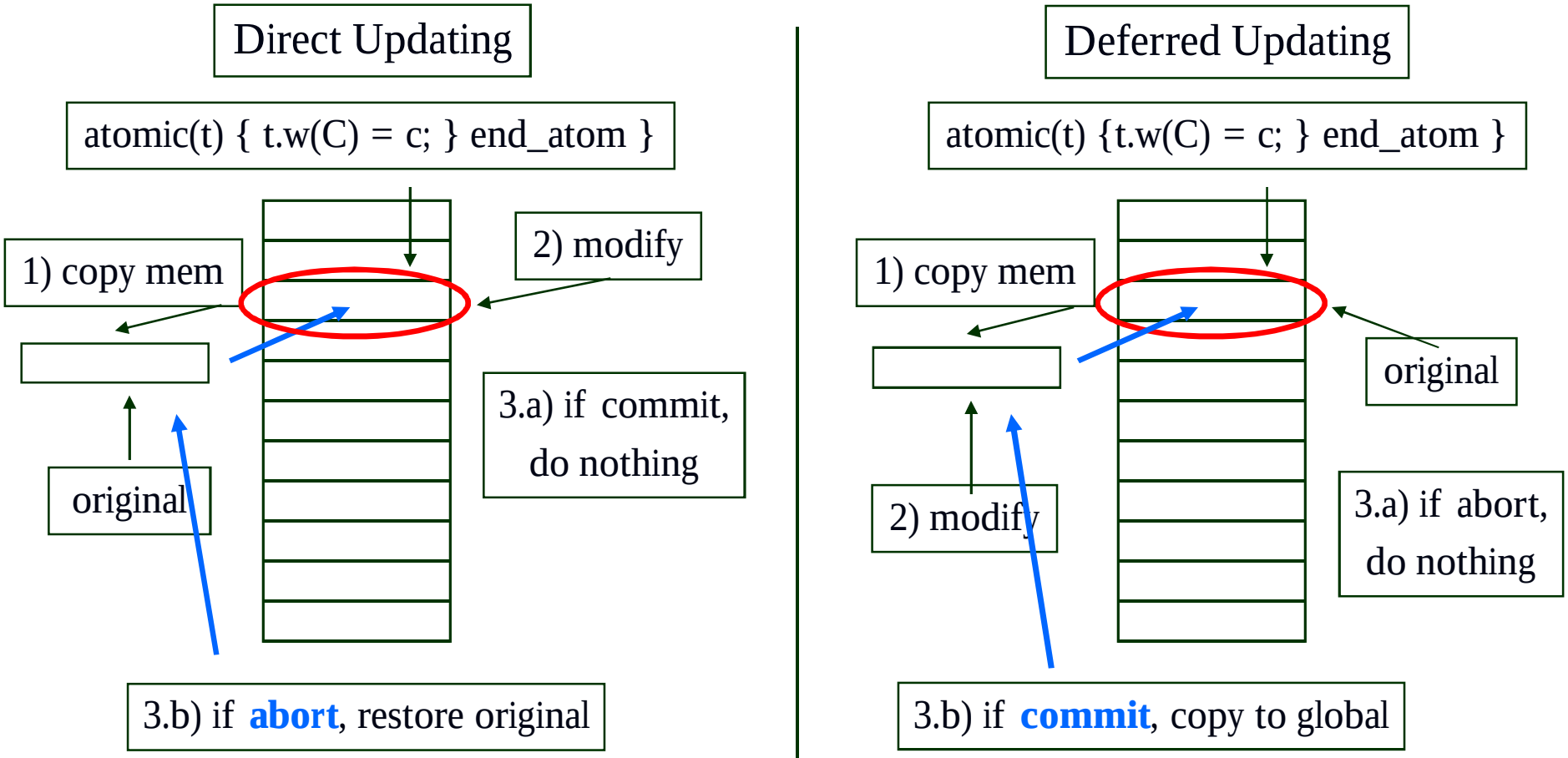
- Great for short txes with many threads

Invalidation

- Great for long txes with fewer threads
- Great for read-dominated workloads
  - Mathematically optimal for read-only txes

TBoost.STM supports both

Updating Policies



Updating Policies

Direct Updating

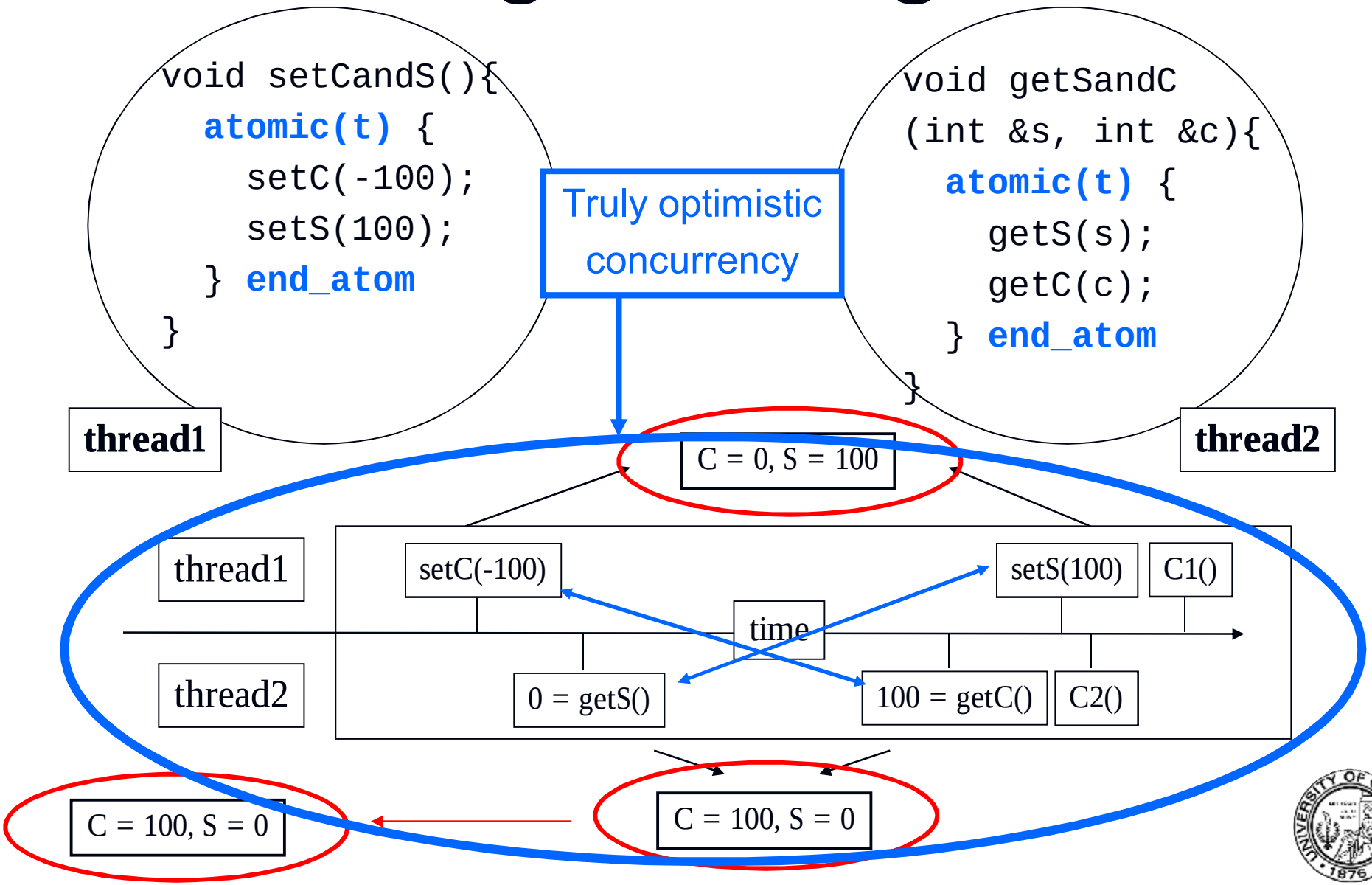
- Advantages
  - fast commit
  - early writer conflict detecti
- Disadvantages
  - single writer per mem
  - speculative contention management

Deferred Updating

- Advantages
  - fast abort
  - **truly** optimistic
  - time
  - detection
  - (no speculation)
- Disadvantages
  - slow commit

TBoost.STM supports both

Putting It All Together



Consistency and Updating in TBoost.STM

Consistency

- #define PERFORM_VALIDATION 1
- #define PERFORM_VALIDATION 0

Updating

- transaction::do_deferred_updating()
- transaction::do_direct_updating()

More Optimizations

TBoost.STM v.0.2

- Competitive with TL2 (state-of-the-art STM)
- +***10x faster*** than DracoSTM v.0.1
- Downloadable from website / boost-sandbox

Roadmap to boost::stm

... And The Big Open Problems

Toward boost STM

TBoost.STM + Boost

Code in Boost sandbox

Identify necessary interfaces

- Future extensions key to success
- Discussion with Boost community

Goal: review of **boost::stm v1.0** early 2010

TBoost.STM + Research

Transactions + locks + others

- Implementation and formal semantics

Efficiency

- Transactional boosting, open nesting, etc.

Test Suites

- Integrate with STAMP, STMBench7
  - ***STMBench7 researchers helping us now***

And much more ...

Parallel Computing Publications

Shifting the Parallel Programming Paradigm (Best Presentation Award) [Raytheon Information Systems and Computing (ISaC), March 2009]

Lock-Aware Transactional Memory [ACM International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS), March 2009]

Optimizing Consistency Checking for Memory-Intensive Transactions [ACM Symposium on Principles of Distributed Computing (PODC), August 2008]

C++ Move Semantics for Exception Safety and Optimization in Software Transactional Libraries [International Workshop on Implementation, Compilation, Optimization of Object-Oriented Languages, Programs and Systems (ICOOOLPS), July 2008]

Extending Contention Managers for User-Defined Priority-Based Transactions [ACM Workshop on Exploiting Parallelism with Transactional Memory and other Hardware Assisted Methods (EPHAM), April 2008]

DracoSTM: A Practical C++ Approach to Software Transactional Memory [ACM Symposium on Library-Centric Software Design (LCSD), October 2007]

Exploration of Lock-Based Software Transactional Memory [MS Thesis, 2007]

Questions?

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