# Programmazione concorrente

Laurea Magistrale in Ingegneria Informatica
Università Tor Vergata
Docente: Romolo Marotta

# Transactional Memory

**Synchronization approaches:**

- **Non-blocking data structures**
- **Locks**
- **Transactional Memory**

# Transactional Memory

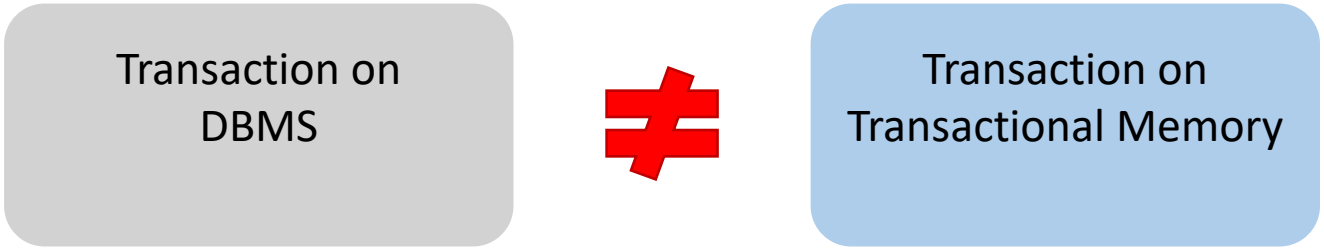
- Why?
  - Fine grain locking (or non-blocking synchronization) can scale but it is hard
  - Locks do not scale in general, but they are hard too:
    - Deadlocks
    - Races (forgotten locks)
    - Do not compose
- Transactions:

```
Begin_transaction
    x.op()
    y.op2(k)
    z.op(j)
End_transaction
```

  - They compose (e.g. nested transactions)
  - Simpler to reason about

# Transactions

- Well known in the context of databases
- Conceived integration of transaction in hardware (1993)
- Software implementations (1995-2005)
- Commercial hardware support (2013)

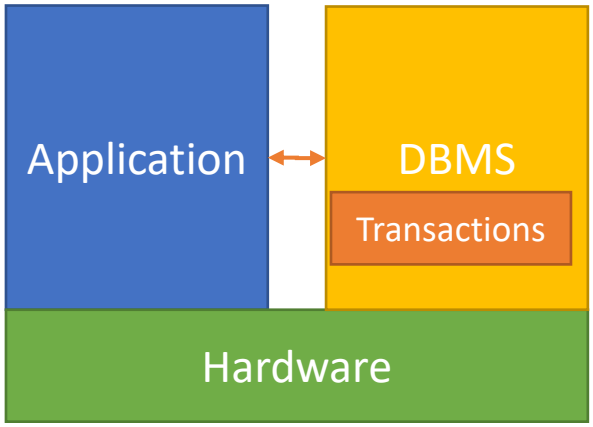


# Transactions

Transaction on top of DBMS

≠

Transaction on top of Transactional Memory




```
x = 2; y = 1
Begin:
    d = x
                                Begin:
                                    y++
                                    x++
                                Commit
    n = y
    write(z, 1/(n-d))
Abort
```

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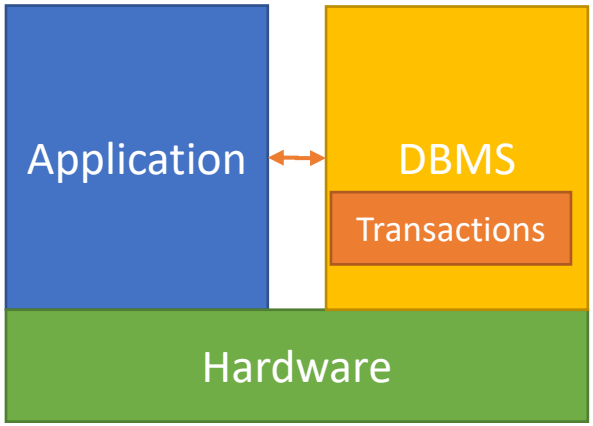


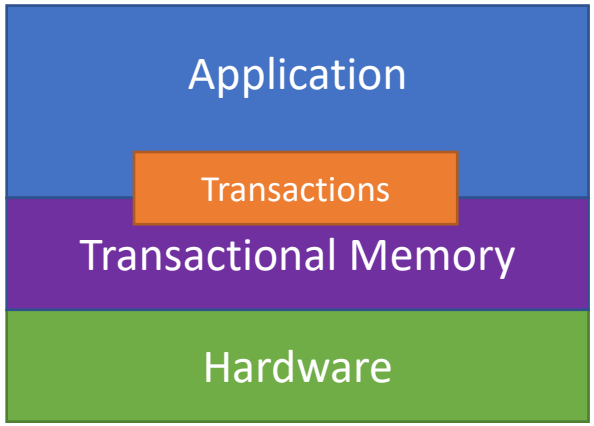


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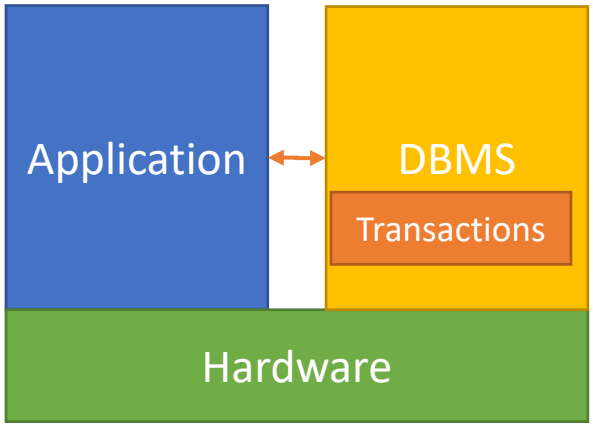


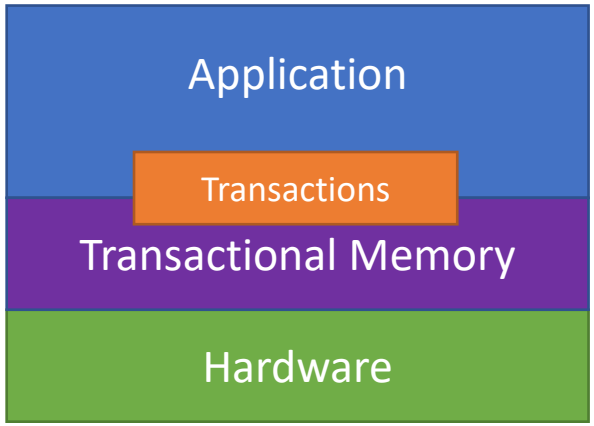


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Managed by DBMS instead of developers

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Begin:
    y++
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Float Exceptions are not transparent to developers

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# Transactions

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**Committed** transactions see consistent values

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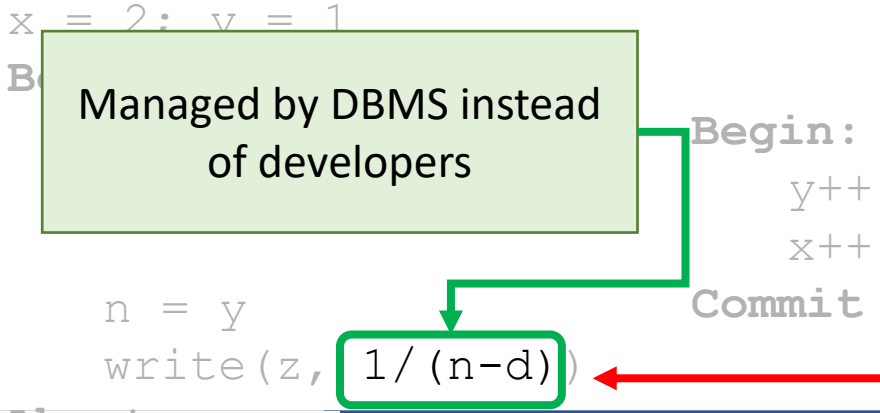


# Histories

- The execution of transaction on a set of objects is modeled by a history
- A history is a sequence of:
  - Operations (e.g., read, write, push, pop …)
  - Commits
  - Aborts
- Two transactions are:
  - **sequential** if one invokes its first operations after the other one commits or aborts
  - **concurrent** otherwise
- A history is:
  - **sequential** if has only sequential transactions
  - **concurrent** otherwise
- Two histories are equivalent if they have the same transactions

# Correctness conditions (recall)

- A **concurrent execution** is correct if it is equivalent to a correct **sequential execution**

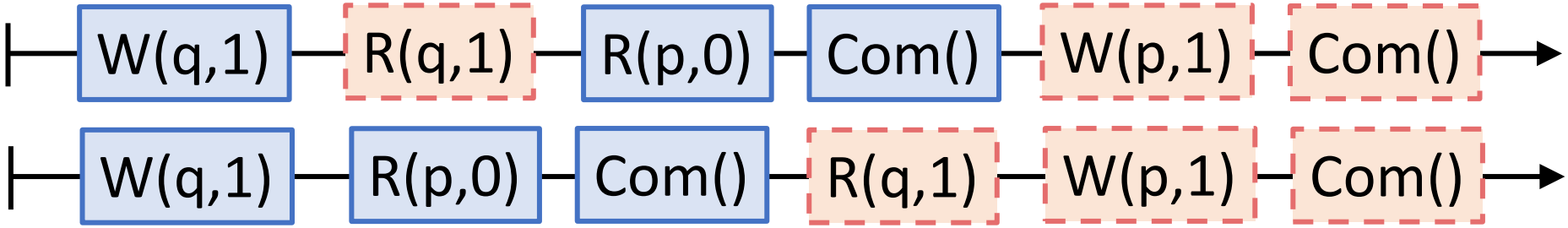
⇒ A **history** is correct if it is **equivalent** to a ~~correct~~ **sequential history** which satisfies a given correctness condition

- A correctness condition specifies the set of histories to be considered as reference

⇒In order to implement correctly a concurrent object wrt a correctness condition, we must guarantee that every possible history on our implementation satisfies the correctness condition

# (View) Serializability [Papadimitriou1979]

- A history H of committed transactions is serializable if
  - It is equivalent to a sequential history H'
  - H' is sequential
  - H' is legal, aka every read returns the last written value
- Serializable?



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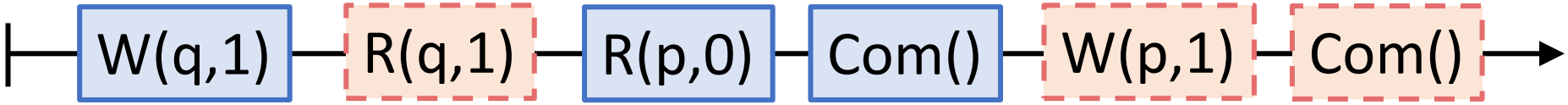


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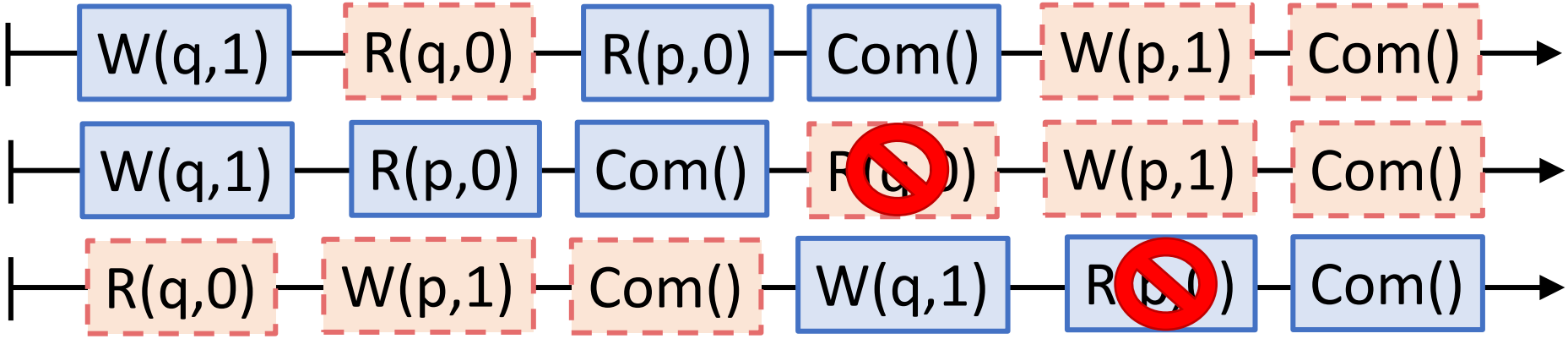

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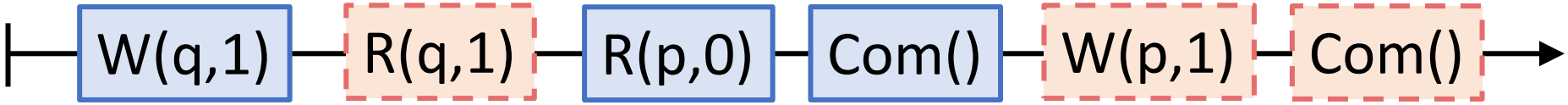


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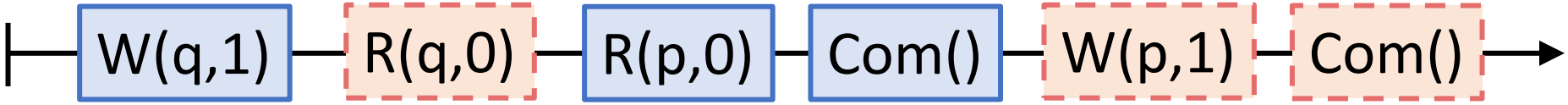

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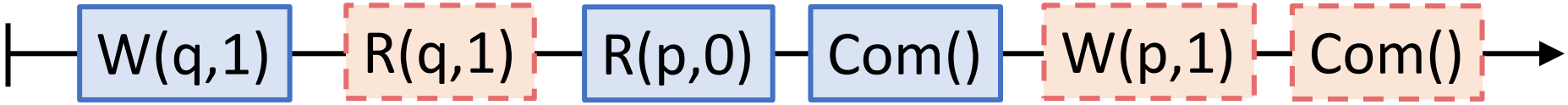


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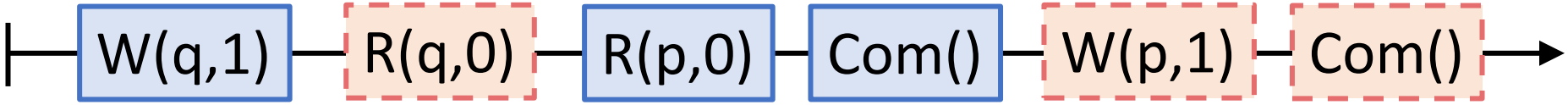


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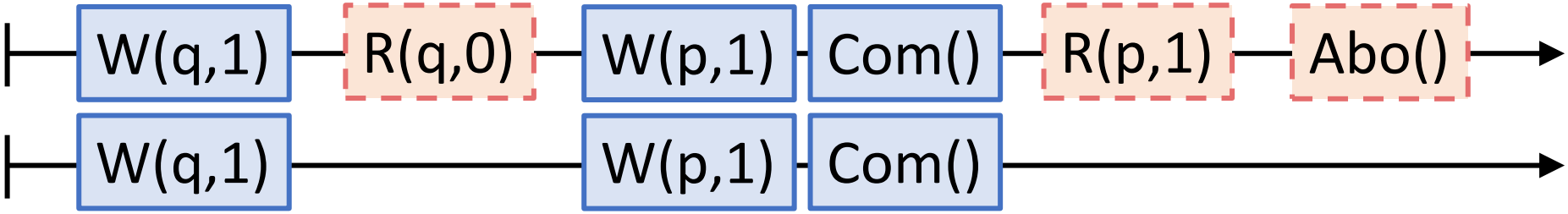
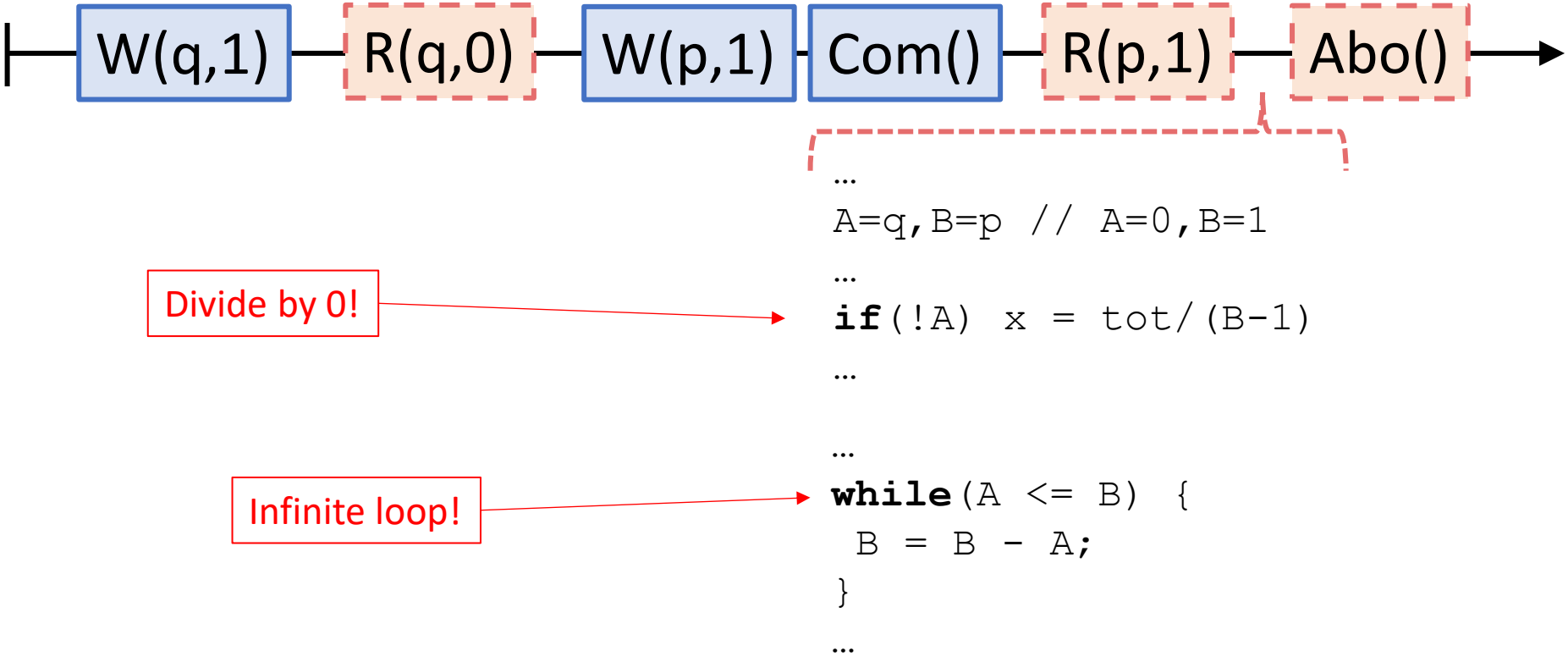


# (View) Serializability [Papadimitriou1979]

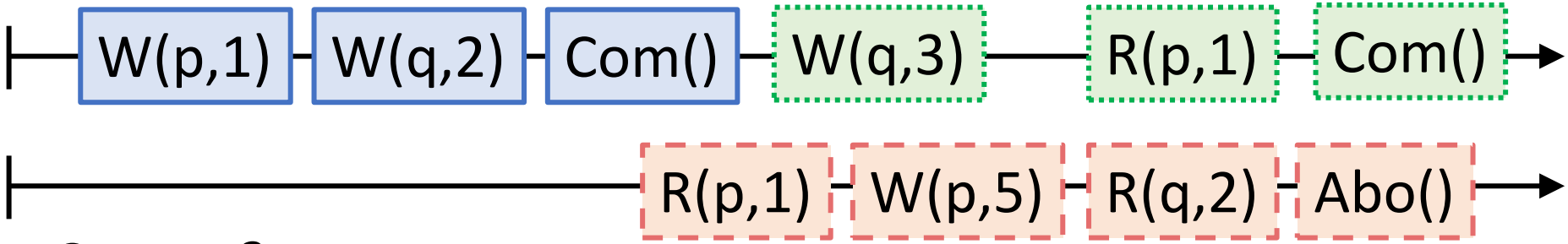
- Serializable? Yes! But, what happens in the case of TM?




- Could strict serializability be of any help?
  - Serializability + Real-time order
  - It predicates only on committed transactions

# Opacity [Guerraoui2008]

- A history H is opaque if
  - It is equivalent to a sequential history H'
  - H' is sequential
  - H' preserves transactions' real-time order
  - H' is legal
- Opaque?

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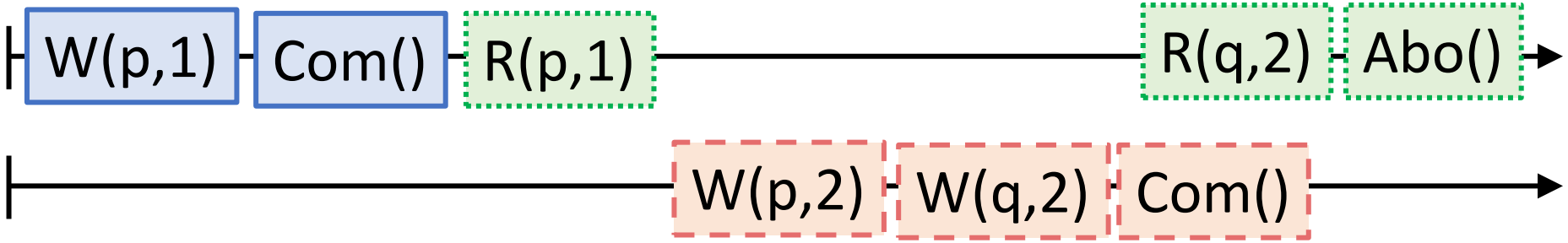

# Transactions

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Managed by DBMS instead of developers

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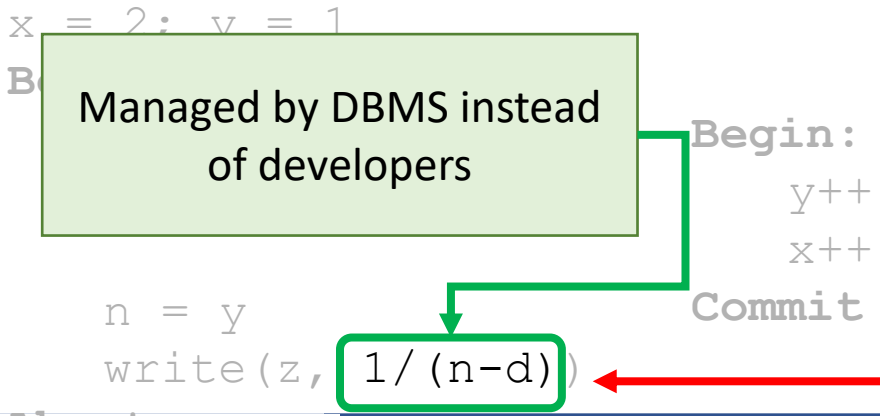

# Transactions

Deadlock or starvation freedom

≠

Obstruction freedom

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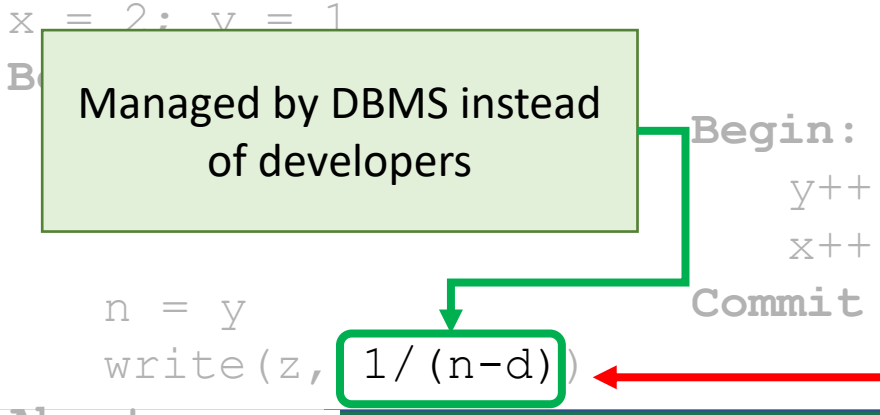
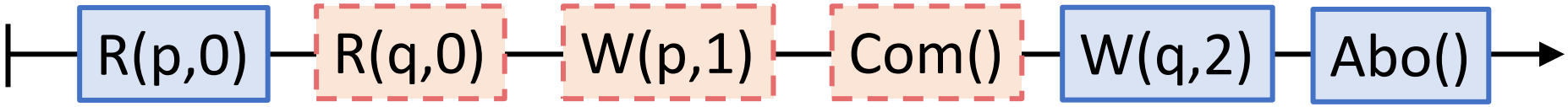


# Wait freedom

- Every correct transaction eventually commits
- Finite number of aborts



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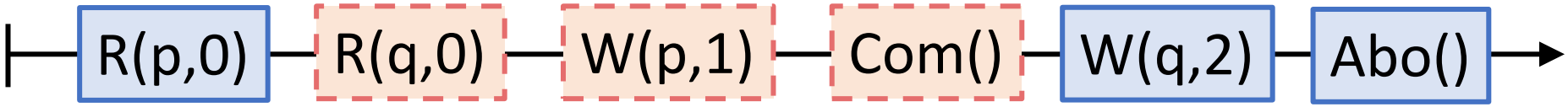

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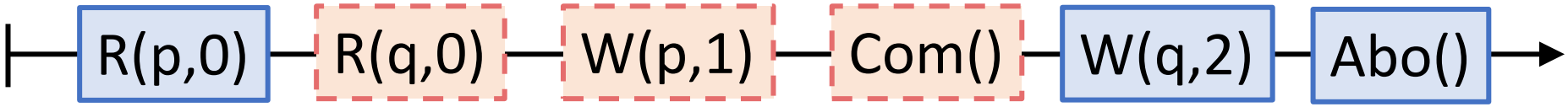


**IMPOSSIBLE IN AN ASYNCHRONOUS SYSTEM**

# Obstruction freedom

- Every correct transaction that runs in isolation (without contention) eventually commits
- Abort is unavoidable
- Contention manager can help with contention scenarios
- When a new transaction A creates a conflict with B
  - Aggressive
    - always abort B
  - Backoff
    - B waits an exp. back-off time, then abort A if still conflicting
  - Karma
    - Assign priority to A and B, abort lowest priority, increase priority after abort
  - Greedy
    - Use start time as priority, if Pb < Pa and A is not waiting then B wait, otherwise abort A

# Transactions

Deadlock or starvation freedom

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Obstruction freedom

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x = 2; y = 1
Begin:
    d = x

                    Begin:
                        y++
                        x++
                    Commit

    n = y
    write(z, 1/(n-d))
Abort
```

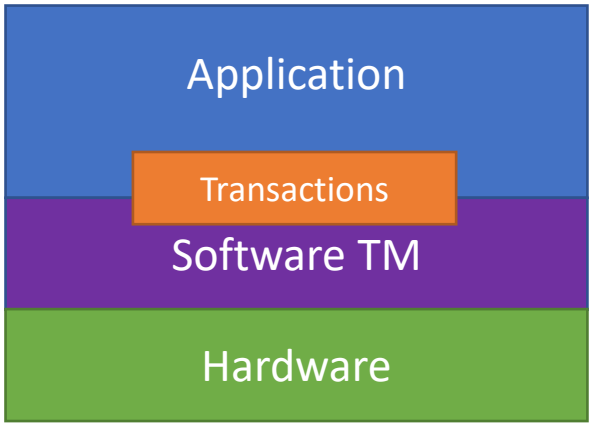
```
x = 2; y = 1
Begin:
    d = x

                    Begin:
                        y++
                        x++
                    Commit

Abort
```

# Software Transactional Memory

- DSTM
- JVSTM
- RSTM
- TL2
- TinySTM
- SwissTM
- McRT-STM
- Bartok-STM
- NOrec
- LSA
- E-STM
- SXM
- ASTM
- WSTM
- PhTM



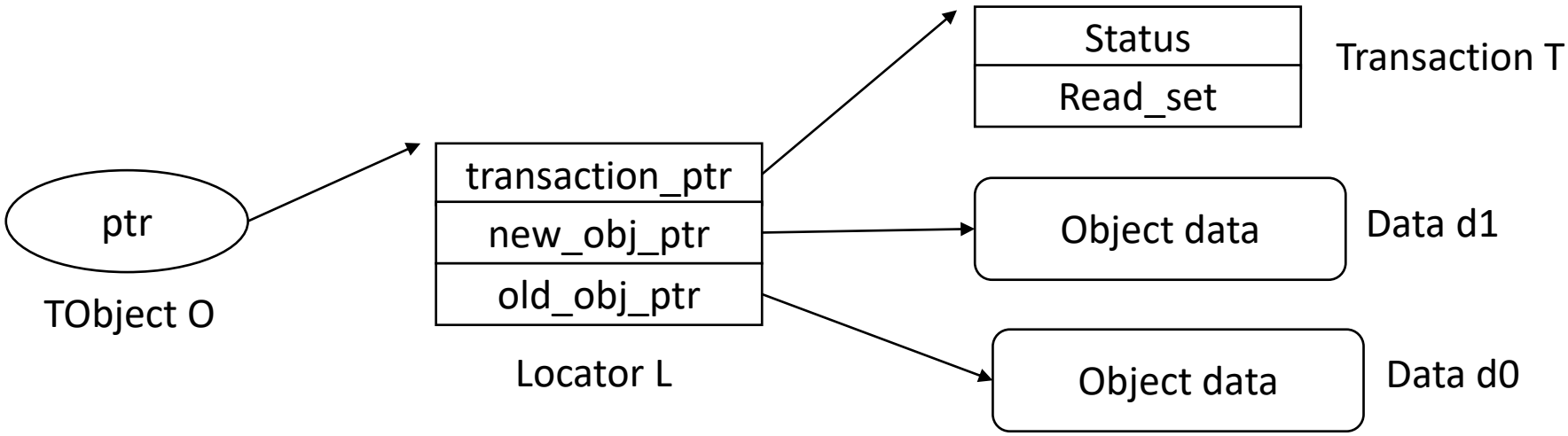
# DSTM [Hearlihy2003]

- Obstruction freedom + contention manager
- It works at object granularity
  - Transactions open objects in READ/WRITE mode to apply an operation
  - Conflicts are detected when opening objects
- A conflicting write makes one of the two conflicting transaction abort via contention manager (**killer write**)
- A read requires that all already-read objects are still the most recently committed version (**careful read**)
- Validate all objects read upon commit

# DSTM [Hearlihy2003]

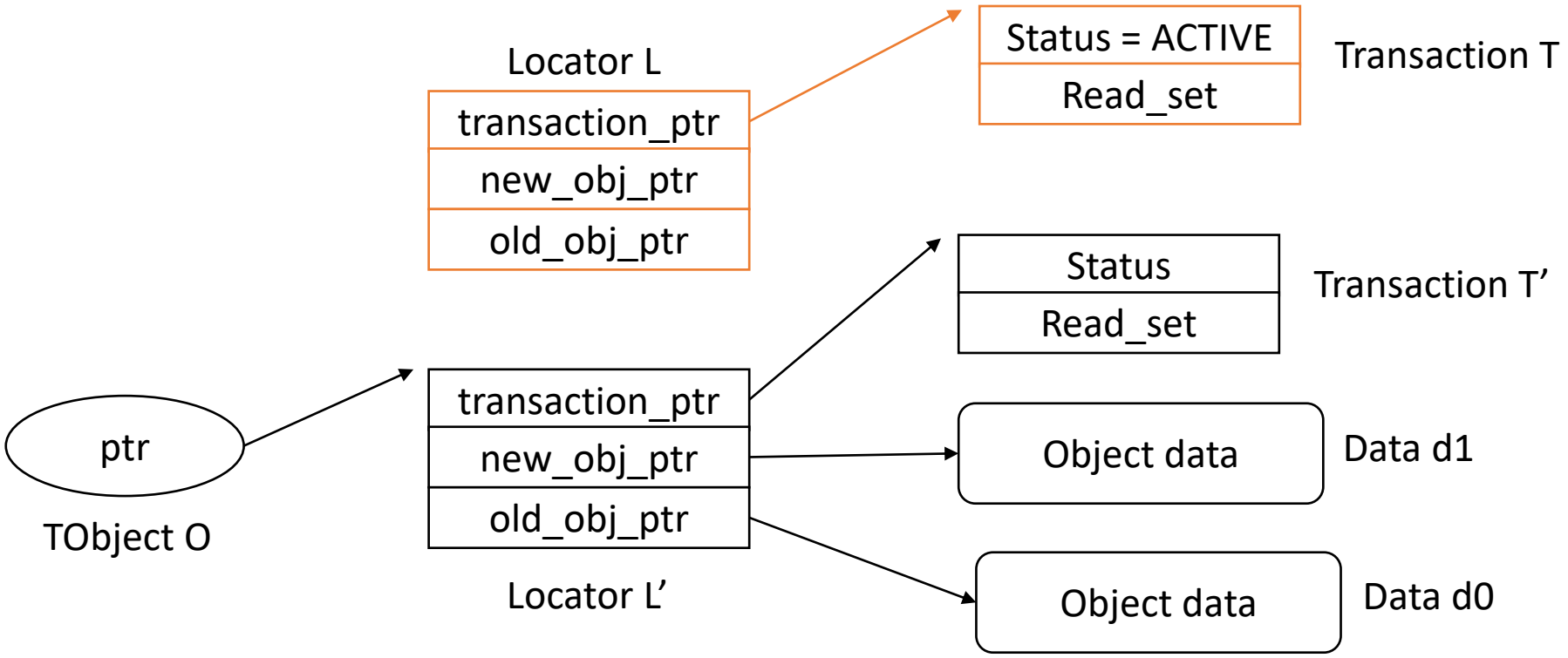
- Transactions have:
  - A status
    - Committed
    - Active
    - Aborted
  - Collection of objects opened in READ mode
- Objects are incapsulated within a Transactional Object which keeps references to
  - Transaction currently manipulating the object in WRITE mode
  - Current and tentative versions of the object

with an intermediate objected called Locator



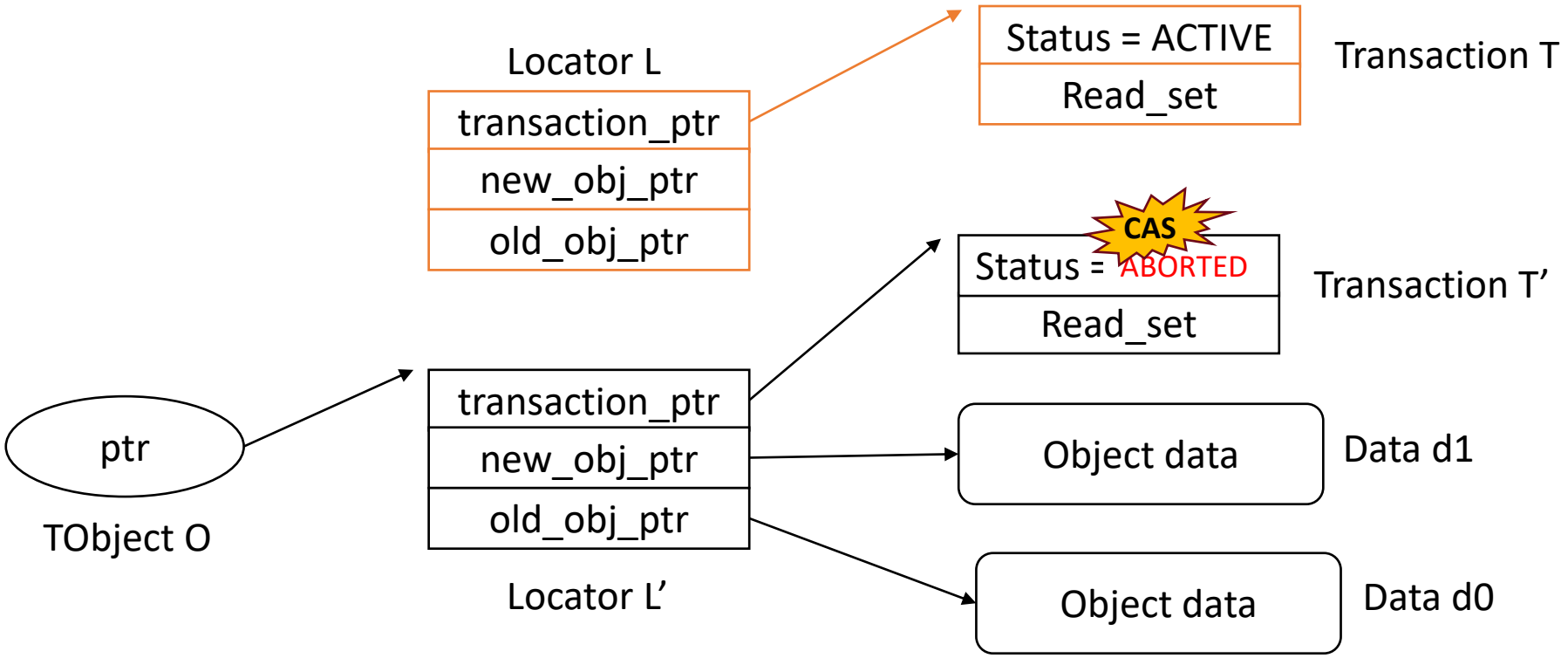
# DSTM – First open in WRITE mode [Hearlihy2003]

- **T** is the current transaction, whose status is **ACTIVE**
- **T** allocates a new Locator **L**
- **T** accesses to current locator **L'** of **O** to retrieve last transaction **T'** that executed the last open in WRITE mode



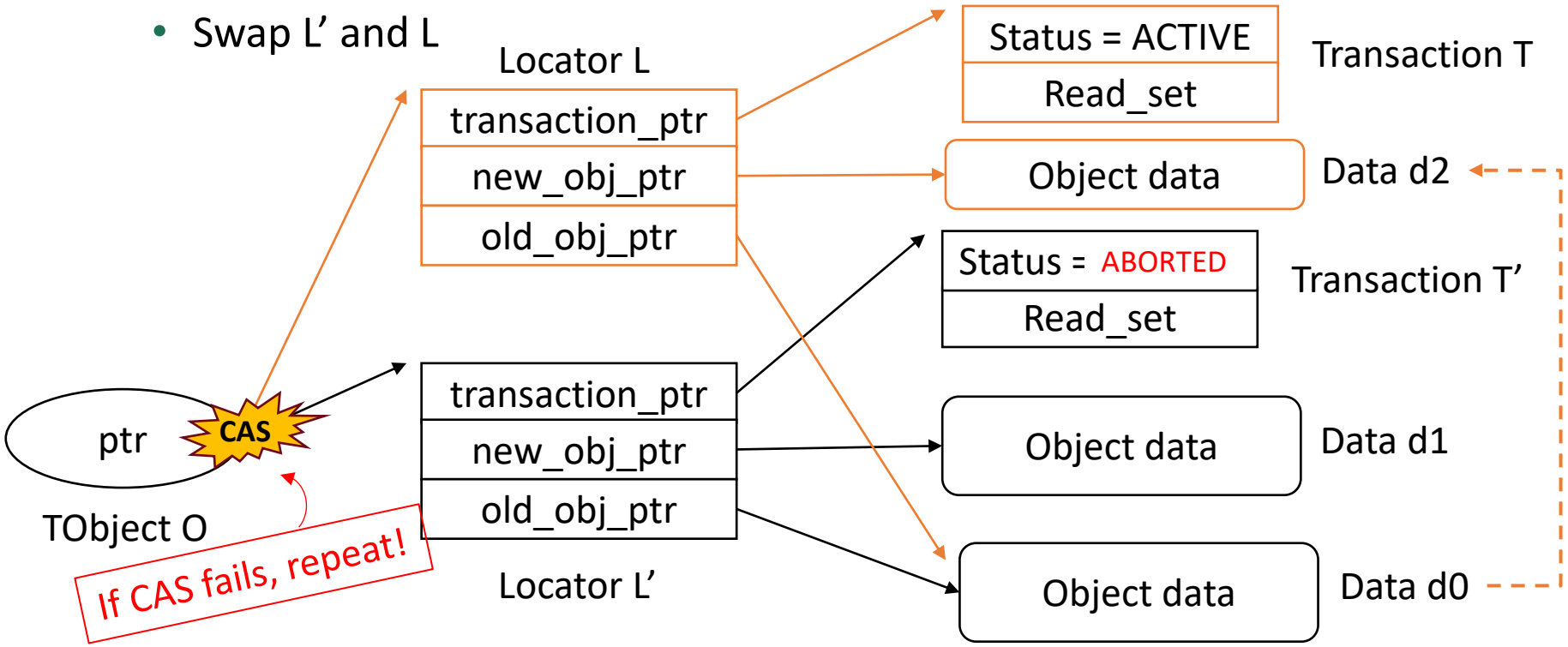
# DSTM – First open in WRITE mode [Hearlihy2003]

- **T** behaves accordingly to **T' status**
  - **ACTIVE: T** calls the contention manager
    - **T** waits a back-off time
    - **T** makes **T'** abort via **Compare&Swap**



# DSTM – First open in WRITE mode [Hearlihy2003]

- **T** behaves accordingly to **T' status**
  - **ABORTED:**
    - **T** use **L'.old_obj_ptr** to get current version of **O**
    - **L.old_obj_ptr = L'.old_obj_ptr**
    - **L.new_obj_ptr = CLONE(L'.old_obj_ptr)**
    - Swap L' and L



# DSTM – First open in WRITE mode [Hearlihy2003]

- **T** behaves accordingly to **T' status**
  - **COMMITTED:**
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    - **L.old_obj_ptr = L'.new_obj_ptr**
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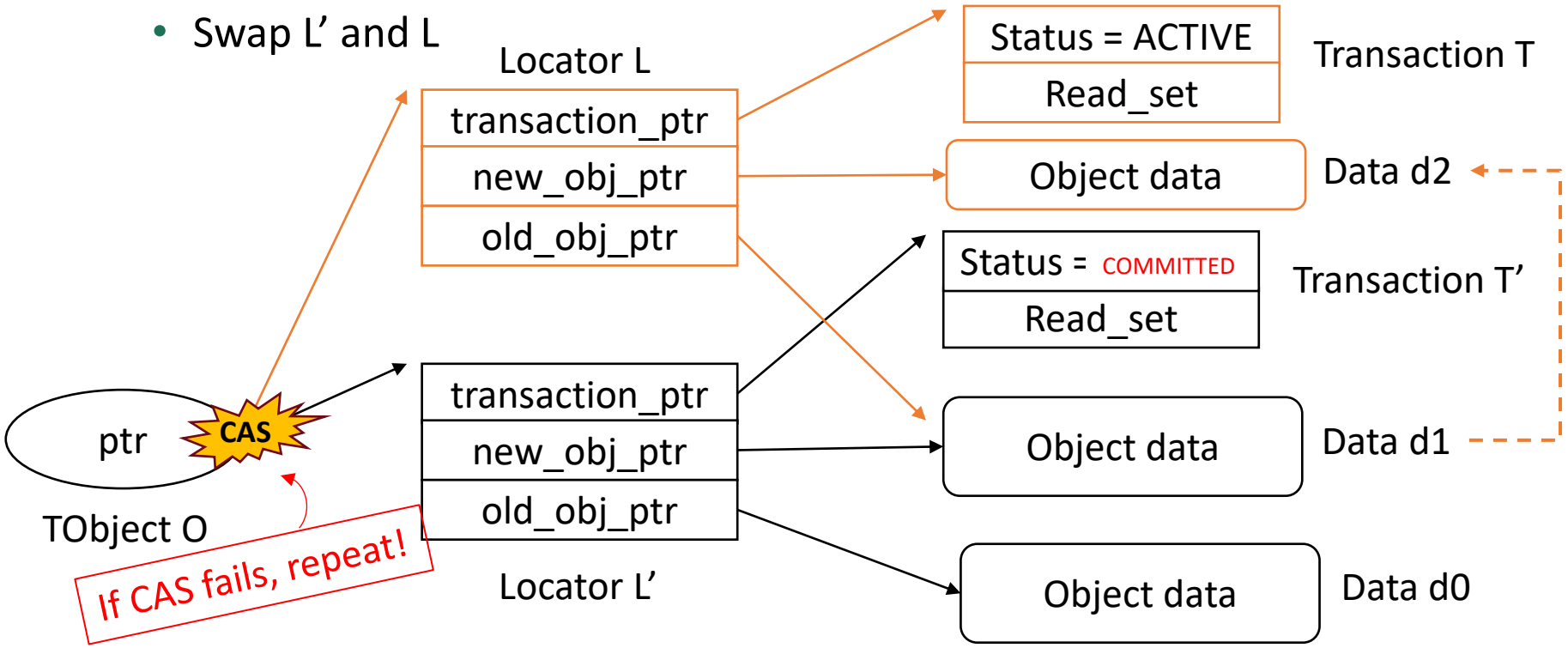
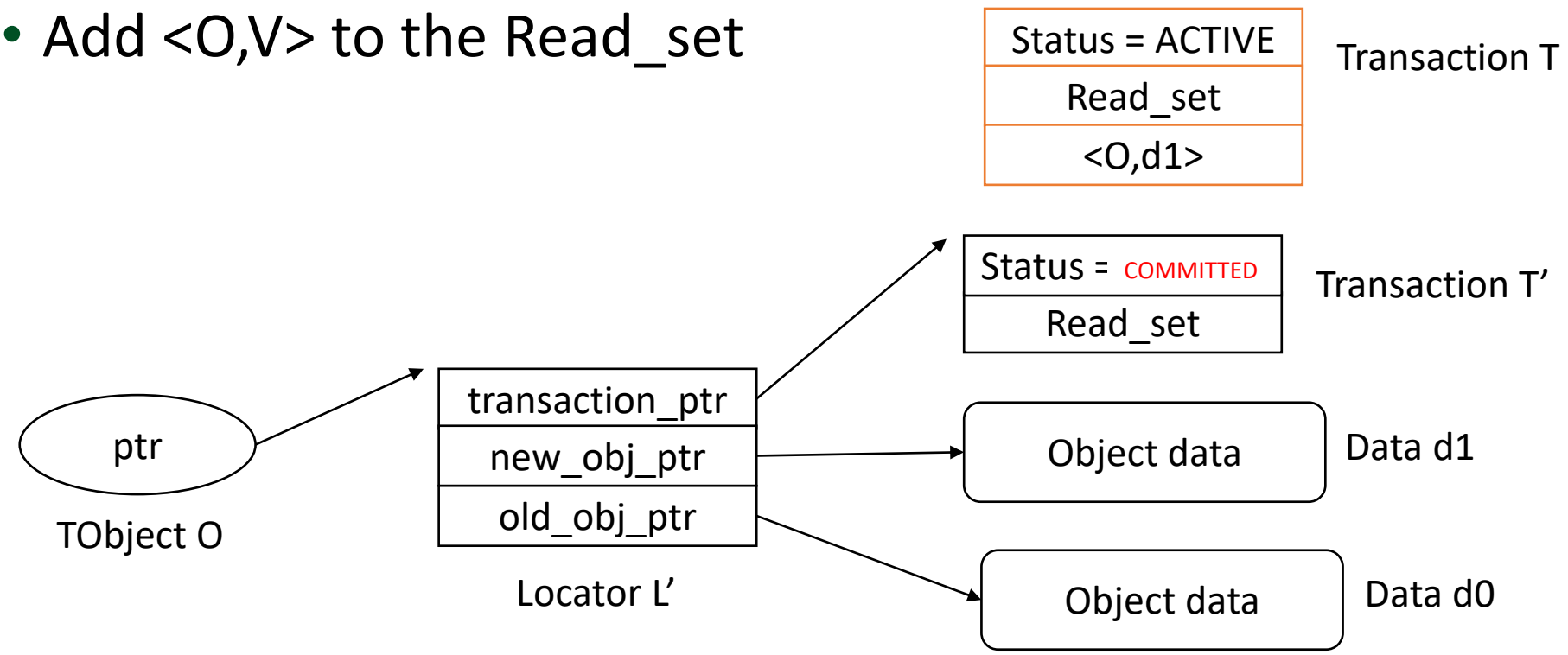


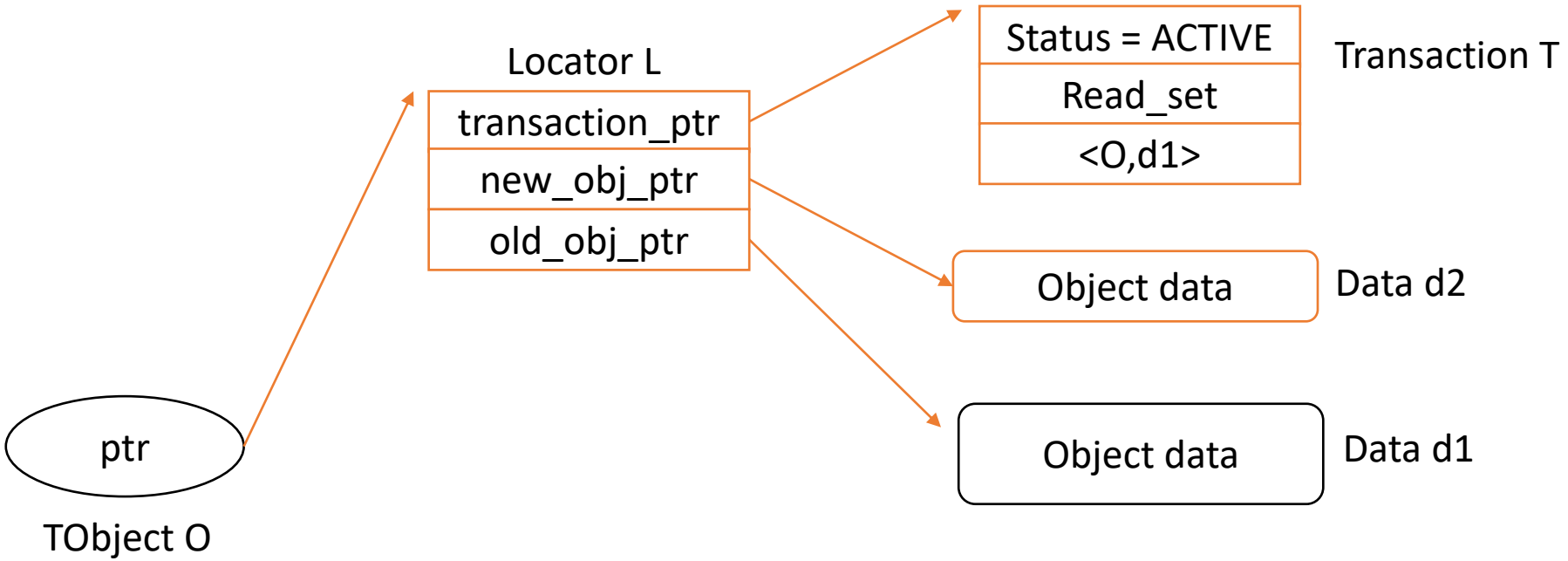
# DSTM – First open in READ mode [Hearlihy2003]

- Validate Read_set (see later)
- Fetch current **committed** version **V** via current locator
  - New_obj_ptr if T' is committed
  - Old_obj_ptr otherwise
- Add <O,V> to the Read_set



# DSTM – Already opened objects [Hearlihy2003]

- Already opened in READ mode:
  - Retrieve **V** from the Read_set
- Already opened in WRITE mode:
  - Retrieve **V** from the current locator



# DSTM – Commit [Hearlihy2003]

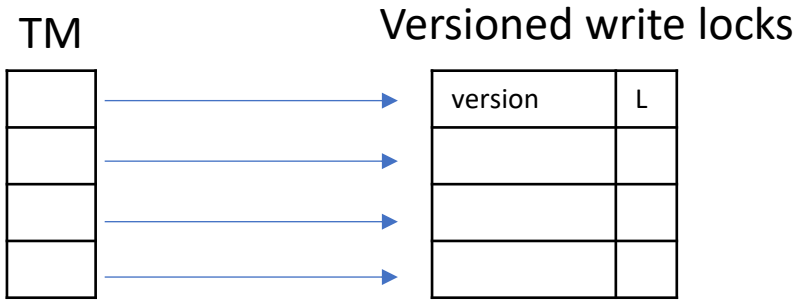
1. Validate the transaction
   - Transaction aborts on WRITE/WRITE conflicts
     - No need to validate WRITE upon commit
   - Validate Read_set
     - For each pair <O,V> check that V is still the most recent committed version
   - Read_set validation is non atomic
     - Check the status is still ACTIVE
2. **If** OK Change status
   **then** from **ACTIVE** to **COMMITTED**
   **else** from **ACTIVE** to **ABORTED**
   - Individual CAS

# DSTM – Final remarks [Hearlihy2003]

- Read-only transactions do not need any ATOMIC instruction for each read
- Committed transactions appear to take effect when the transition ACTIVE->COMMITTED occurs
  - Linearizable/Strict serializable
- Why careful read (validation at each read)?
- Obstruction freedom
  - Transactions abort iff conflicts occur

# Transational Locking 2 [Dice2006]

- Word-based STM
  - Each transactional memory location is associated with a **versioned write lock** <version,is_locked>




- Exploits a Global Version Clock (GVC) to quickly detect updates (it increases before a write-transaction commits)
- Transactions keep track of
  - GVC
  - Read set
  - Write set

# Transational Locking 2 [Dice2006]

- BEGIN:
  - Sample GVC and store it in a transaction(thread)-local variable RV
- WRITE(m,v) operation:
  - Add <m,v> to the write set
- READ(m)(v) operation:
  - **IF** m in write set **THEN** return the associated v
  - **ELSE**
    - Load the versioned lock <version,locked> associated to m
      - IF locked or version > RV abort
    - Load v from m
    - IF locked or version > RV abort
    - Add <m> to the readset

# Transational Locking 2 [Dice2006]

- COMMIT:
  - For each m in the write set acquire the related versioned lock
    - If acquisition fails abort
  - Increment GVC via Add&Fetch obtaining WV
  - **IF WV != RV+1**
    - Validate the read set (abort if locked or version > RV)
  - Store each value in the read set
  - Release each versioned lock by using WV as version

# Transational Locking 2 [Dice2006]

- REMARKS:
  - Re-validating the read set before applying updates is required due to possible concurrent updates during write-set locking and GVC increment
- Read-only transactions
  - Do not need to increase GVC
  - Do not need to acquire any lock
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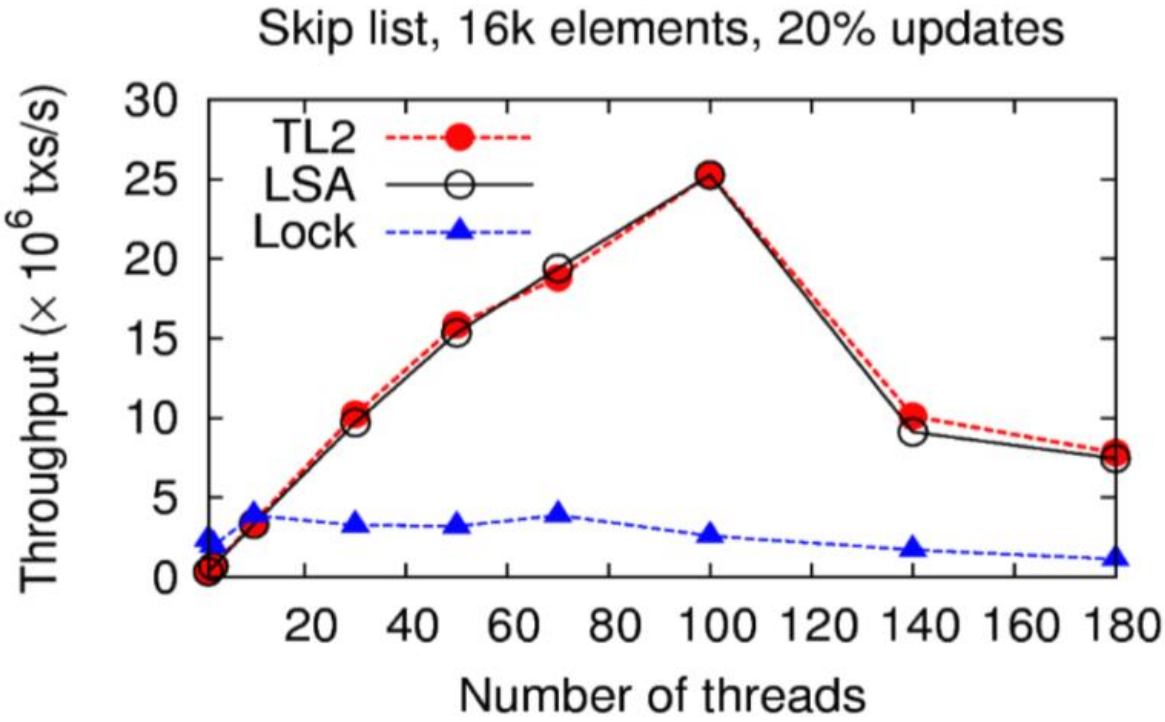
# What about Software Transactional Memory



# What about Software Transactional Memory

- Scale as (or better than) fine-grain locking
- Overheads hamper scalability
  - Due to instrumented access (overhead for each read/write)
  - Read set validation
- Hot topic in 2000s
  - A pletora of implementations for several programming languages
    - C/C++: TinySTM, G++ v4.7 (still expertimental)
    - C#: SXM by Microsoft (discontinued)
    - Haskell: STM is part of the Haskell platform
    - Scala: Akka framework
- Large debate on its practical impact
  - Software Transactional Memory: Why Is It Only a Research Toy?: The promise of STM may likely be undermined by its overheads and workload applicabilities. [Cascaval2008]
  - Transactional Memory Should Be an Implementation Technique, Not a Programming Interface [Boehm2009]
  - Why STM can be more than a Research Toy [Dragojević2011]