Lecture 31: Optimistic Linked Lists

COSC 273: Parallel and Distributed Computing

Spring 2023

Annoucements

1. Leaderboard submission results tomorrow
2. Next leaderboard submission is ~~Friday~~? Monday?
3. Take-home quiz: released Wednesday (Gradescope), due Friday
    - concurrent linked lists

Today

Concurrent Linked Lists, Three Ways:

1. Coarse locking
2. Fine-grained locking
3. Optimistic locking ←

A Generic Task

Store, access, & modify collection of *distinct* elements:

no duplicate elts

The `Set` ADT:

- `add` an element
  - no effect if element already there
- `remove` an element
  - no effect if not present
- check if set `contains` an element

Java `SimpleSet` Interface

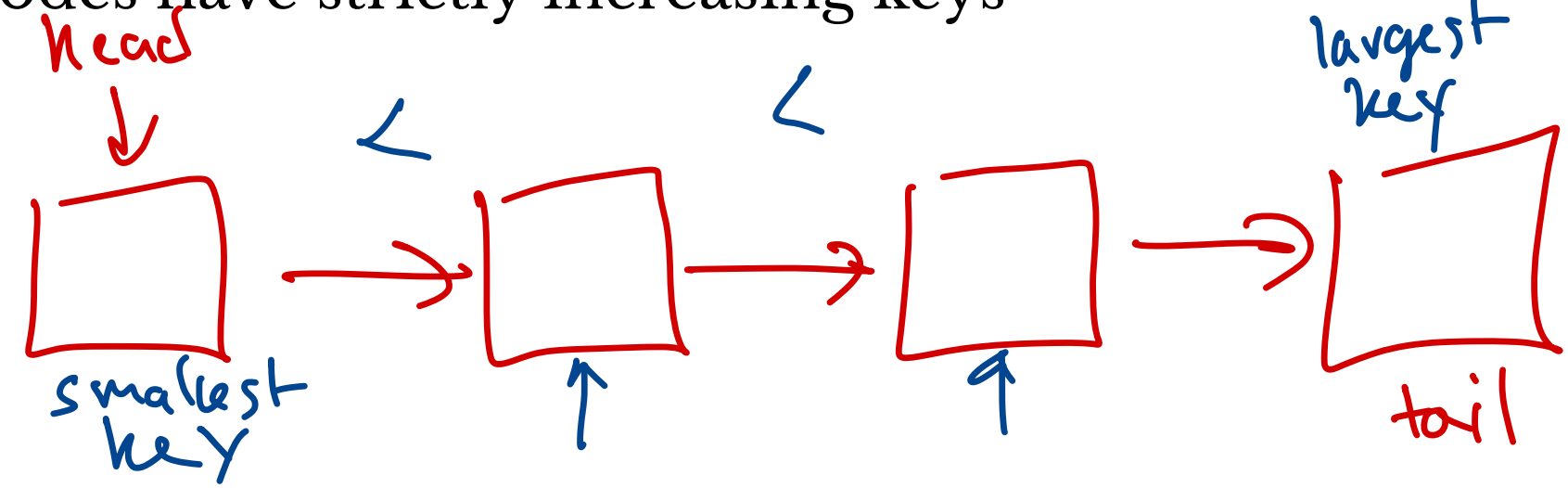
```
public interface SimpleSet<T> {
// Add an element to the SimpleSet. Returns true if the element
// was not already in the set.
boolean add(T x);

// Remove an element from the SimpleSet. Returns true if the
// element was previously in the set.
boolean remove(T x);

// Test if a given element is contained in the set.
boolean contains(T x);
}
```

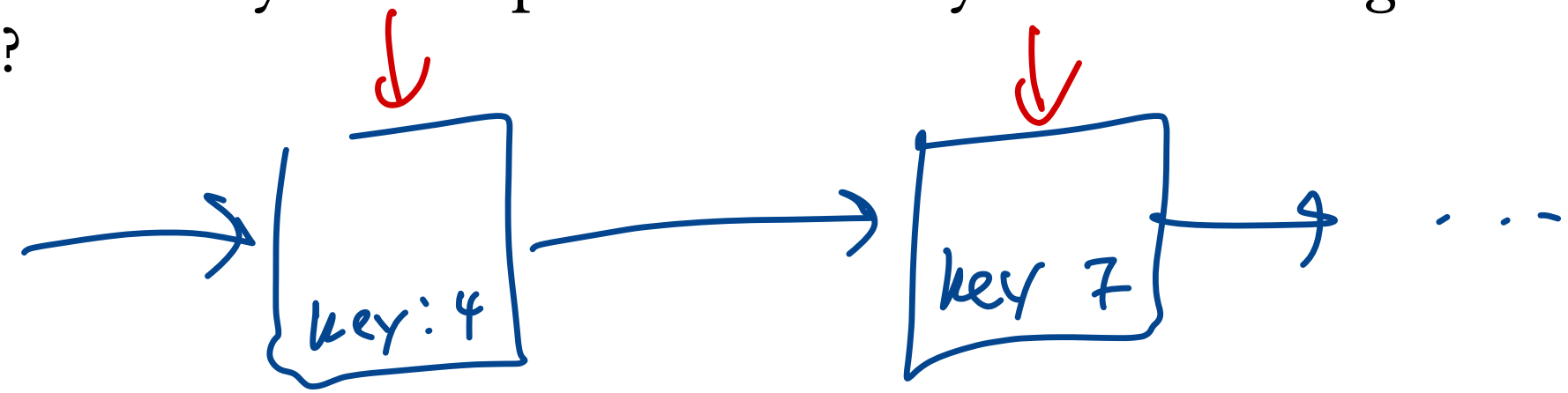
Linked List `SimpleSets`

- Each `Node` stores:
  - reference to the stored object
  - reference to the next `Node`
  - a numerical *key* associated with the object
- The list stores
  - reference to `head` node
  - a `tail` node
  - `head` and `tail` have min and max key values
  - nodes have strictly increasing keys



Why Keys?

Question. Why is it helpful to store keys in increasing order?



looking for elt. w/ key 6

- can stop search before end of list
- gives unique locations for modification.

Our Goals

1. Correctness, safety, liveness
    - deadlock-freedom
    - starvation-freedom?
    - nonblocking??
    - linearizability???
2. Performance
    - parallelism?

Synchronization Philosophies

1. Coarse-Grained (`CoarseList.java`)
   - lock whole data structure for every operation
2. Fine-Grained (`FineList.java`)
   - only lock what is needed to avoid disaster
3. Optimistic (`OptimisticList.java`)
   - don't lock anything to read, only lock to modify
4. Lazy (`LazyList.java`)
   - use "logical" removal, only lock occasionally
5. Nonblocking (`NonblockingList.java`)
   - use atomics, not locks!

Coarse-grained Locking

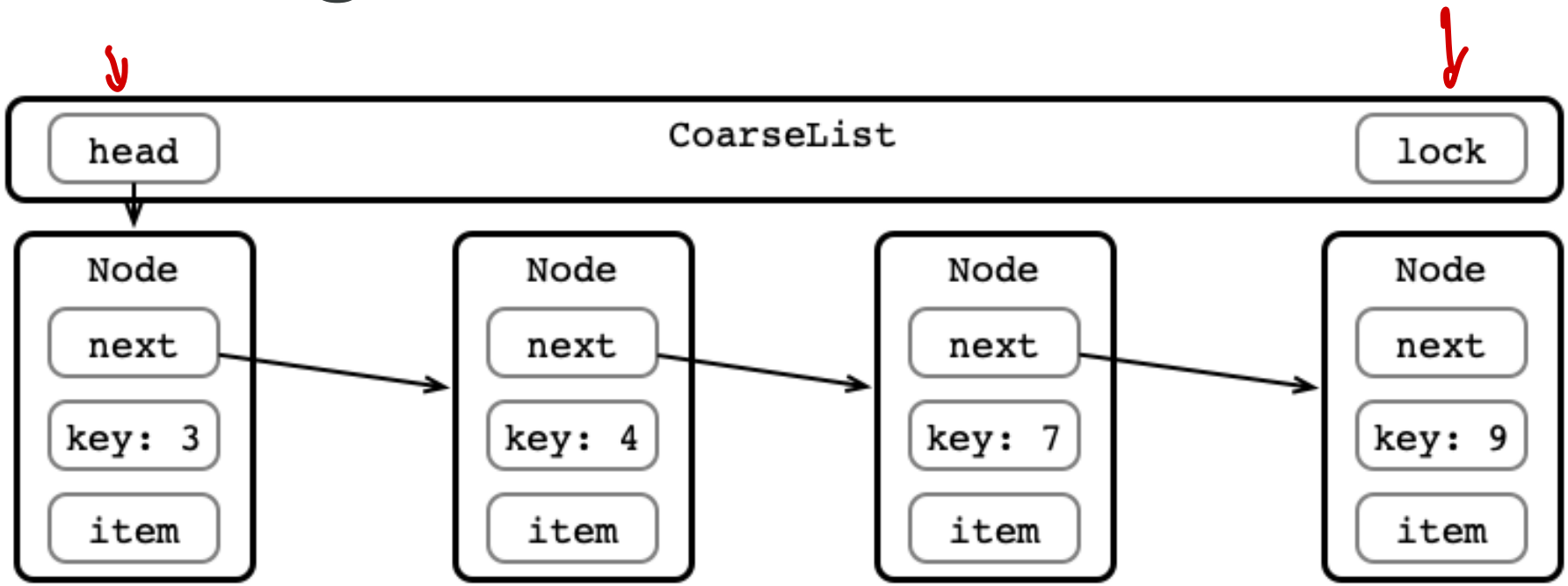
One lock for whole data structure

For any operation:

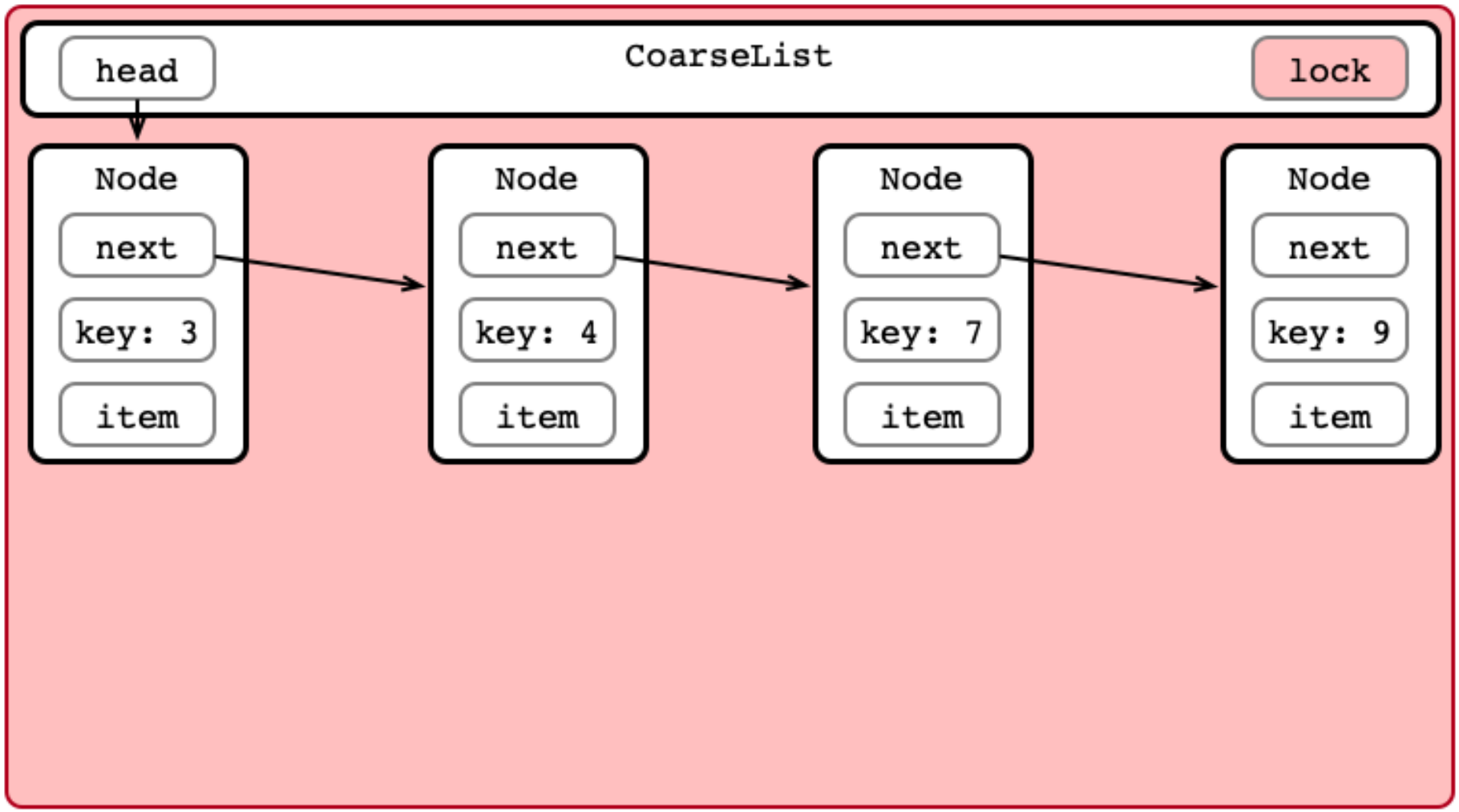
1. Lock entire list
2. Perform operation
3. Unlock list

See `CoarseList.java`

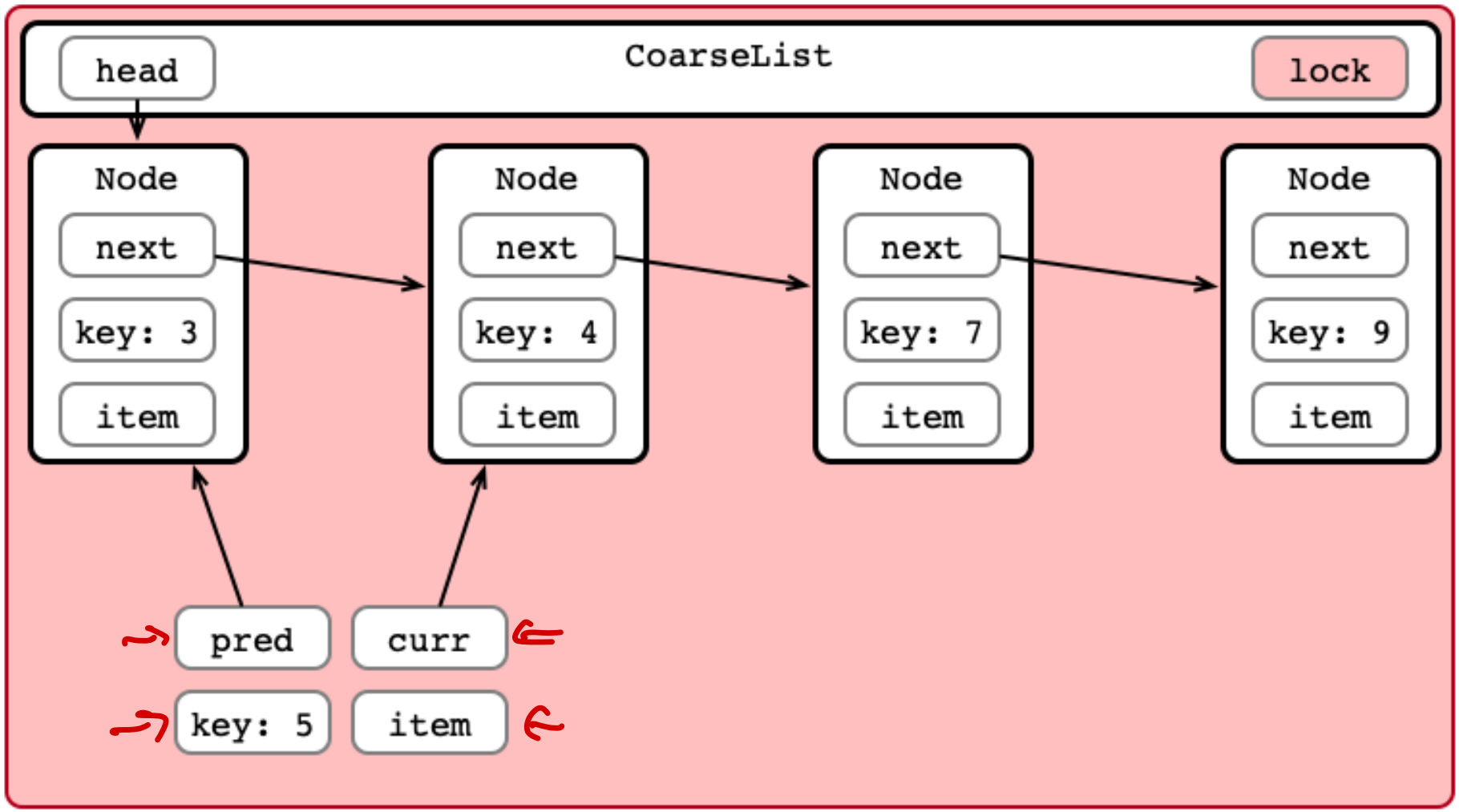
Coarse-grained Insertion



Step 1: Acquire Lock



Step 2: Iterate to Find Location



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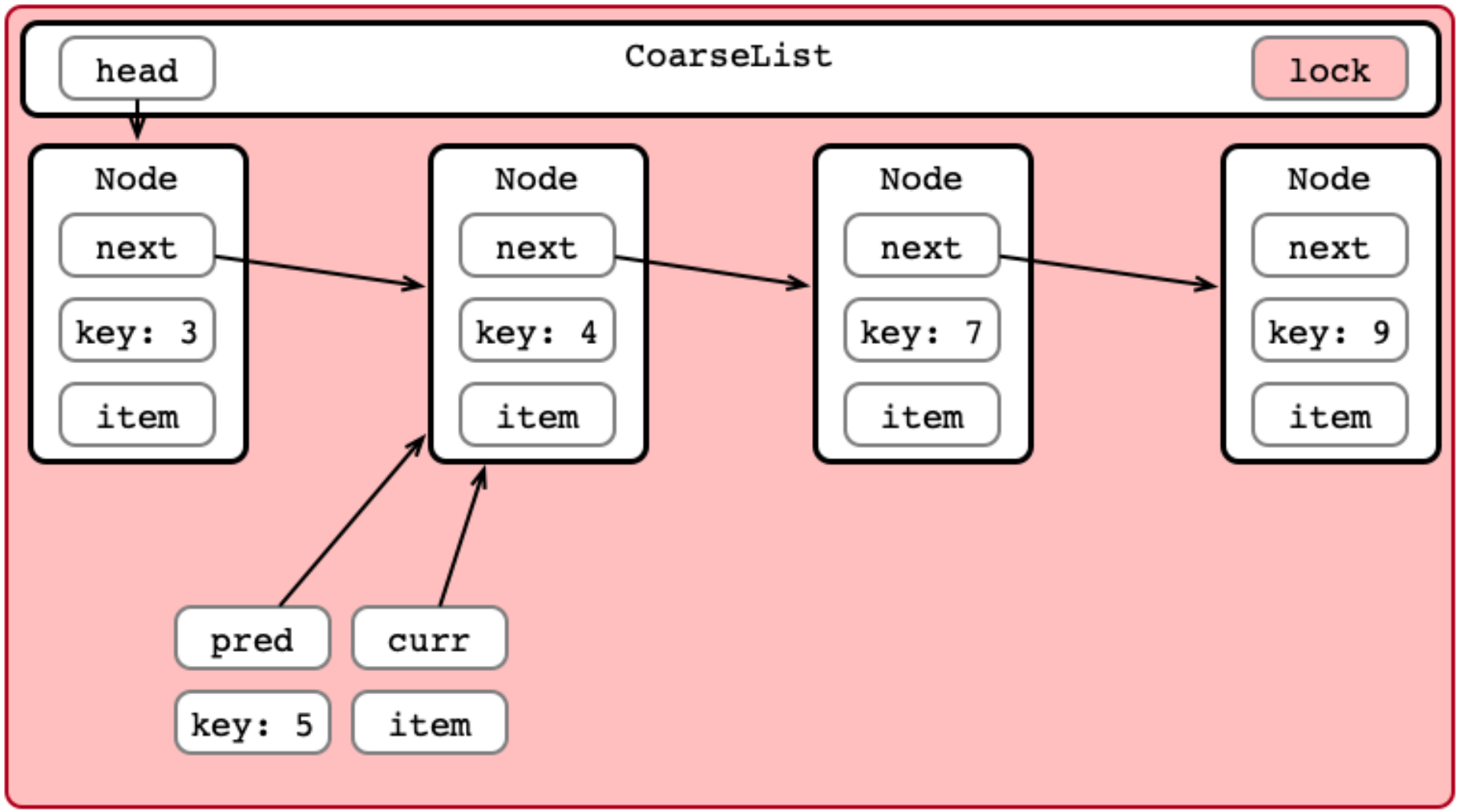

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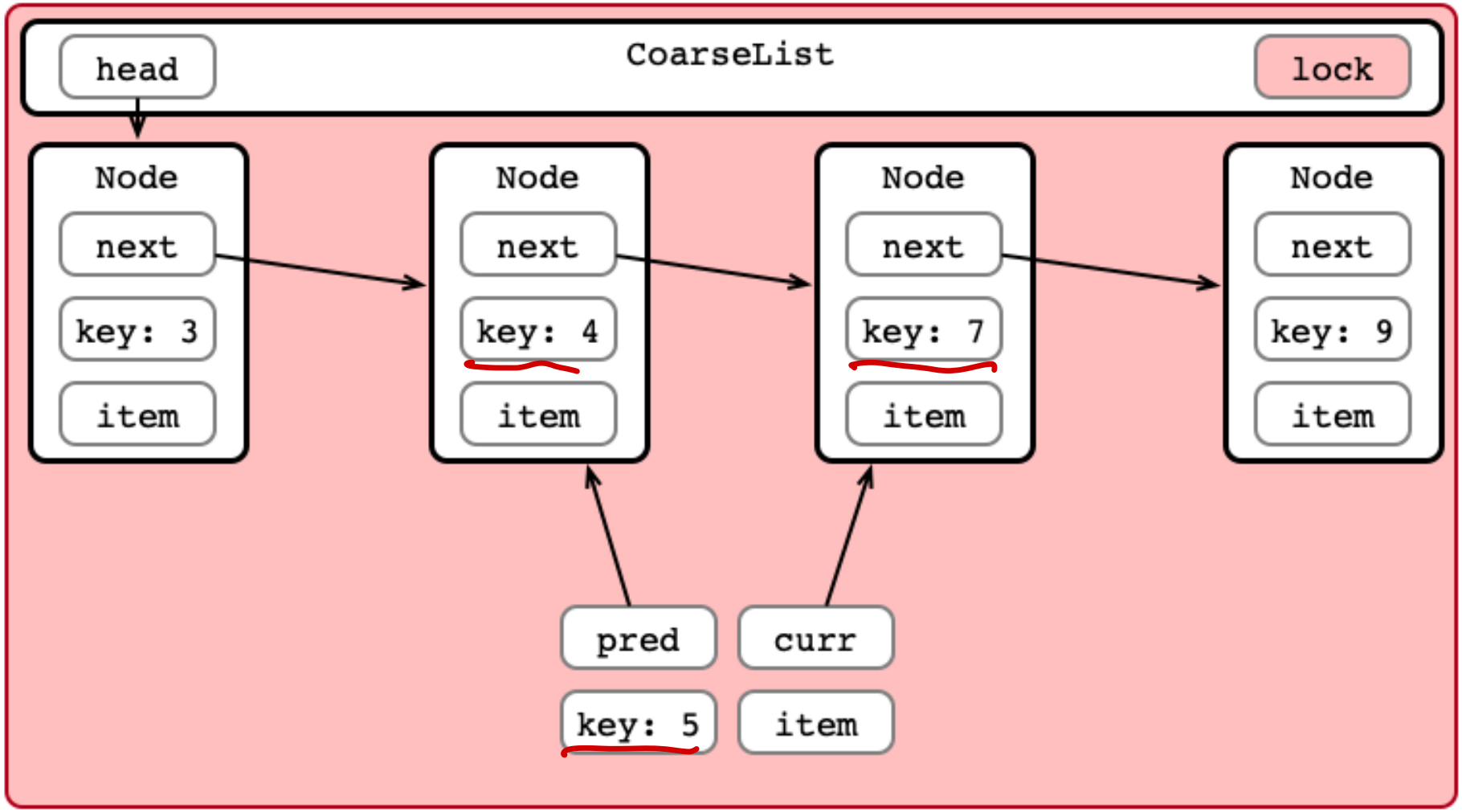
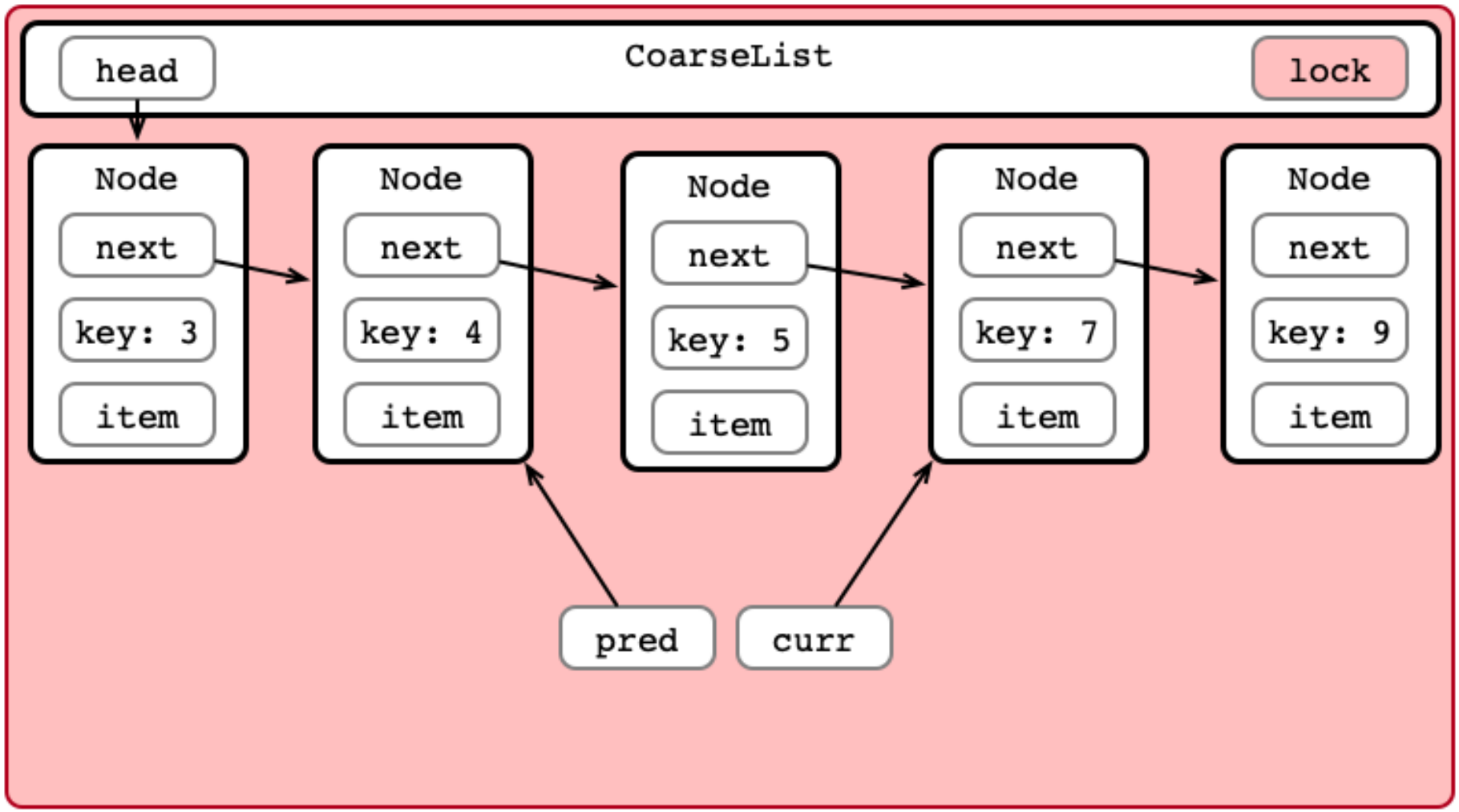
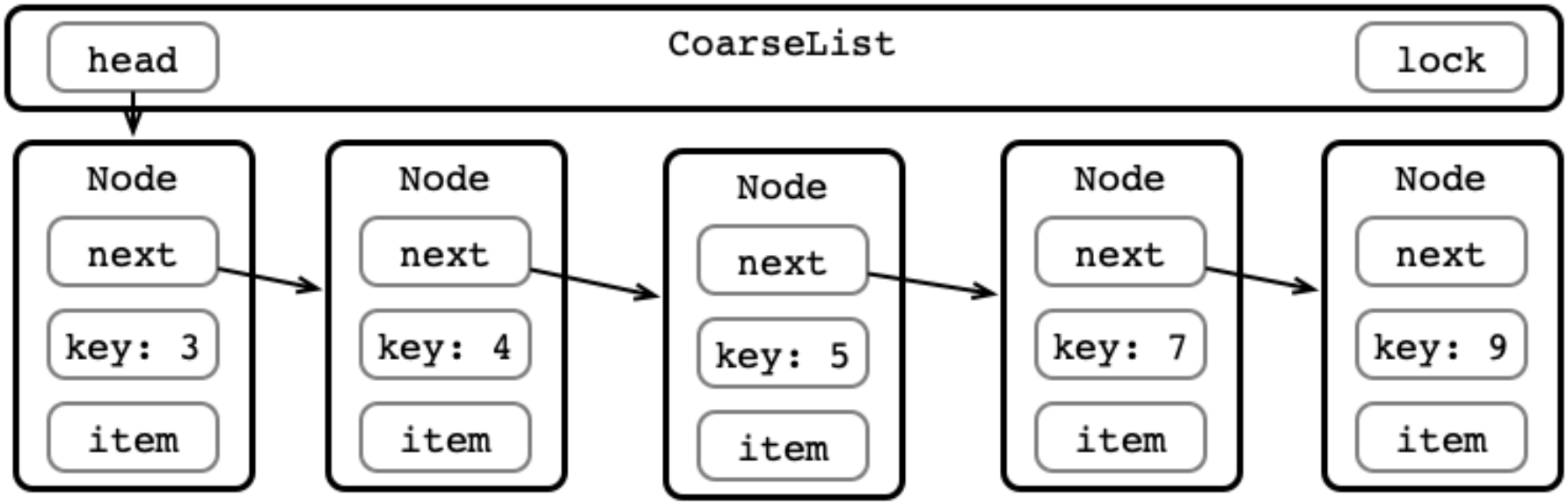


Step 3: Insert Item



Step 4: Unlock List



Coarse-grained Appraisal

Advantages:

- Easy to reason about
- Easy to implement

Disadvantages:

- No parallelism
- All operations are blocking

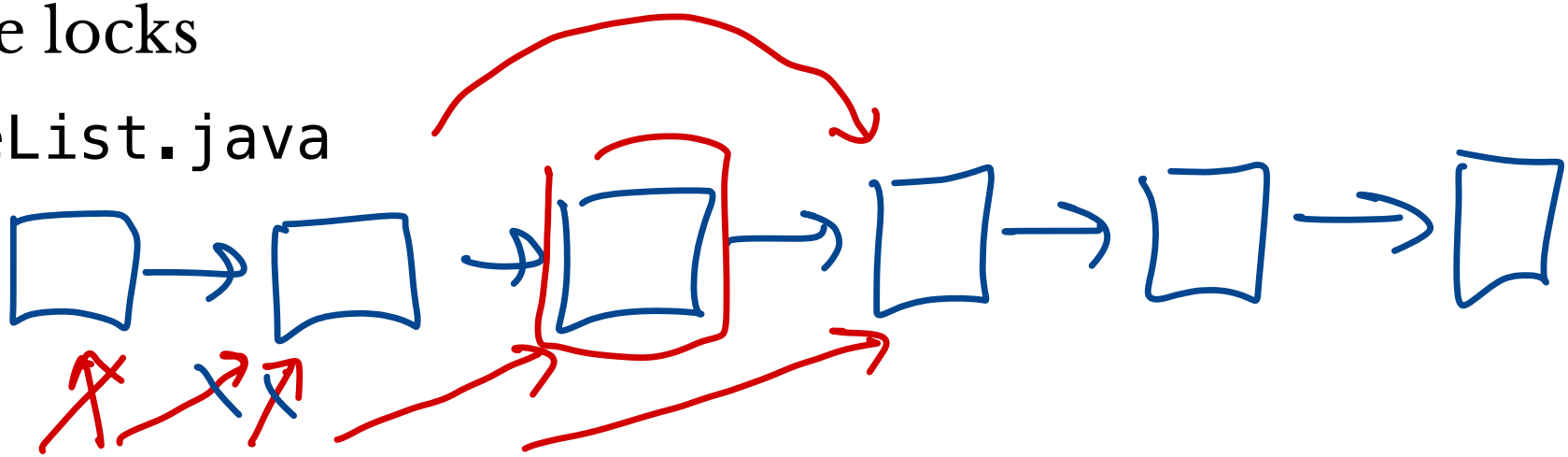
Fine-grained Locking

One lock per node

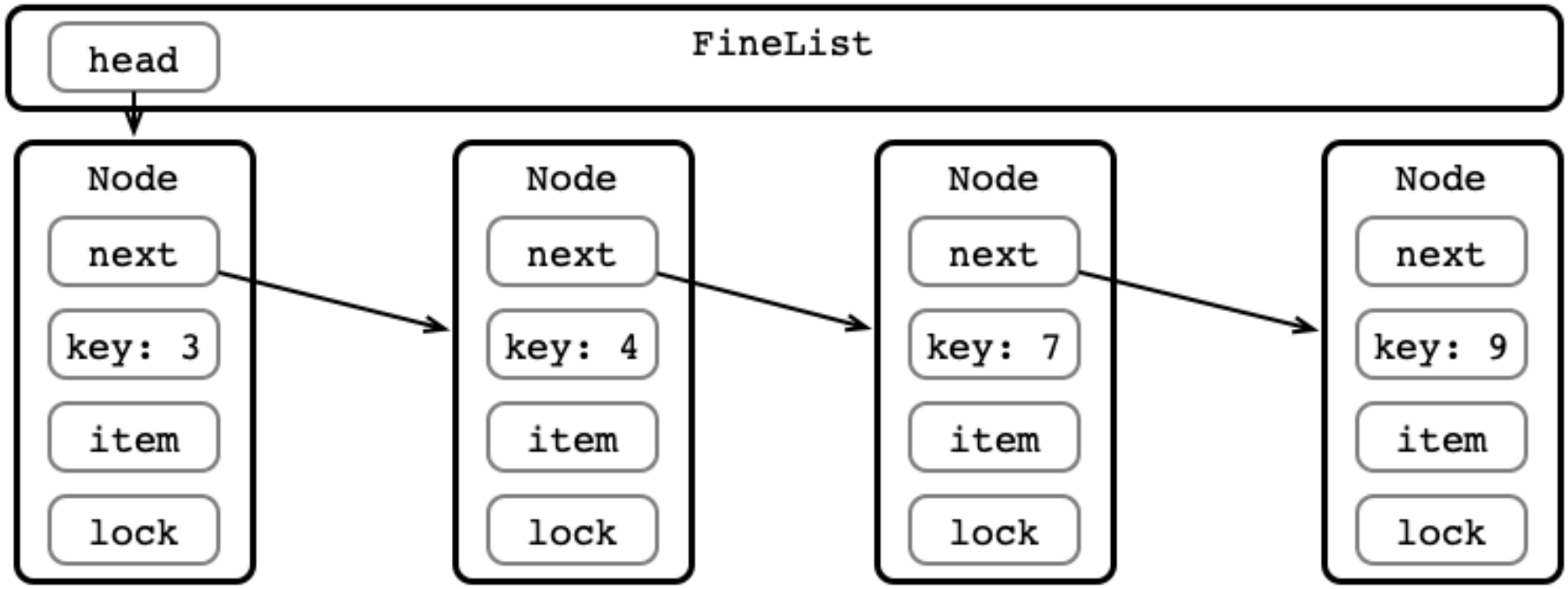
For any operation:

1. Lock head and its next
2. Hand-over-hand locking while searching
   - always hold at least one lock
3. Perform operation
4. Release locks

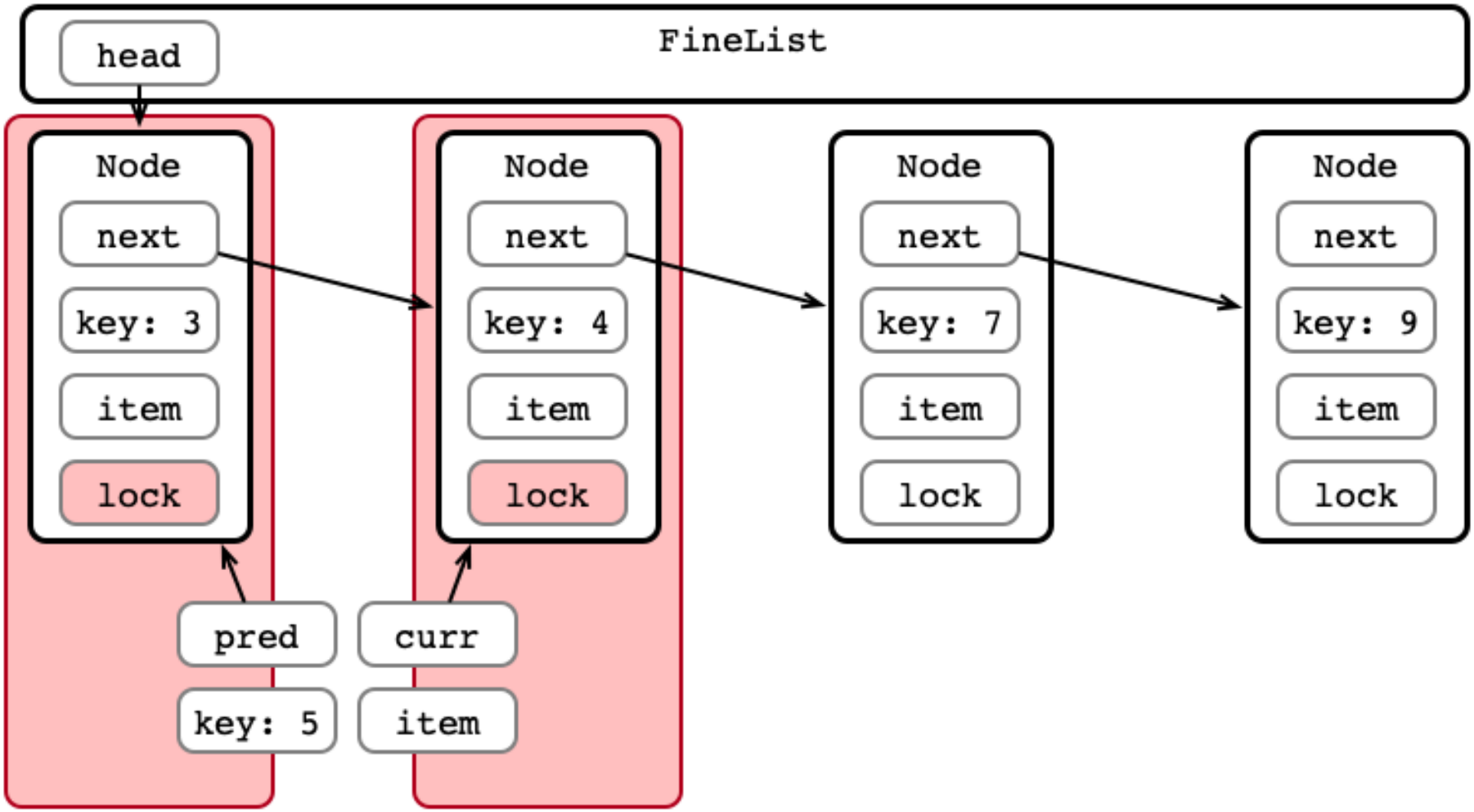
See `FineList.java`



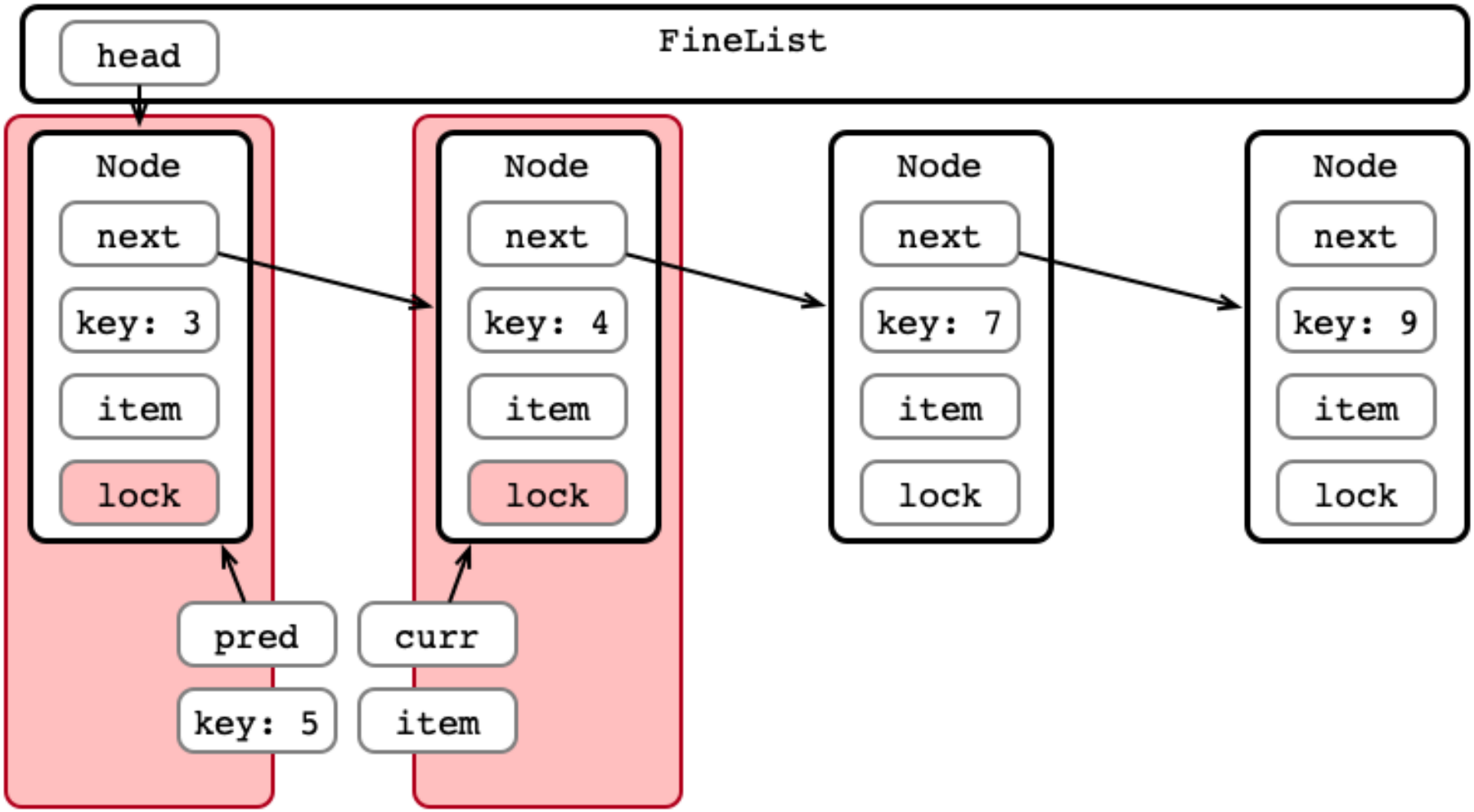
A Fine-grained Insertion



Step 1: Lock Initial Nodes



Step 2: Hand-over-hand Locking



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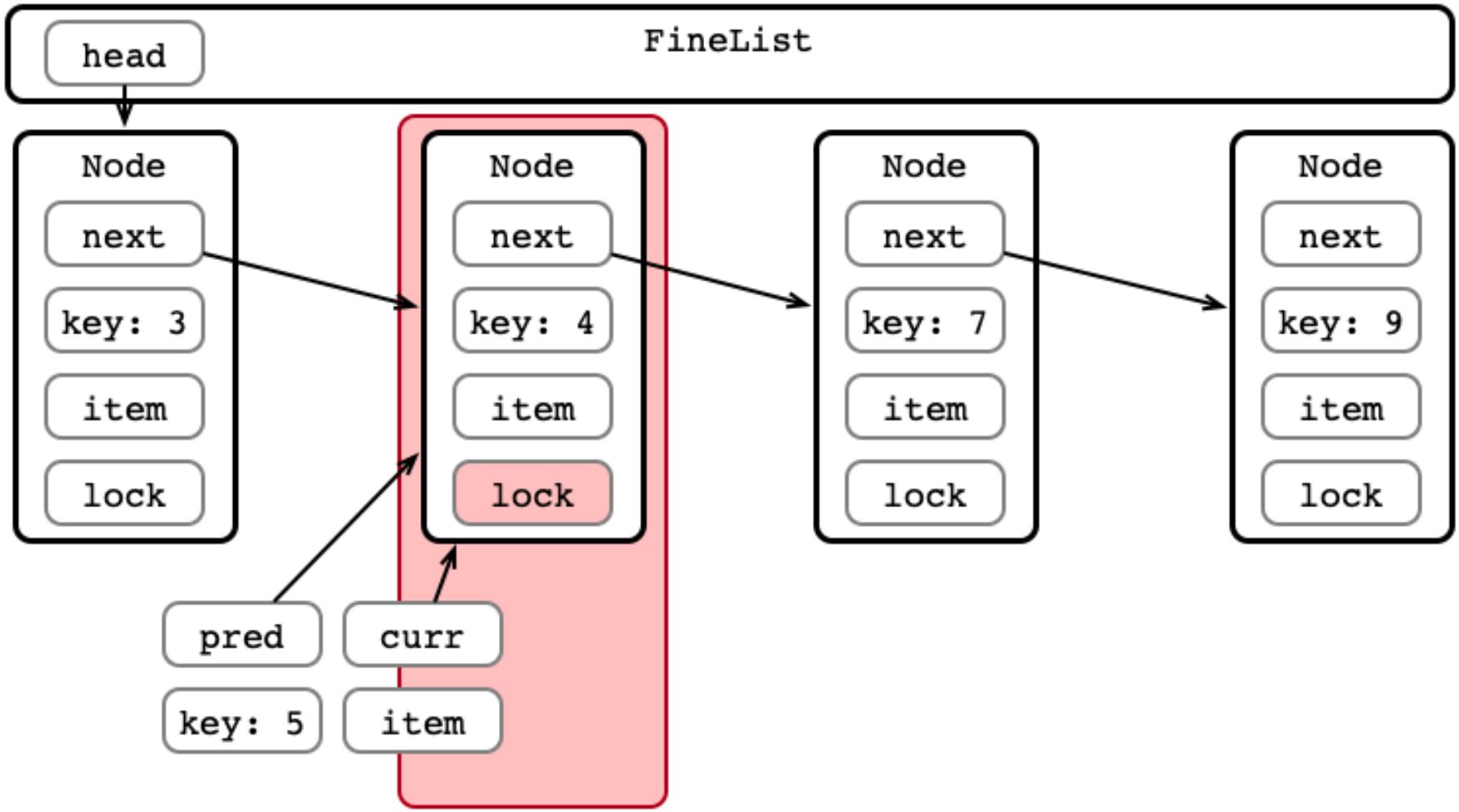
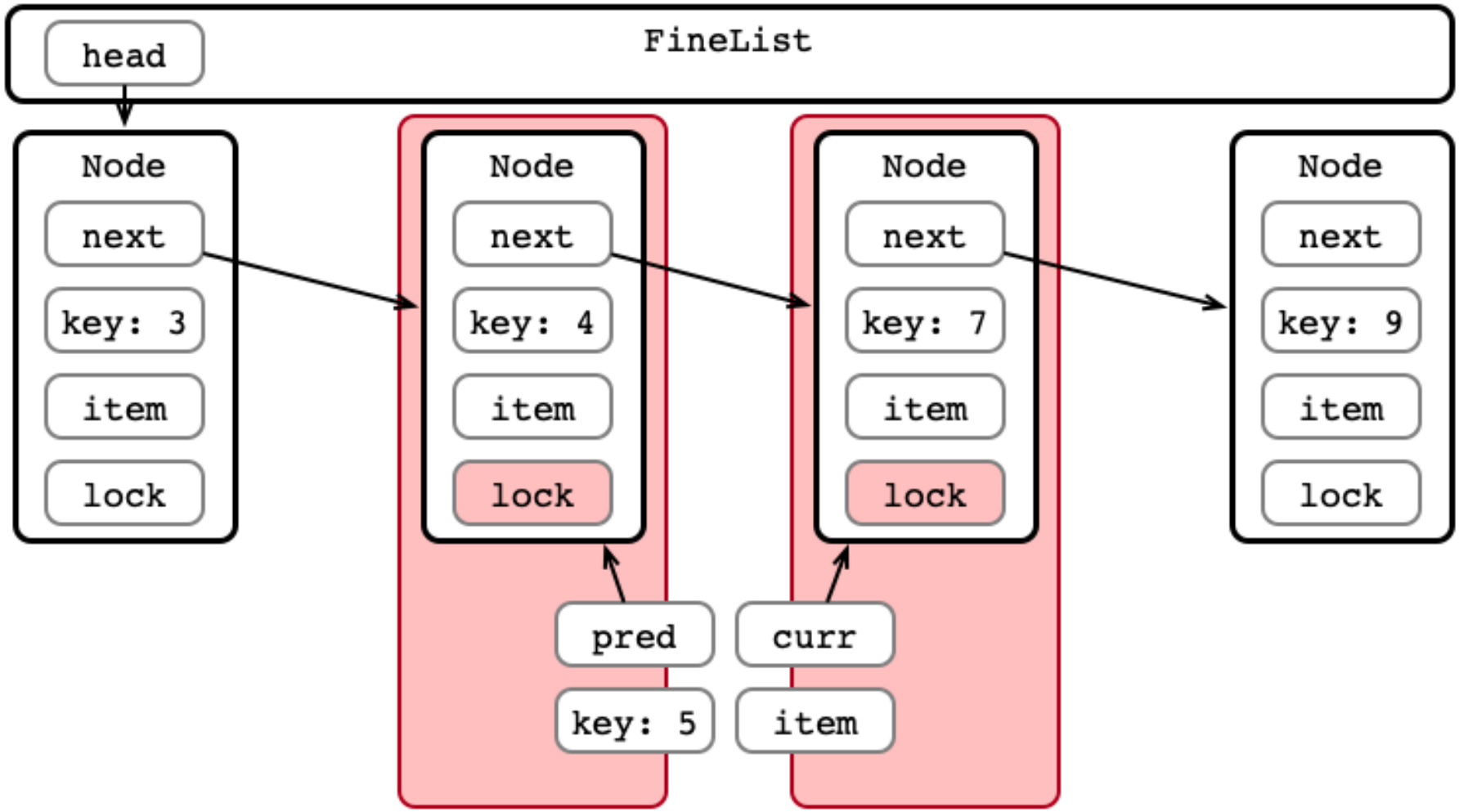
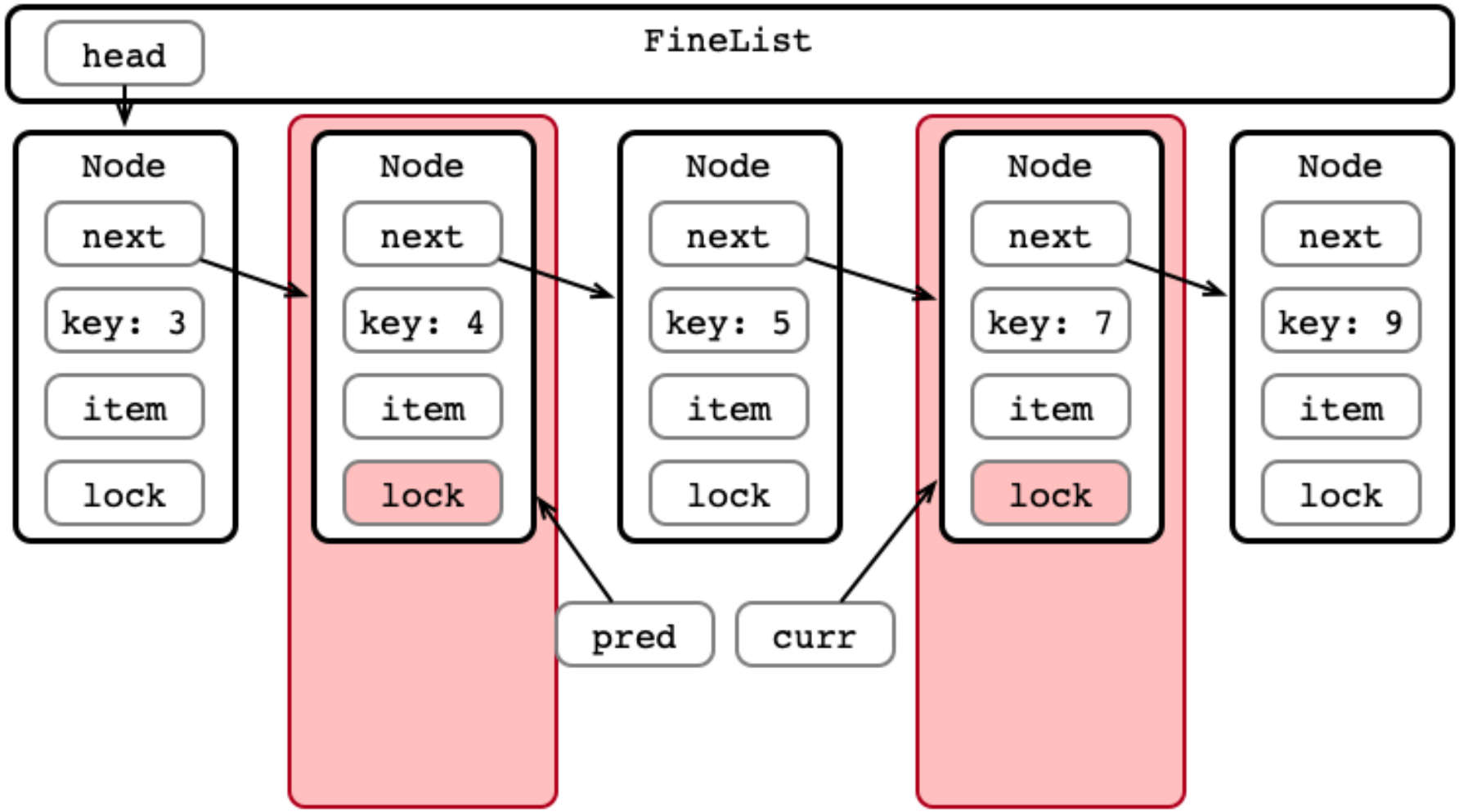


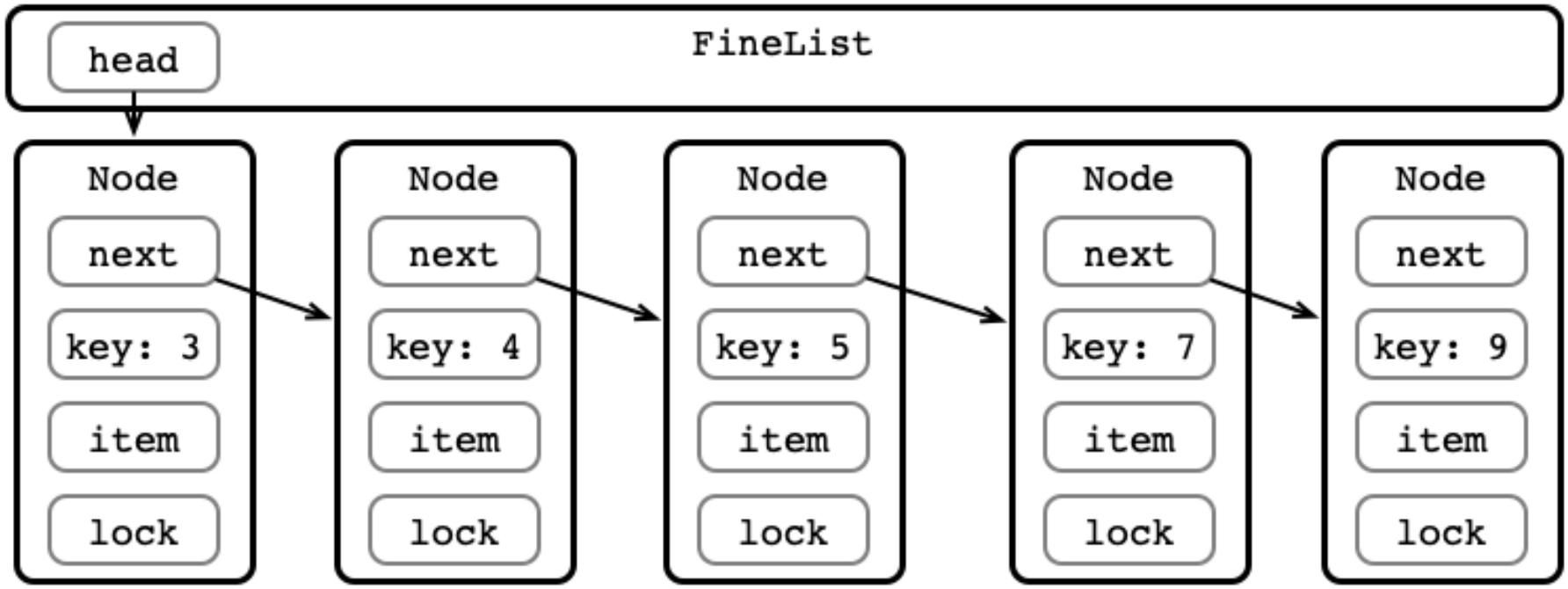
Step 2: Hand-over-hand Locking



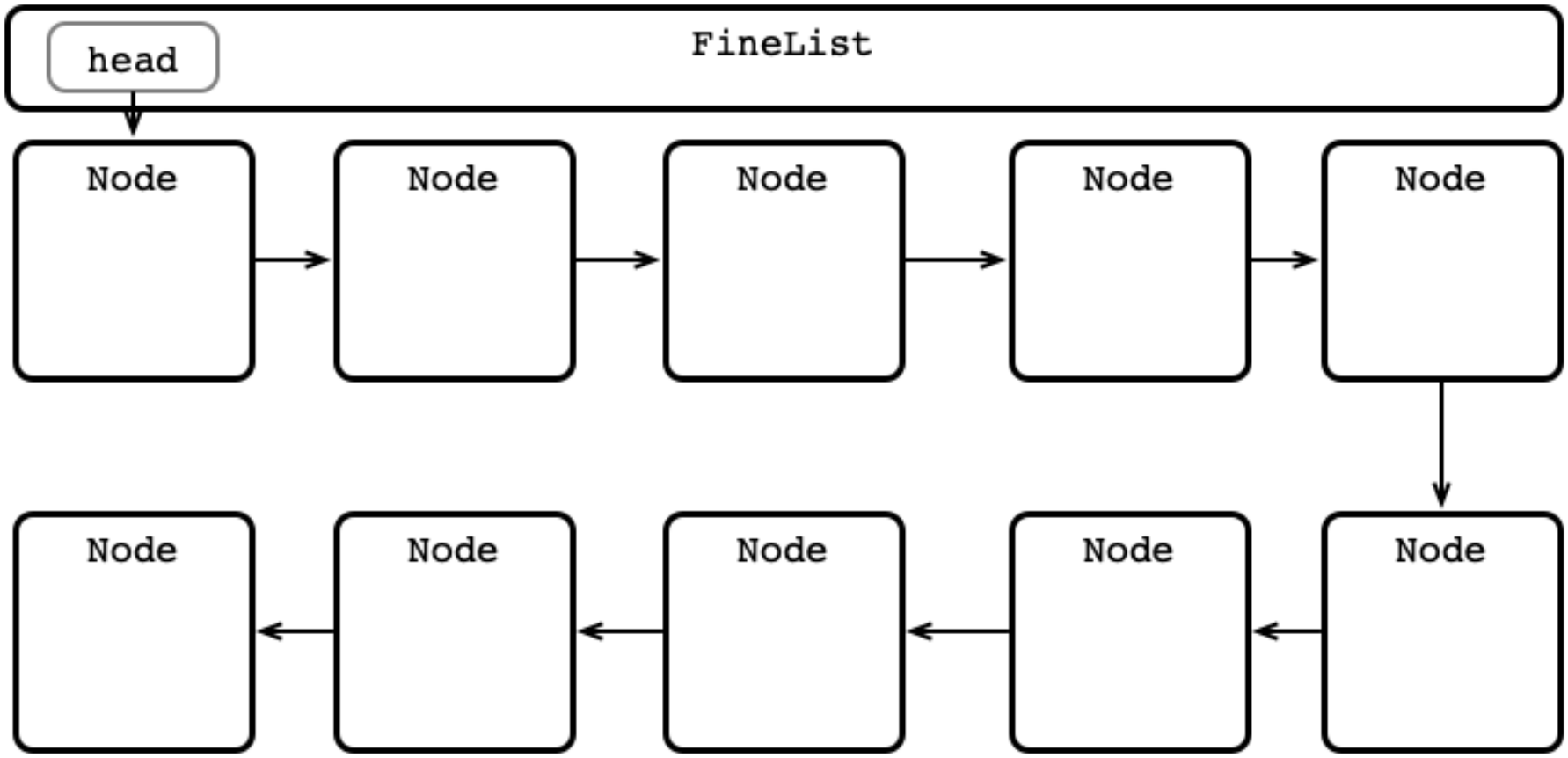
Step 3: Perform Insertion



Step 4: Unlock Nodes



An Advantage: Parallel Access



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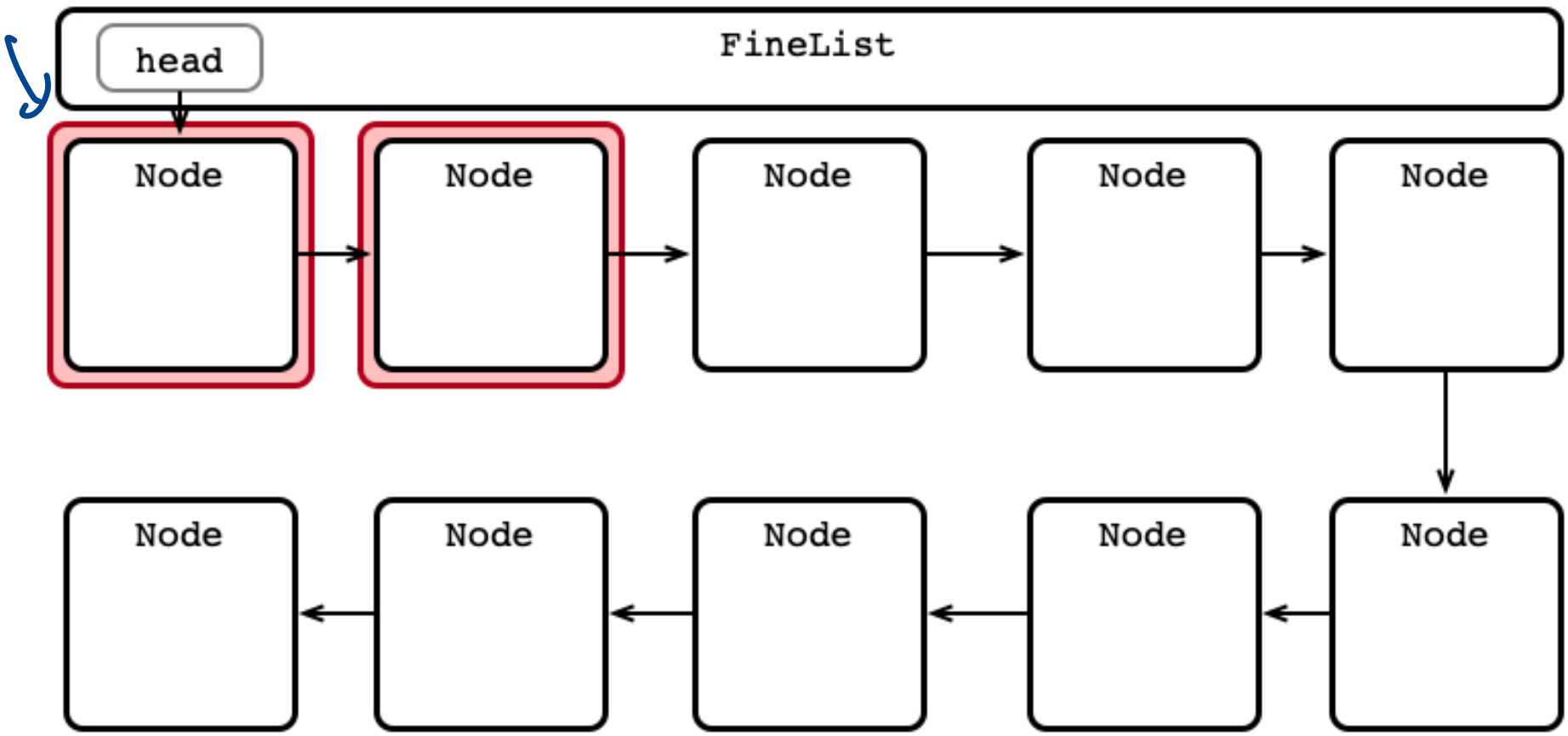
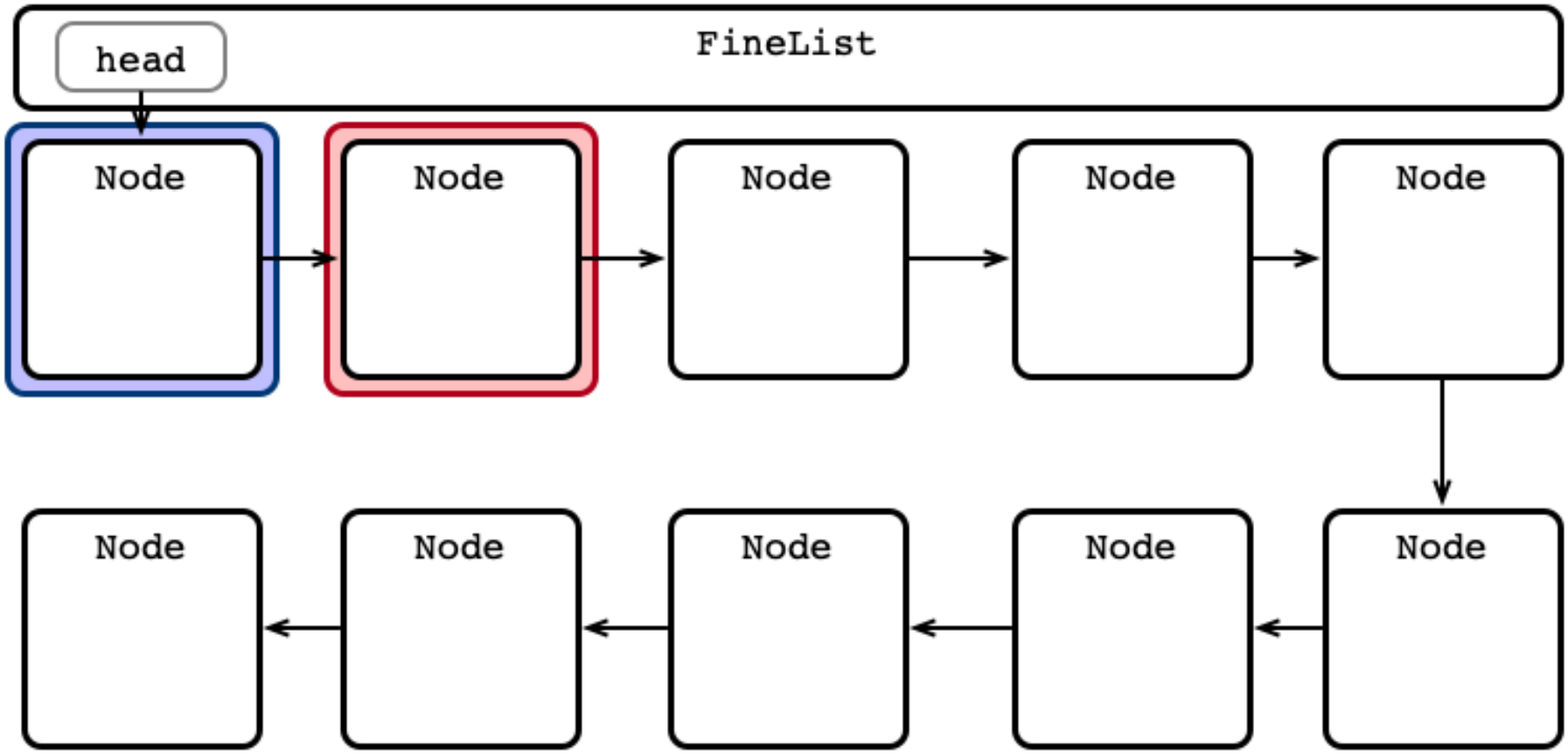


An Advantage: Parallel Access



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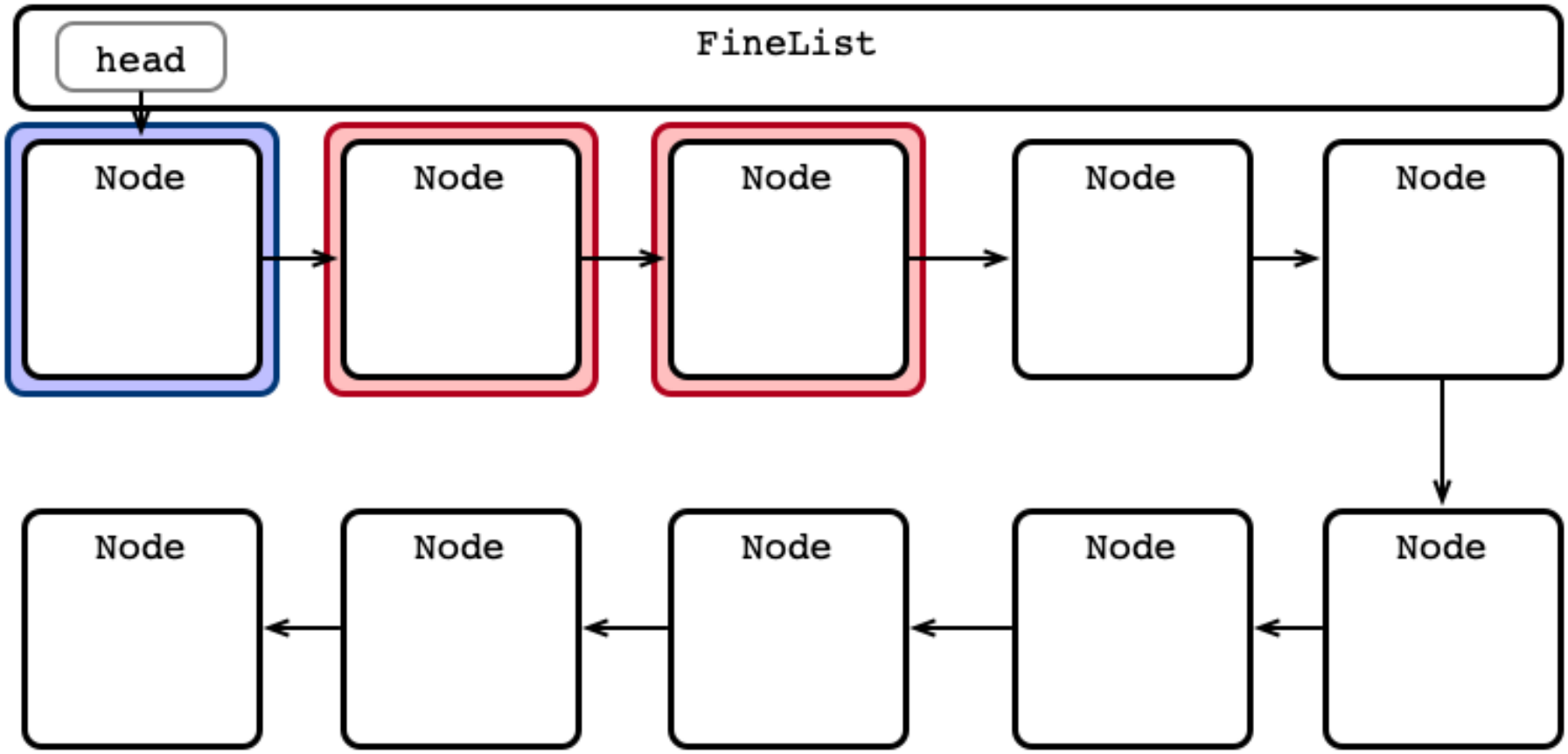

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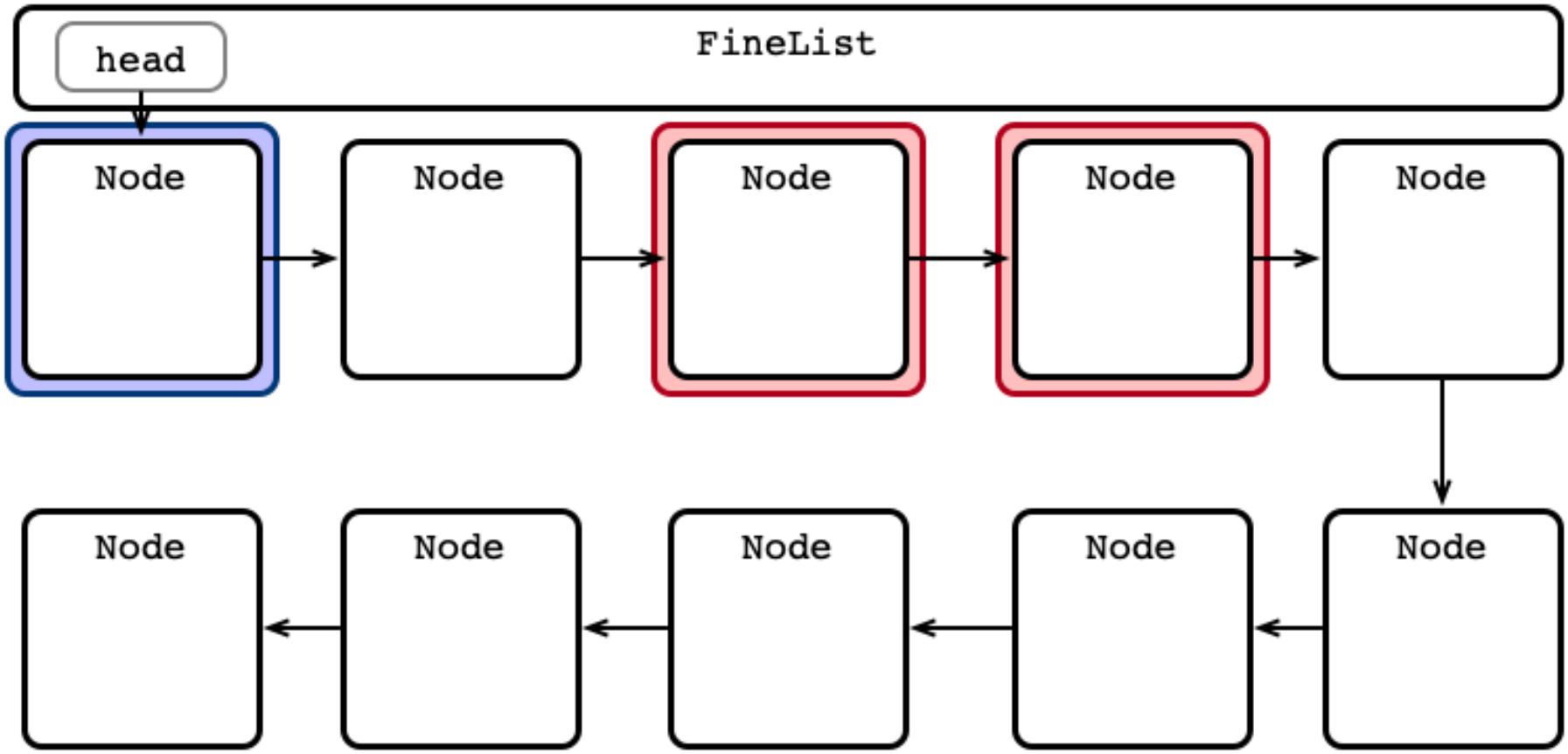

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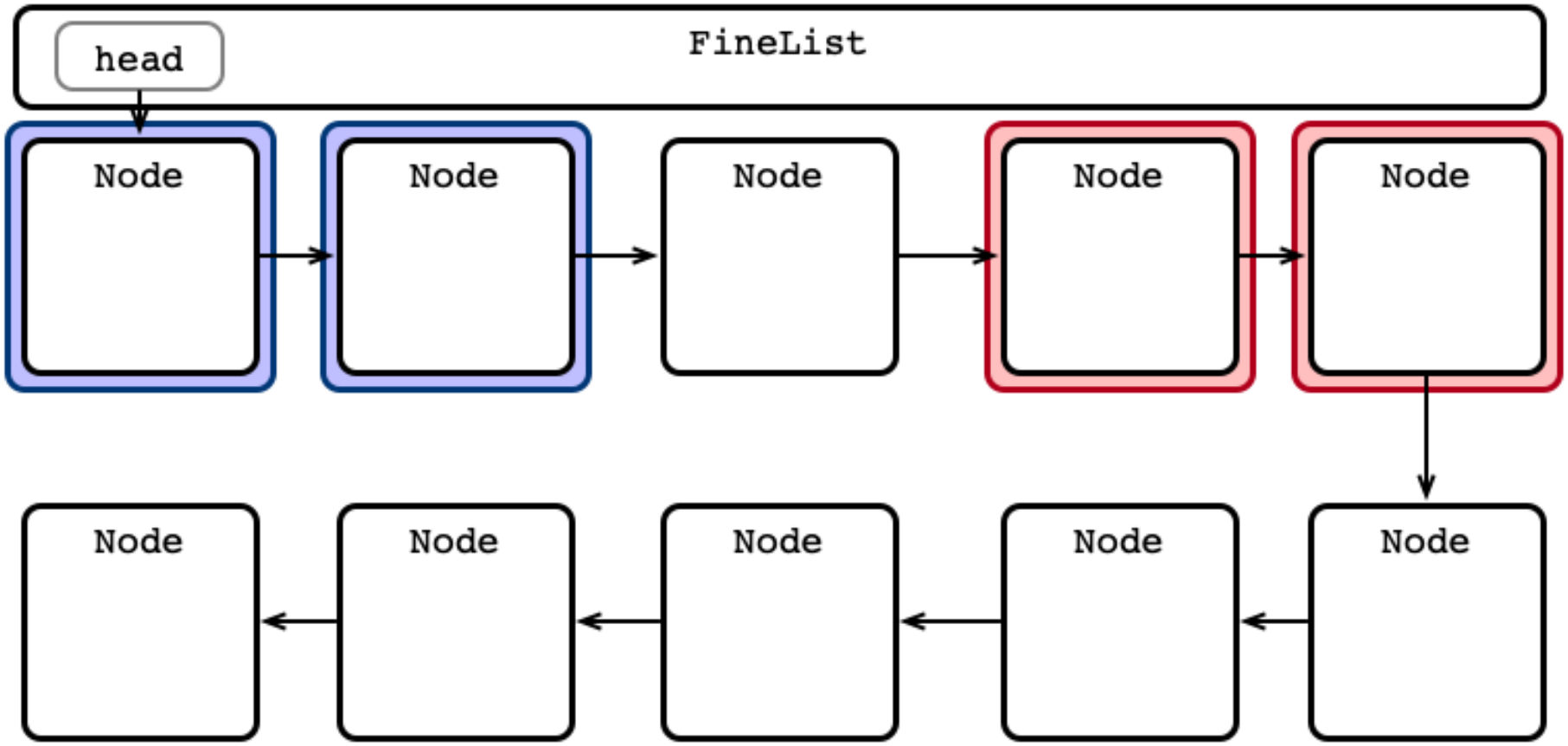

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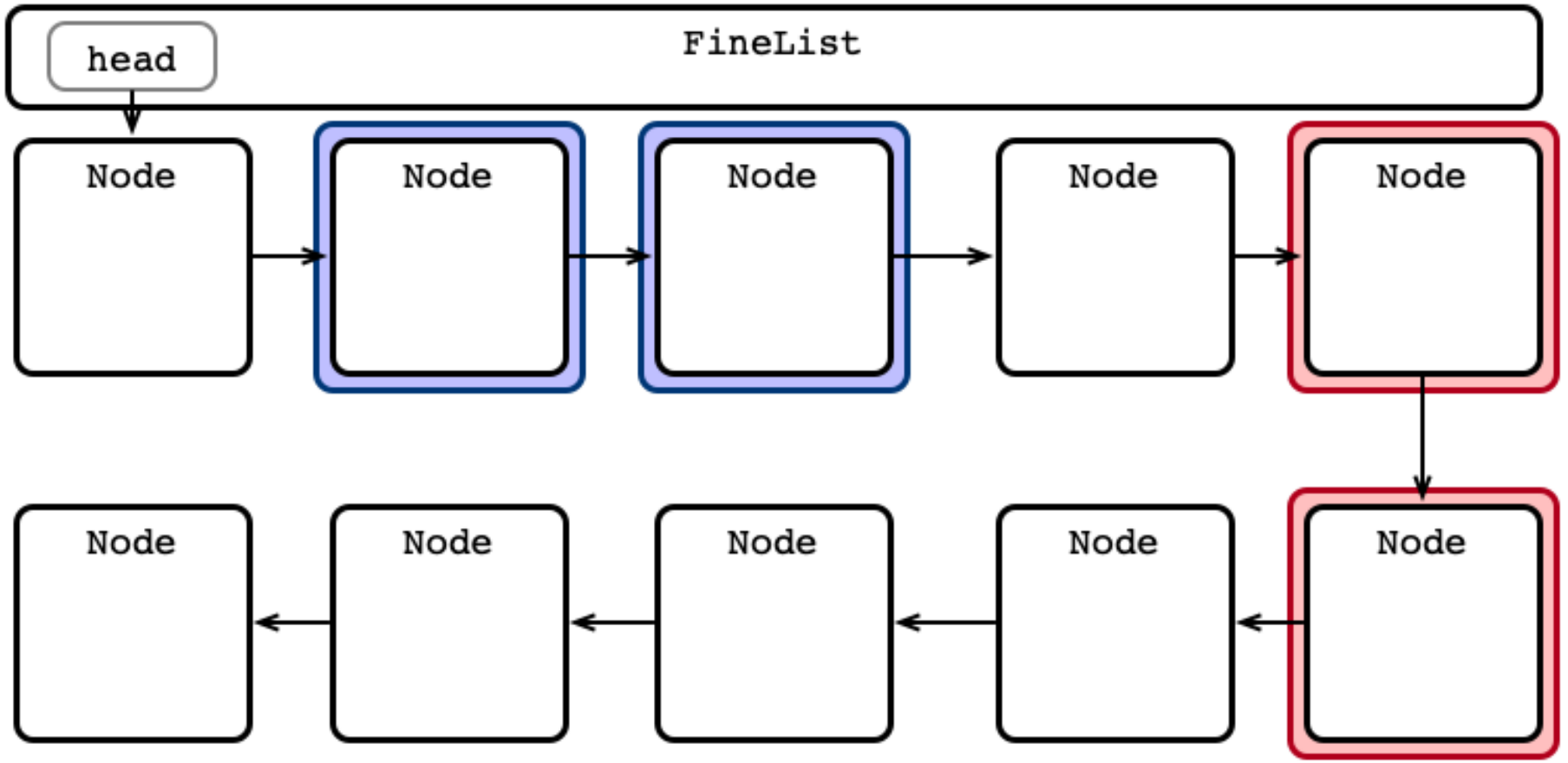

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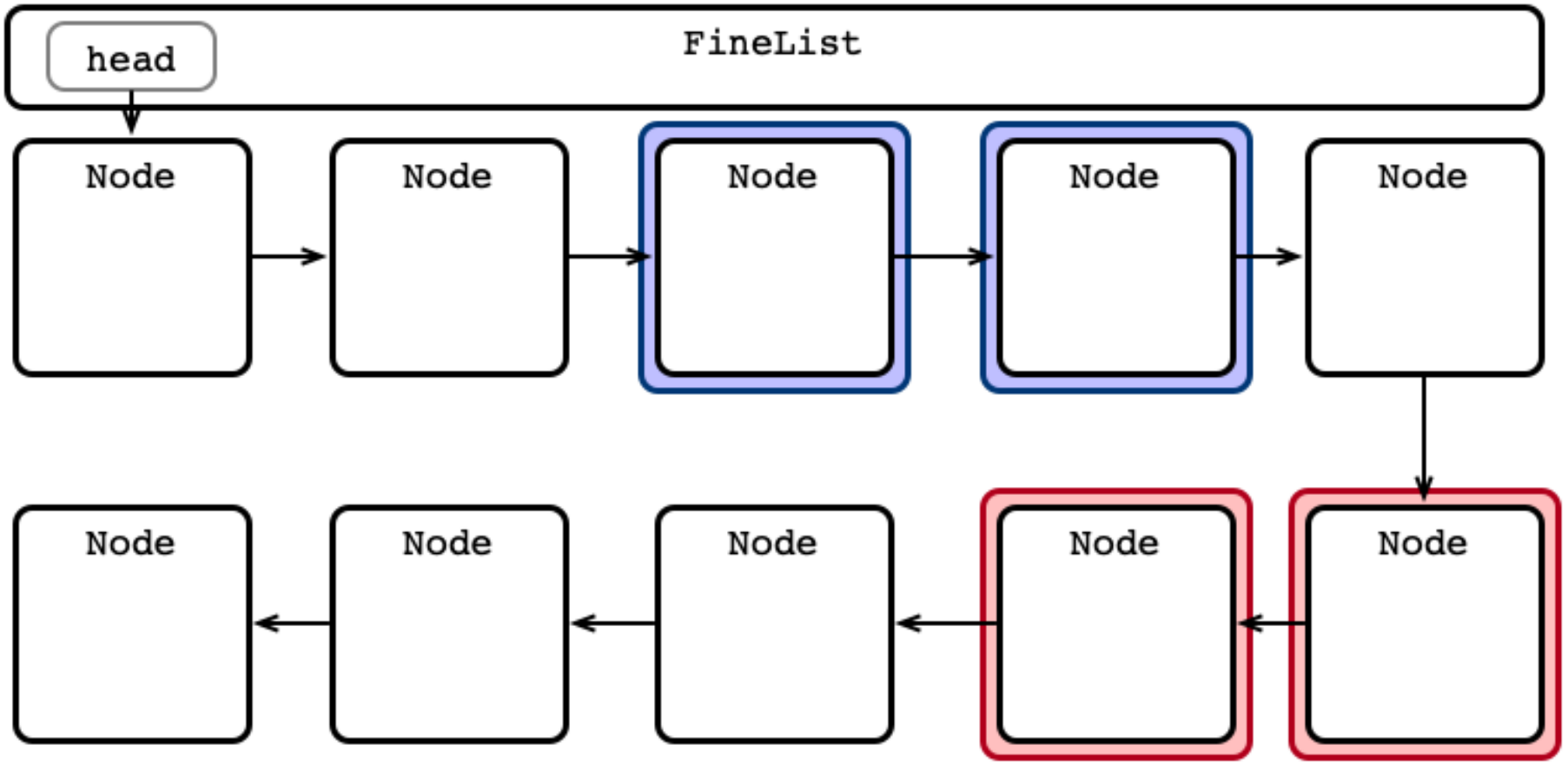

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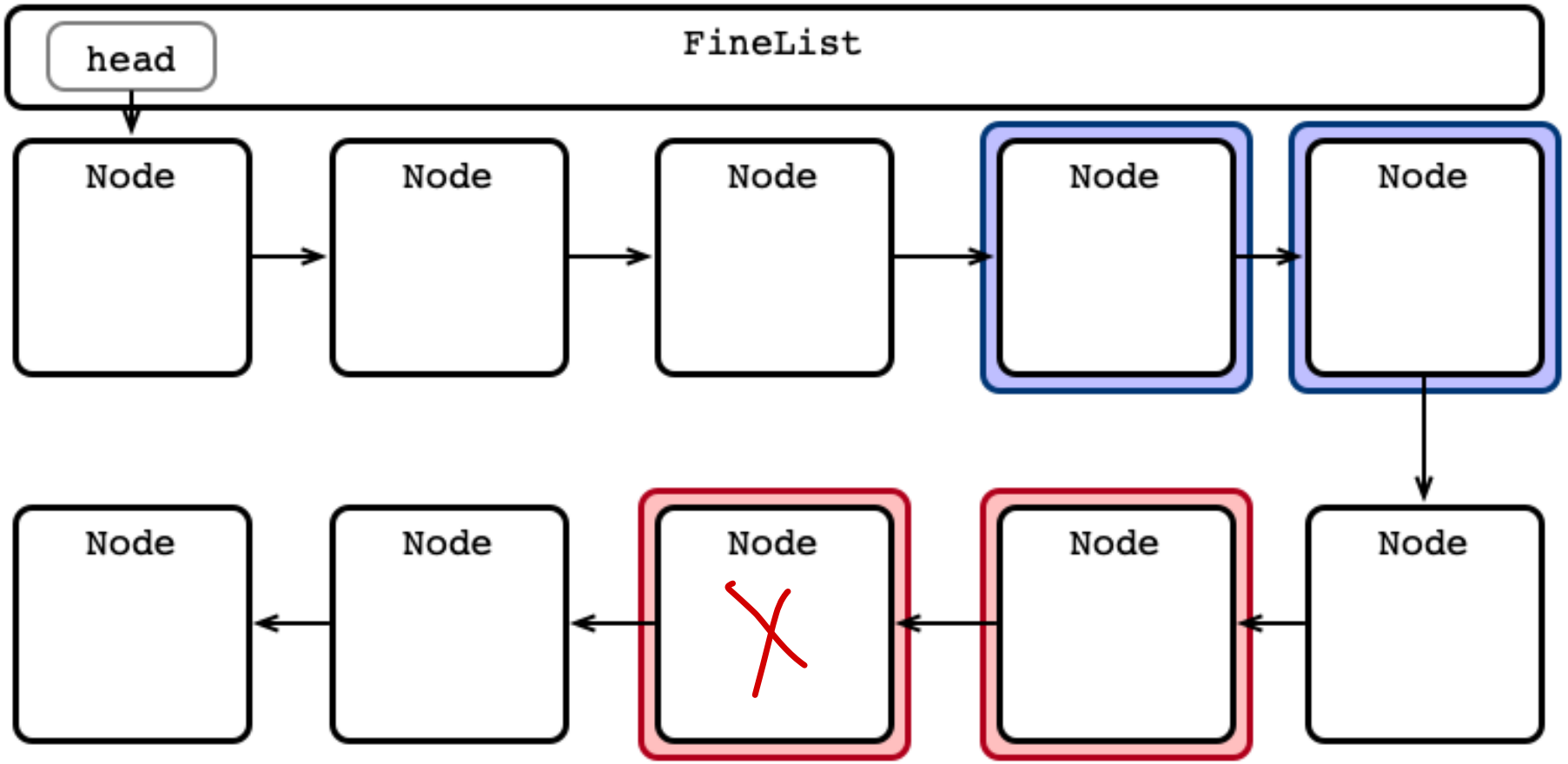

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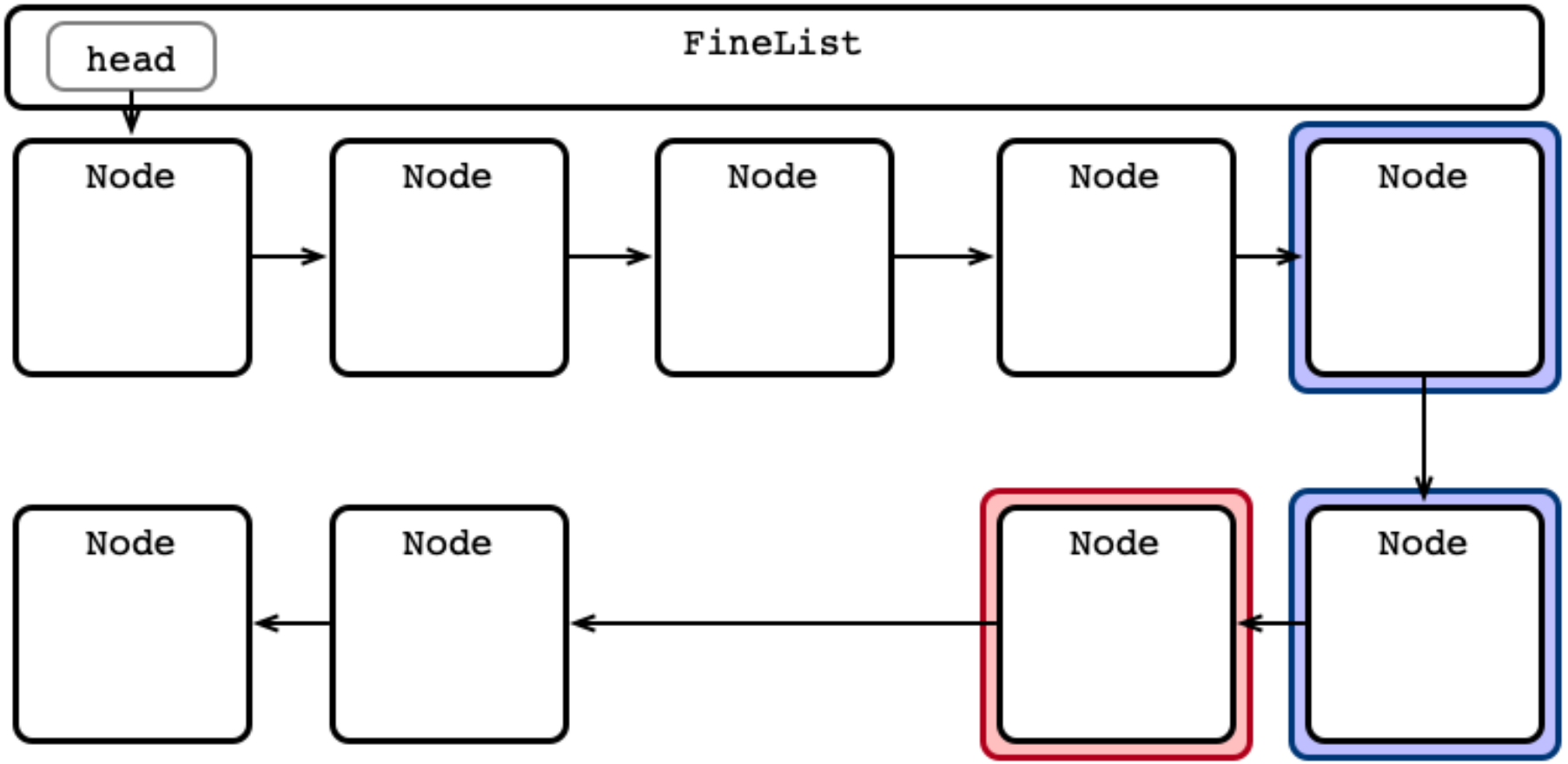

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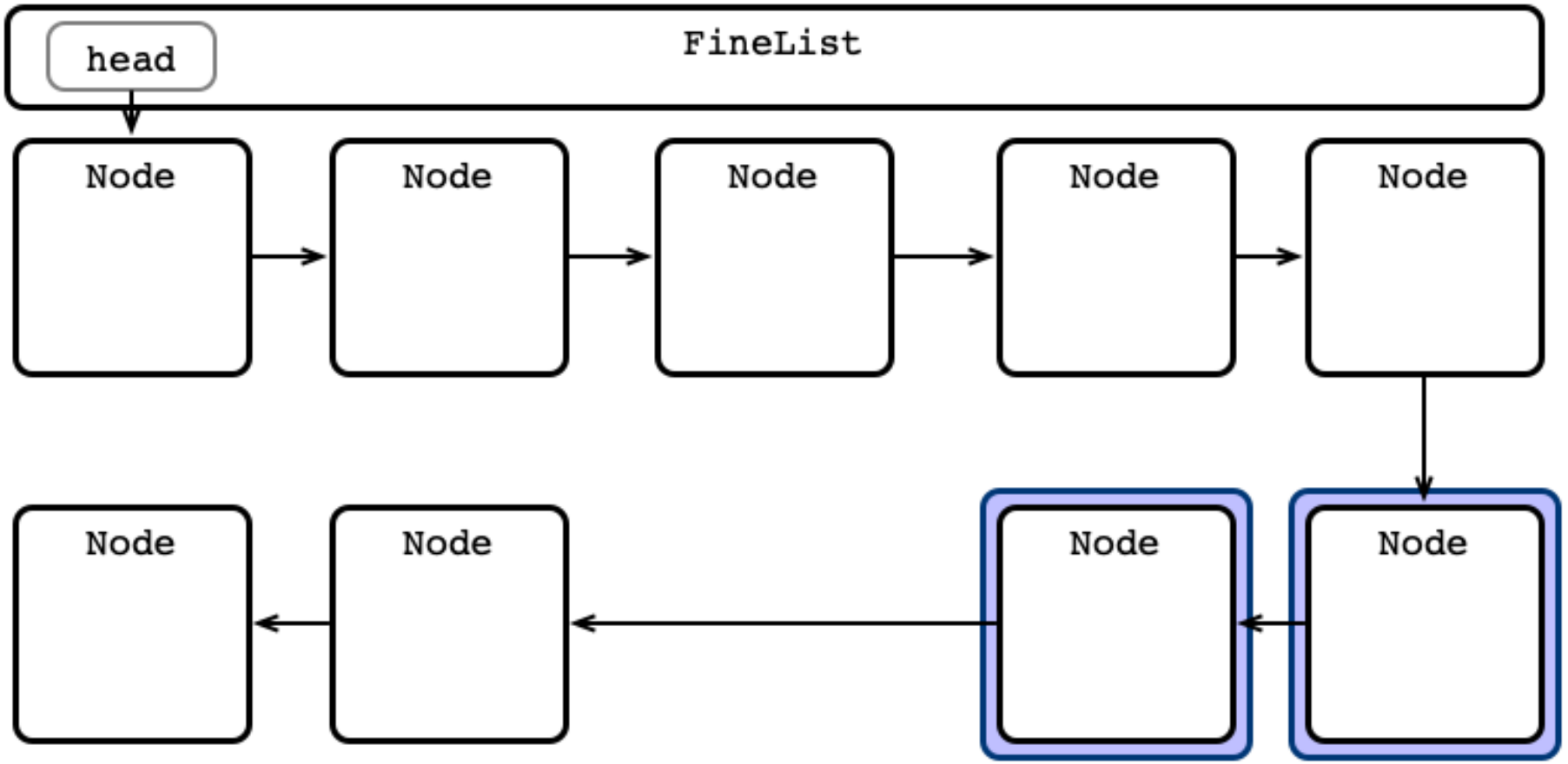

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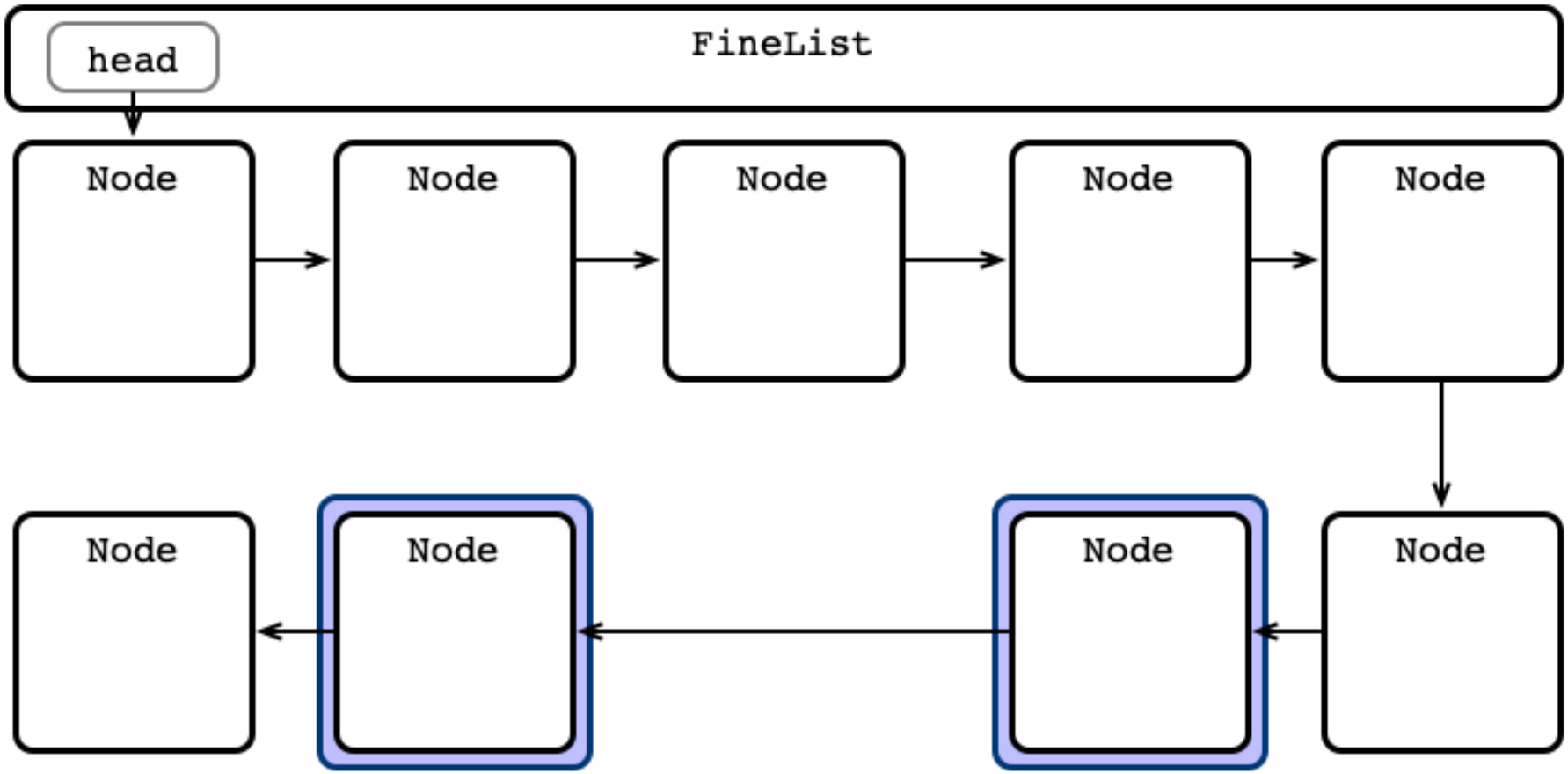


Fine-grained Appraisal

Advantages:

- Parallel access
- Reasonably simple implementation

Disadvantages:

- More locking overhead
  - can be much slower than coarse-grained
- All operations are blocking

Optimistic Synchronization

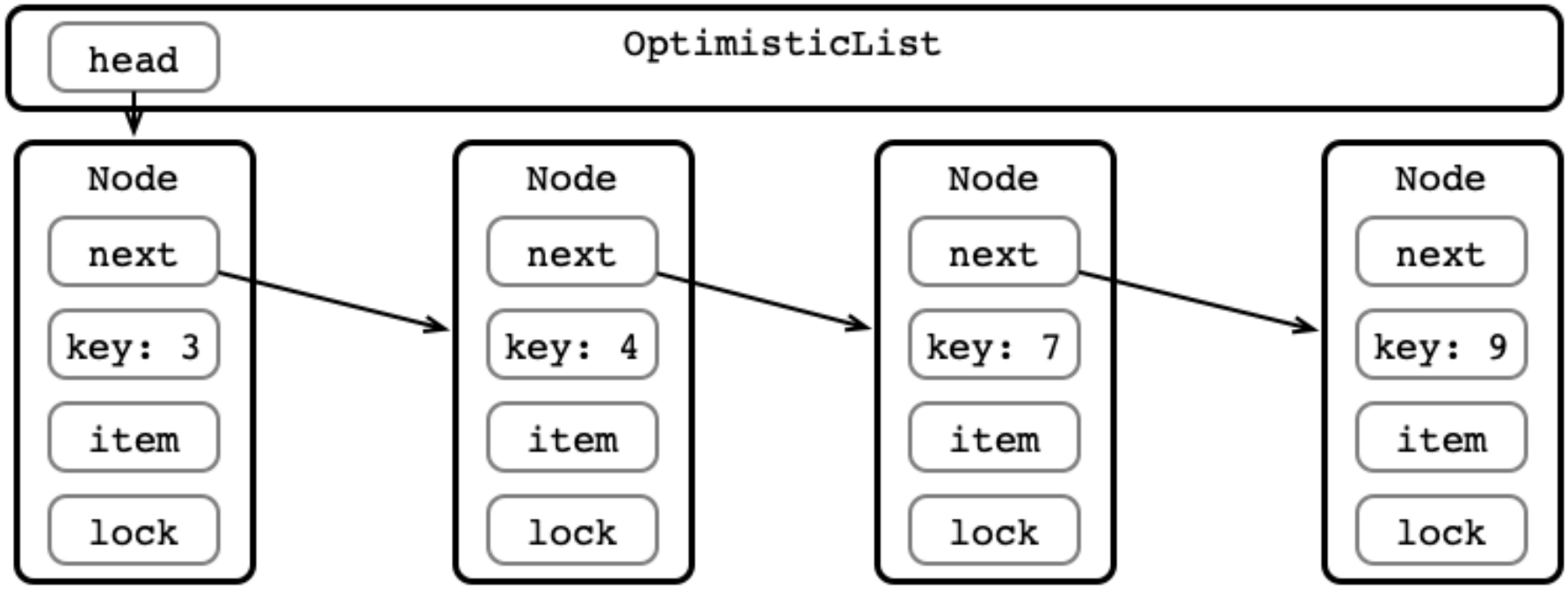
Fine-grained wastes resources locking

- Nodes are locked when traversed
- Locked even if not modified!

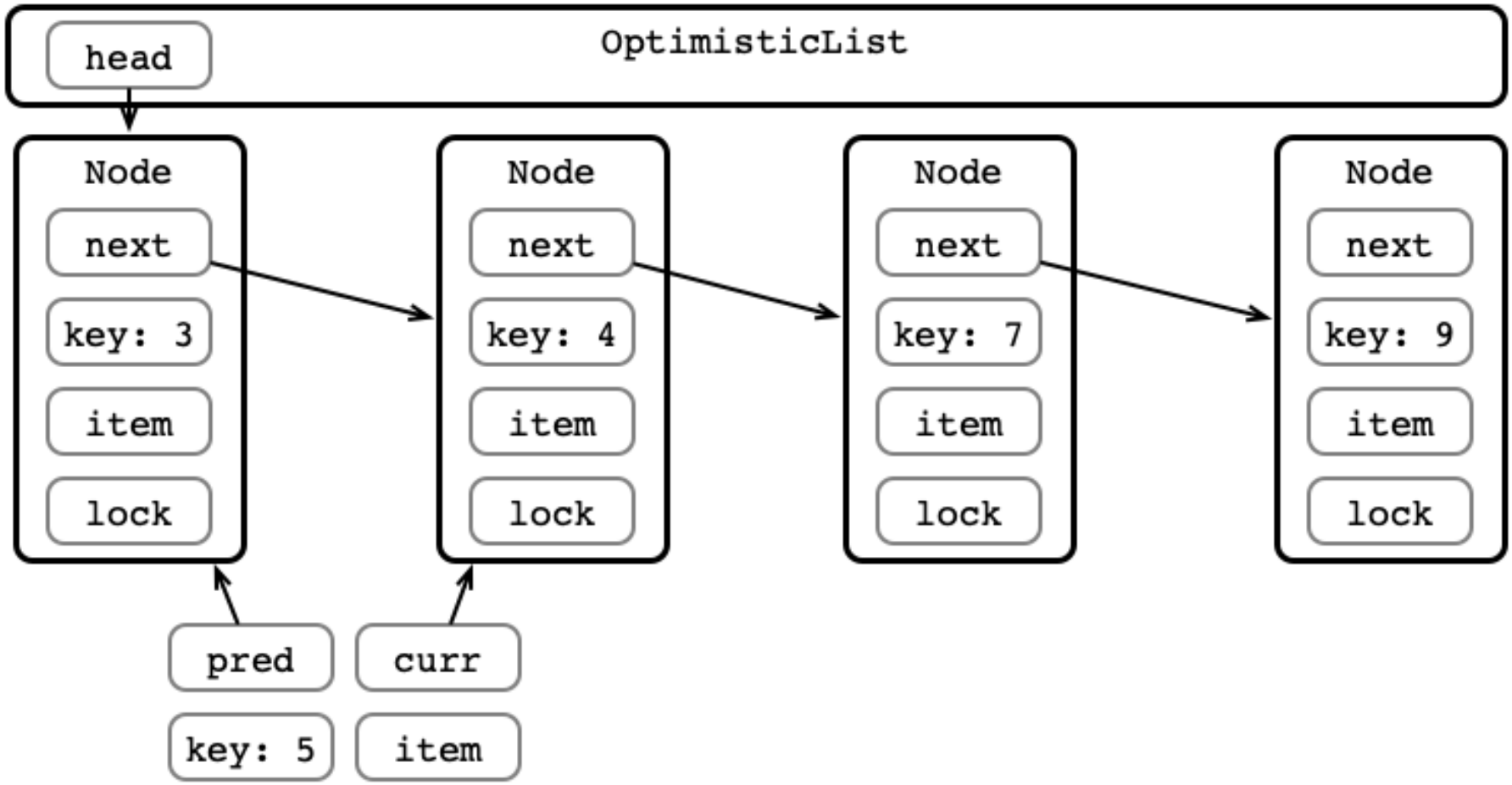
A better procedure?

1. Traverse without locking
2. Lock relevant nodes
3. Perform operation
4. Unlock nodes

A Better Way?


head
OptimisticList
Node
next
key: 3
item
lock
Node
next
key: 4
item
lock
Node
next
key: 7
item
lock
Node
next
key: 9
item
lock

A Better Way?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key: 7
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Node
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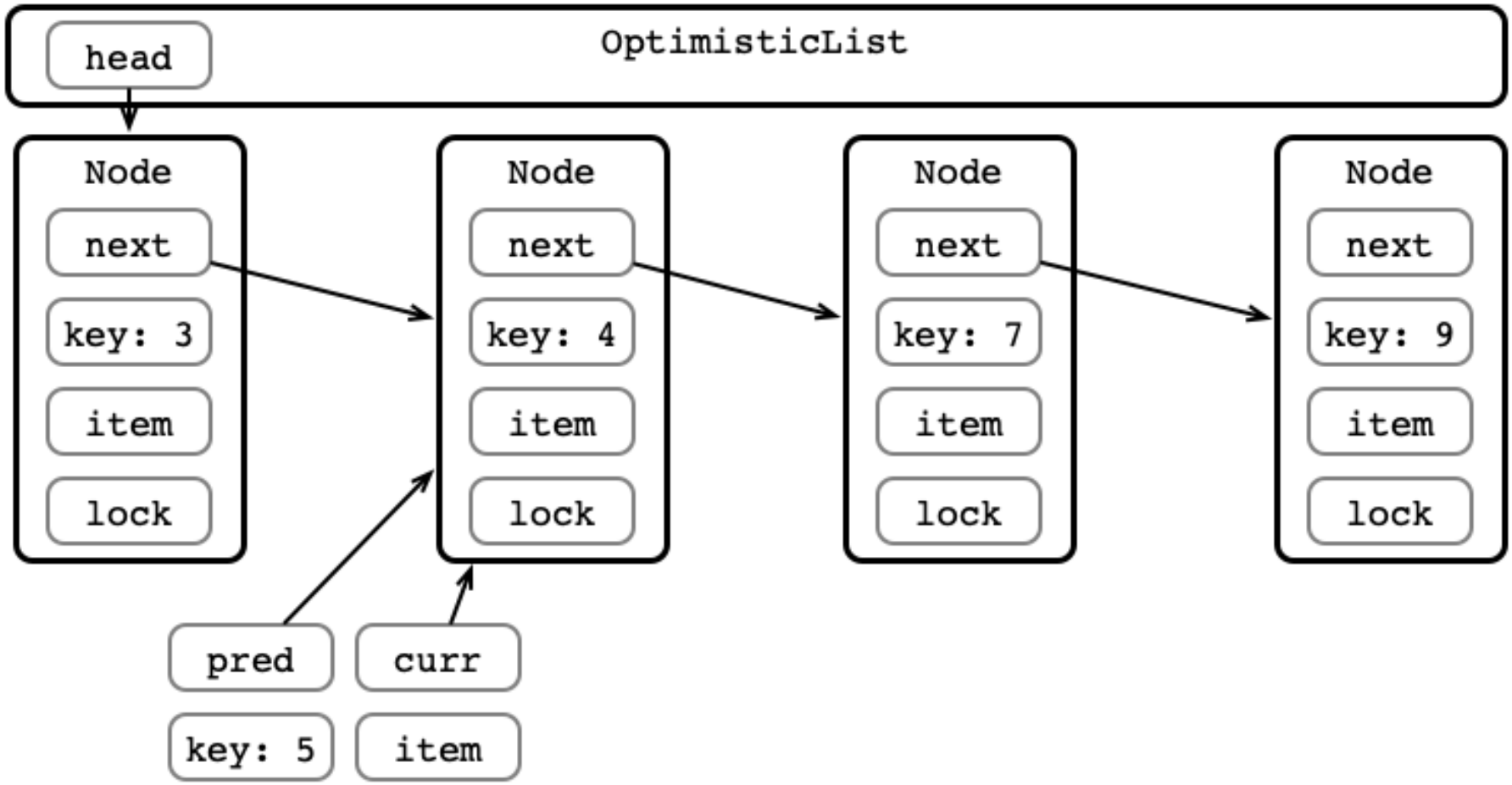
key: 9
item
lock
pred
key: 5
curr
item

A Better Way?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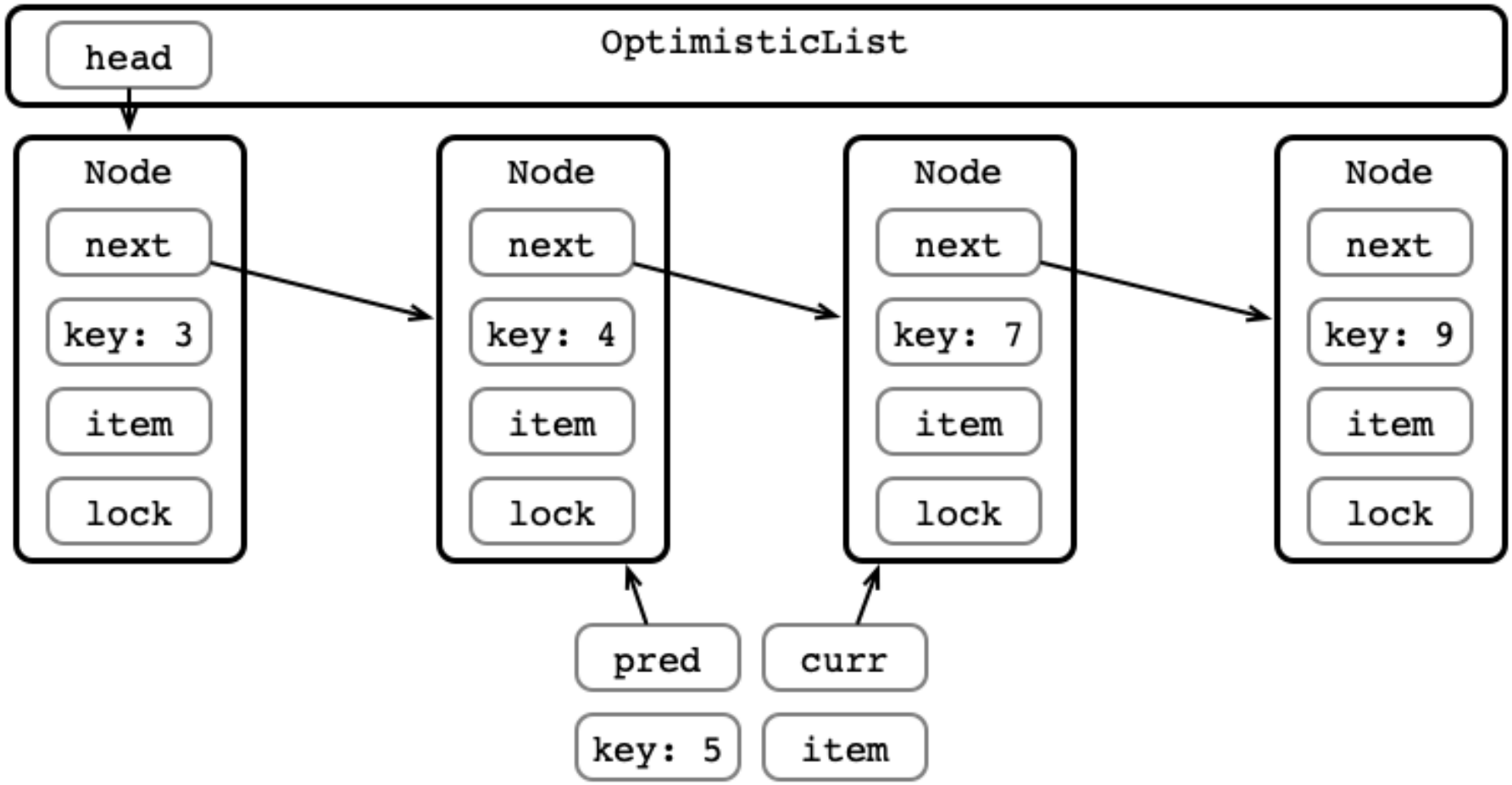
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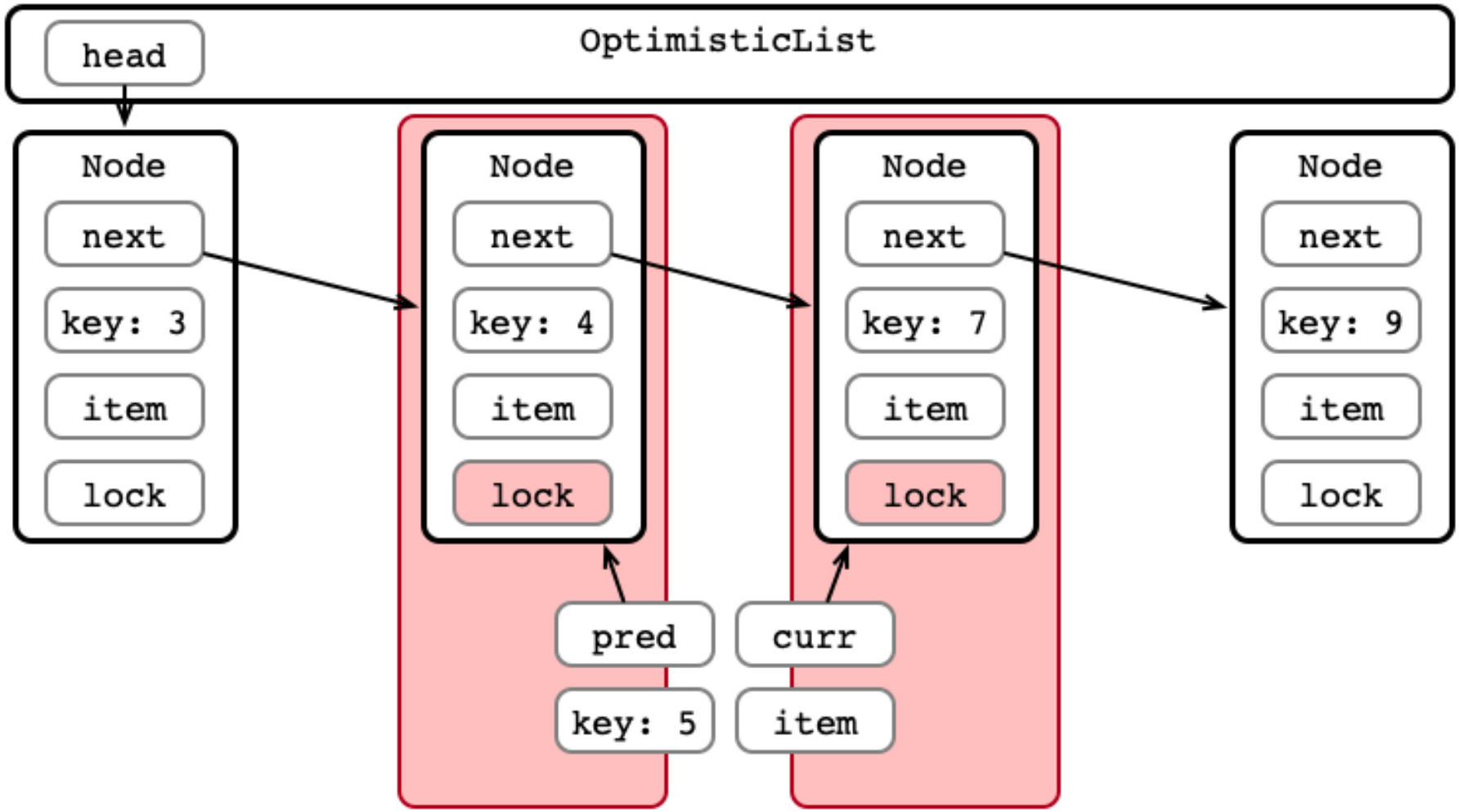
A Better Way?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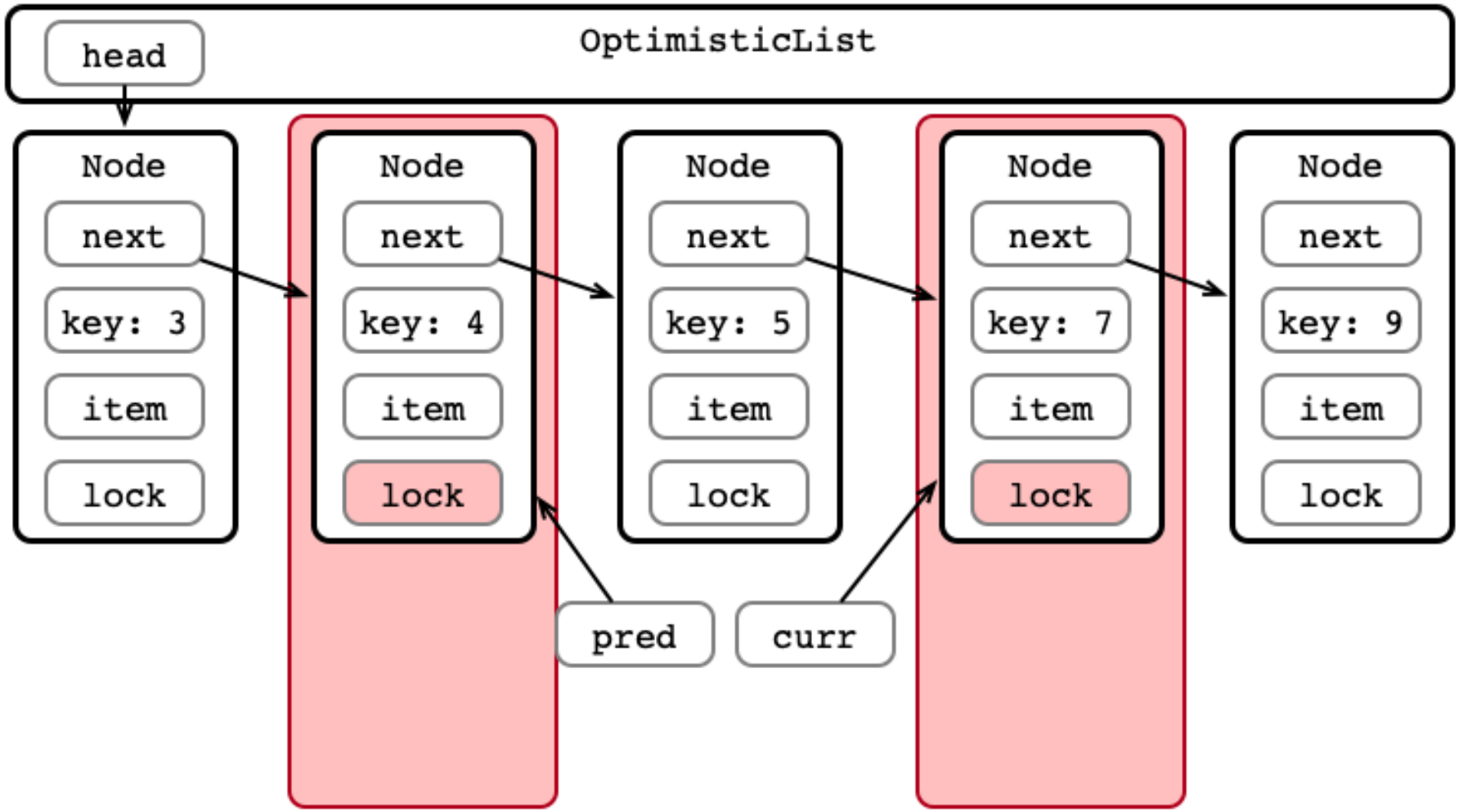
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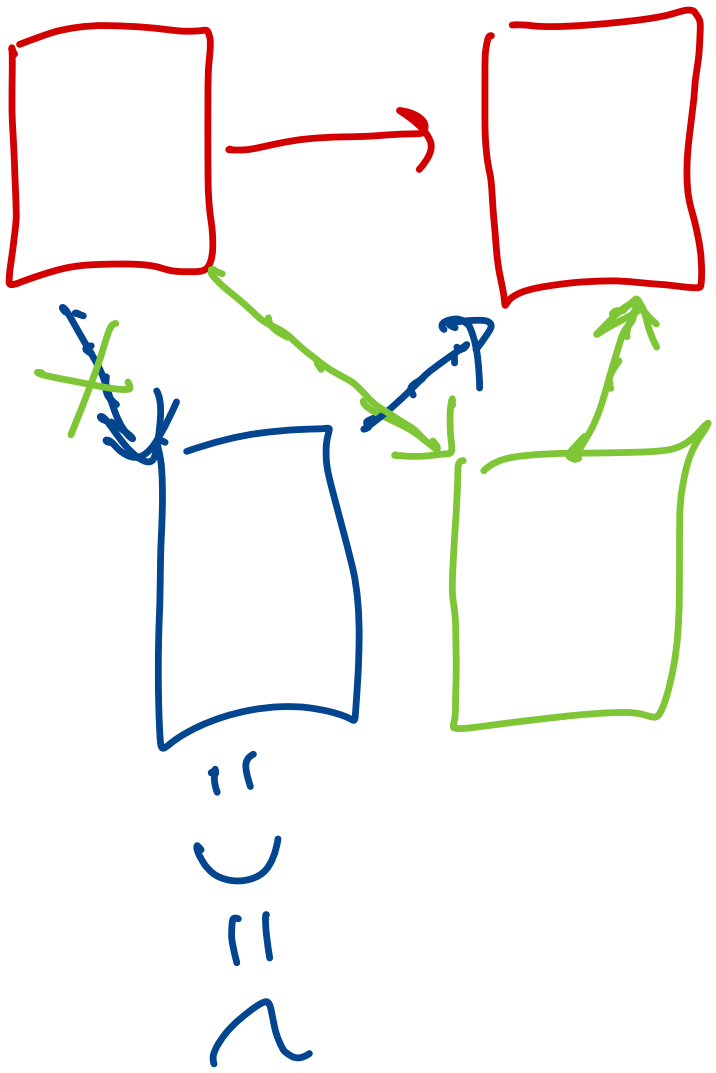
What Could Go Wrong?

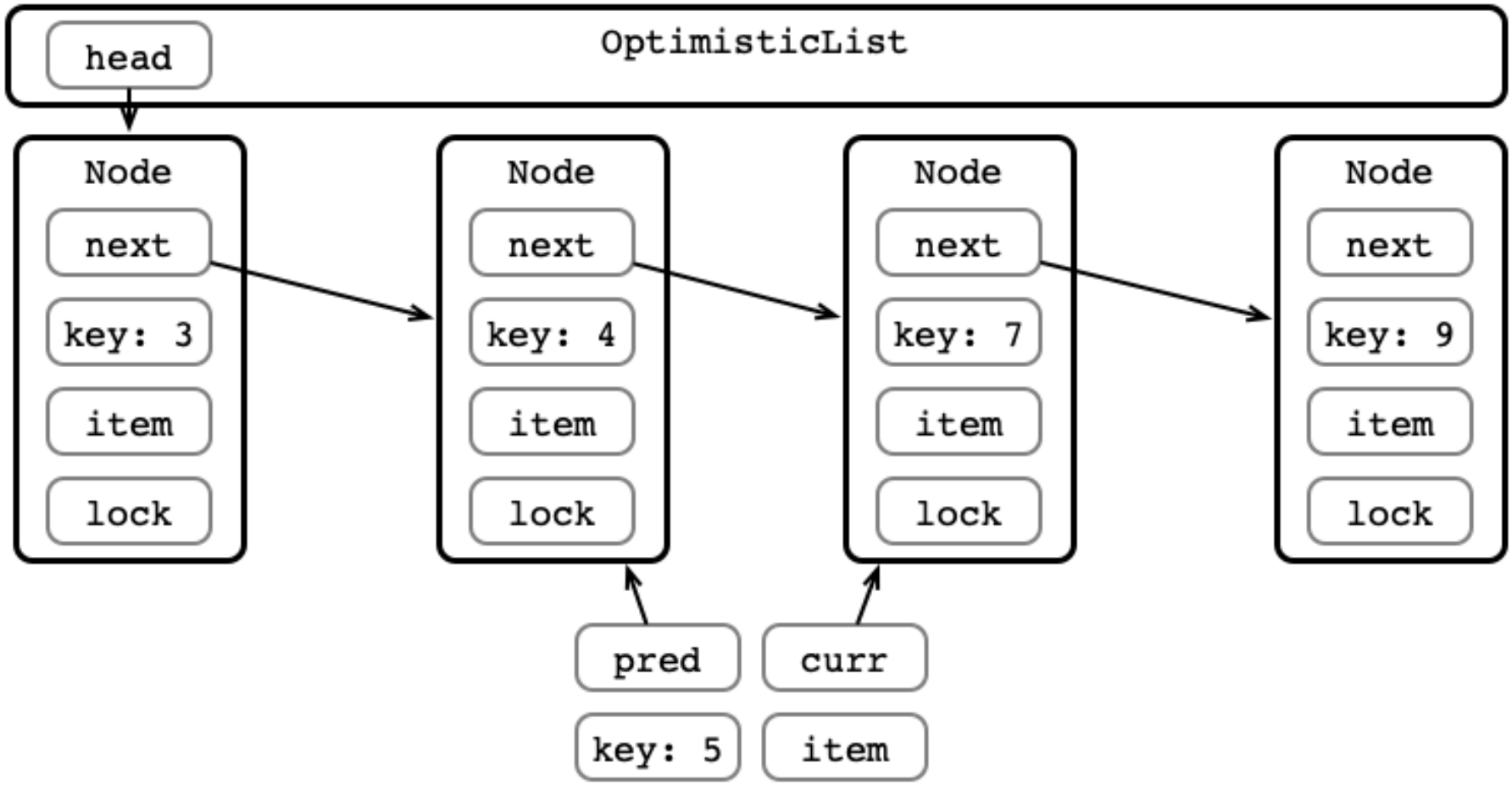


An Issue!

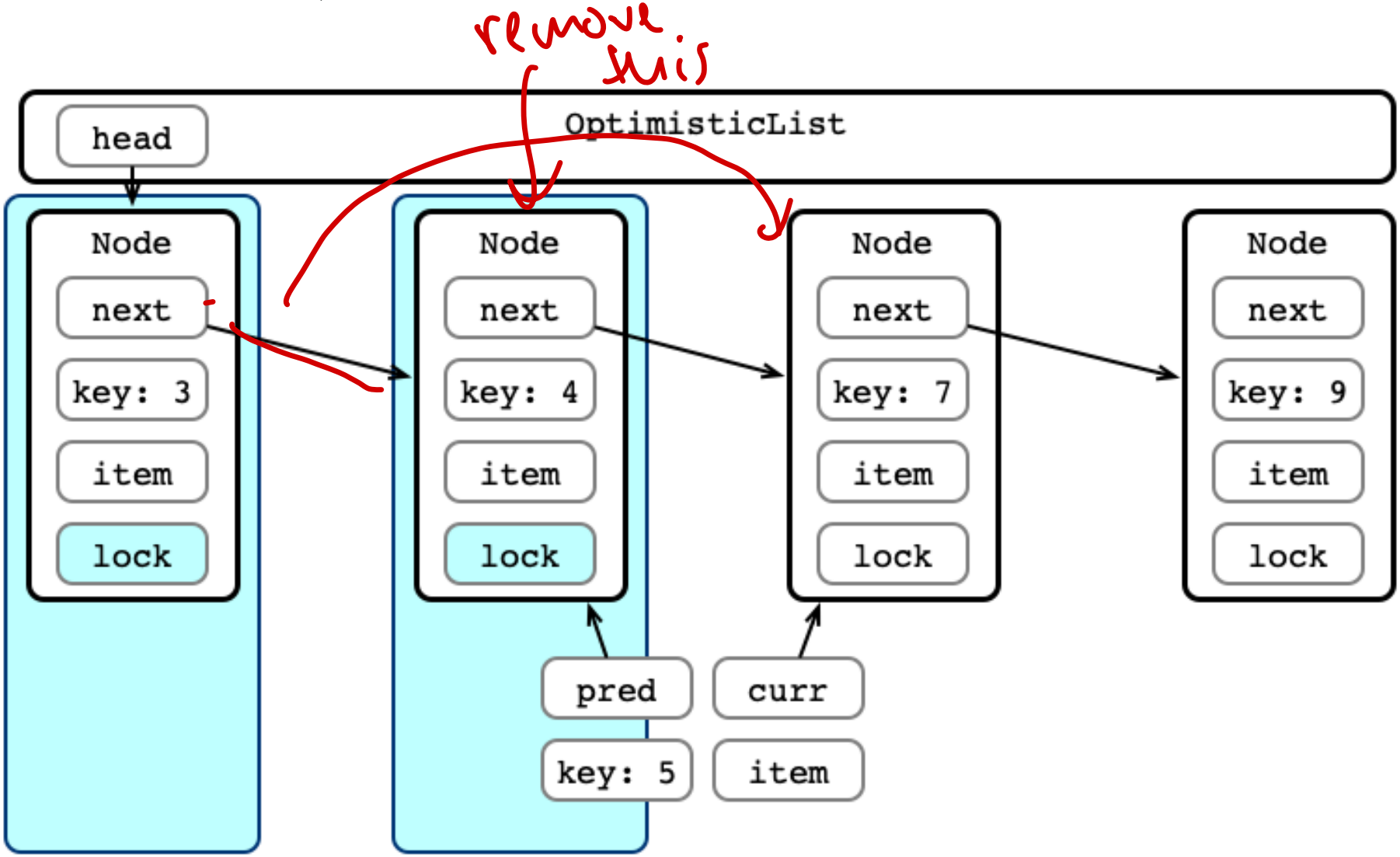
Between traversing and locking

- Another thread modifies the list
- Now locked nodes aren’t the right nodes!

An Issue, Illustrated



An Issue, Illustrated



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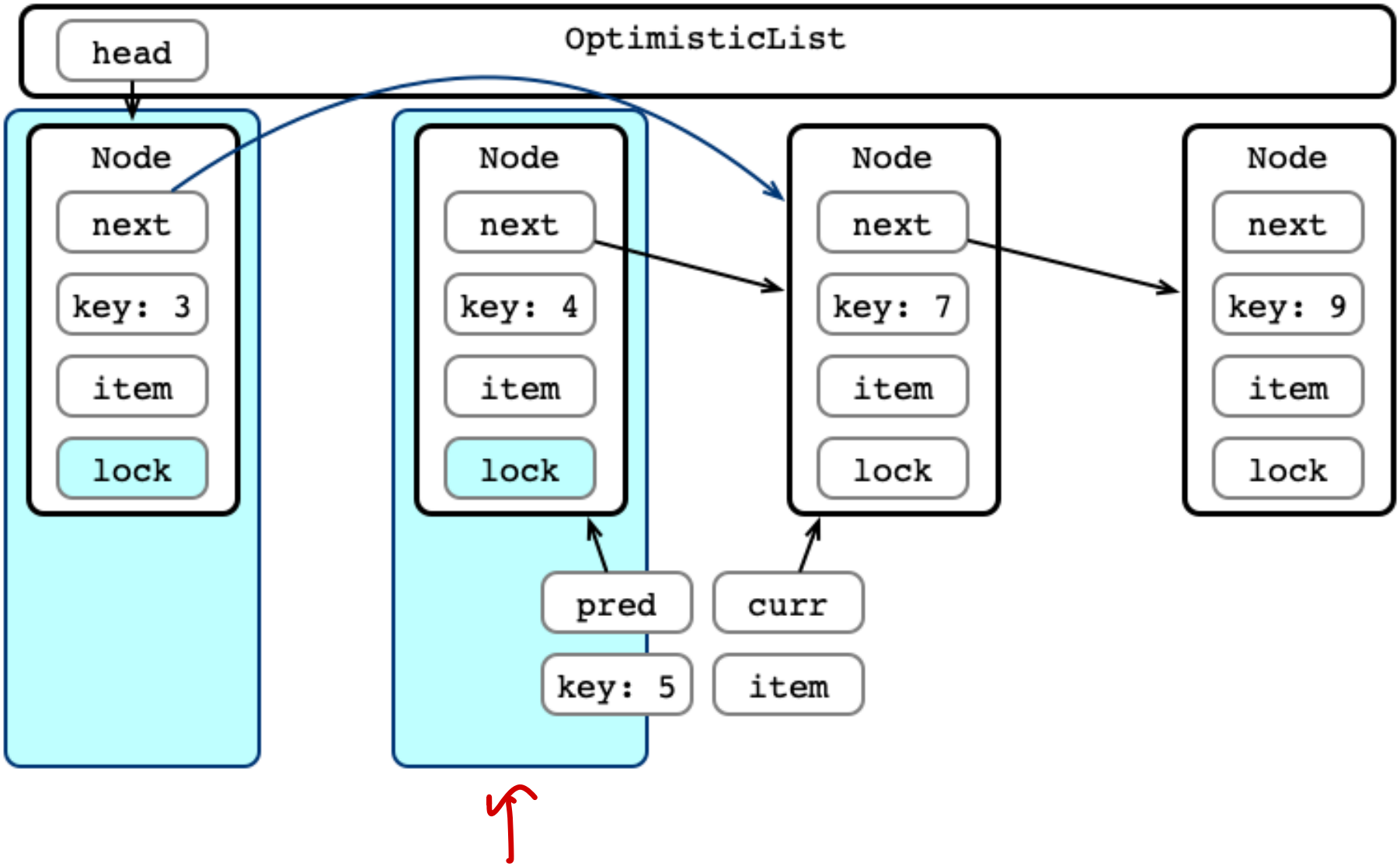

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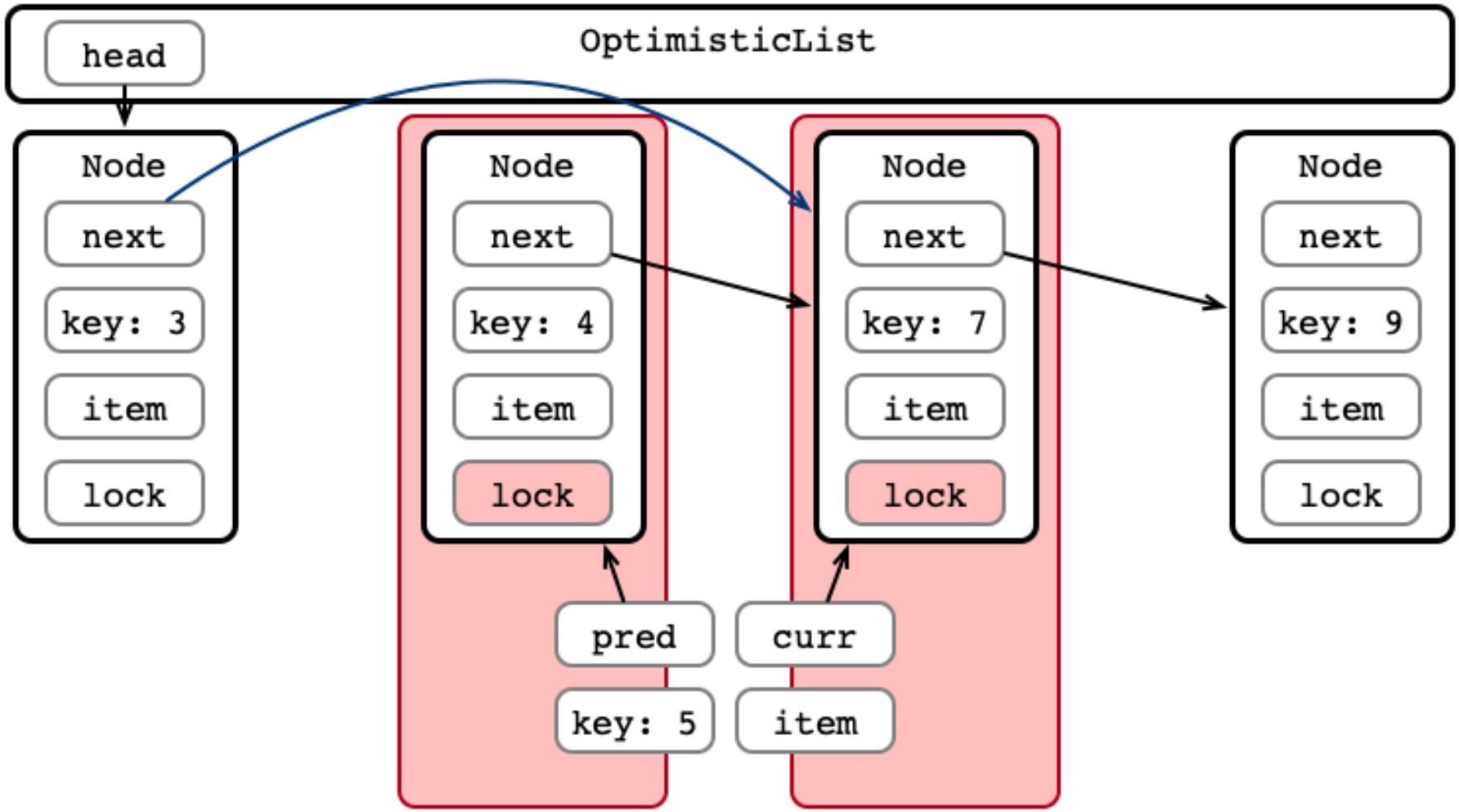

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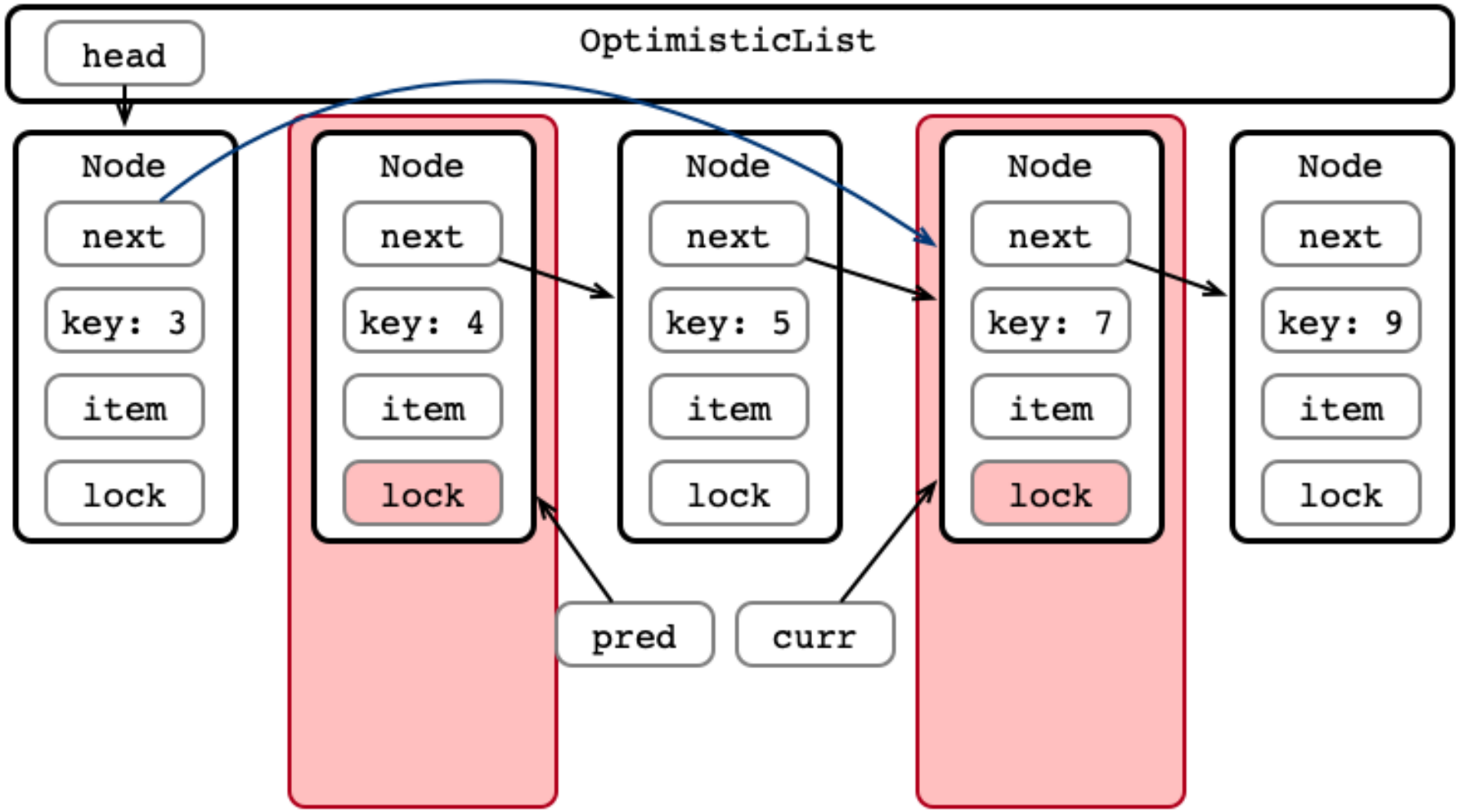

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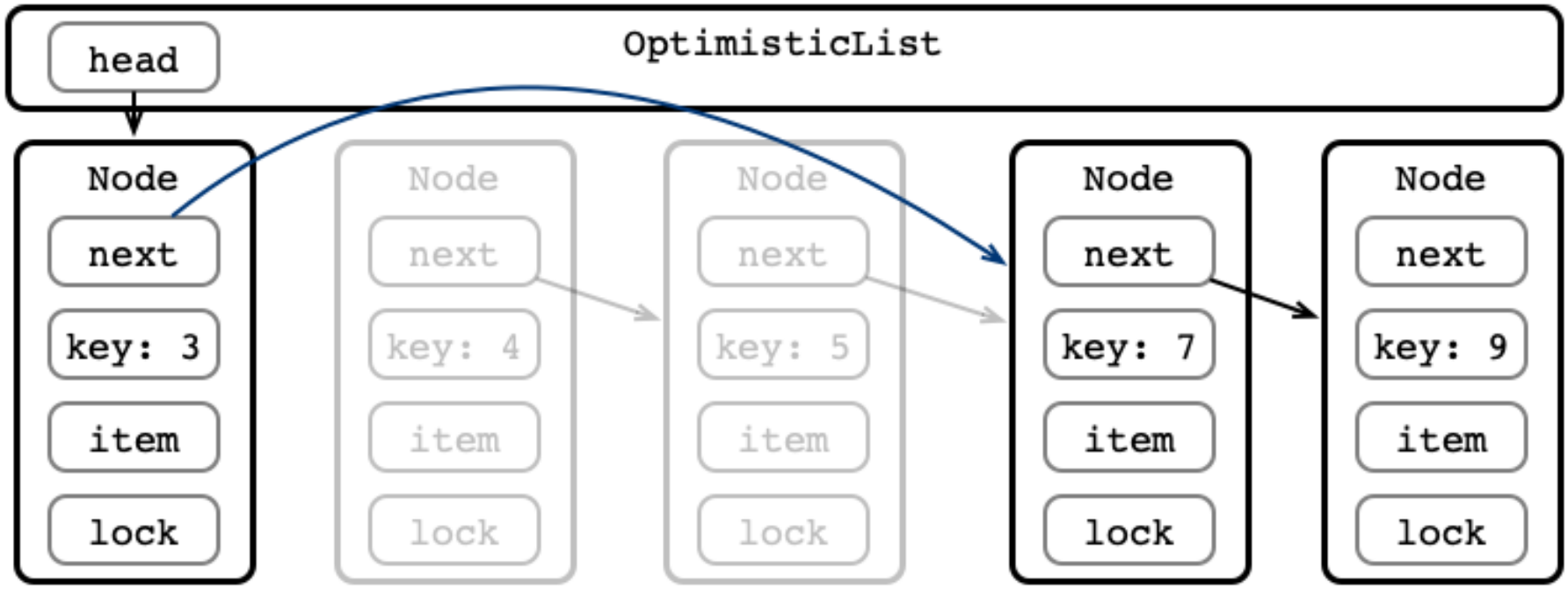
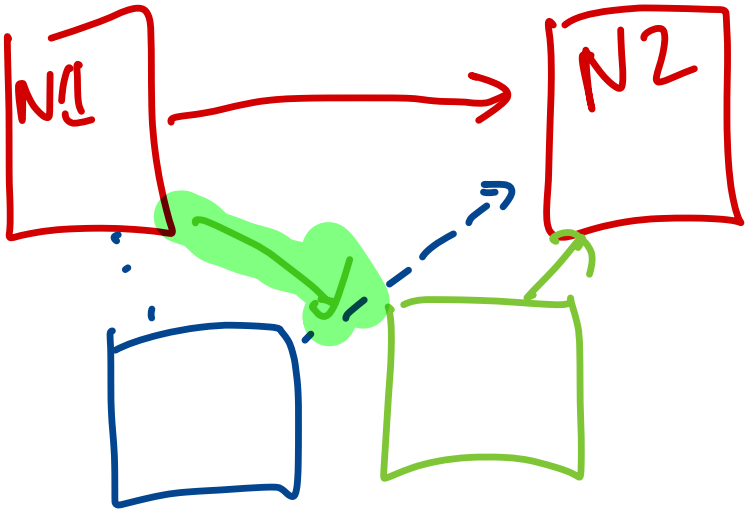


How can we Address this Issue?



Optimistic Synchronization, Validated

1. Traverse without locking
2. Lock relevant nodes
3. **Validate list**
   - if validation fails, go back to Step 1
4. Perform operation
5. Unlock nodes

See `OptimisticList.java`

How do we Validate?

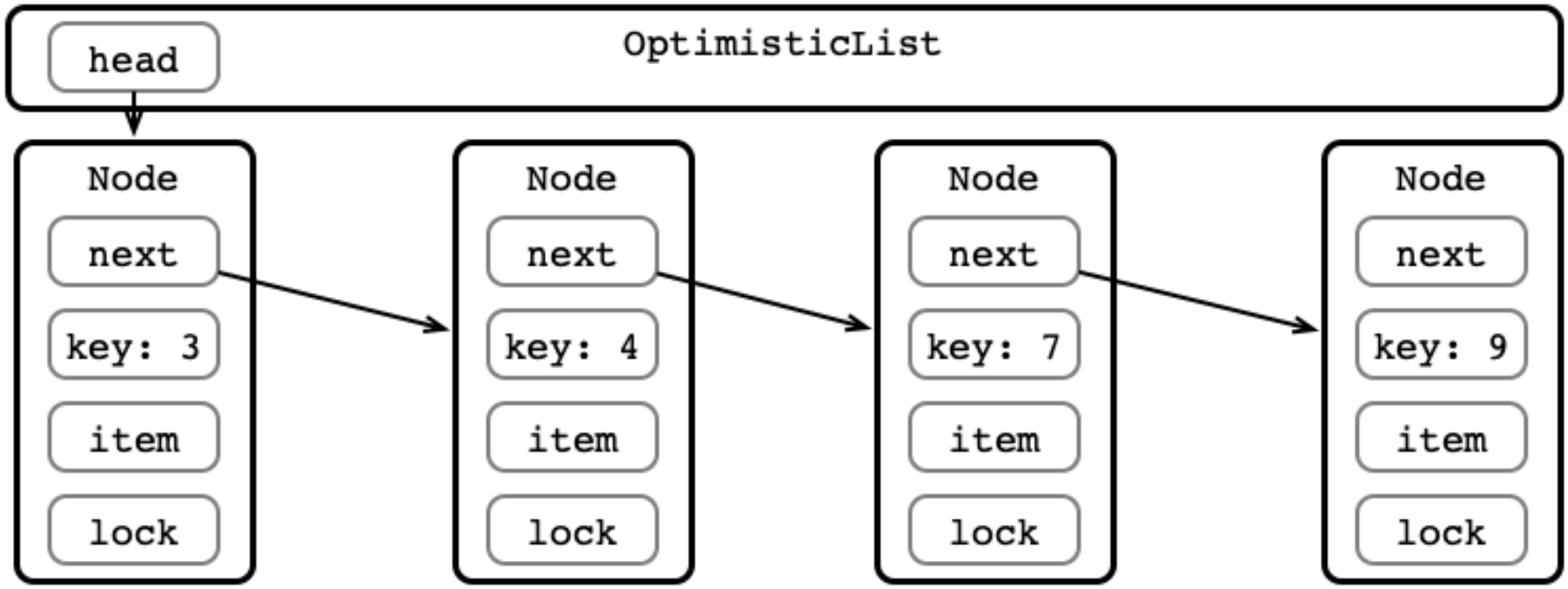
After locking, ensure that:

1. `pred` is reachable from `head`
2. `curr` is `pred`'s successor

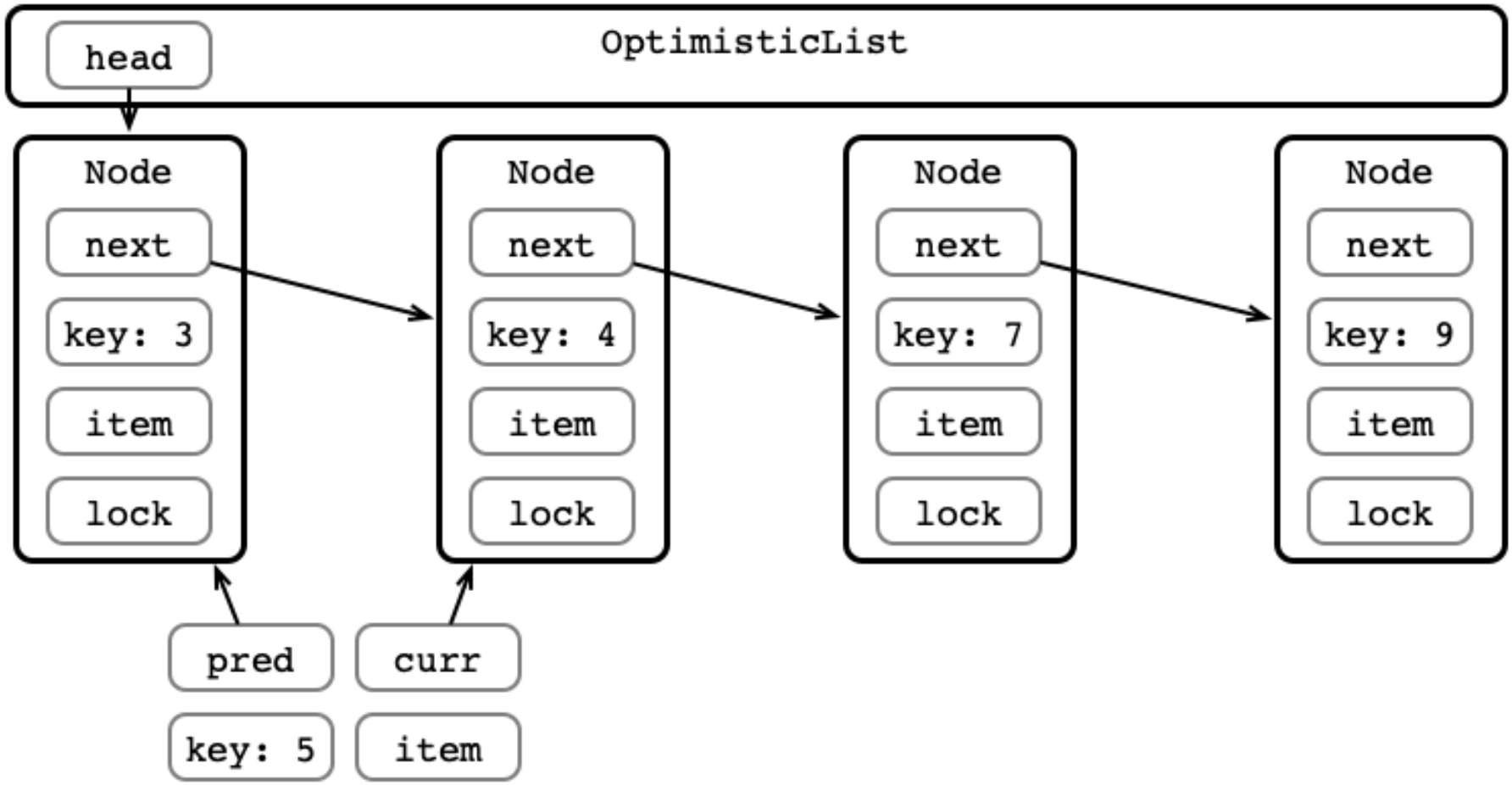
If these conditions aren't met:

- Start over!

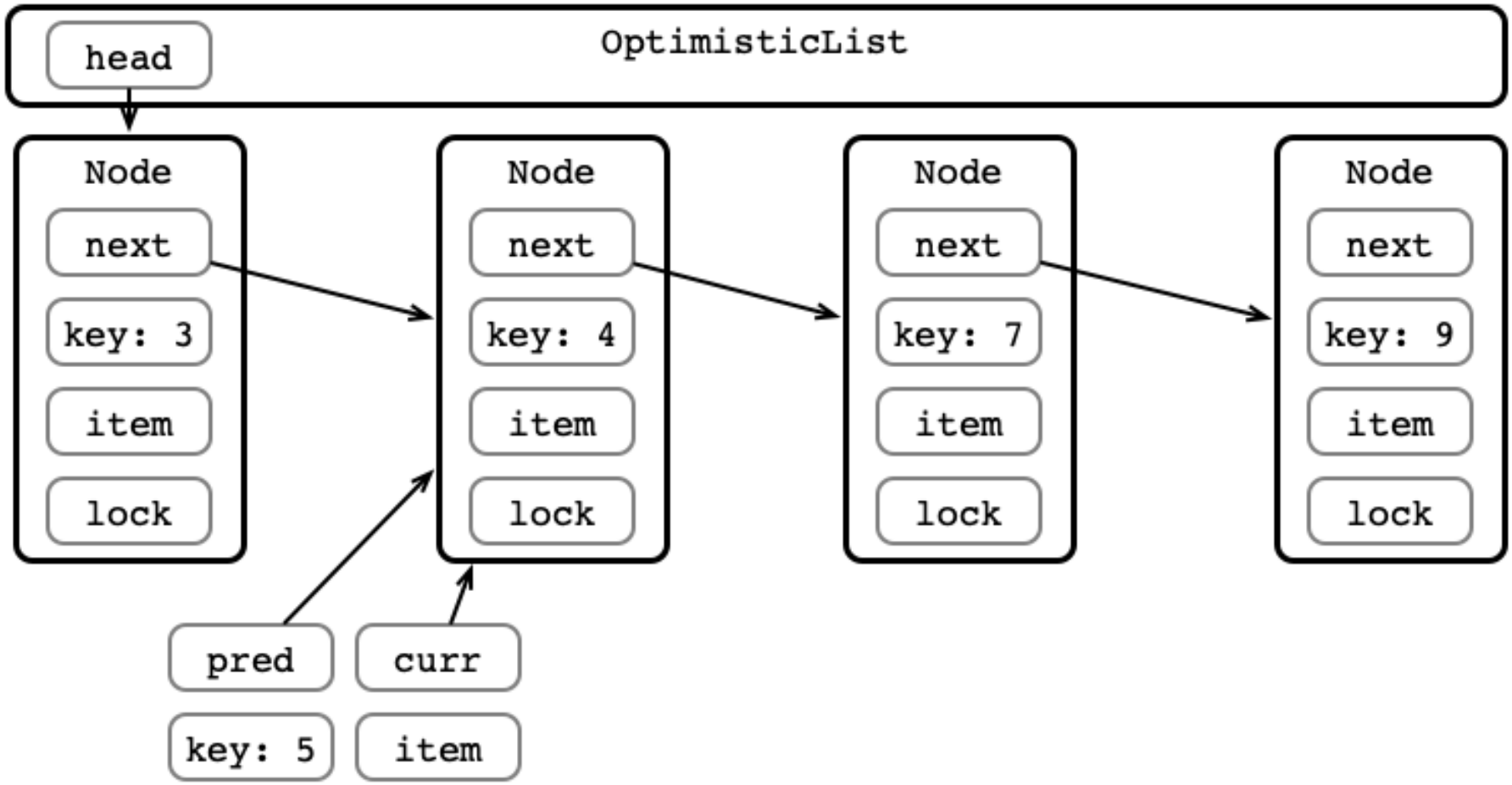
Optimistic Insertion



Step 1: Traverse the List



Step 1: Traverse the List



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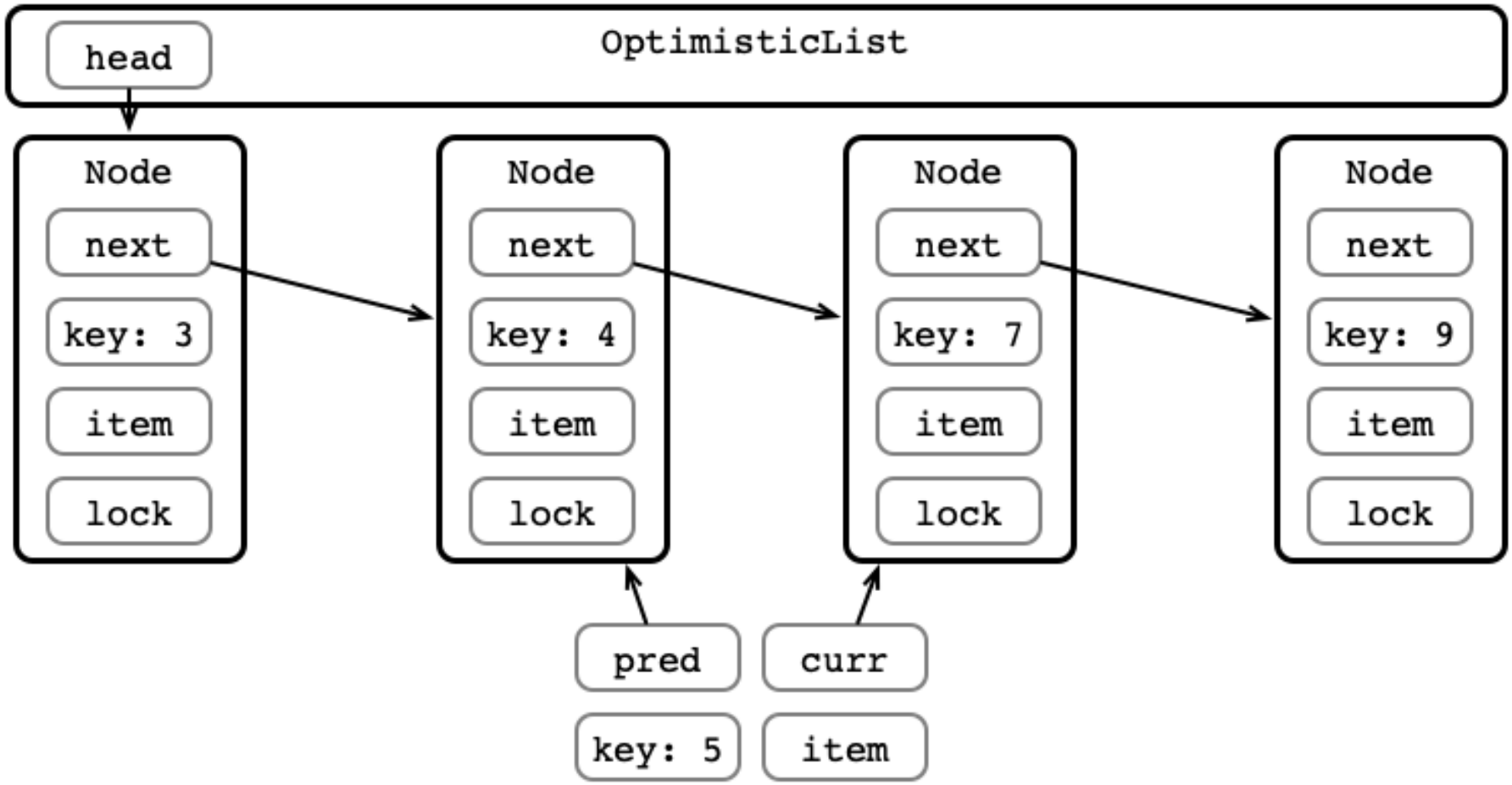
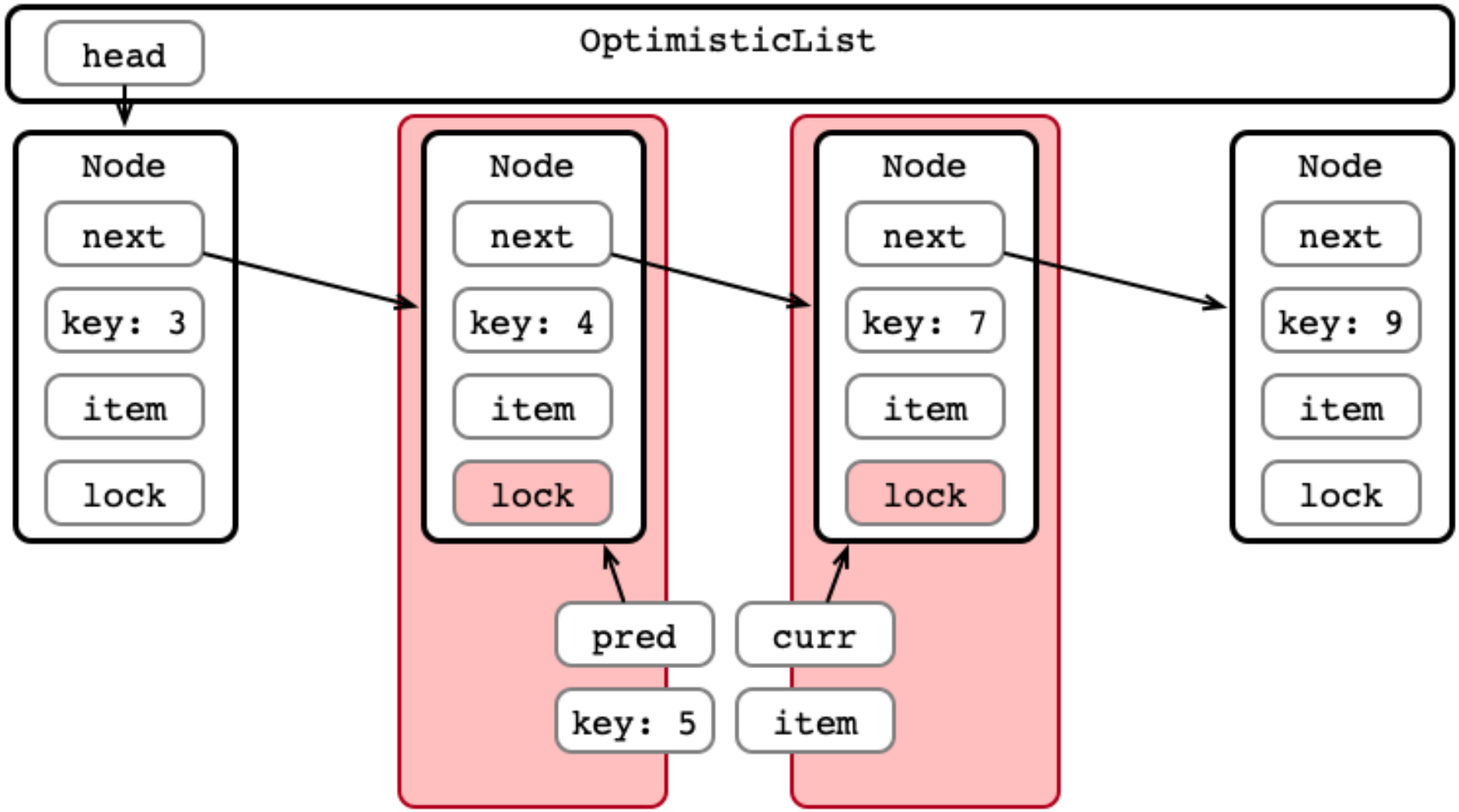
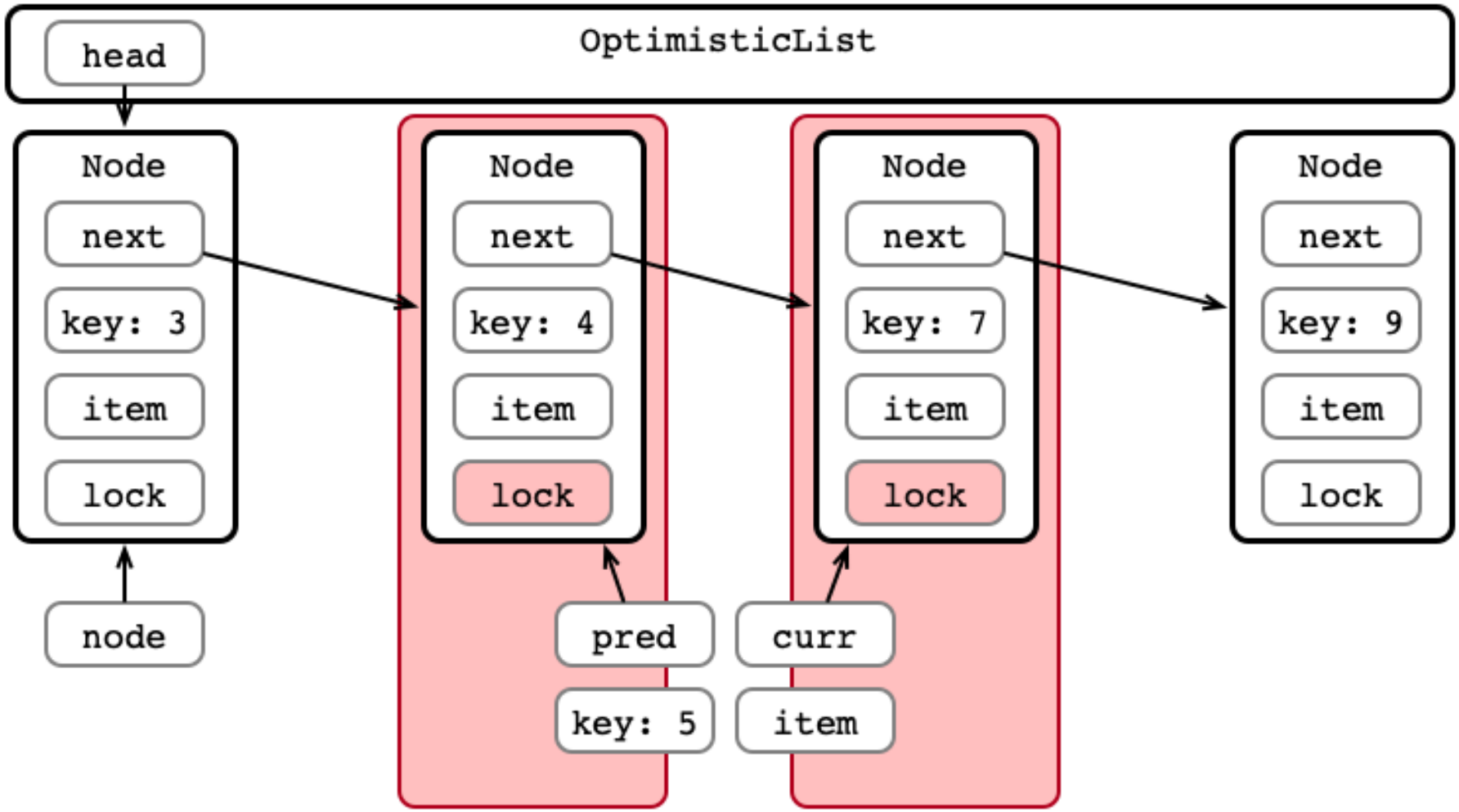


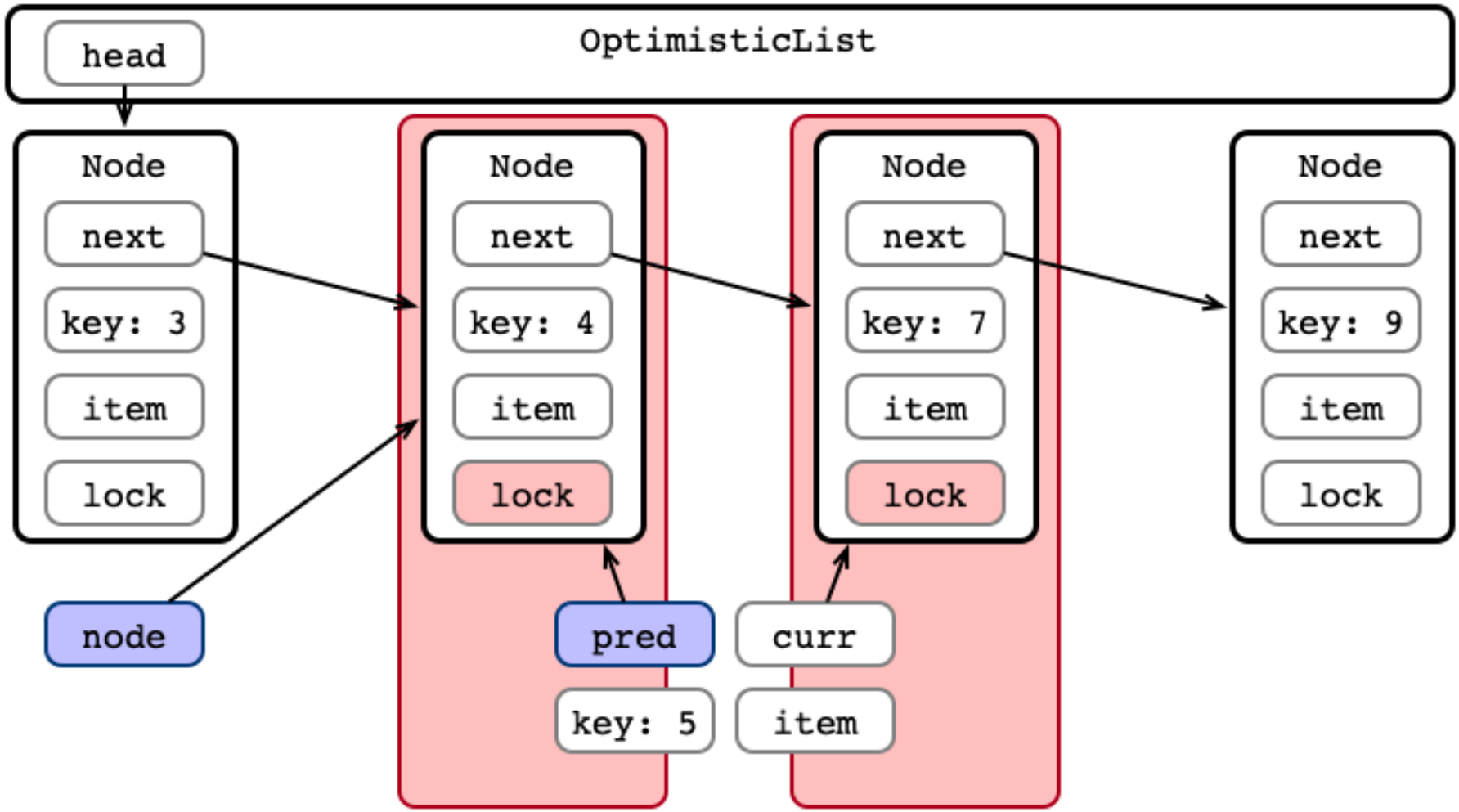
Step 2: Acquire Locks



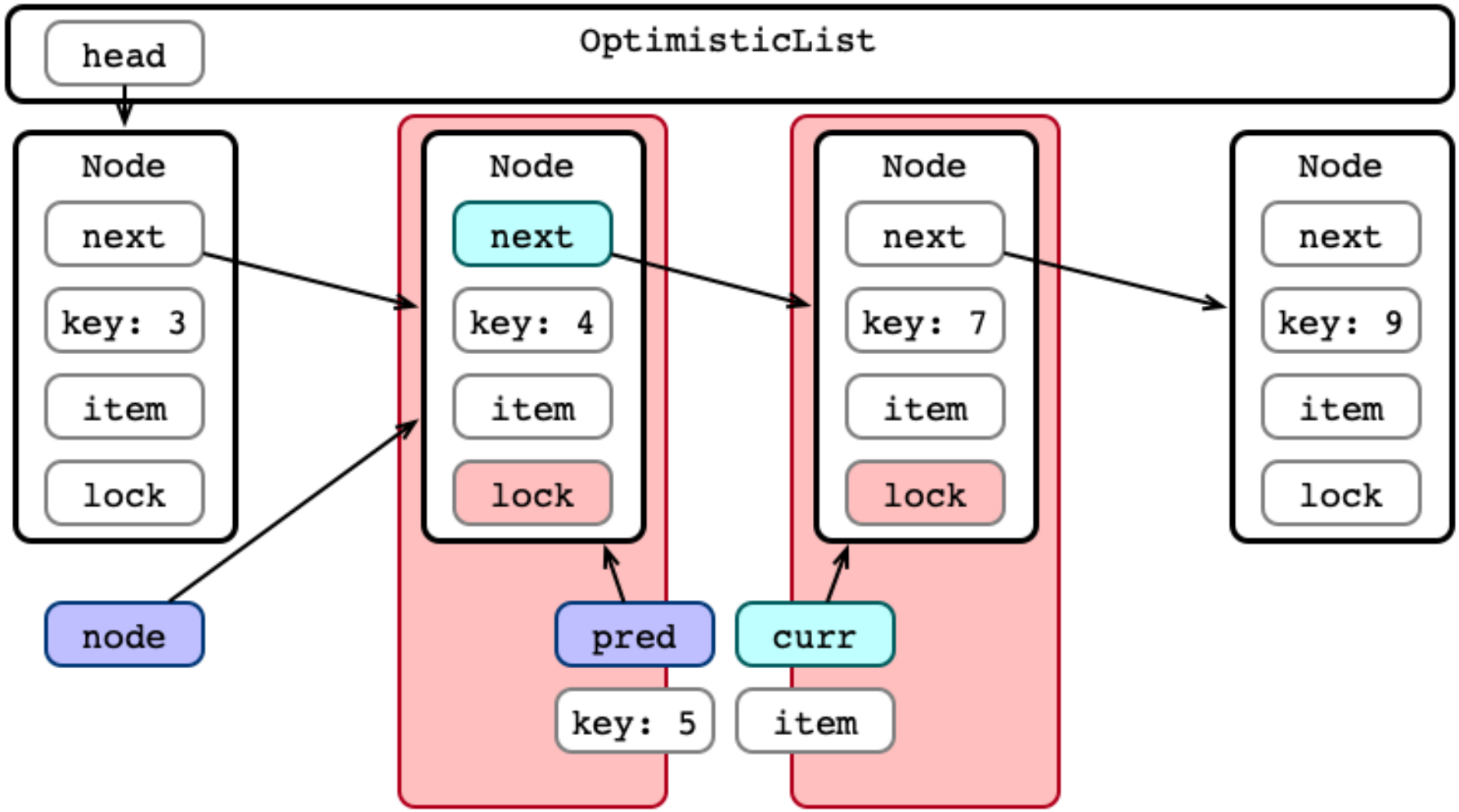
Step 3: Validate List - Traverse



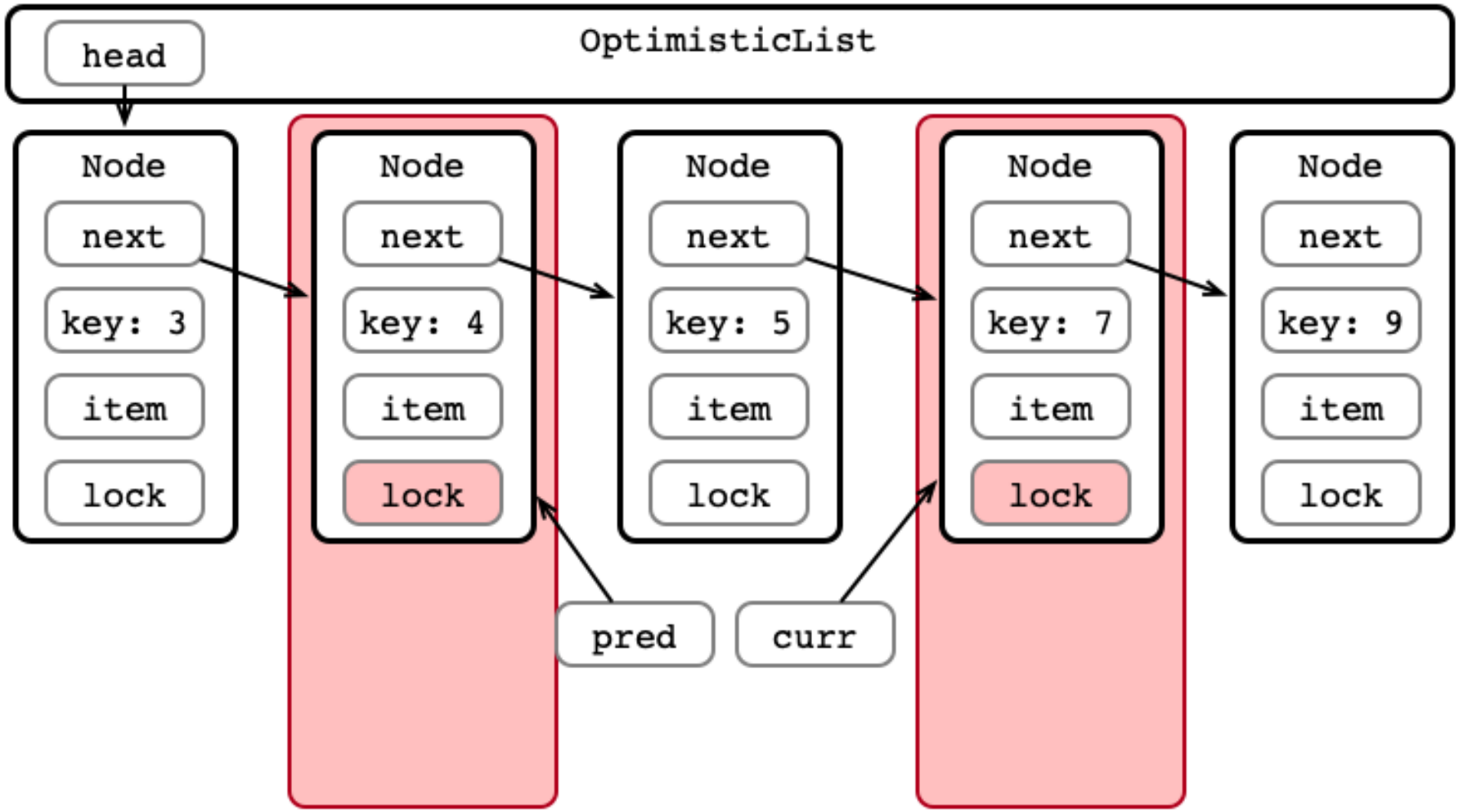
Step 3: Validate List - pred Reachable?



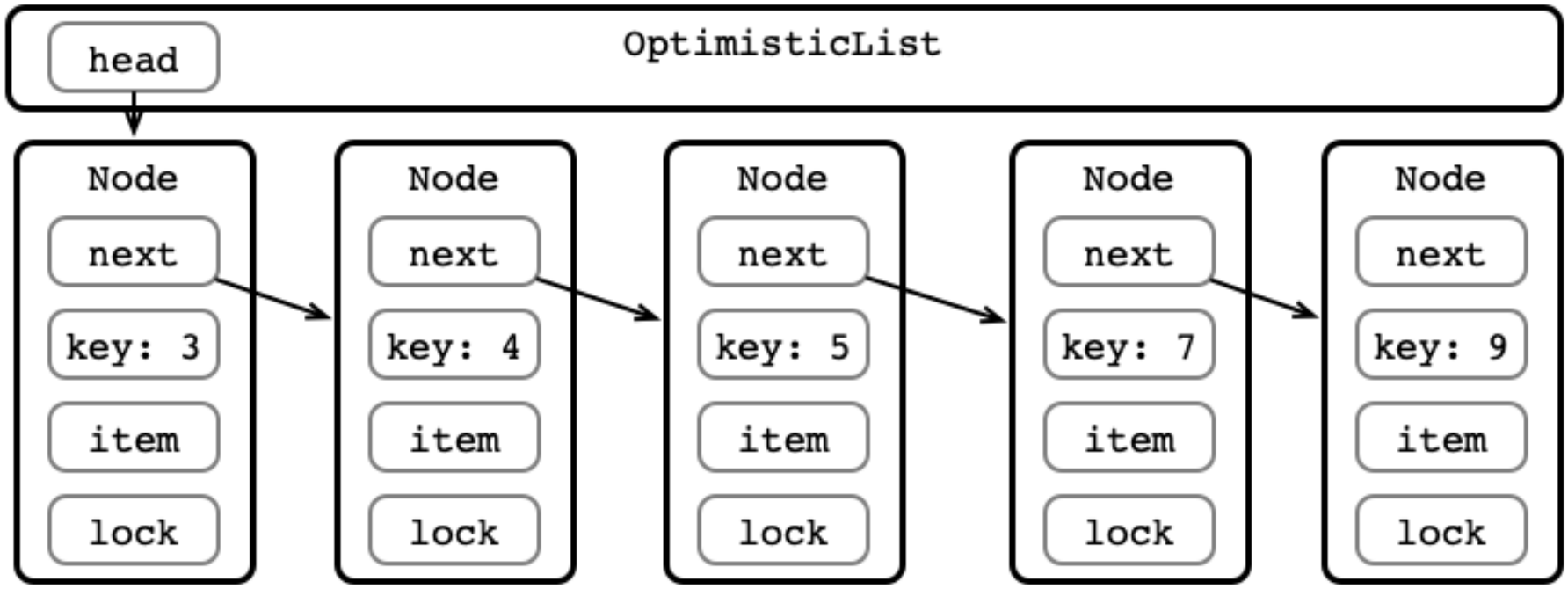
Step 3: Validate List - Is curr next?



Step 4: Perform Insertion



Step 5: Release Locks



Implementing Validation

```
private boolean validate (Node pred, Node curr) {
    Node node = head;
    while (node.key <= pred.key) {
        if (node == pred) {
            return pred.next == curr;
        }
        node = node.next;
    }
    return false;
}
```

Optimistic Appraisal

Advantages:

- Less locking than fine-grained
- More opportunities for parallelism than coarse-grained

Disadvantages:

- Validation could fail
- Not starvation-free
  - even if locks are starvation-free

Performance Tests

On HPC Cluster:

- Compare running times of performing 1M operations
  - `add`/`remove`/`contains` sequence chosen at random
  - elements chosen from `1` to `N` at random
    - `N` is universe size
- Parameters
  - universe size ≈ set size
  - number of threads

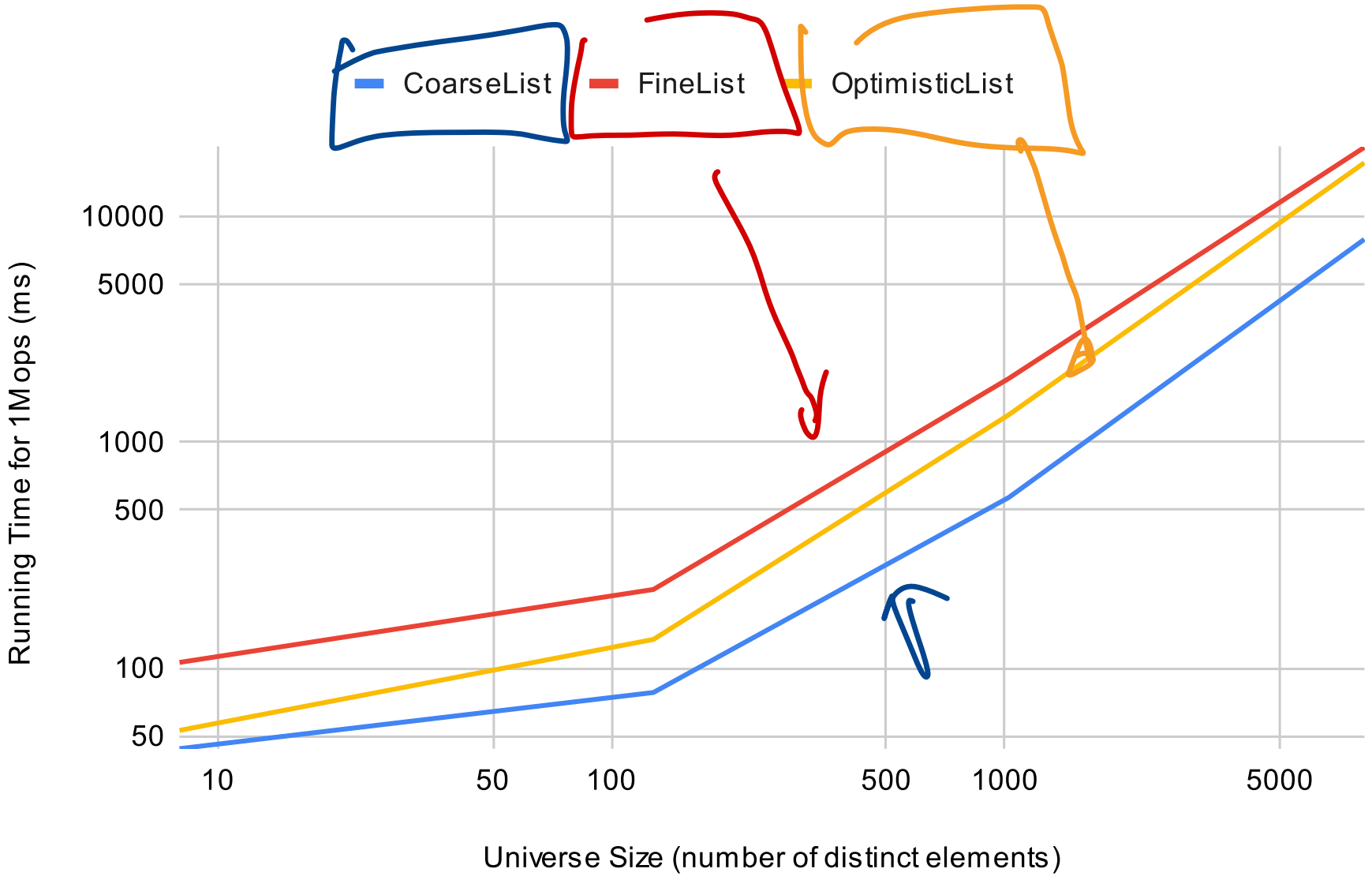
See `SetTester.java`

Performance Predictions?

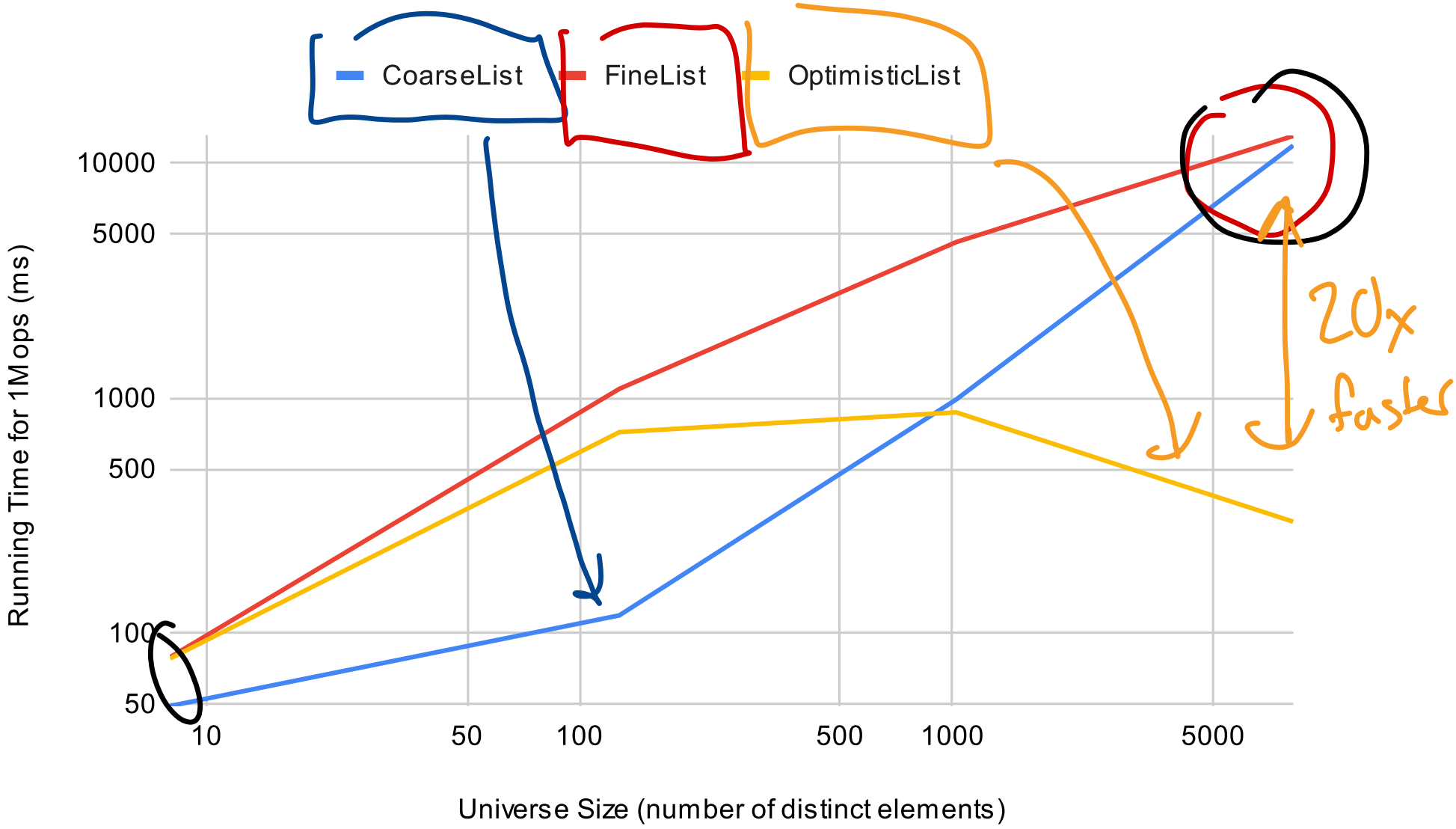
Under what conditions do you expect coarse/fine/optimistic strategies to be performant?

- Number of threads (1 to 128 on HPC)
- Set universe size (8 to 8,192)

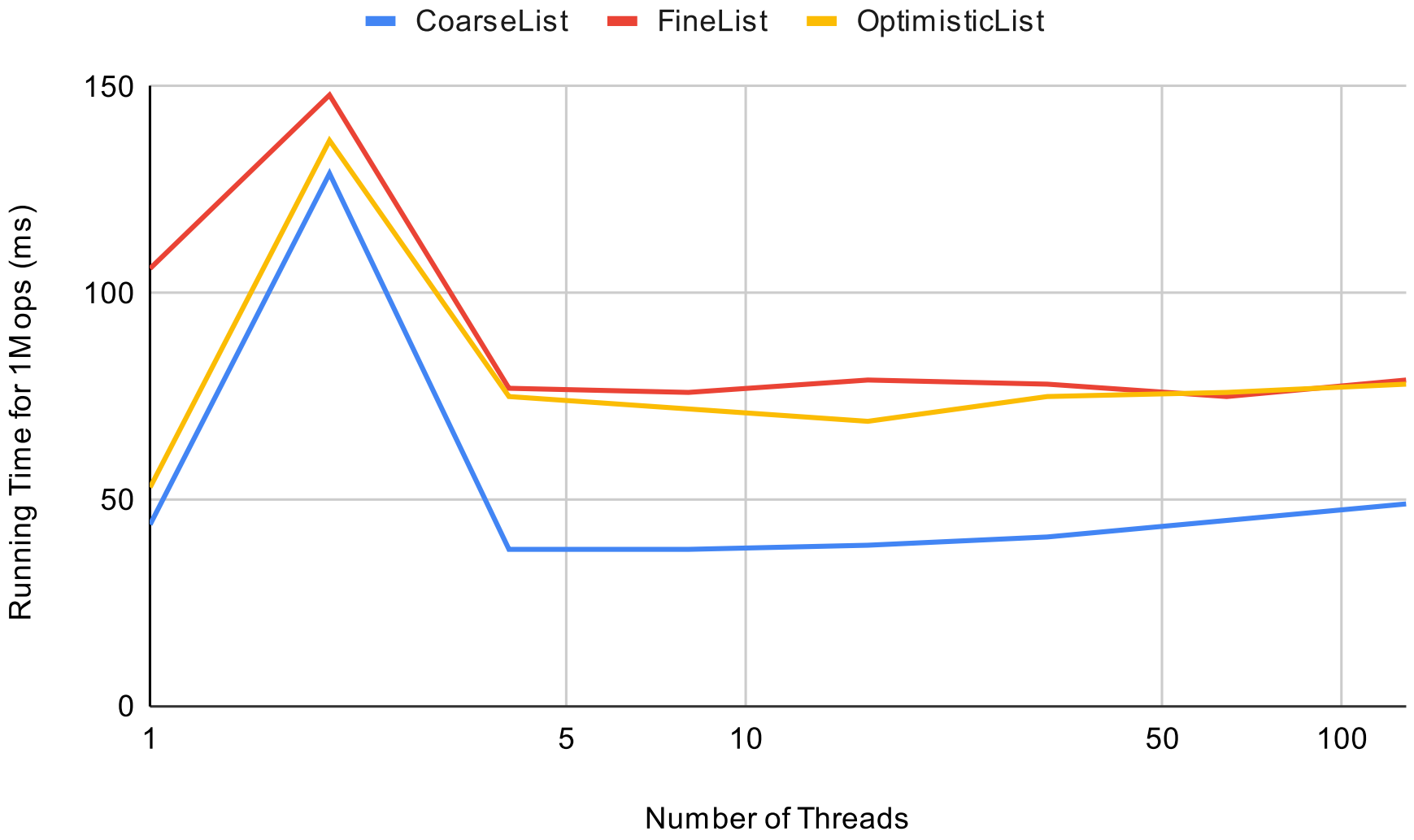
Performance v. Size, 1 Thread



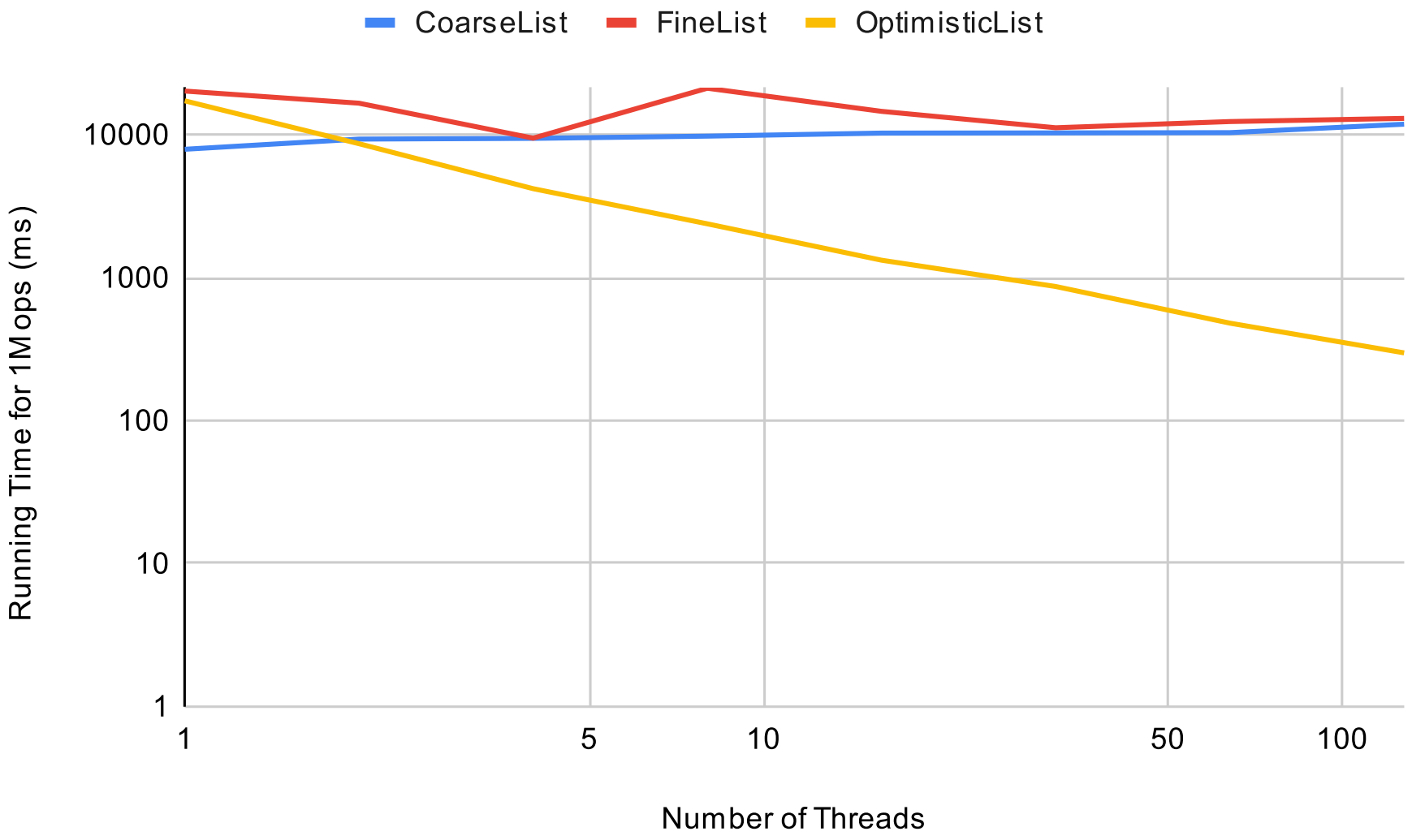
Performance v. Size, 128 Threads



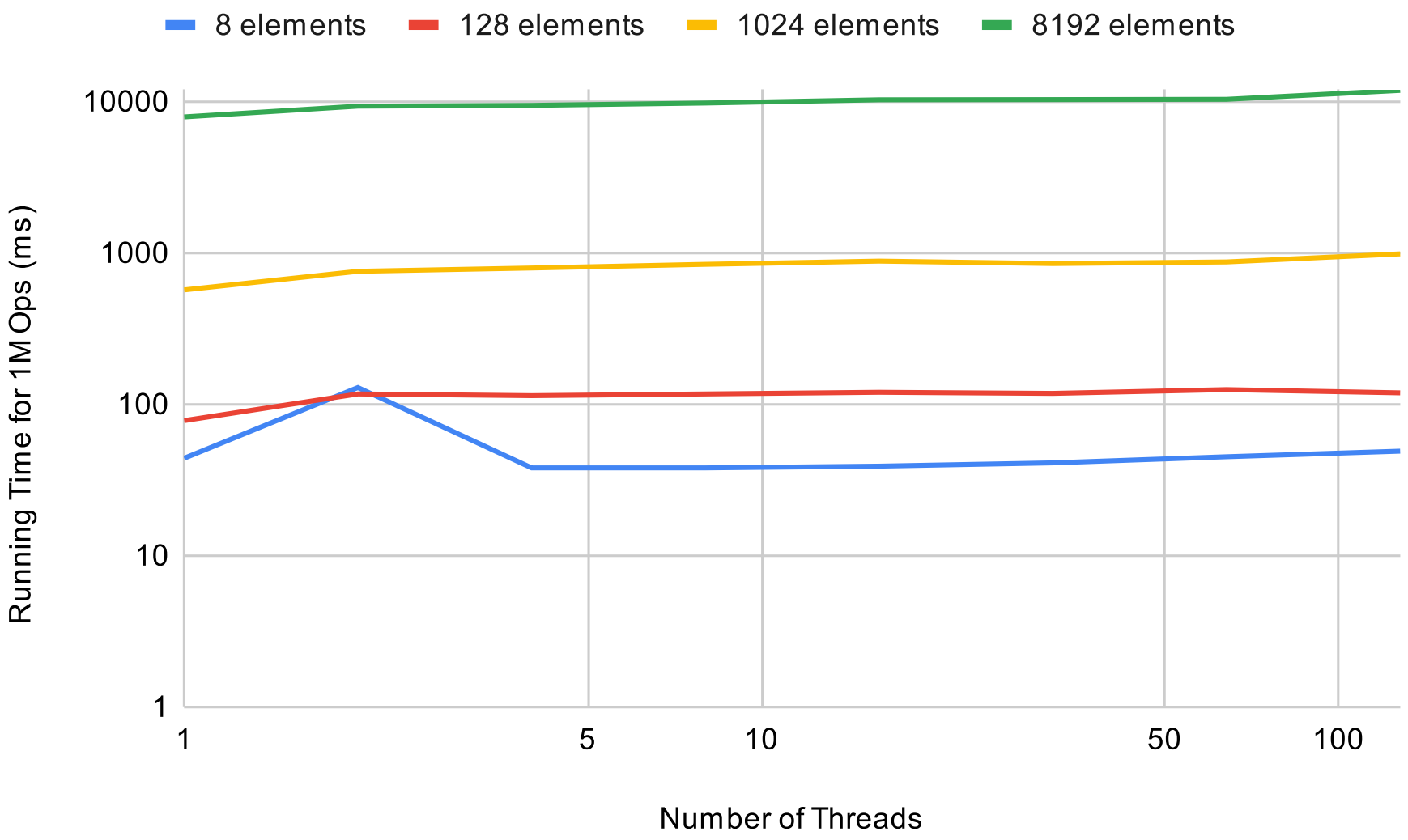
Time v. Threads, 8 Elements



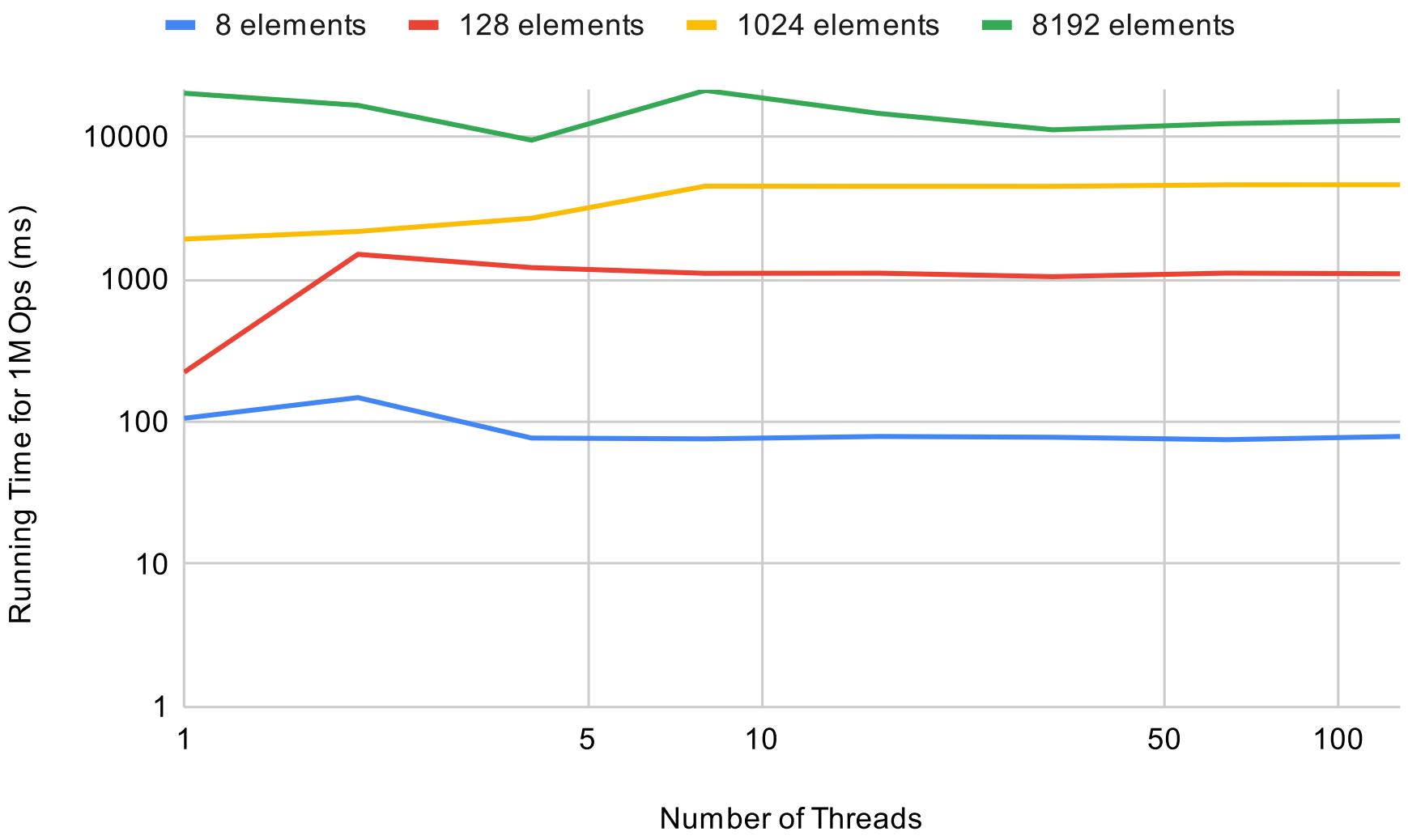
Time v. Threads, 8,192 Elements



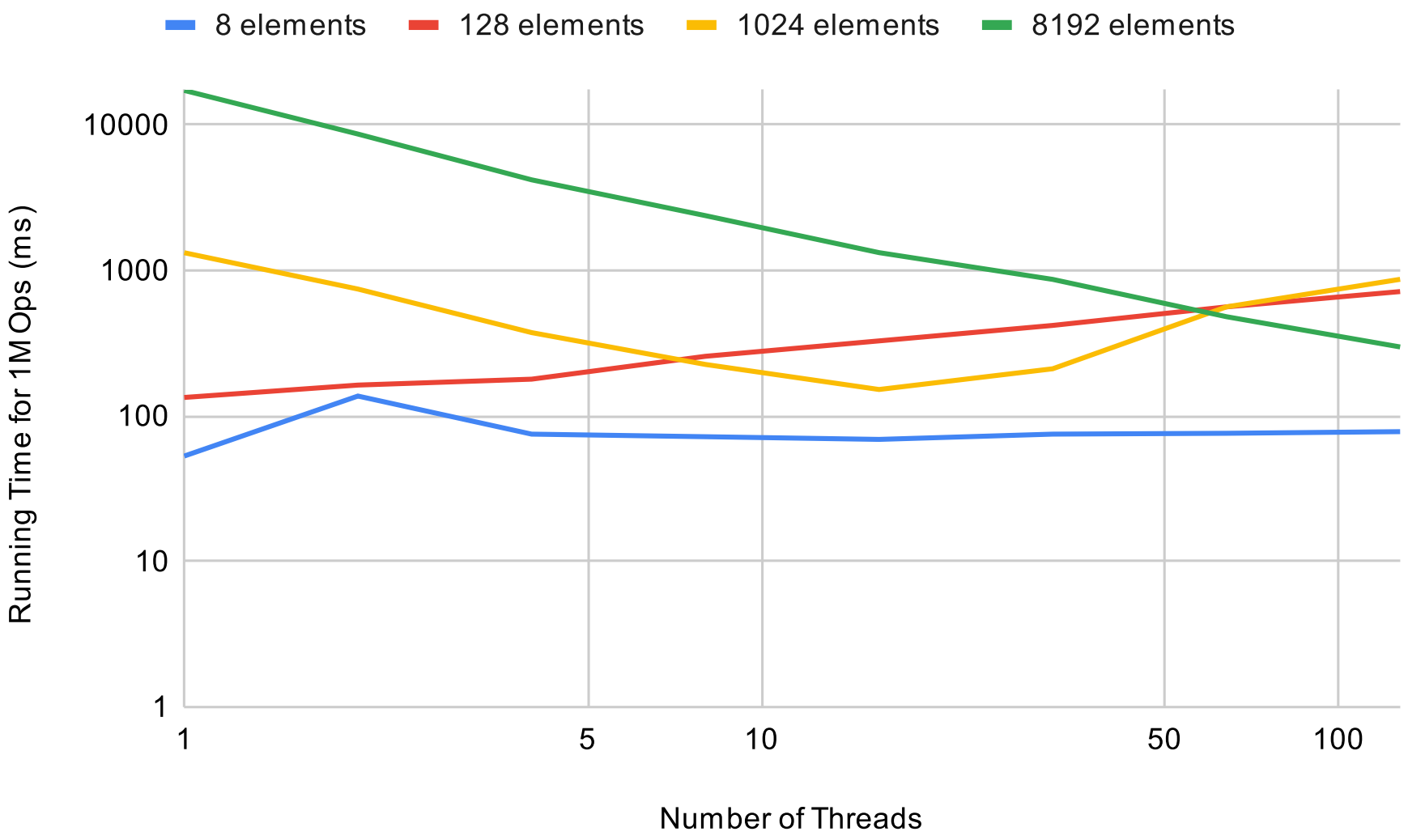
Coarse Time v. Threads



Fine Time v. Threads



Optimistic Time v. Threads



Next Time

Another Way: Lazy Synchronization

- don’t modify the list unless you *really* have to