Transactional Memory

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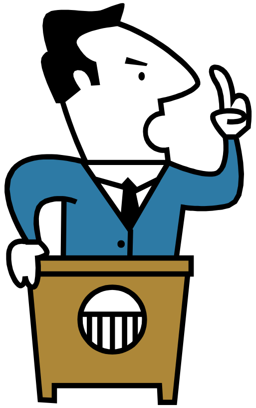
Locking is "history"

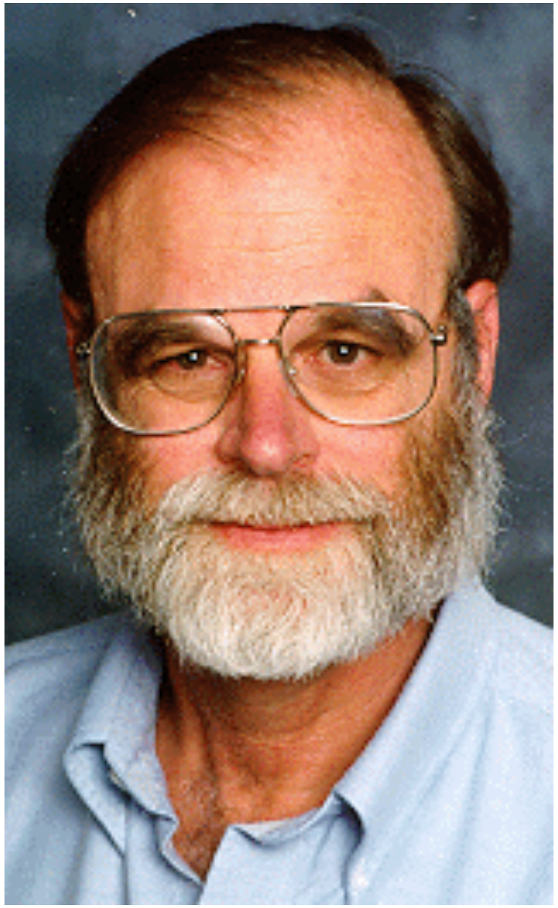
Lock-freedom is "difficult"

Wanted



A synchronisation abstraction that is simple, robust and efficient

Transactions



Historical perspective

- Eswaran et al (CACM’76) Databases
- Papadimitriou (JACM’79) Theory
- Liskov/Sheifler (TOPLAS’82) Language
- Knight (ICFP’86) Architecture
- Herlihy/Moss (ISCA’93) Hardware
- Shavit/Touitou (PODC’95) Software
- Herlihy et al (PODC’03) Software – Dynamic

Back to the sequential level

- accessing object 1;
- accessing object 2;

Back to the sequential level

atomic {

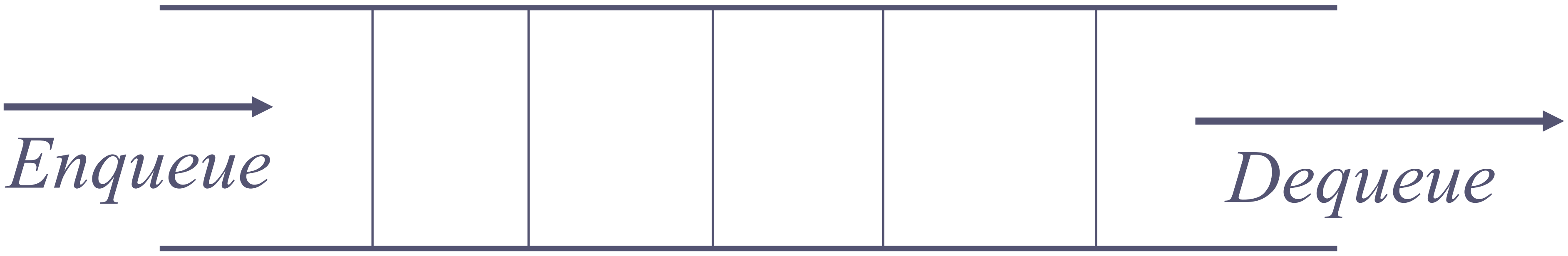
- accessing object 1;
- accessing object 2;

}

Semantics (serialisability)

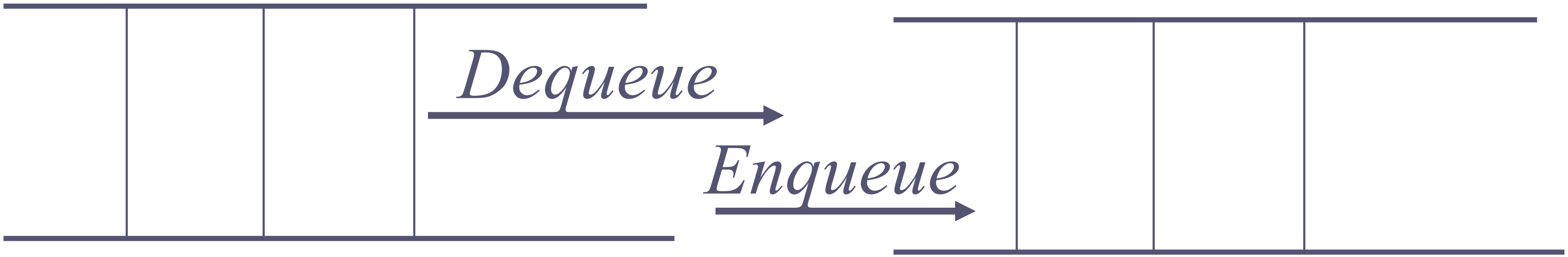
Every transaction appears to execute at an indivisible point in time (linearizability of transactions)

Double-ended queue



```
class Queue {
  QNode head;
  QNode tail;
  public enq(Object x) {
    atomic {
      QNode q = new QNode(x);
      q.next = head;
      head = q;
    }
  }
  ... }
```

Queue composition



```
class Queue {
  …
  public transfer(Queue q) {
    atomic {
      Qnode n = this.dequeue();
      q.enqueue(n) }
  }
  ... }
```

Simple example

(consistency invariant)

$$0 < x < y$$

Simple example

(transaction)

- `T: x := x+1 ; y:= y+1`

The illusion of a critical section

atomic {

- accessing object 1;
- accessing object 2;

}

- *"It is better for Intel to get involved in this [**Transactional Memory**] now so when we get to the point of having …tons… of cores we will have the answers"*
- ***Justin Rattner, Intel Chief Technology Officer***

- *"…we need to explore new techniques like* ***transactional memory*** *that will allow us to get the full benefit of all those transistors and map that into higher and higher performance."*
  - ***Bill Gates***

- *"…manual synchronization is intractable…**transactions** are the only plausible solution…."*
  - ***Tim Sweeney, Epic Games***

The TM Topic has been a VERY HOT topic

- Sun/Oracle, Intel, AMD, IBM, MSR
- Fortress (Sun); X10 (IBM); Chapel (Cray)

The TM API
(a simple view)

- ***begin()*** returns *ok*

- ***read()*** returns a value or *abort*
- ***write()*** returns an *ok* or *abort*

- ***commit()*** returns *ok* or *abort*
- ***abort()*** returns *ok*

Two-phase locking

- To ***write*** or ***read*** O, T requires a ***lock*** on O;
T ***waits*** if some T’ acquired a ***lock*** on O

- At the end, T ***releases*** all its locks

Two-phase locking (more details)

- Every object O, with state s(O) (a ***register***), is protected by a lock l(O) (a **c&s**)
- Every transaction has local variables wSet and wLog
- Initially: l(O) = unlocked, wSet = wLog = ∅

Two-phase locking

```
Upon op = read() or write(v) on object O
if O ∉ wSet then
   wait until unlocked= l(O).c&s(unlocked,locked)
   wSet = wSet U O
   wLog = wLog U S(O).read()
if op = read() then return S(O).read()
S(O).write(v)
return ok
```

Two-phase locking (cont’d)

Upon ***commit()***
cleanup()
return ok

Upon ***abort()***
rollback()
cleanup()
return ok

Two-phase locking (cont’d)

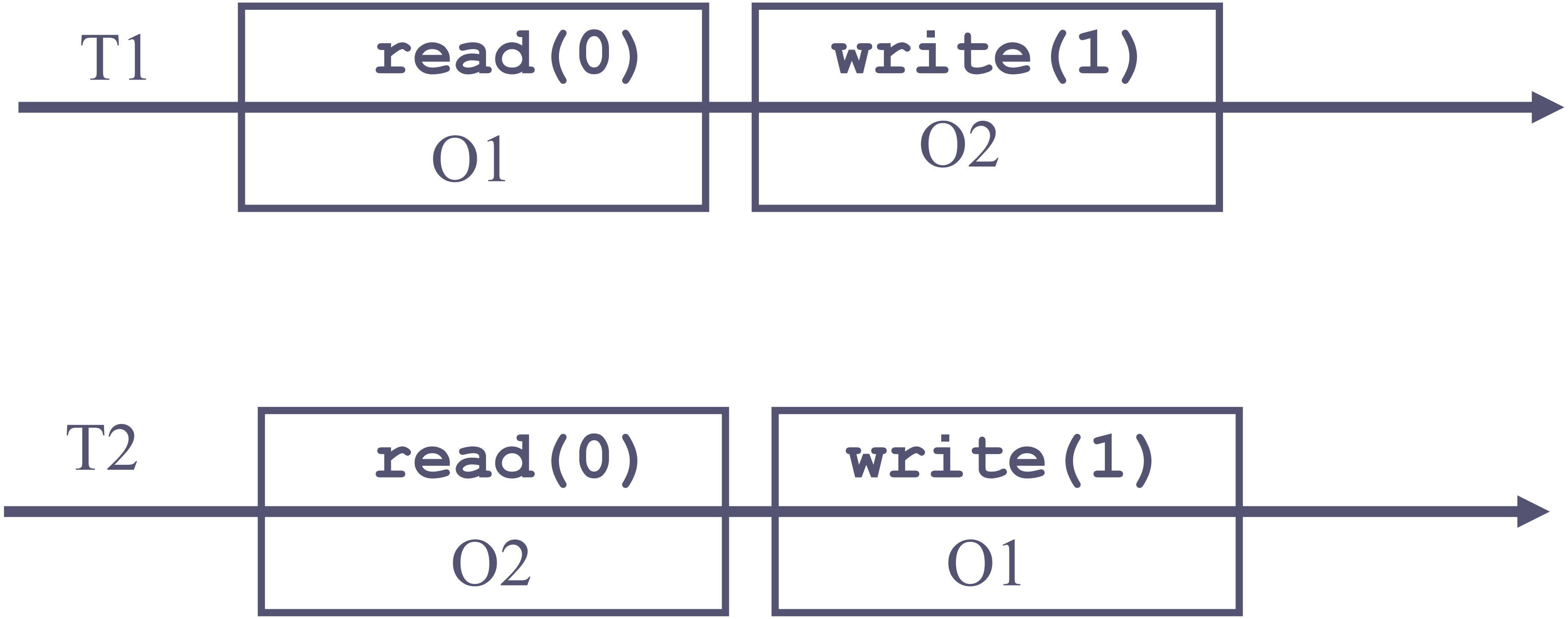
```
Upon rollback()
for all $O \in wSet$ do S(O).write(wLog(O))
wLog = $\emptyset$

Upon cleanup()
for all $O \in wSet$ do l(O).write(unlocked)
wSet = $\emptyset$
```

Why two phases?
(what if?)

- To ***write*** or ***read*** O, T requires a ***lock*** on O;
T ***waits*** if some T' acquired a ***lock*** on O
-
- T ***releases*** the lock on O when T is done with O

Why two phases?



T1 `read(0)` `write(1)`

O1 O2

T2 `read(0)` `write(1)`

O2 O1

Two-phase locking (read-write lock)

- To ***write*** O, T requires a ***write-lock*** on O;
T ***waits*** if some T’ acquired a ***lock*** on O

- To ***read*** O, T requires a ***read-lock*** on O;
T ***waits*** if some T’ acquired a ***write-lock*** on O

- Before committing, T ***releases*** all its locks

Two-phase locking
- better dead than wait -

- To ***write*** O, T requires a ***write-lock on*** O;
T ***aborts*** if some T′ acquired a ***lock*** on O

- To ***read*** O, T requires a ***read-lock*** on O;
T ***aborts*** if some T′ acquired a ***write-lock*** on O

- Before committing, T releases all its locks
- A transaction that aborts restarts again

Two-phase locking
- better kill than wait -

- To ***write*** O, T requires a ***write-lock on*** O;
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- To ***read*** O, T requires a ***read-lock*** on O;
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Two-phase locking
- better kill than wait -

- To ***write*** O, T requires a ***write-lock on*** O;
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- To ***read*** O, T requires a ***read-lock*** on O;
T ***waits*** if some T' acquired a ***write-lock*** on O

- Before committing, T releases all its locks
- A transaction that is aborted restarts again

Visible Read
(SXM, RSTM, TLRW)

- ***Write is mega killer***: to write an object, a transaction aborts any live one which has read or written the object
- ***Visible but not so careful read***: when a transaction reads an object, it says so

Visible Read

- A visible read invalidates cache lines
- For read-dominated workloads, this means a lot of traffic on the bus between processors

  - This reduces the throughput

  - Not a big deal with single-CPU, but with many core machines (e.g. SPART T2 Niagara)

Two-phase locking with invisible reads

- To ***write*** O, T requires a ***write-lock on*** O;
T **waits** if some T' acquired a ***write-lock*** on O

- To ***read*** O, T checks if ***all objects read remain valid*** - else T **aborts**

- Before committing, T checks if all objects read remain valid and releases all its locks

Invisible reads (more details)

- Every object O, with state s(O) (register), is protected by a lock l(O) (c&s)
- Every transaction maintains, besides wSet and wLog:
- - a local variable rset(O) for every object

Invisible reads

```
Upon write(v) on object O
if O ∉ wSet then
    wait until unlocked= l(O).c&s(unlocked,locked)
    wSet = wSet U O
    wLog = wLog U S(O).read()
(*,ts) = S(O).read()
S(O).write(v,ts)
return ok
```

Invisible reads

Upon ***read()*** on object O

```
(v,ts) = S(O).read()
if O $\in$ wSet then return v
if l(O) = locked or not validate() then abort()
if rset(O) = 0 then rset(O) = ts
return v
```

Invisible reads

```
Upon validate()
for all O s.t rset(O) > 0 do
 (v,ts) = S(O).read()
 if $ts \neq rset(O)$ or
    ($O \notin wset$ and l(O) = locked)
then return false
else return true
```

Invisible reads

```
Upon commit()
if not validate() then abort()
for all $O \in wset$ do
    (v,ts) = S(O).read()
S(O).write(v,ts+1)
cleanup()
```

Invisible reads

```
Upon rollback()
for all O $\in$ wSet do S(O).write(wLog(O))
wLog = $\emptyset$

Upon cleanup()
for all O $\in$ wset do l(O).write(unlocked)
wset = $\emptyset$
rset(O) = 0 for all O
```

DSTM (SUN)

- To ***write*** O, T requires a ***write-lock on*** O;

T aborts T′ if some T′ acquired a ***write-lock*** on O

- To ***read*** O, T checks if all objects read remain valid – else T **abort**
- Before committing, T releases all its locks

DSTM

- ***Killer write*** (ownership)
- ***Careful read*** (validation)

More efficient algorithm?

Apologizing versus asking permission

- ***Killer write***
- ***Optimistic read***
  - validity check only at commit time

Example

Invariant: $0 < x < y$

Initially: $x := 1; y := 2$

Division by zero

- T1: x := x+1 ; y:= y+1

- T2: z := 1 / (y - x)

Infinite loop

- T1: x := 3; y:= 6

- T2: a := y; b:= x;
  repeat b:= b + 1 until a = b

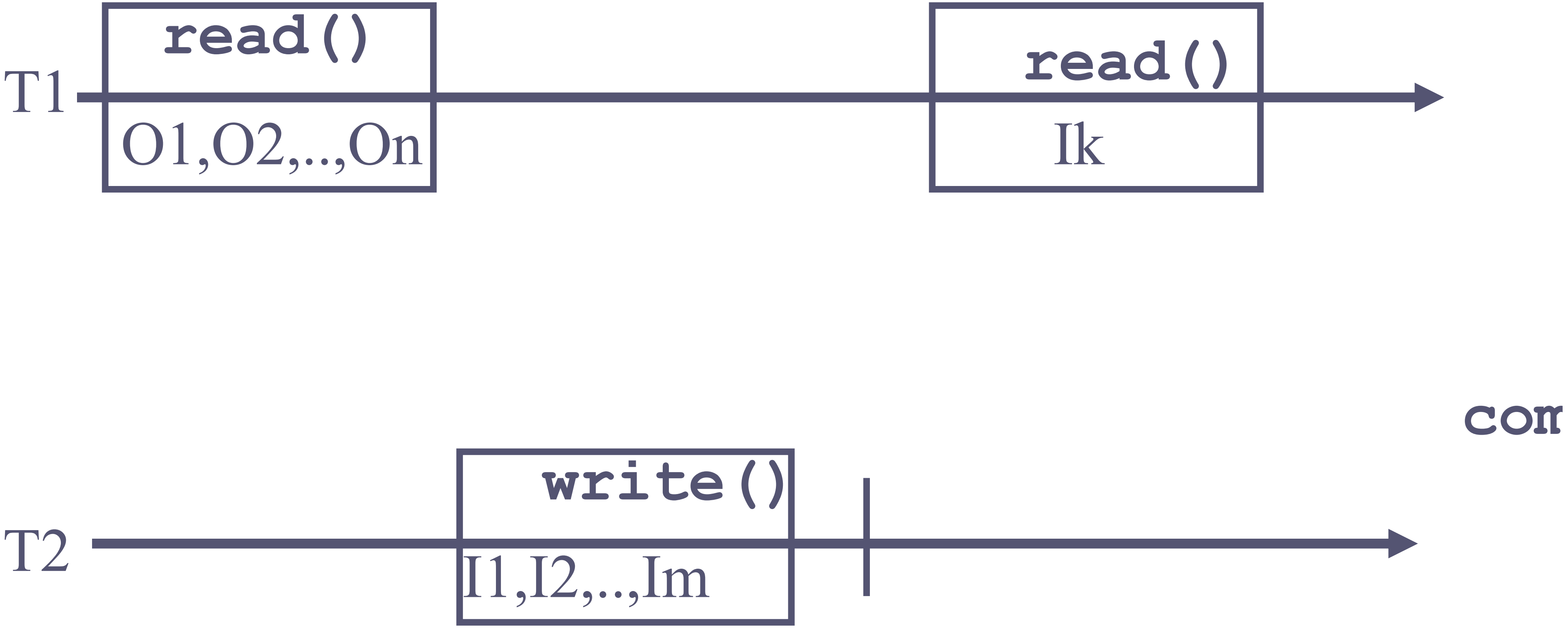
Opacity

- Serializability
- Consistent memory view

Trade-off

The read is either
visible or ***careful***

Intuition



Read invisibility

- The fact that the read is invisible means T1 cannot inform T2, which would in turn abort T1 if it accessed similar objects (SXM, RSTM)
- NB. Another way out is the use of multiversions: T2 would not have written “on” T1

Conditional progress - obstruction-freedom -

- A correct transaction that eventually does not encounter ***contention*** eventually commits

- ***Obstruction-freedom*** seems reasonable and is indeed possible

DSTM

- To ***write*** O, T requires a ***write-lock on*** O (use C&S);

T aborts T’ if some T’ acquired a ***write-lock*** on O (use C&S)

- To ***read*** O, T checks if all objects read remain valid - else abort (use C&S)
- Before committing, T releases all its locks (use C&S)

Progress

- If a transaction T wants to write an object O owned by another transaction T’, T calls a ***contention manager***

- The contention manager can decide to wait, retry or abort T’

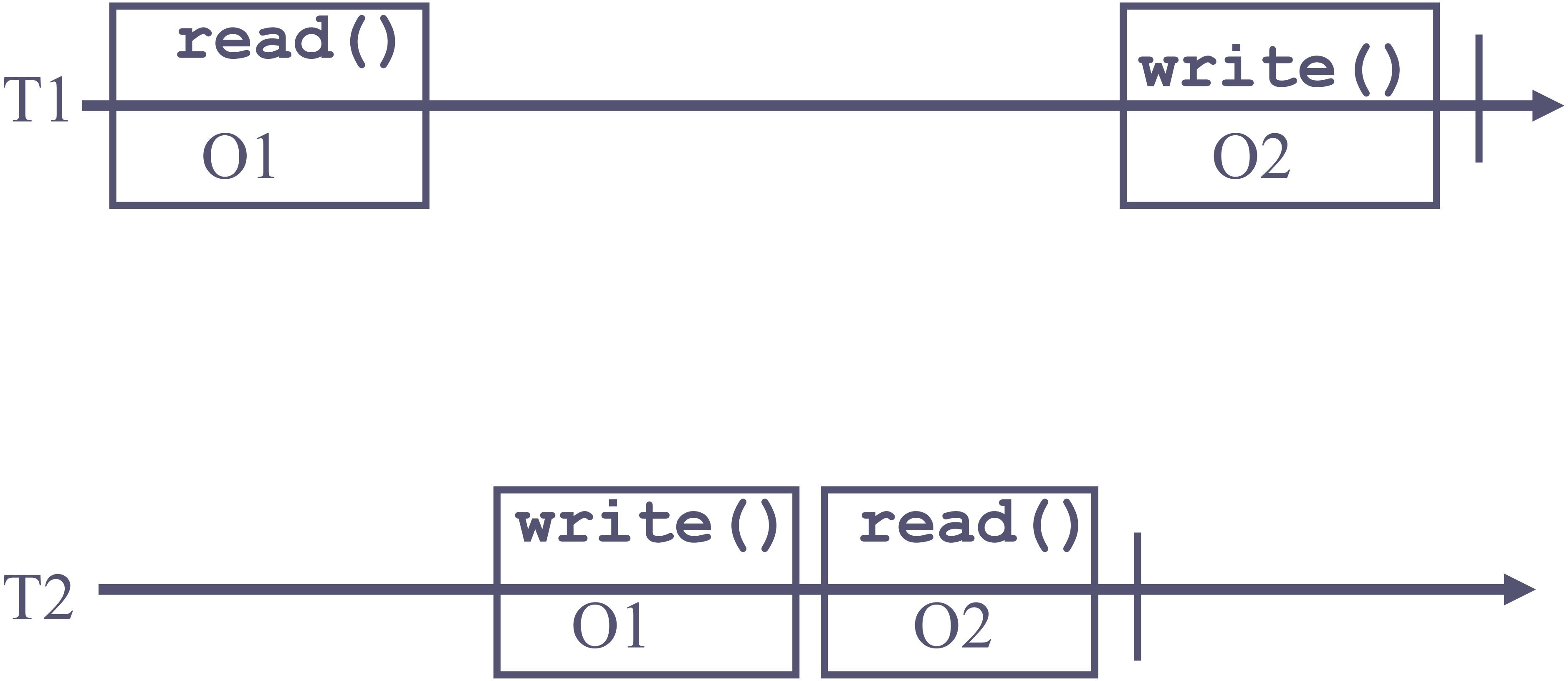
Contention managers

- **Aggressive**: always aborts the victim
- **Backoff**: wait for some time (exponential backoff) and then abort the victim
- **Karma**: priority = cumulative number of shared objects accessed – work estimate. Abort the victim when number of retries exceeds difference in priorities.
- **Polka**: Karma + backoff waiting

Greedy contention manager

- State
  - Priority (based on start time)
  - Waiting flag (set while waiting)
- ***Wait*** if other has
  - Higher priority AND not waiting
- ***Abort*** other if
  - Lower priority OR waiting

Aborting is a fatality



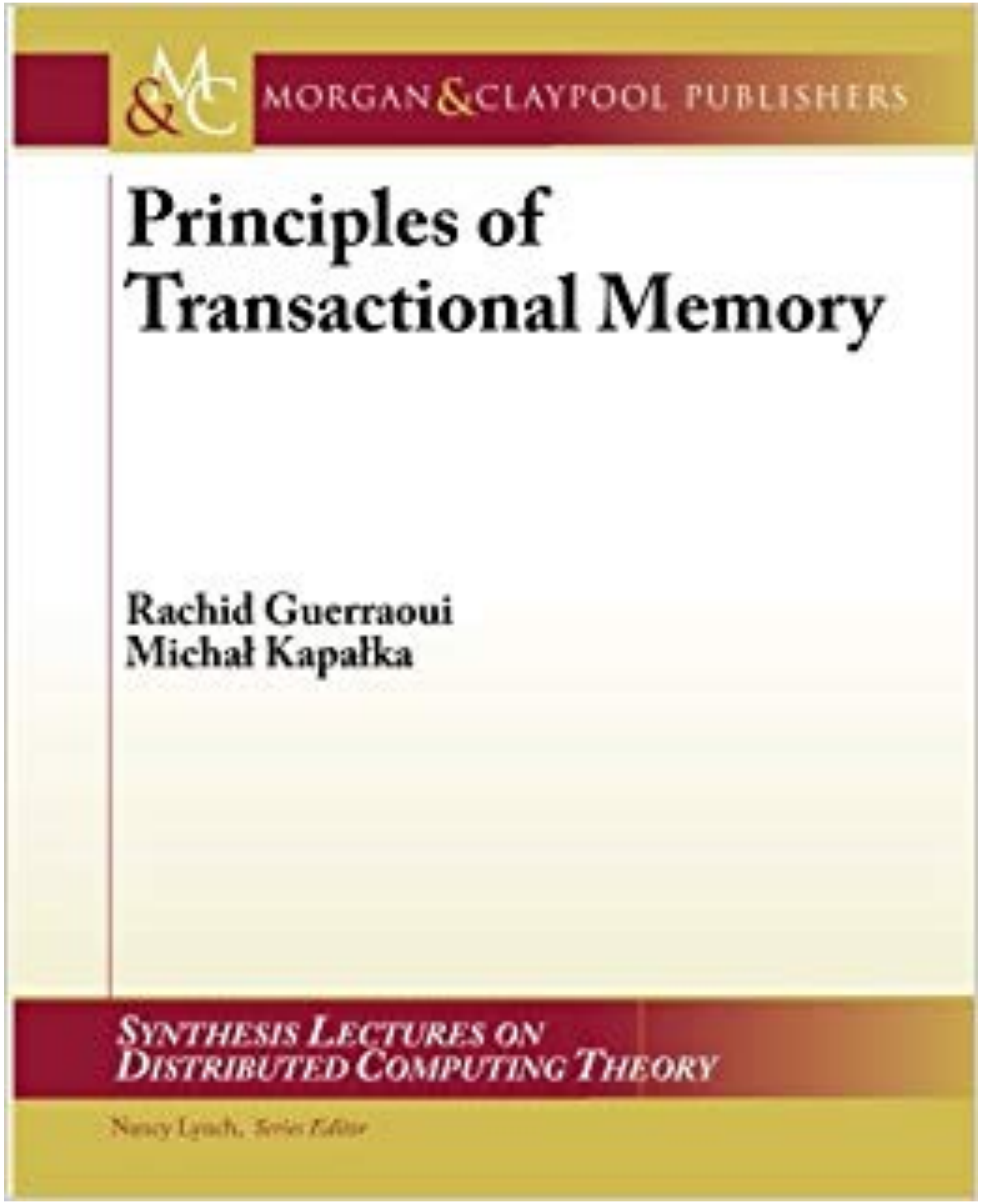
Concluding remarks

TM does not always replace locks:
it hides them

Memory transactions look like db transactions but are different

The garbage-collection analogy

- In the early times, the programmers had to take care of allocating and de-allocating memory
- Garbage collectors do it for you: they are now incorporated in Java and other languages
- Hardware support was initially expected, but now software solutions are very effective



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Principles of Transactional Memory

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