On the Benefits of Being Optimistic and Relaxed

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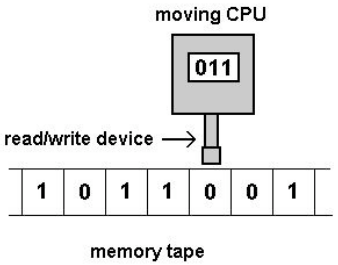
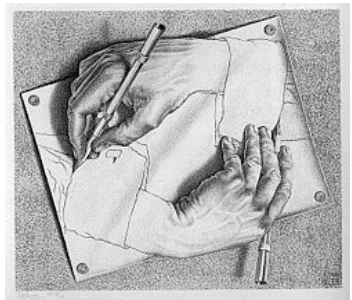
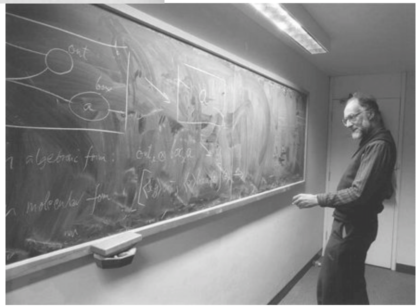
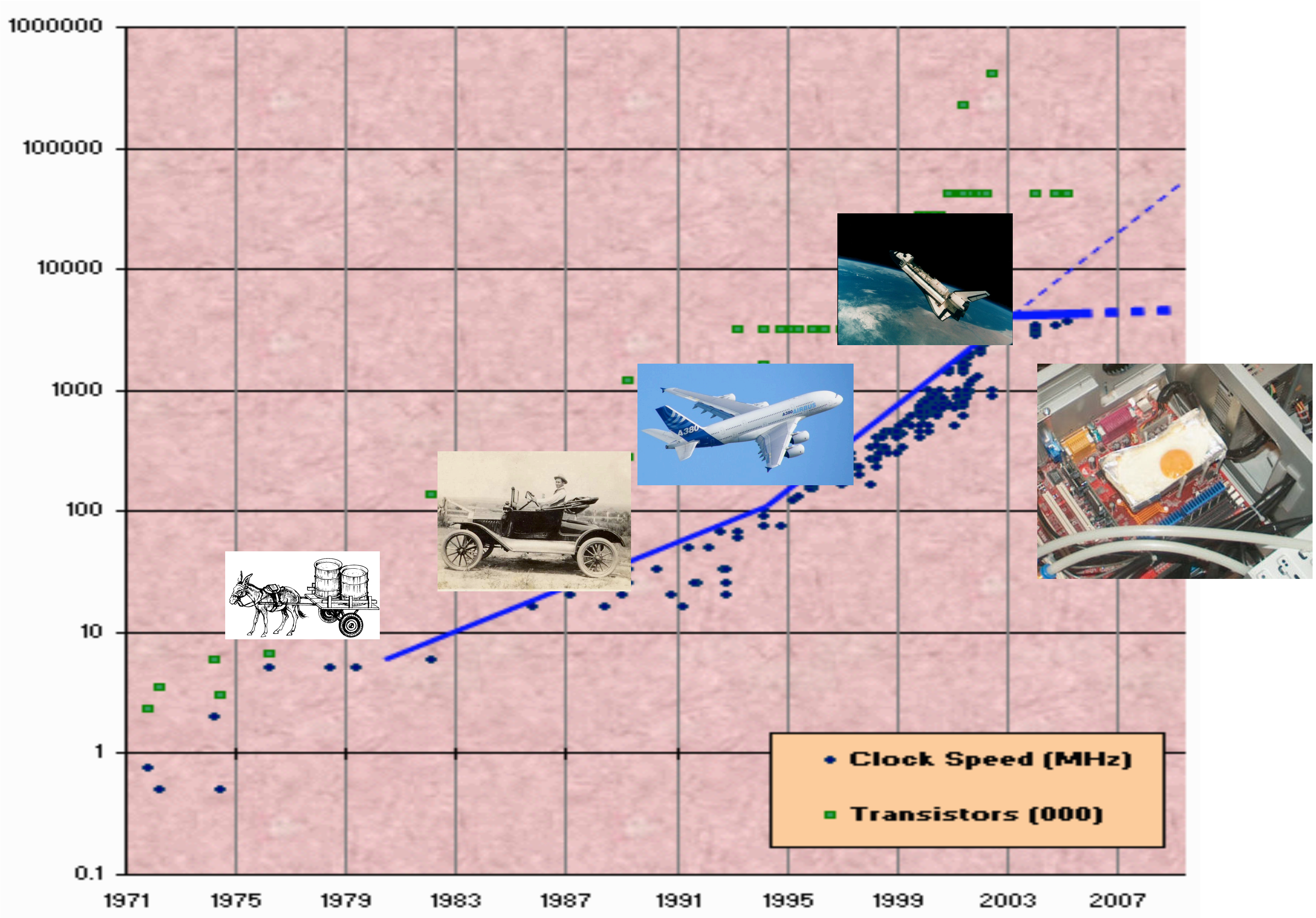
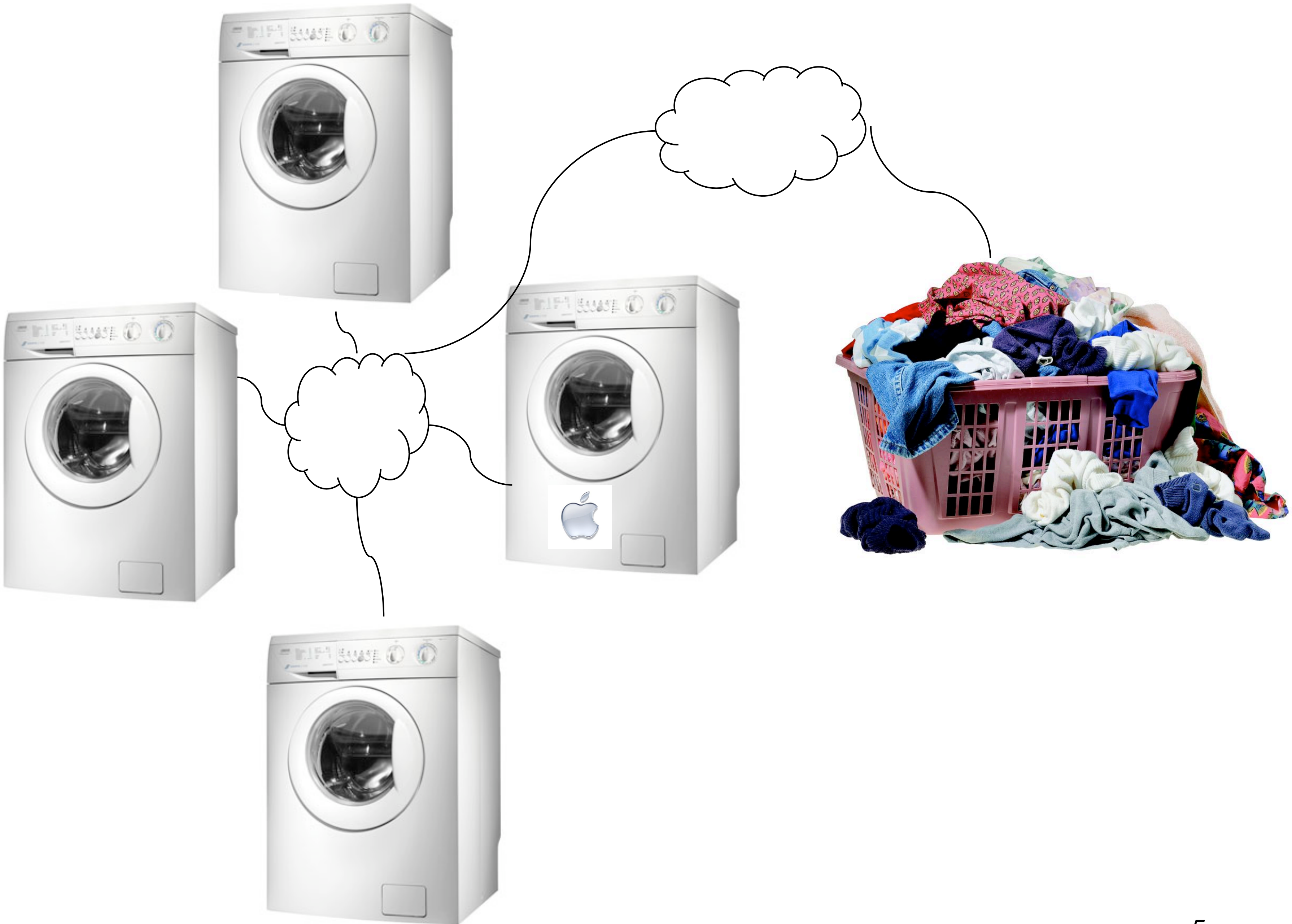
What is computing?

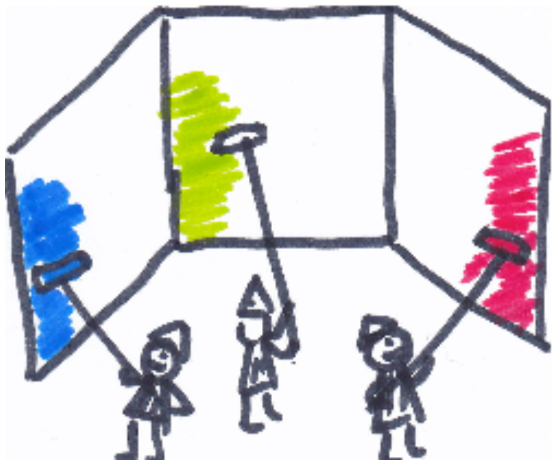


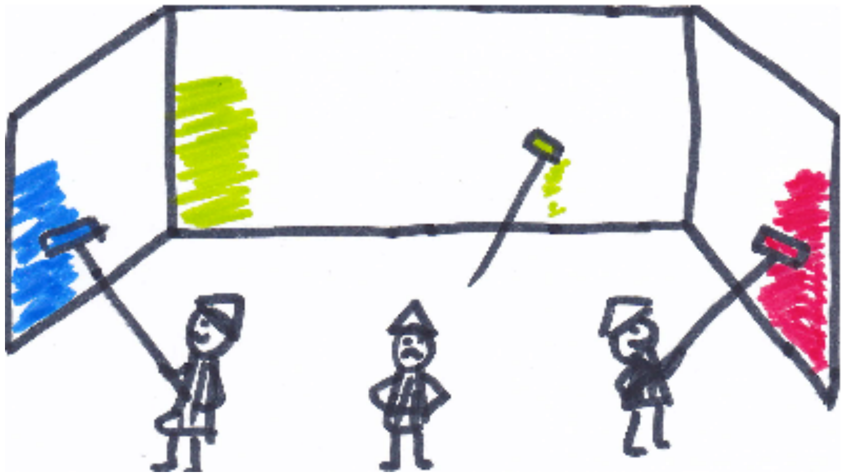





1000000
100000
10000
1000
100
10
1
0.1
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
Clock Speed (MHz)
Transistors (000)







$$S = \frac{1}{1 - p + p/n}$$

Amdahl's Law

- *p* – fraction of the work that can be done in parallel (no synchronization), 1-p for synchronization
- *n* - the number of processors

$$S = \frac{1}{1 - p + p/n}$$

For n=9, p=9/10, S=5! S<9, regardless of n!

Minimizing synchronization costs is crucial!

But…

- Concurrent programming is hard
  - ✓A new algorithm worth a PhD (or a paper at least)
- Sequential programming is "easy"
  - ✓e.g., for data structures (queues, trees, skip lists, hash tables,…)
- What about a "wrapper" that allows for running sequential operations concurrently?
  - ✓Let the wrapper care about conflicts
- How? Locks, transactional memory…

Our contribution

- What it means to share a sequential program
  ✓ Locally serializable (LS) linearizability

- What it means for sharing to be efficient
  ✓ Relative concurrency of different synchronization techniques (e.g., locks vs. TMs)

- What are the benefits of being relaxed and optimistic
  ✓ Type-specific (relaxed) consistency and transactional (optimistic) concurrency control supersede both

Correctly sharing sequential code?

Given a sequential implementation P of a data structure type T, provide a concurrent one that:

- Locally appears sequential – the user simply runs the sequential code of P
  - ✓Local serializability
- Globally makes sense – the high-level operations give consistent global order wrt T
  - ✓Linearizability [HW90]

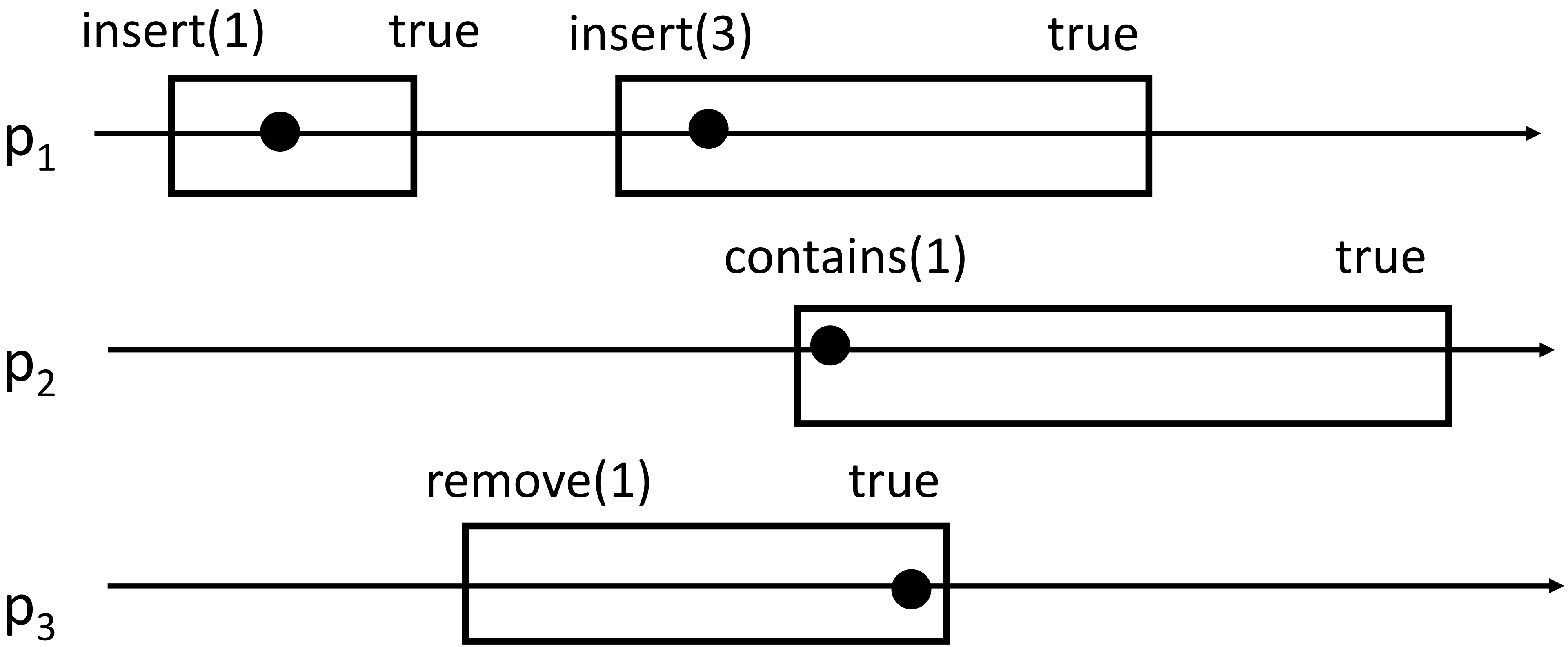
Example: Integer Set

Type: Integer Set:

- *boolean insert(x)*
- *boolean remove(x)*
- *boolean contains(x)*

Implemented sequentially as a sorted linked list:

Linearizable histories



The history is equivalent to a legal sequential history on a set (real-time order preserved)

Linked-list for Integer Set: sequential implementation

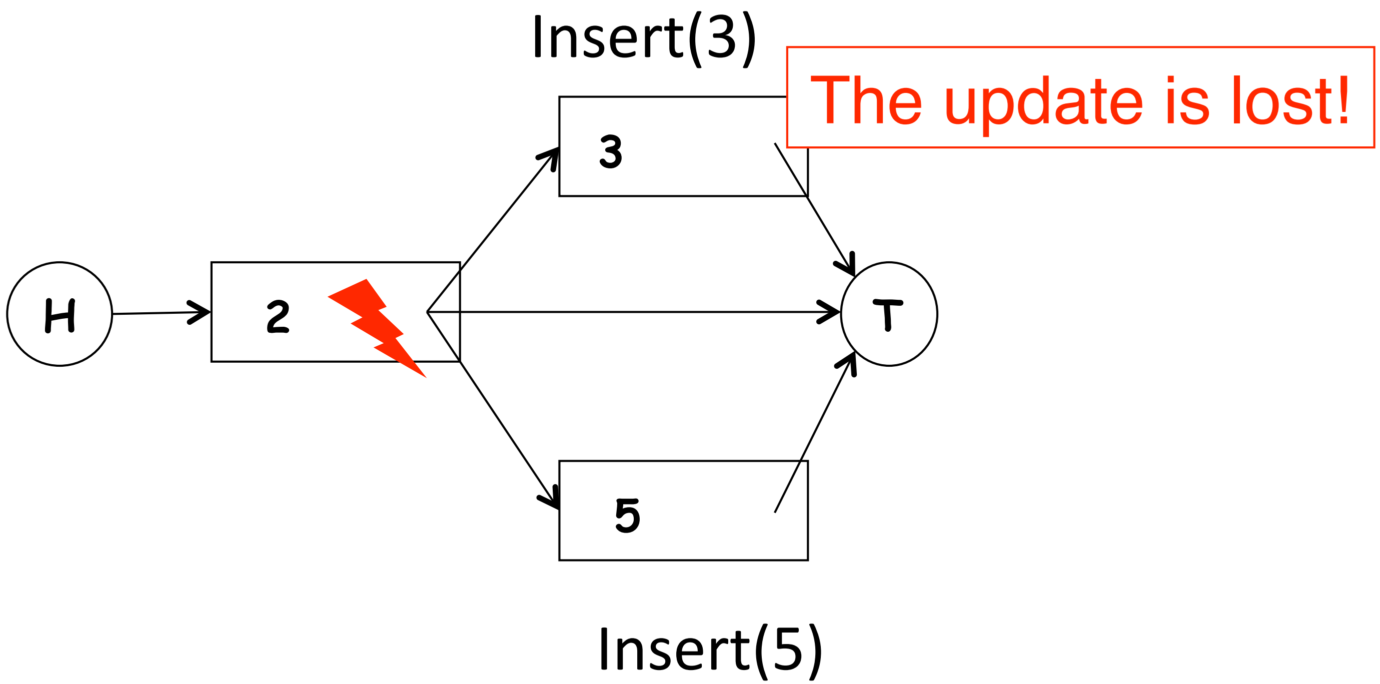
Locate(s):
 $prev \leftarrow Head$
 $curr \leftarrow prev.next$
 while $(curr.val < s \vee curr = Tail)$ **do**
  $prev \leftarrow curr$
  $curr \leftarrow curr.next$
 end while
 return $\langle prev, curr \rangle$

Contains(s):
 $\langle prev, curr \rangle \leftarrow$ Locate(s)
 if $curr.val = s$ **then**
  $result \leftarrow$ true
 else
  $result \leftarrow$ false
 return $result$

Insert(s):
 $\langle prev, curr \rangle \leftarrow$ Locate(s)
 if $curr.val \neq s$ **then**
  $X_s \leftarrow$ new-node(s)
  $X_s.next \leftarrow curr$
  $prev.next \leftarrow X_s$
 return ok

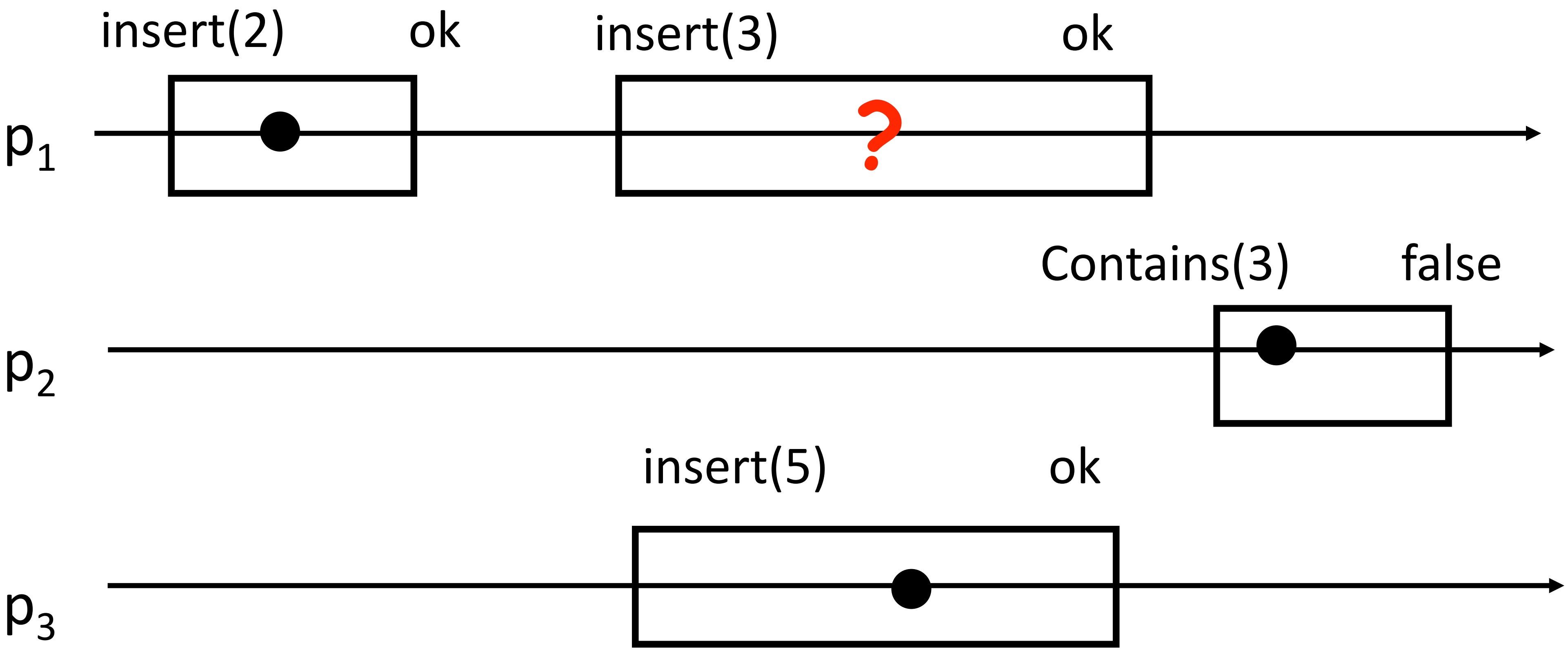
Remove(s):
 $\langle prev, curr \rangle \leftarrow$ Locate(s)
 if $curr.val = s$ **then**
  $curr.marked \leftarrow$ true
  // Mark node for removal
  $prev.next \leftarrow curr.next$
 return ok

As is?



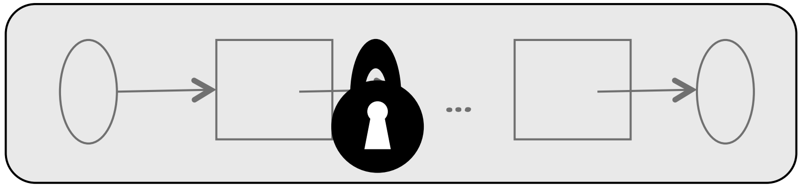
Not LS-linearizable: locally serializable,

but not linearizable…



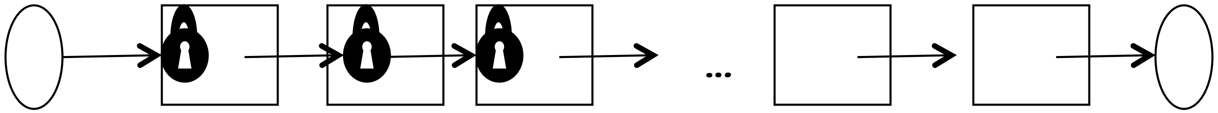
- protect data items (critical sections),
- provide roll-backs (transactions)

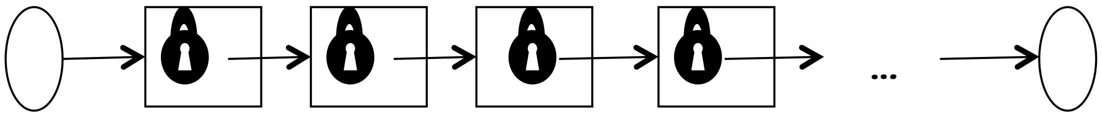
Locking schemes for a linked-list



Coarse-grained locking

2-phase locking





Hand-over-hand locking: relaxed for specific data structures

Optimistic wrapper for a linked-list

```
startTxn
Contains(s):
    ⟨prev, curr⟩ ← Locate(s)
    if curr.val = s then
        result ← true
    else
        result ← false
    return result
tryCommit
```

```
startTxn

Insert(s):
    ⟨prev, curr⟩ ← Locate(s)
    if curr.val ≠ s then
        X_s ← new-node(s)
        X_s.next ← curr
        prev.next ← X_s
    return ok
tryCommit
```

```
startTxn

Remove(s):
    ⟨prev, curr⟩ ← Locate(s)
    if curr.val = s then
        curr.marked ← true
        // Mark node for removal
        prev.next ← curr.next
    return ok

tryCommit
```

Plenty of STMs exist:

- Opaque
- Strictly serializable
- Elastic
- …

What about efficiency?

"Amount of concurrency": the sets of accepted schedules (orderings of sequential steps)

- ✓Each (correct) implementation accepts a subset of schedules
- ✓The more schedules are accepted the better

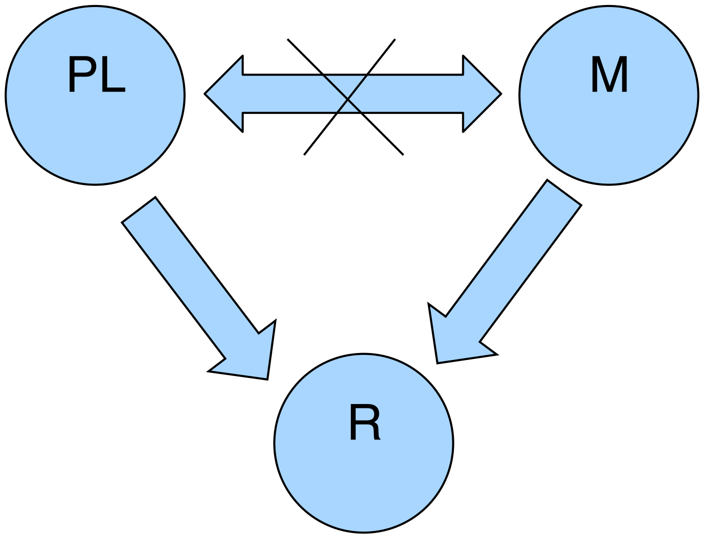
Which technique provides most concurrency?

Relaxation vs. Optimism

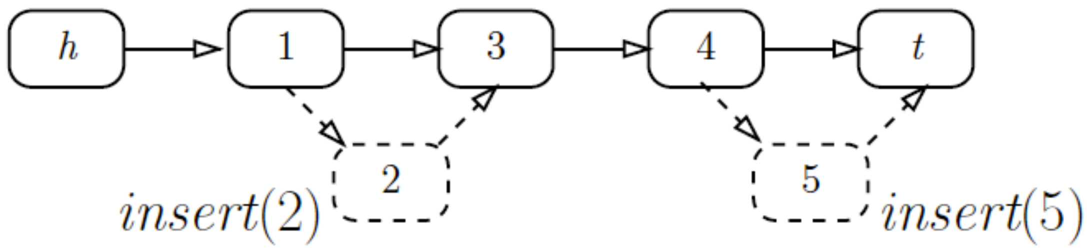
PL: deadlock-free (fine-grained) lock-based

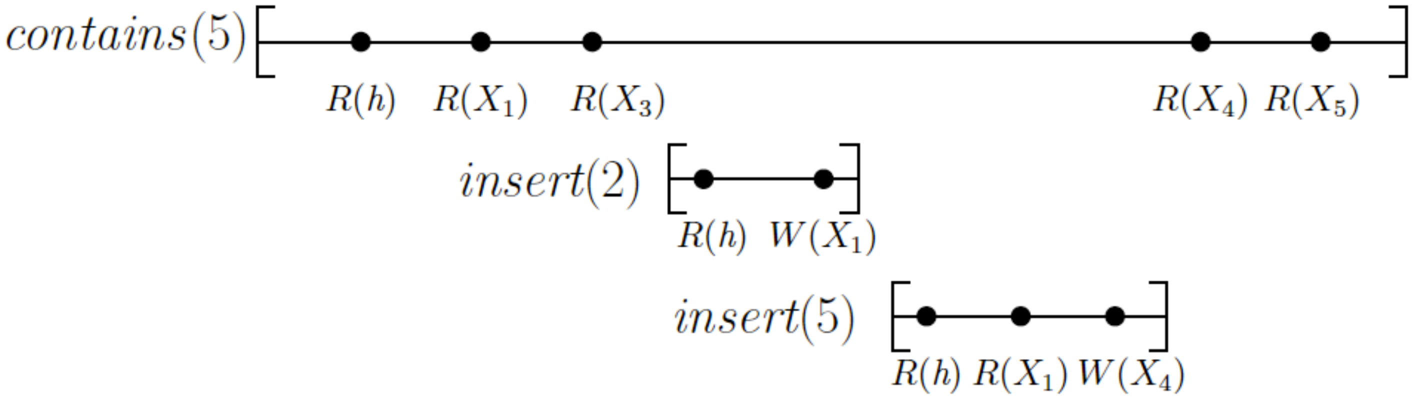
M: strongly consistent (serializable) TMs

R: relaxed (data-type-aware) TMs

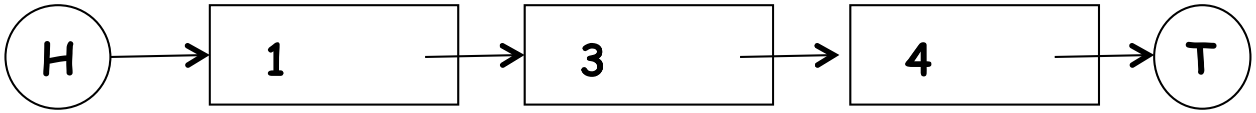


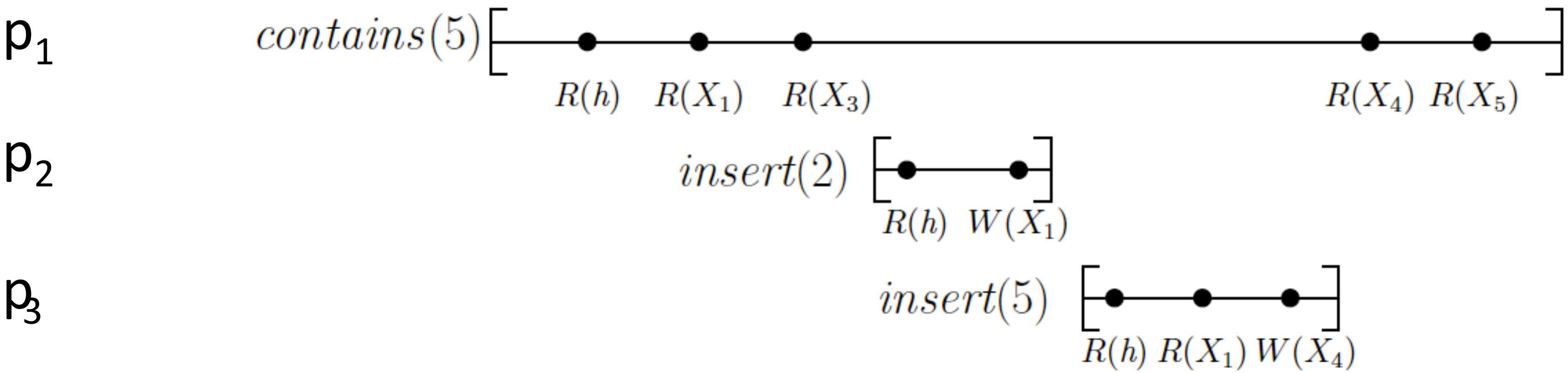
$M \not\preceq_{(LL,set)} PL$





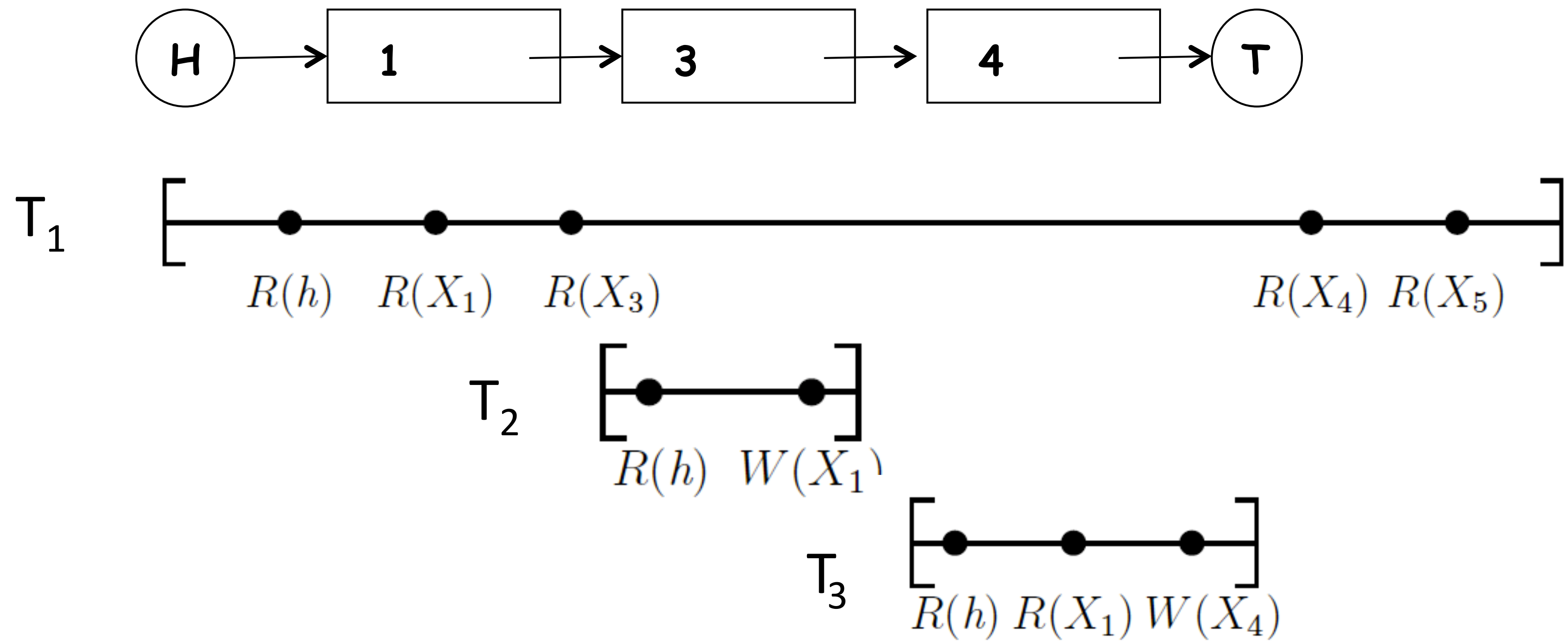
Accepted by locks





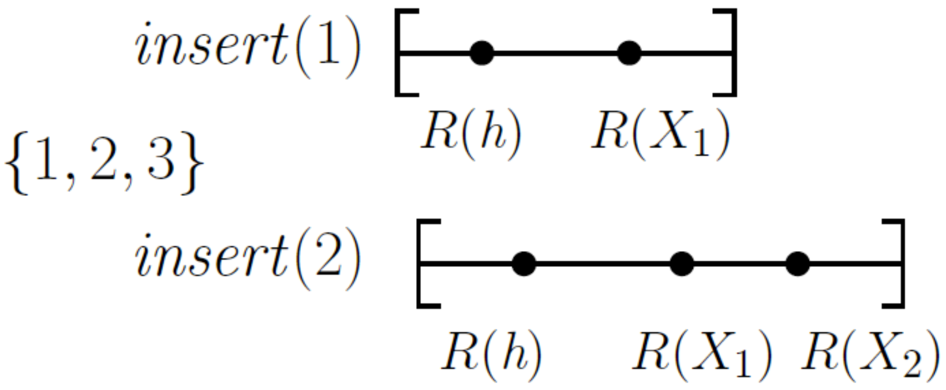
- Accepted by hand-over-hand
  - ✓ p_1 and p_3 are consistent with different serializations

But not serializable!



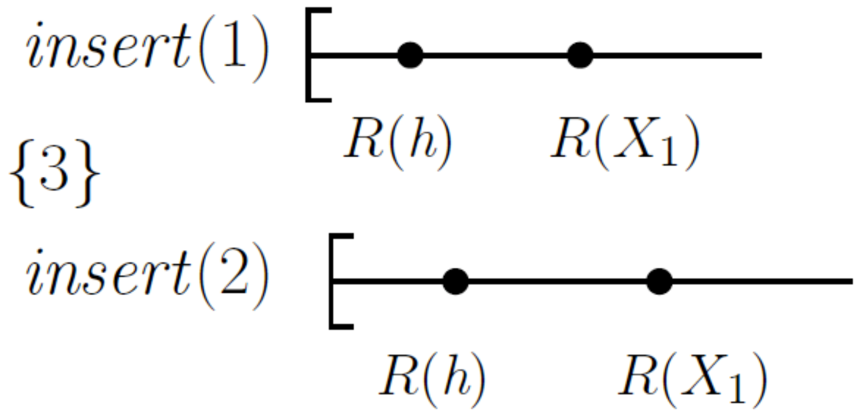
- T_1->T_2 (T_1 read X_1 before T_2 updated it)
- T_2->T_3 (T_3 sees the effect of T_2)
- T_3-> T_1 (T_1 sees the effect T_3)

$PL \not\preceq_{(LL,set)} M$



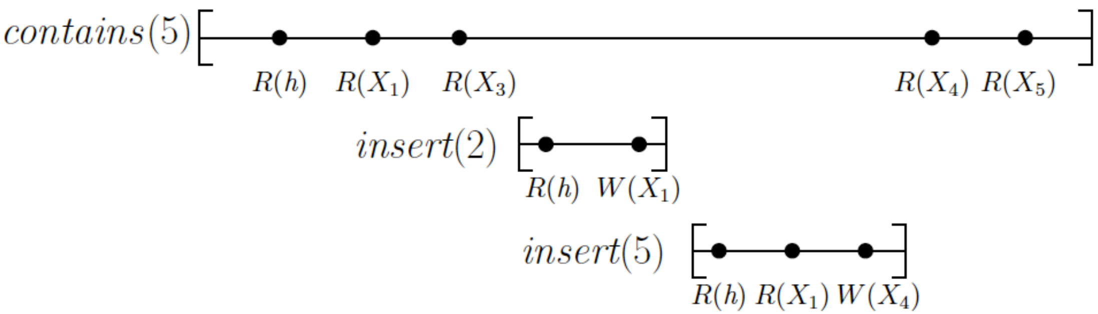
No writes: accepted by M

- Both ops are about to write: rejected by M (at least one txn aborts)
- But must be accepted by PL too!

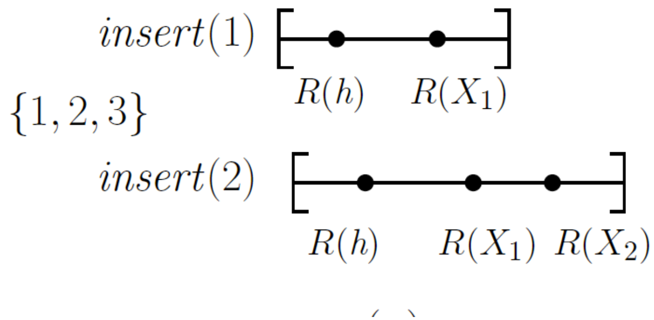


$$M \prec_{(LL,set)} R \qquad PL \prec_{(LL,set)} R$$

- *R* accepts every observable correct schedule of *(LL,set)*
- *R* accepts the linearizable but not serializable schedules of non-conflicting updates (1)
- *R* accepts the potentially conflicting-update schedule (2)



(1)



(2)

Results and implications

- What is a correct concurrent wrapper?
  - ✓LS-linearizability
- How to measure relative efficiency of concurrent wrappers?
  - ✓Accepted schedule sets
- Benefits of relaxation and optimism formally captured
- A language to reason about the “best” synchronization technique, the “most suitable” data structure

Open questions

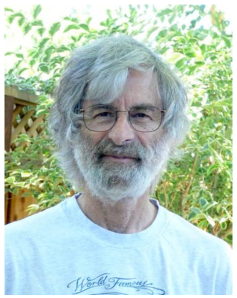
- Extend the results to more general classes of types, data structures
- Workload analysis: which schedules are relevant?
- What concurrency tells us? The cost of concurrency?

Details: http://arxiv.org/abs/1203.4751

Distributed ≠ Parallel

- The main challenge is efficient and robust synchronization

- “you know you have a distributed system when the crash of a computer you’ve never heard of stops you from getting any work done” (Lamport)



Merci beaucoup!