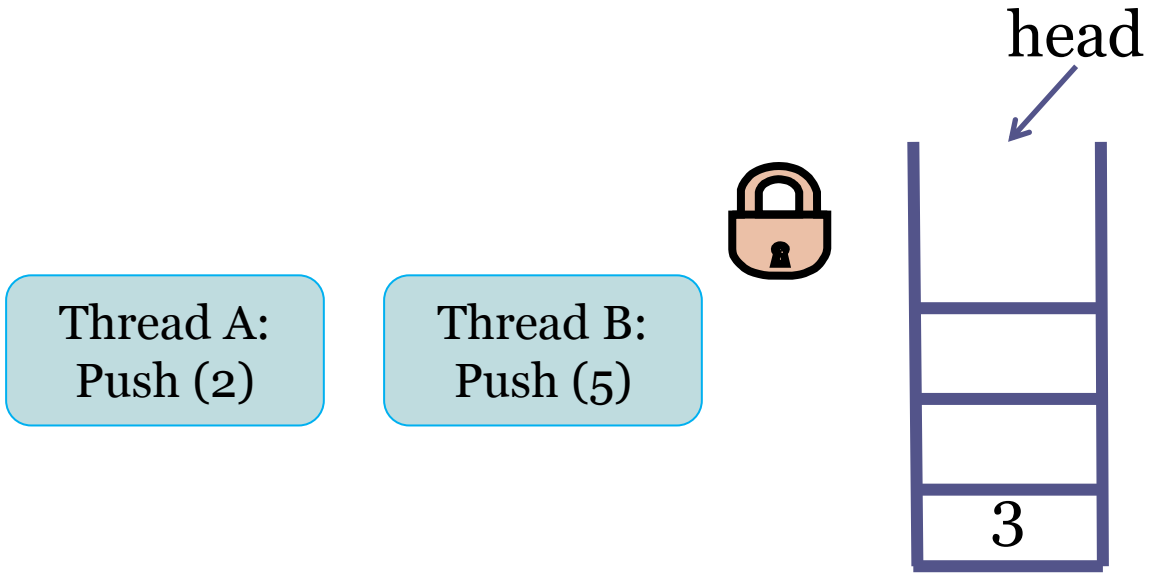
LCD: Local Combining on Demand

Dana Drachsler-Cohen and Erez Petrank
Technion , Israel

Combining Motivation

- Concurrent data structures are fundamental building blocks in various algorithms
- A common mean of synchronization: locks



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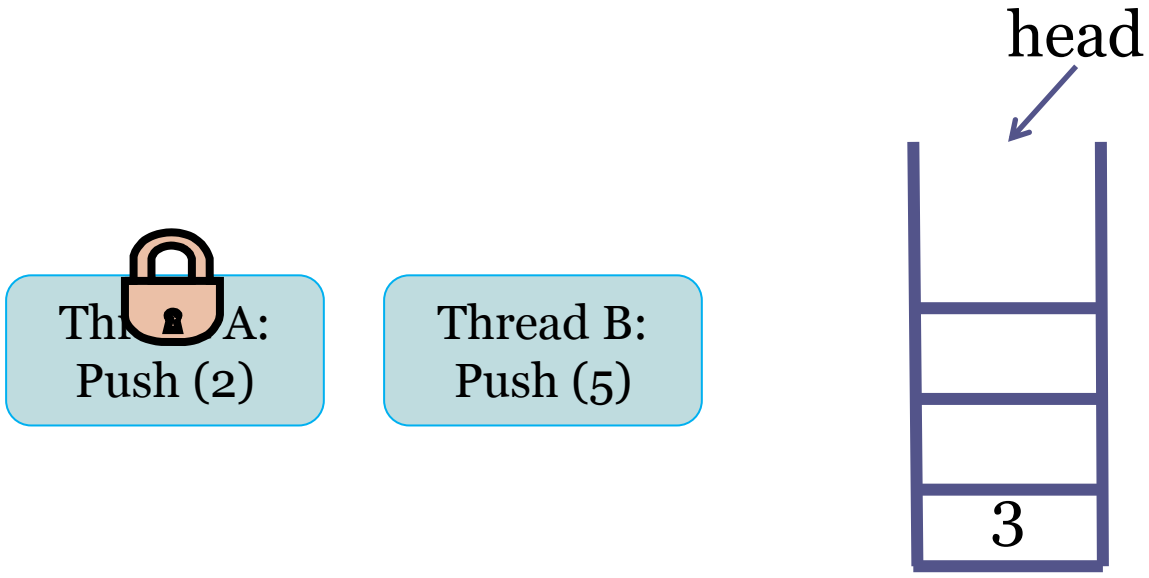

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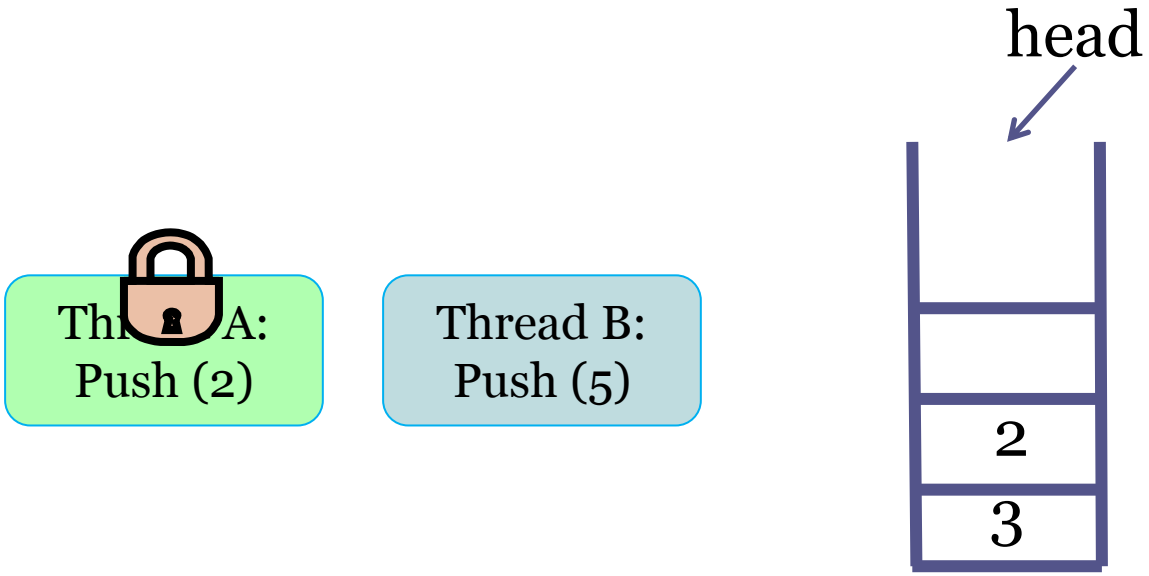

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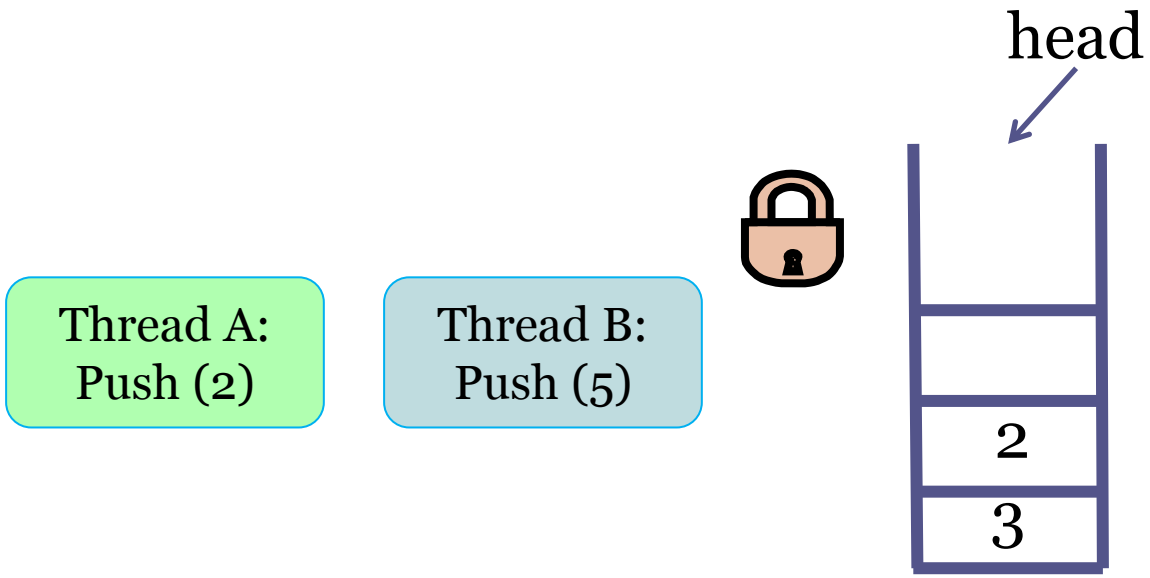

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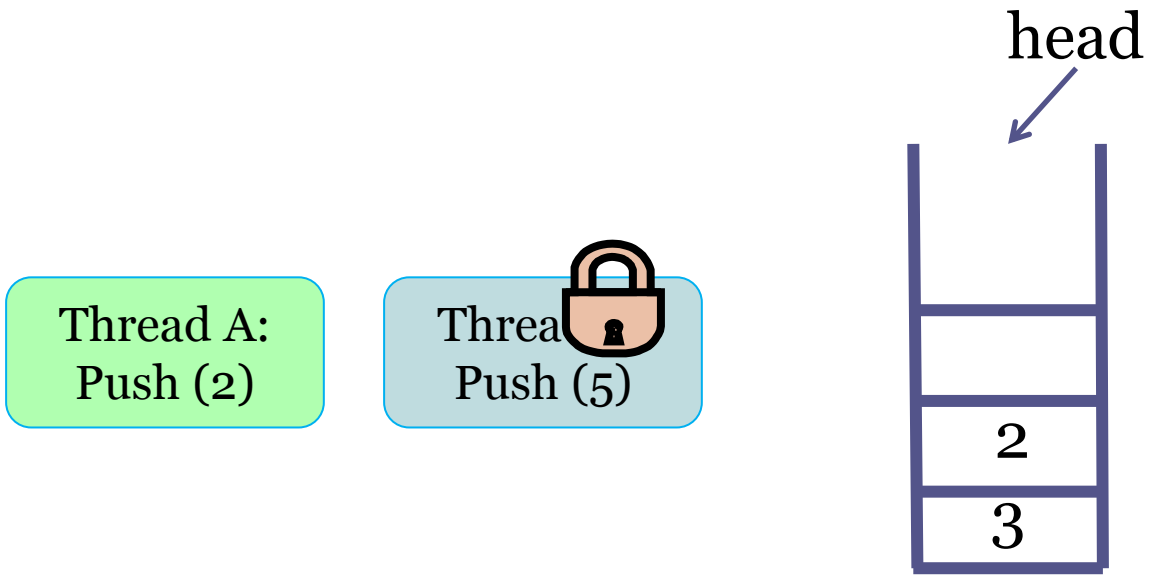

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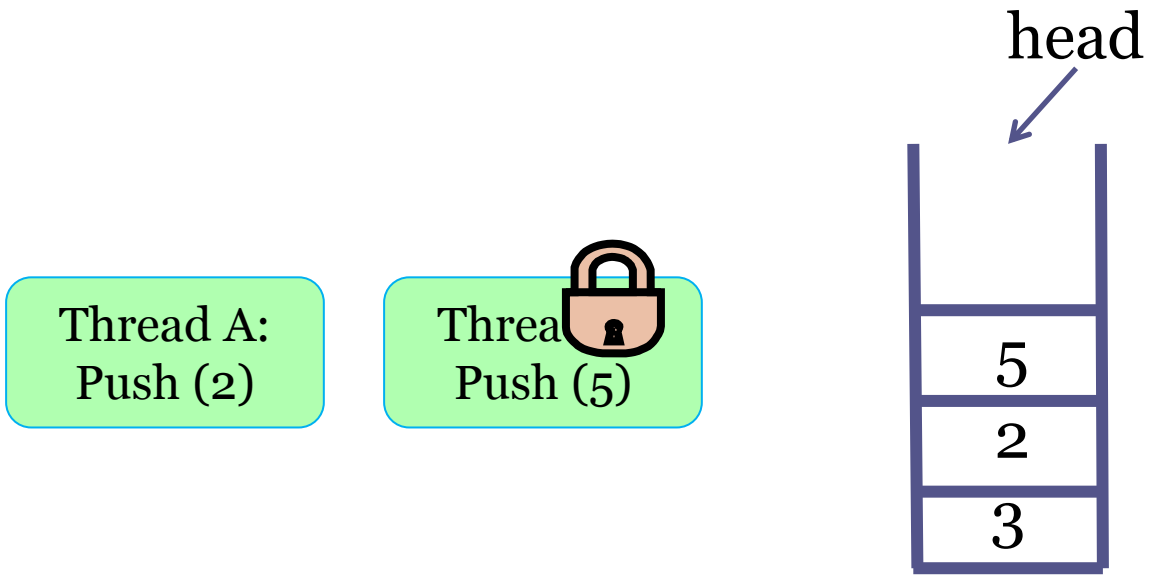

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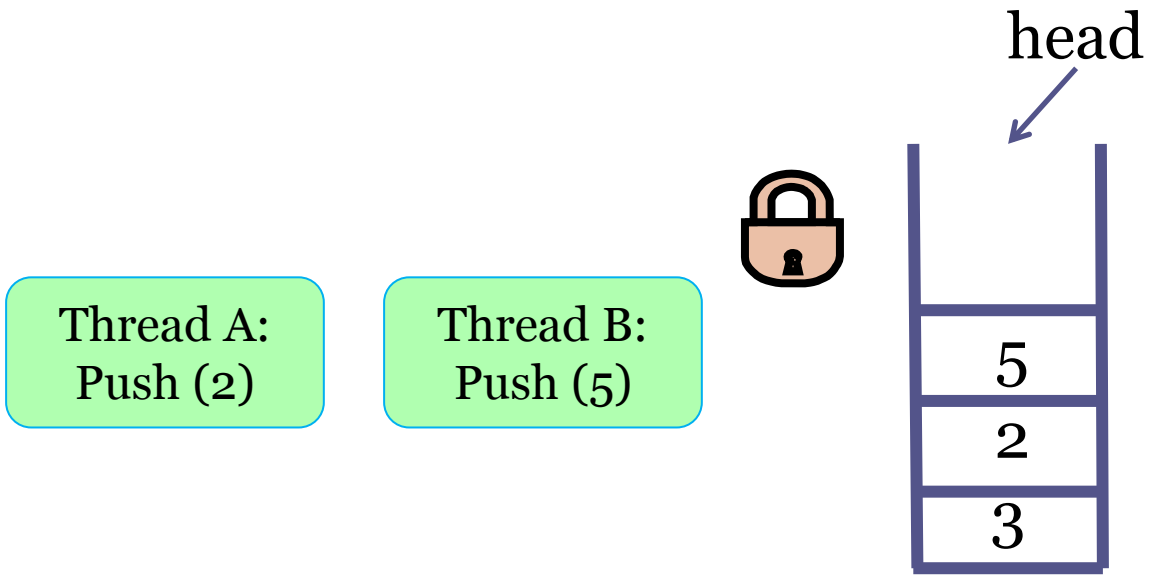

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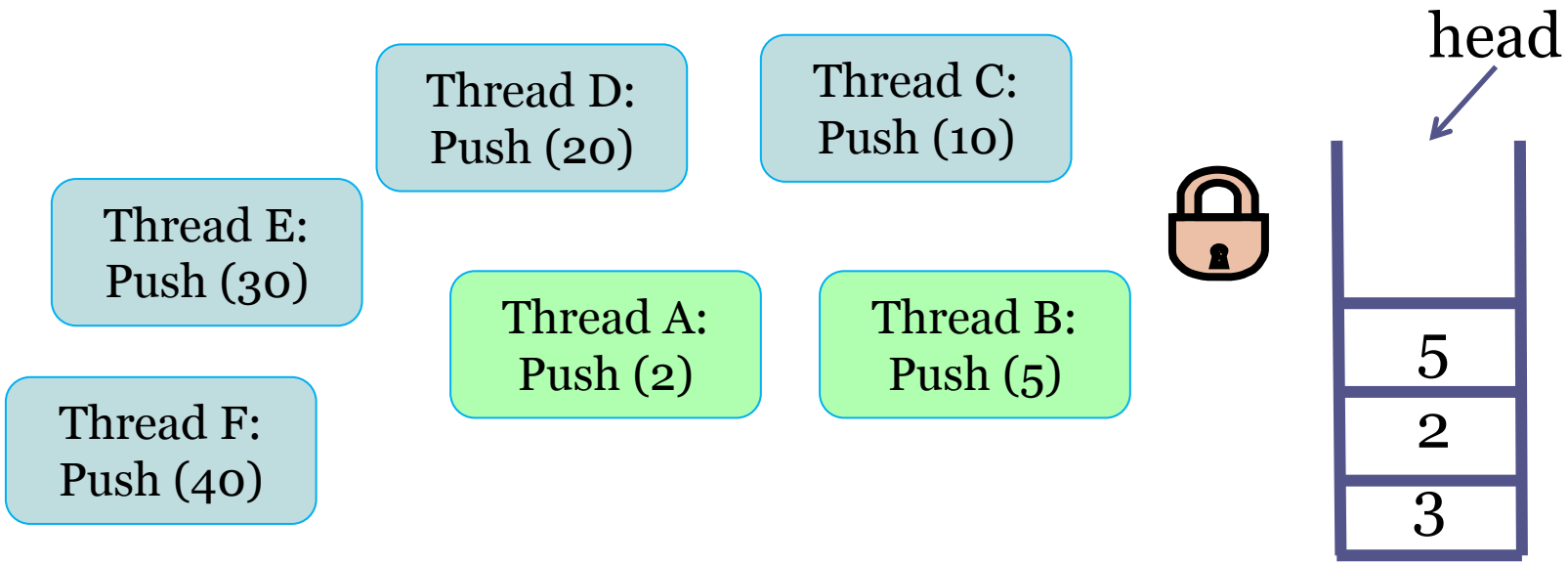

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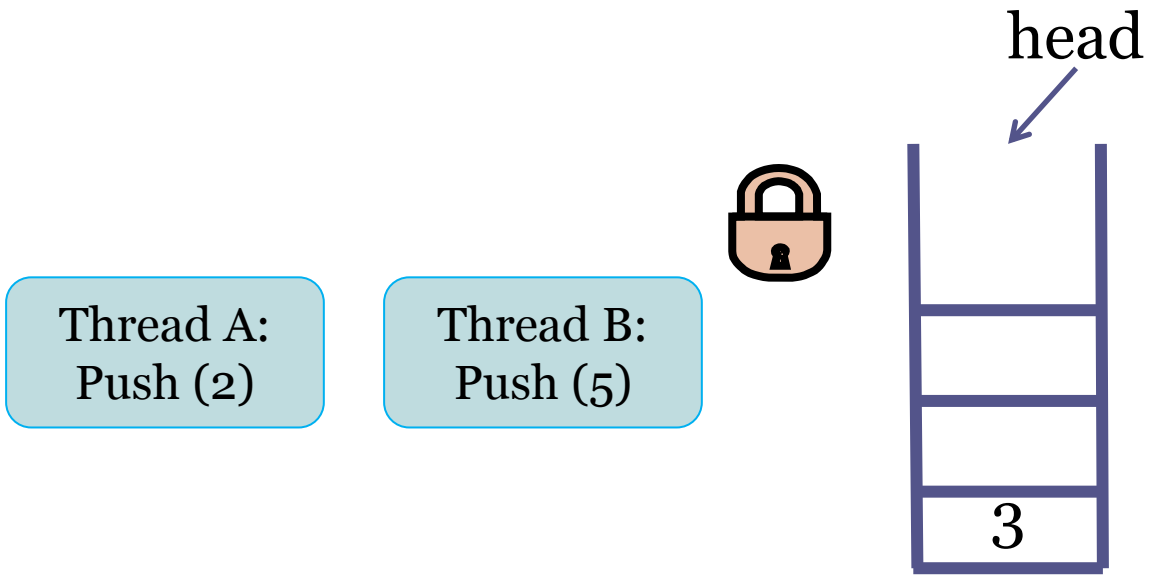
- Common approach: a thread acquires a global lock and executes operations of contending threads



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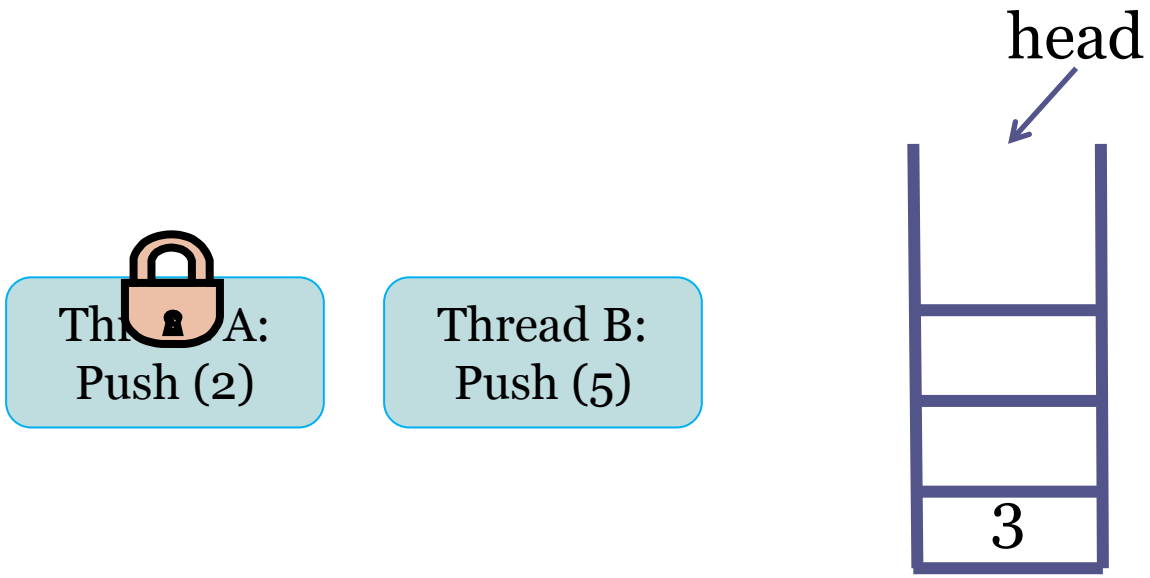

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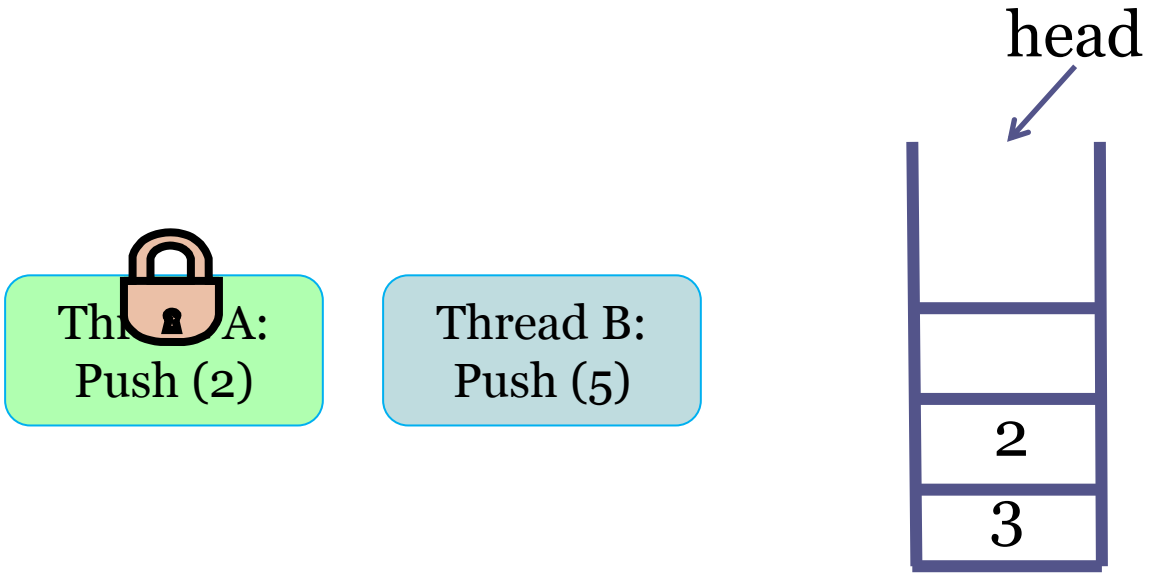

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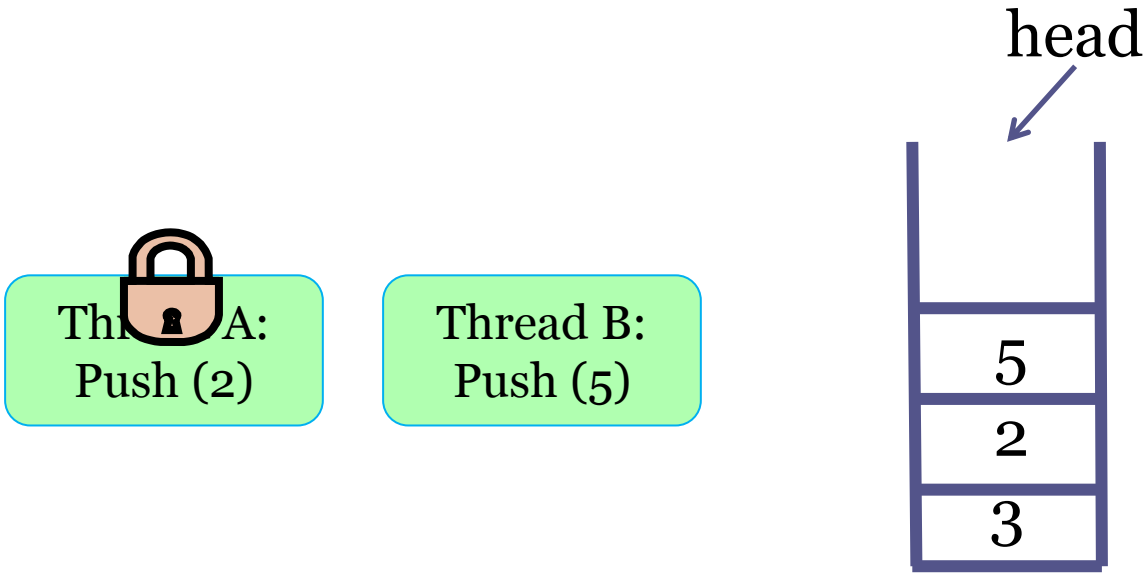

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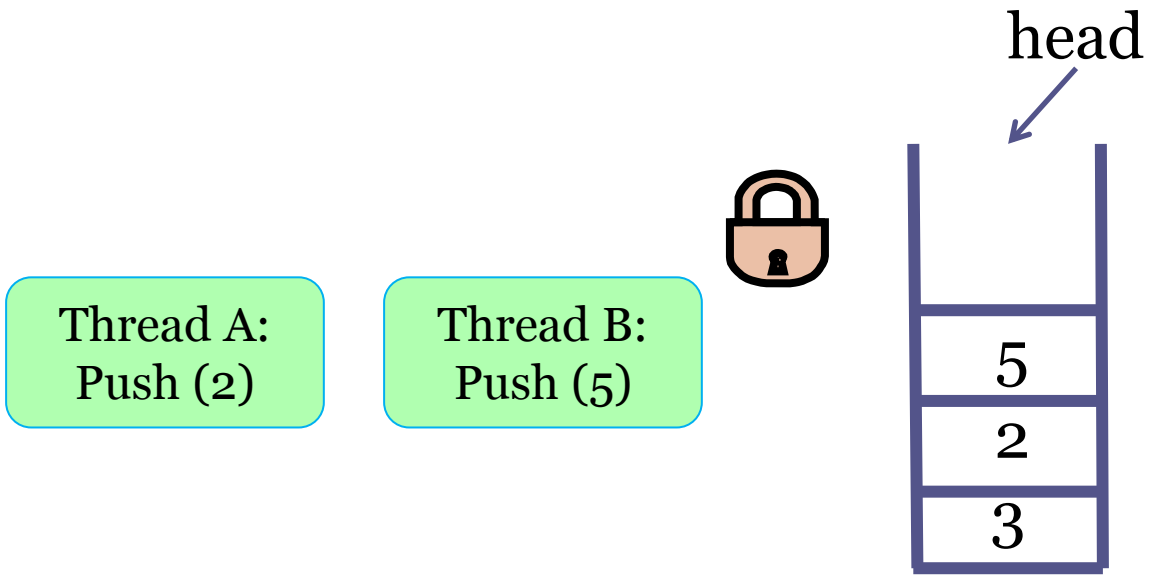

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- In combining, threads help each other
- Common approach: a thread acquires a global lock and executes operations of contending threads
  - Was shown to improve performance of data structures with 1-2 contention points
    - [Hendler, Incze, Shavit, Tzafrir], [Fatourou, Kallimanis], [Dice, Marathe, Shavit]
- Namely, they were already protected by 1-2 locks
  - The global lock did not reduce scalability

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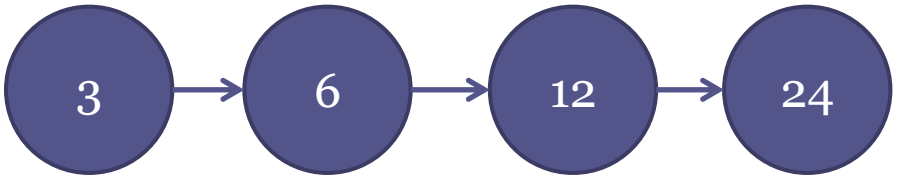
- J

What about data structures with unbounded number of contention points (e.g., the linked-list)?

Linked-List

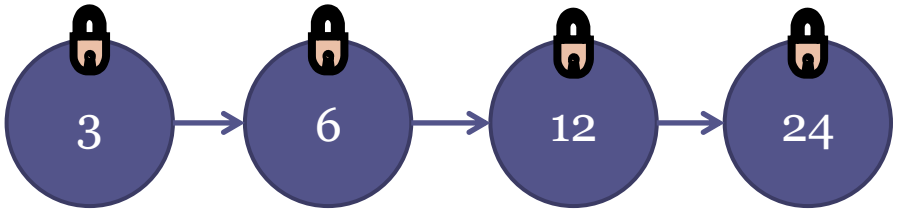


- Consists of nodes each with a unique key
- Sorted by the keys
  - Each node points to its successor in the list
- Supports three operations
  - Insert(k): insert k if it is not yet present
  - Remove(k): remove k if present
  - Contains(k): return true if k is present
- A simple and practical concurrent implementation
  - The Lazy List

The Lazy List

[Heller, Herlihy, Luchangco, Moir, Scherer III, Shavit]

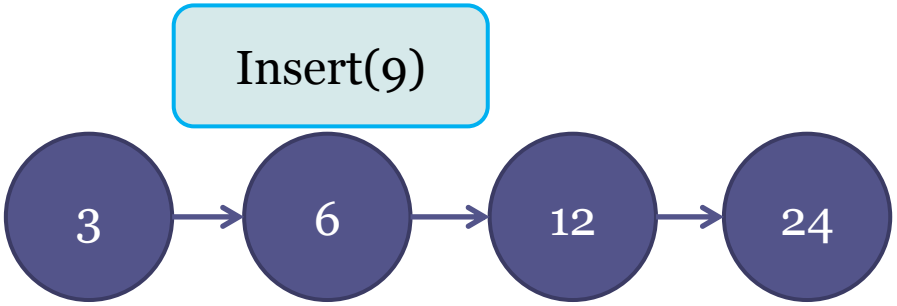
- Lock-based – each node has a lock
  - Insert(k): 1 lock
  - Remove(k): 2 locks
  - Contains(k): no locks



- We focus on combining of locked-based operations
  - Thus, combining only affects insert and remove

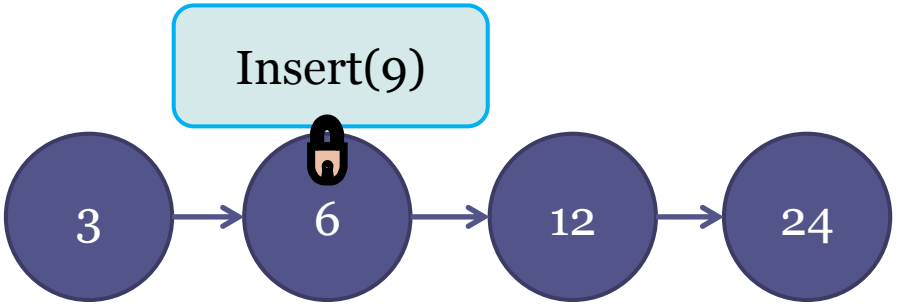
The Lazy List Insert(k)

- Search for a node p s.t.: $p.key < k \leq next(p).key$



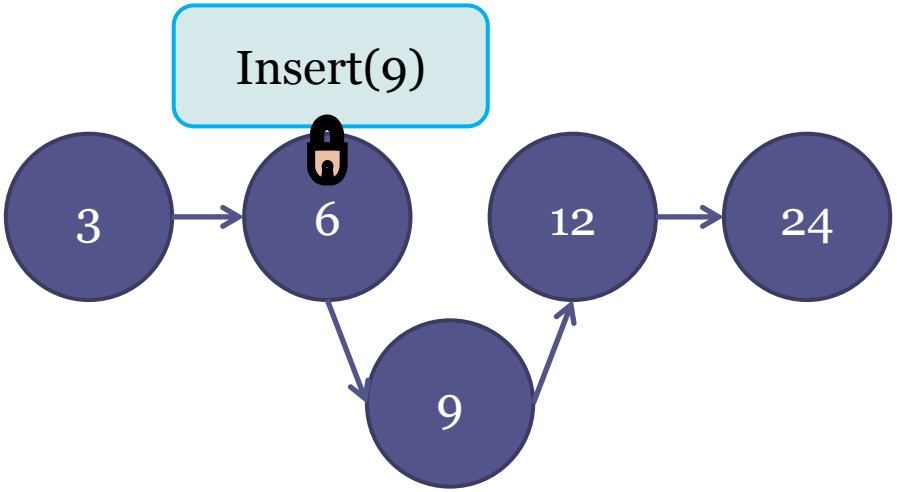
The Lazy List Insert(k)

- Search for a node p s.t.: $p.key < k \leq next(p).key$
- Lock p



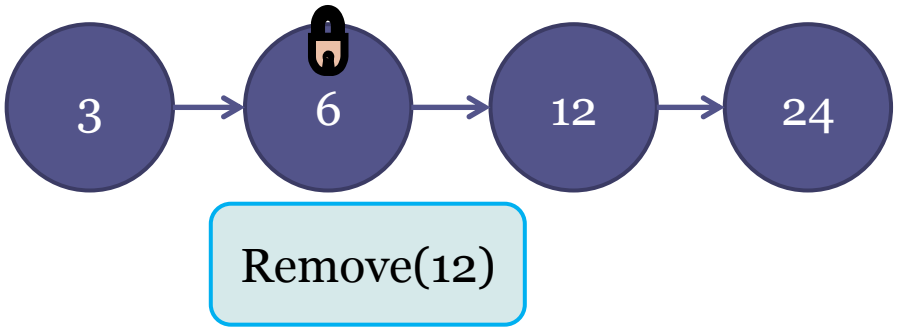
The Lazy List Insert(k)

- Search for a node p s.t.: $p.key < k \leq next(p).key$
- Lock p
- If the key of p's successor is k: cannot insert
- Otherwise, add k after p



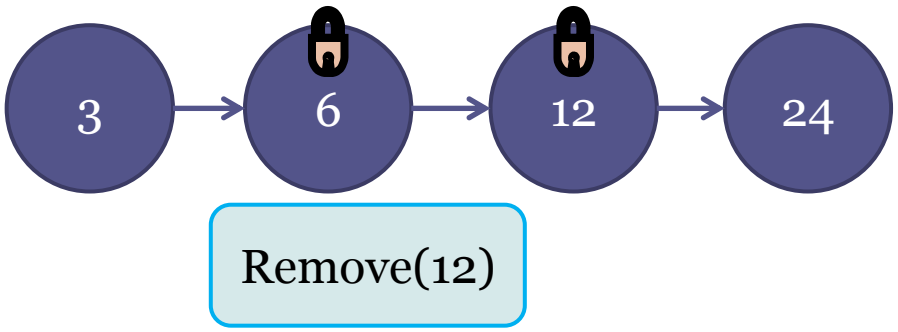
The Lazy List Remove(k)

- Search for a node p s.t.: $p.key < k \leq next(p).key$
- Lock p



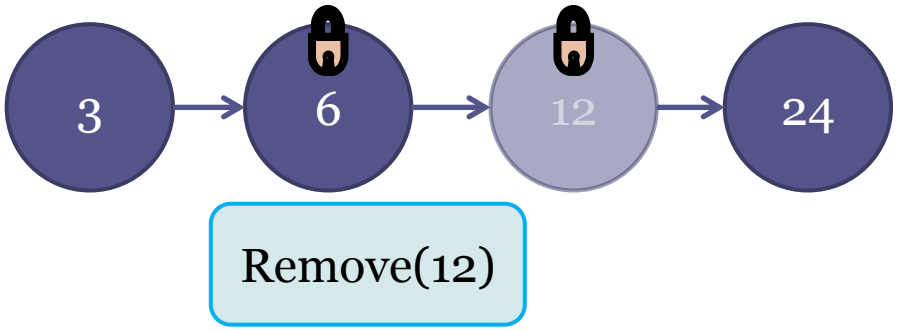
The Lazy List Remove(k)

- Search for a node p s.t.: $p.key < k \leq next(p).key$
- Lock p
- If the key of p's successor is not k: cannot remove
- Otherwise
  - Lock p's successor



The Lazy List Remove(k)

- Search for a node p s.t.: $p.key < k \leq next(p).key$
- Lock p
- If the key of p's successor is not k: cannot remove
- Otherwise
  - Lock p's successor
  - Mark the successor as removed



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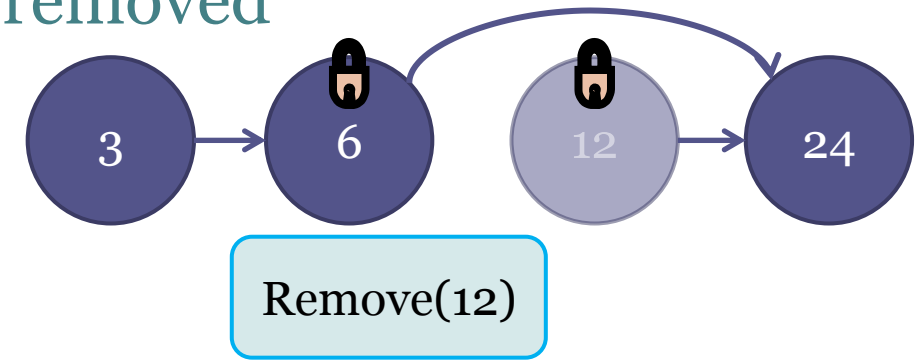
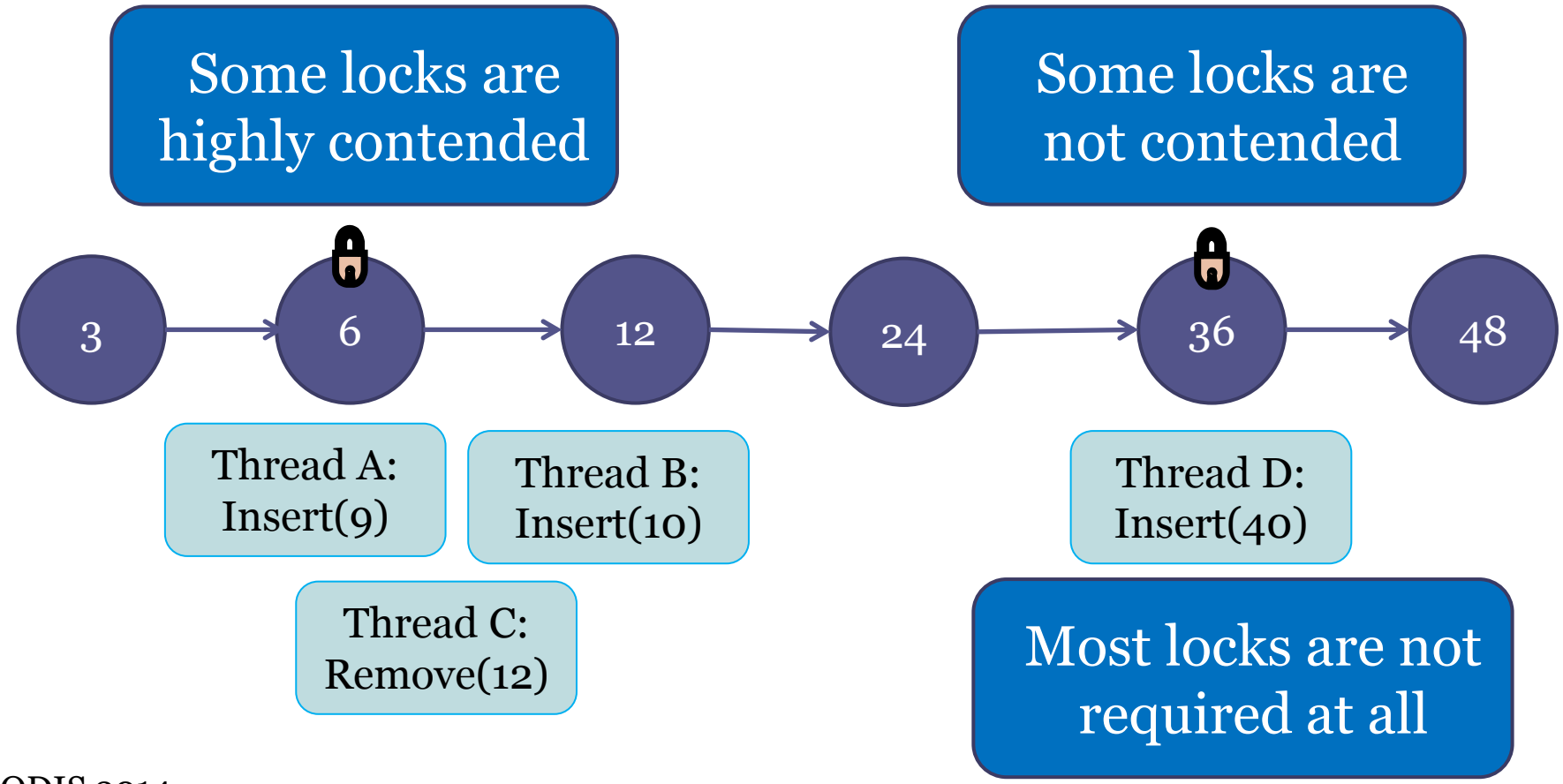
- Lock p
- If the key of p's successor is not k: cannot remove
- Otherwise
  - Lock p's successor
  - Mark the successor as removed
  - Update p's successor



Contention in Linked-Lists



Our Contribution: LCD: Local Combining on Demand

- We present a new combining technique for such data structures which is *Local* and *On demand*
  - *Local* – combine for each lock independently
    - No global lock
  - *On demand* – do not introduce overhead if there is no contention
- We demonstrate it on linked-lists
  - The *LCD-list*
    - An extension of the Lazy List

Key Ideas of LCD

- What are the combining types?
- How does on-demand combining work?
- How does the local combining work?
- How to handle operations requiring multiple locks?
- How to integrate LCD with the Java lock?

What are the combining types?

Combining Types

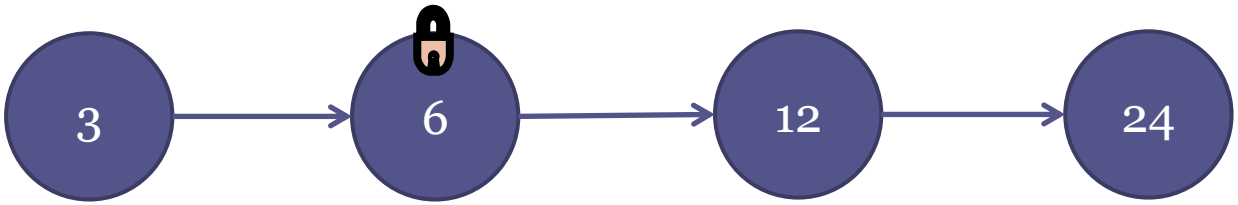
1. Execute other thread operations

Thread A:
Insert(7)

Thread B:
Insert(8)

Thread C:
Insert(9)

Thread D:
Remove(12)



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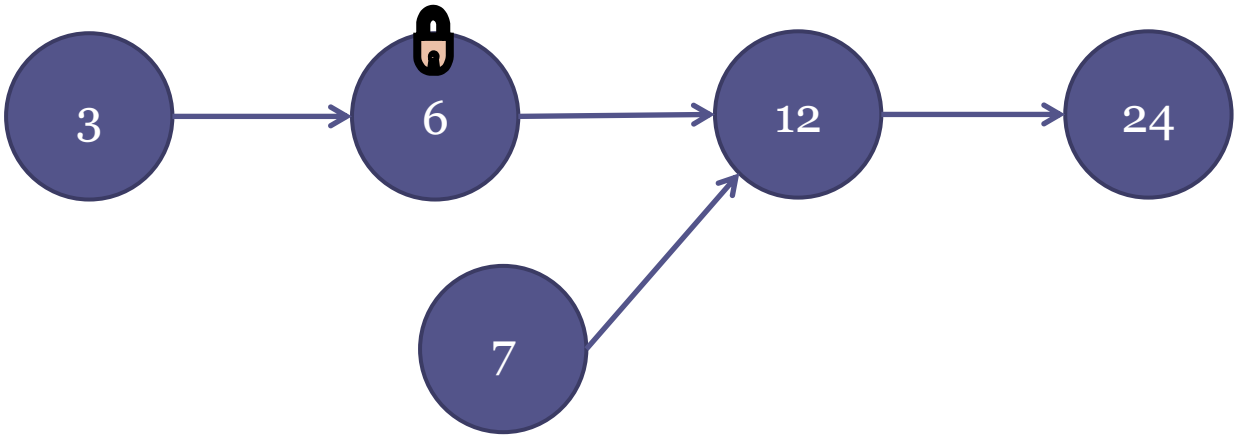

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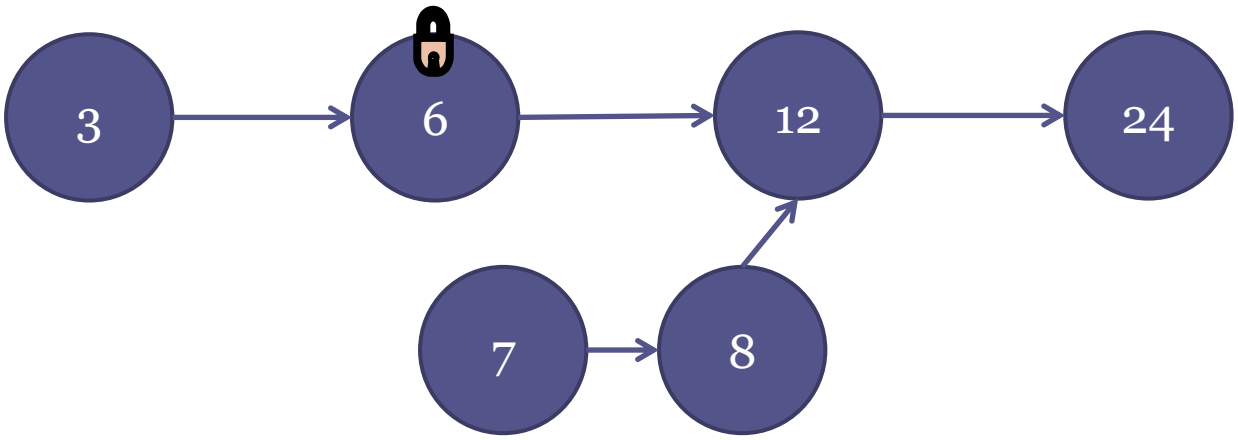

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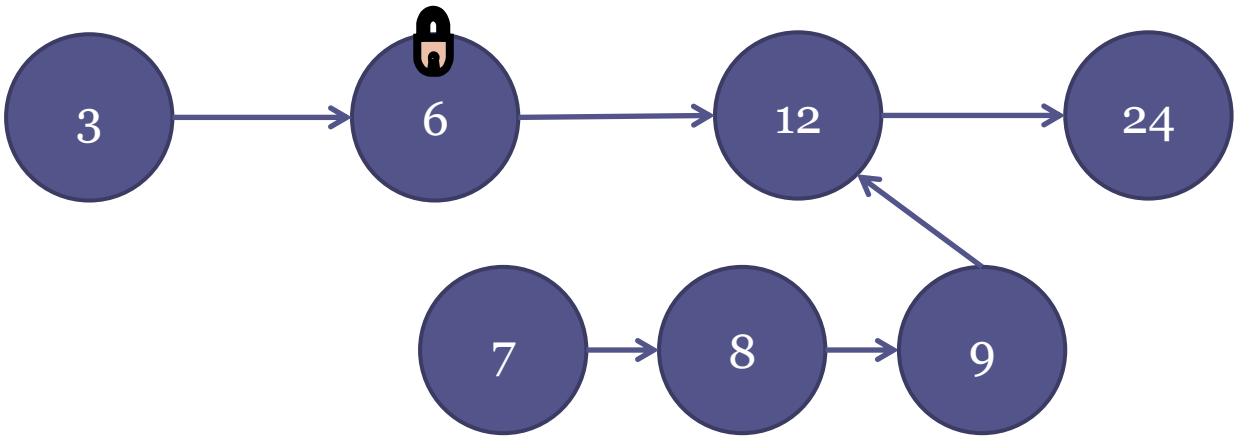

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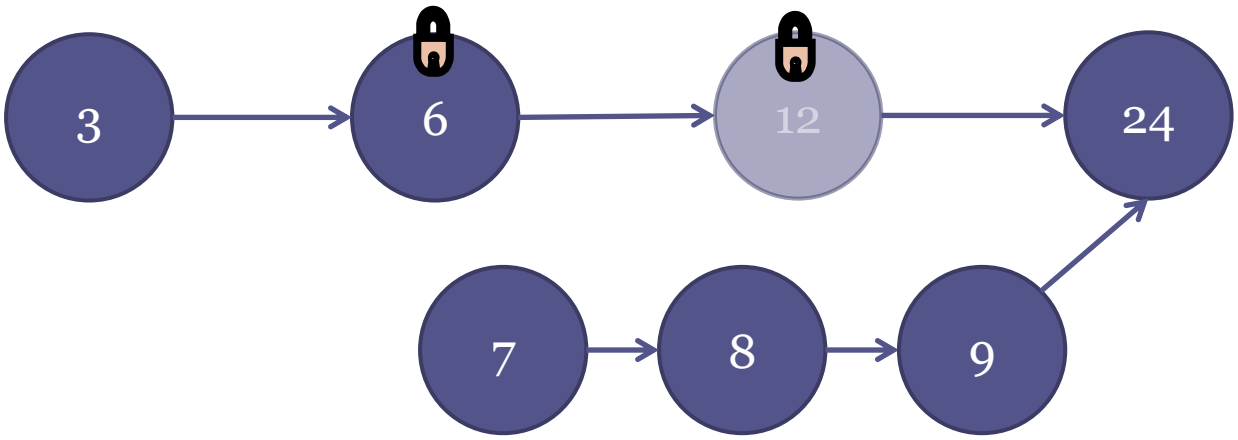

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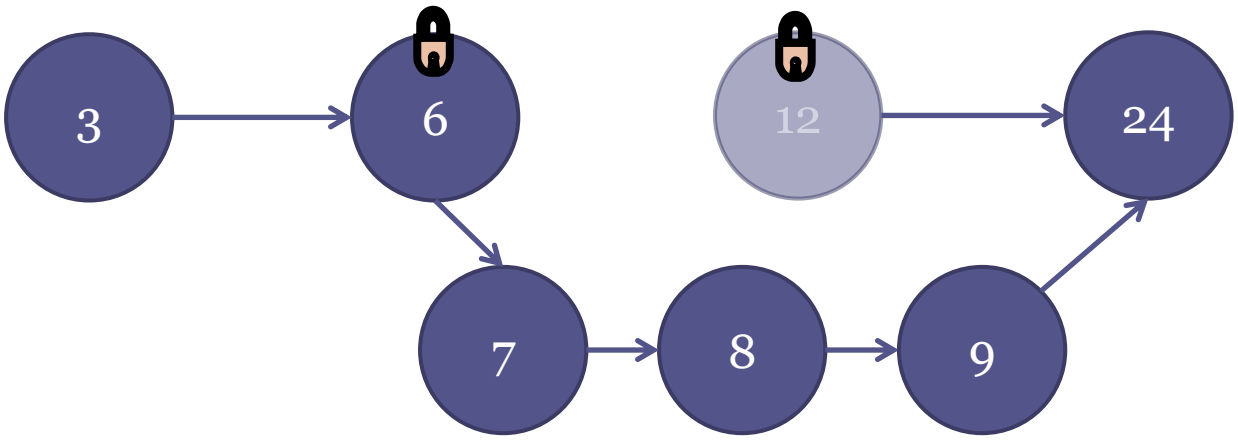

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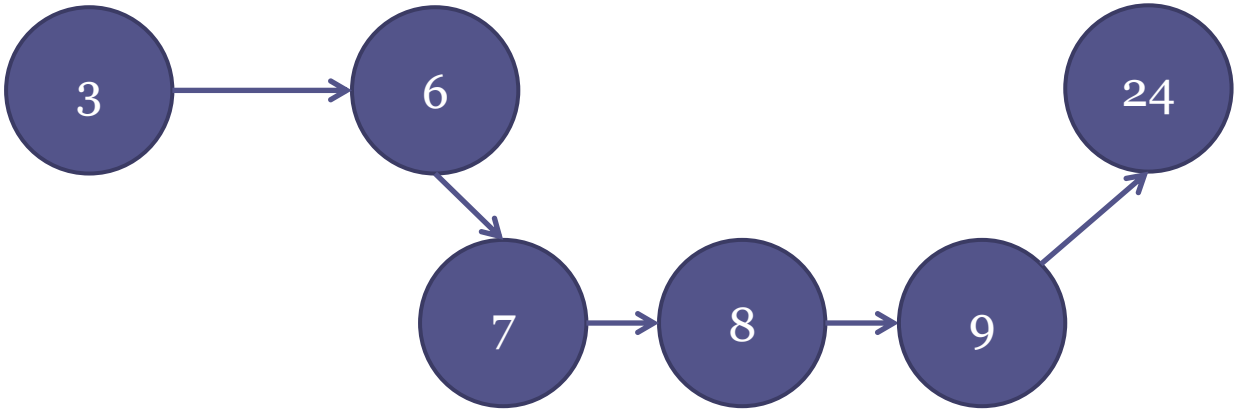

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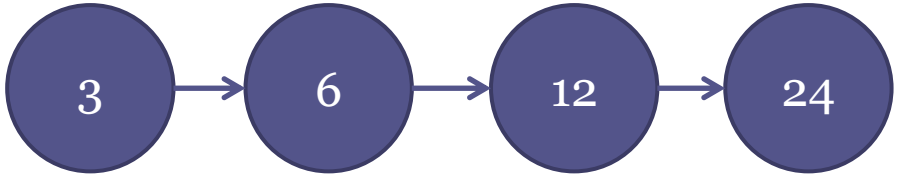

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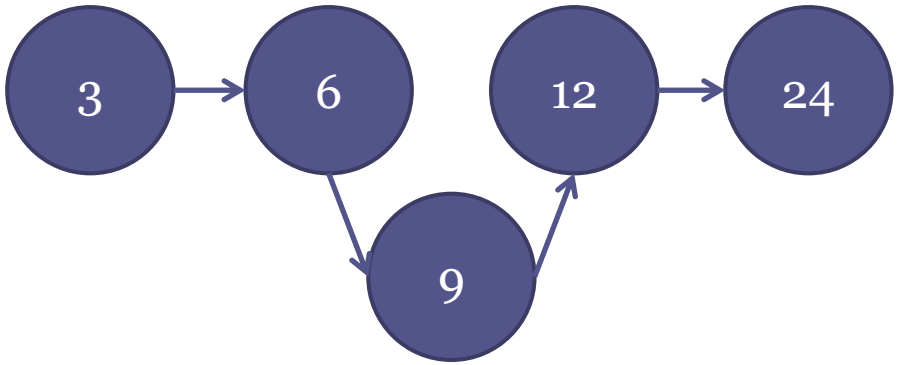

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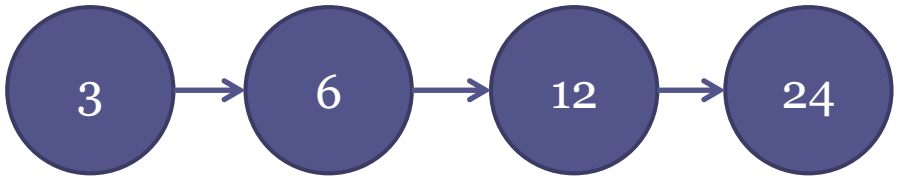

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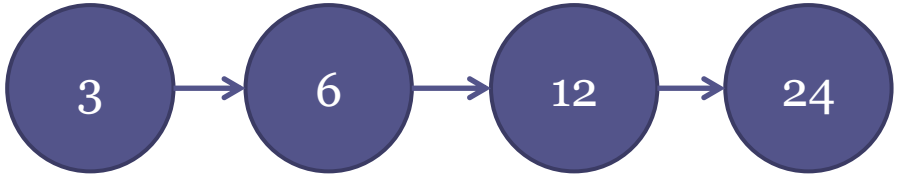

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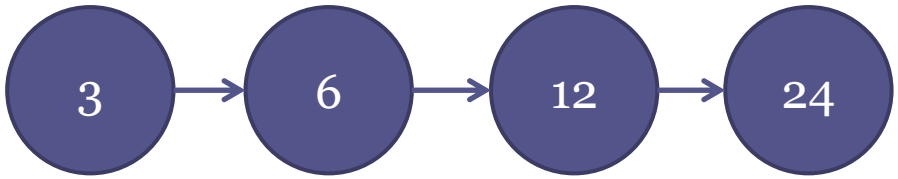

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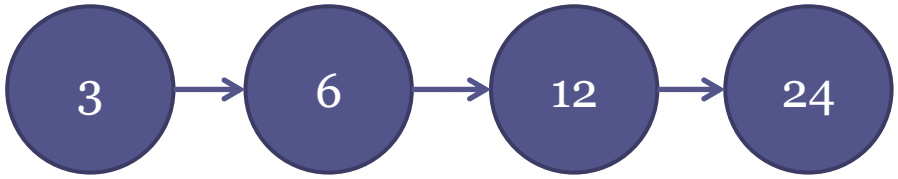

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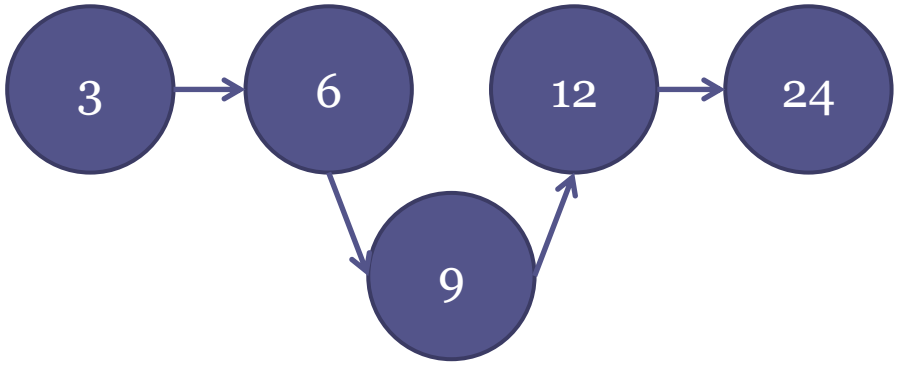

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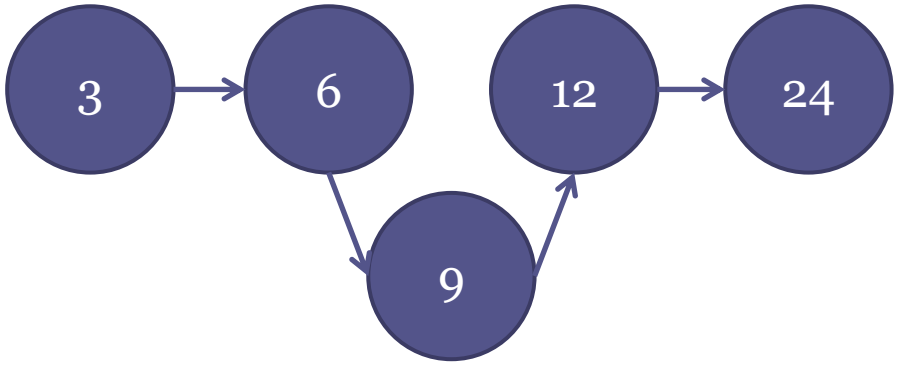

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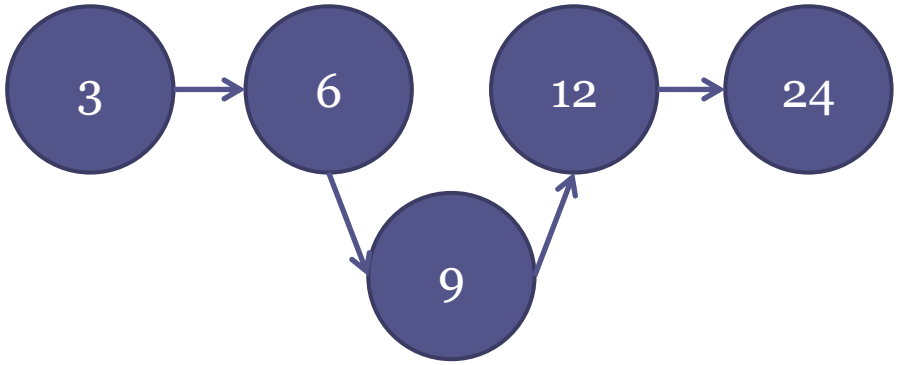

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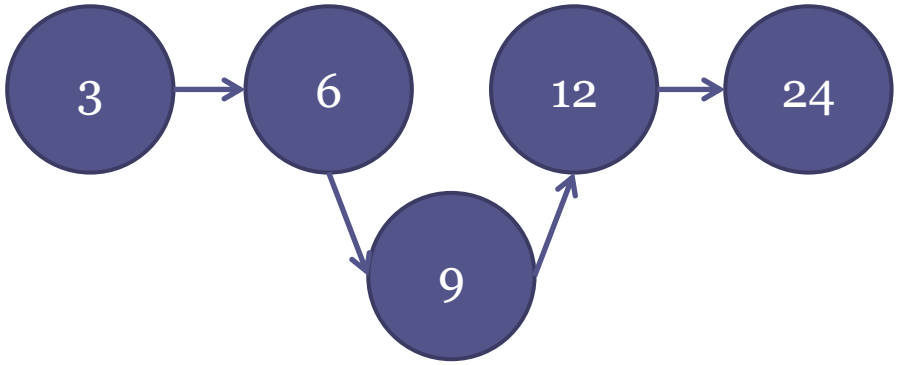

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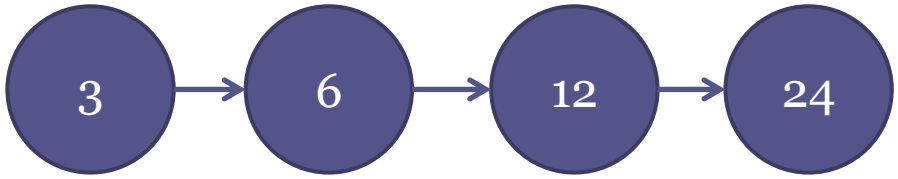

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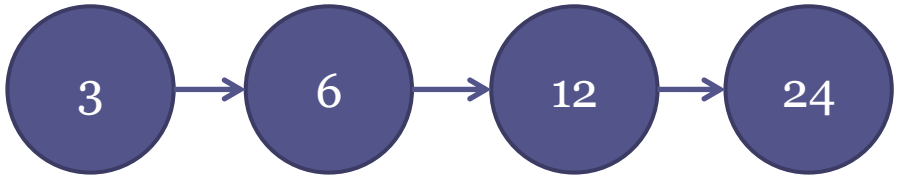

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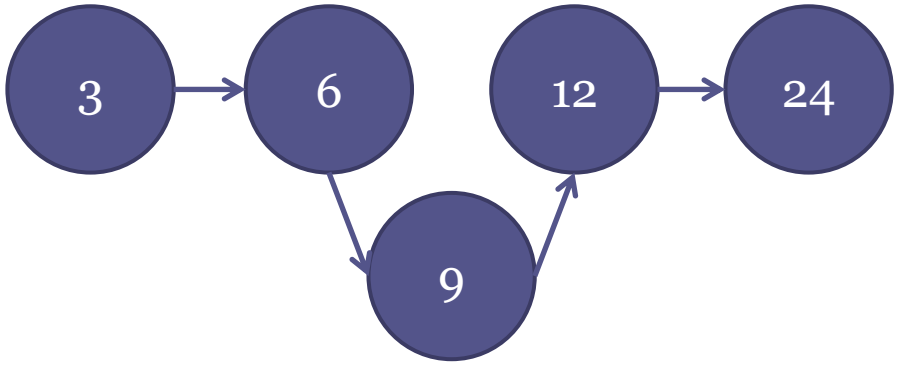
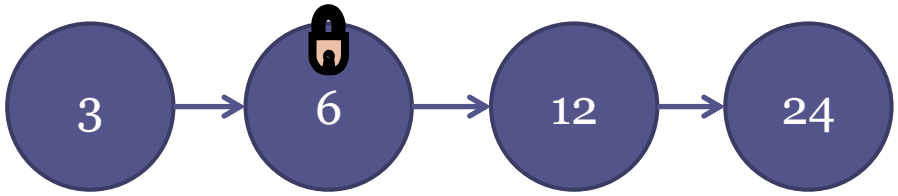


Combining Types

4. Wrong lock notification

Thread A:
Insert(9)



Combining Types

4. Wrong lock notification

Thread A: Insert(9)

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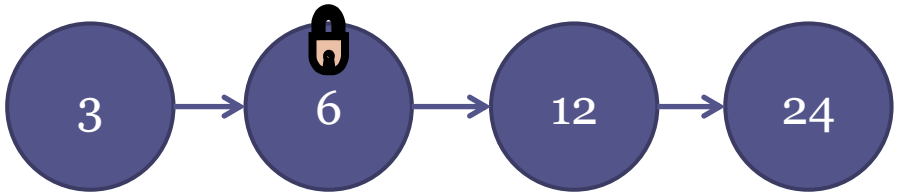
Thread C: Insert(11)



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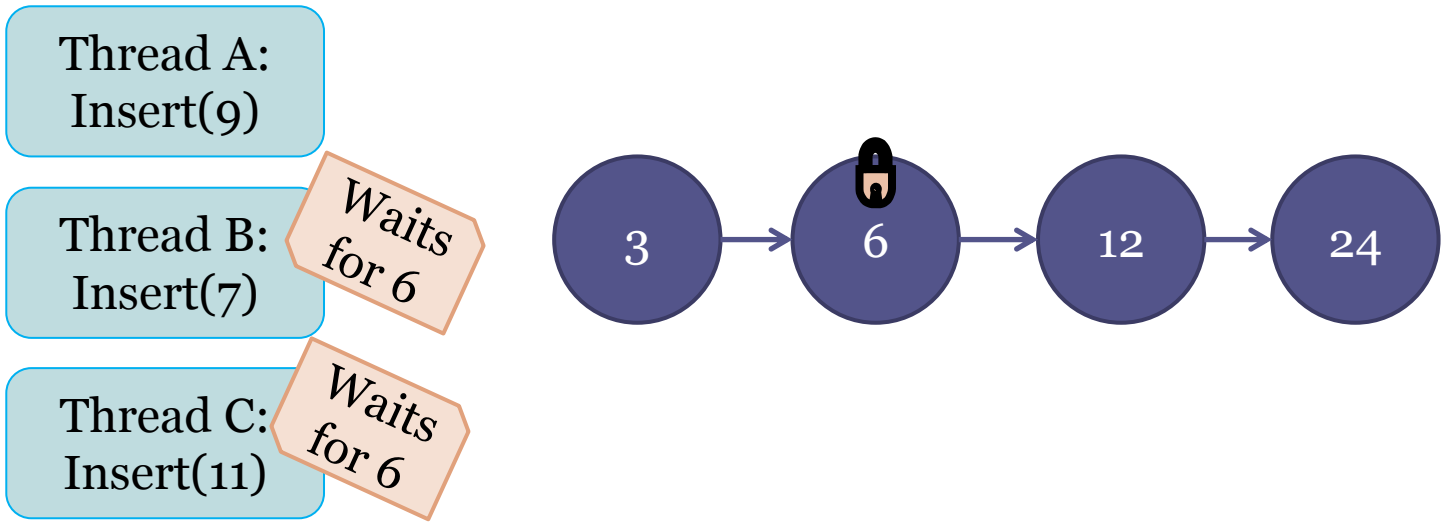

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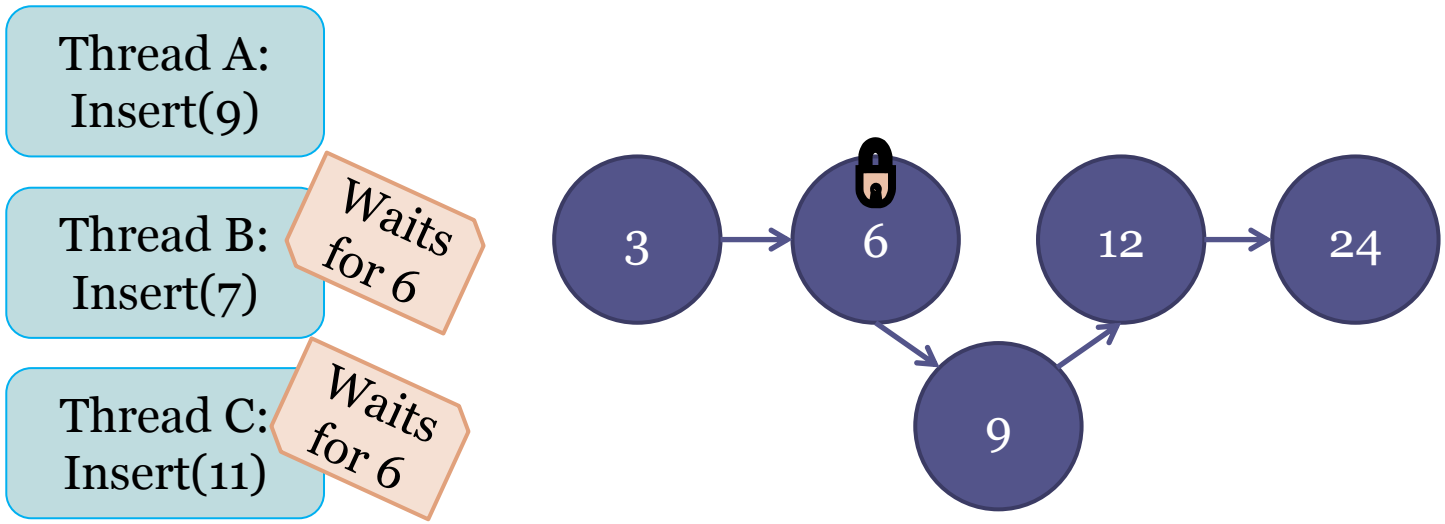

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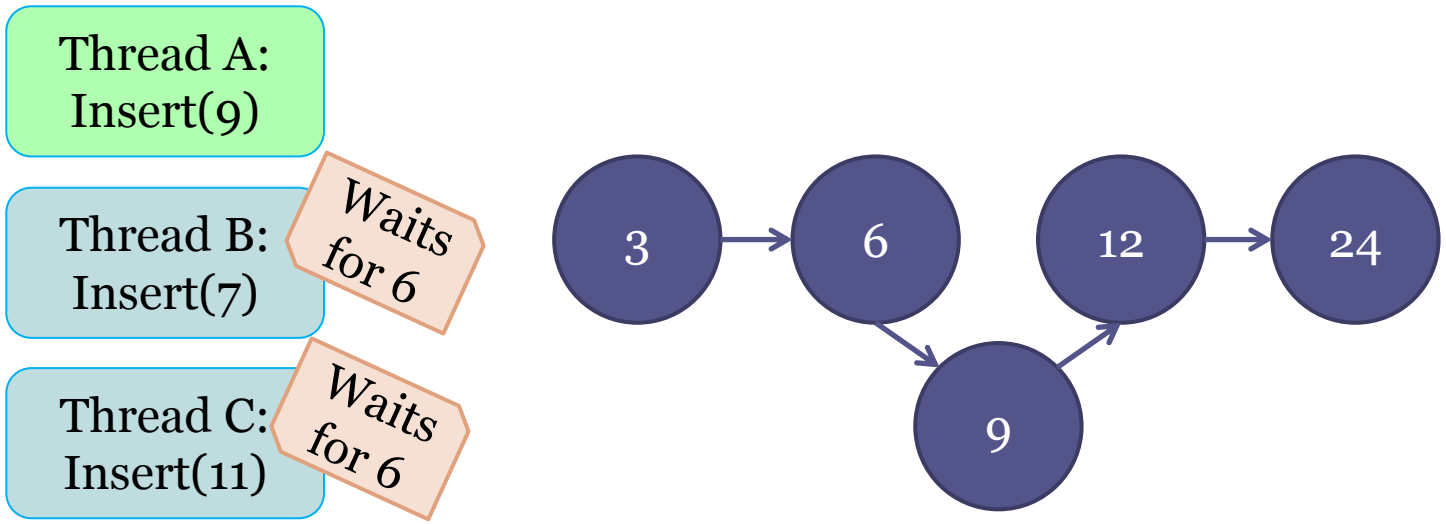

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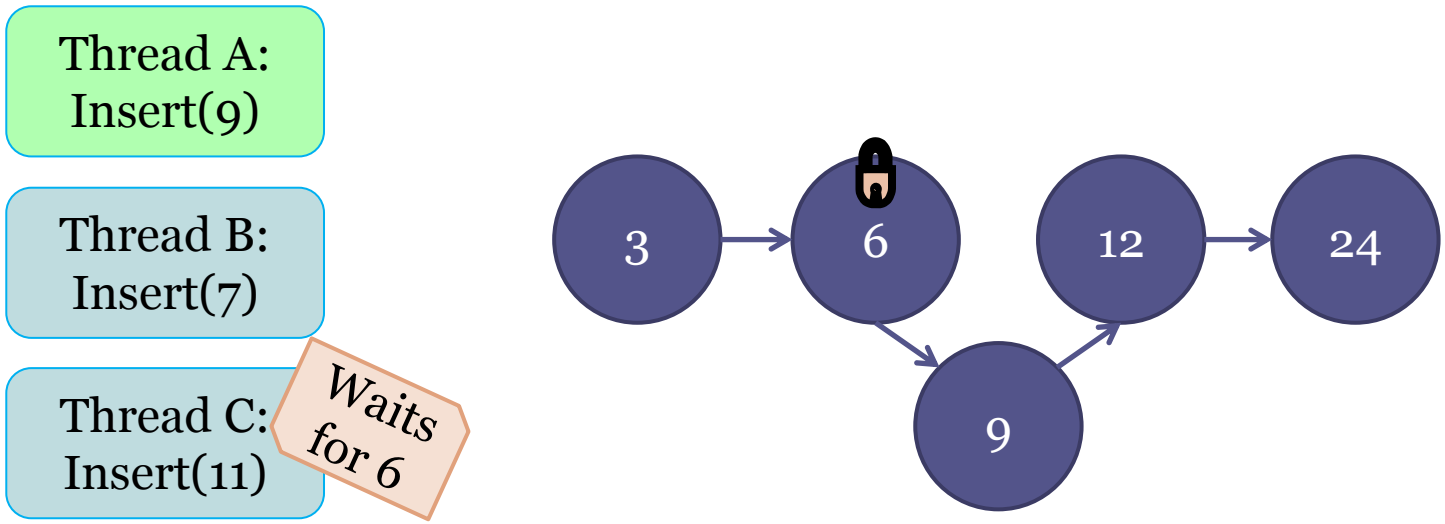

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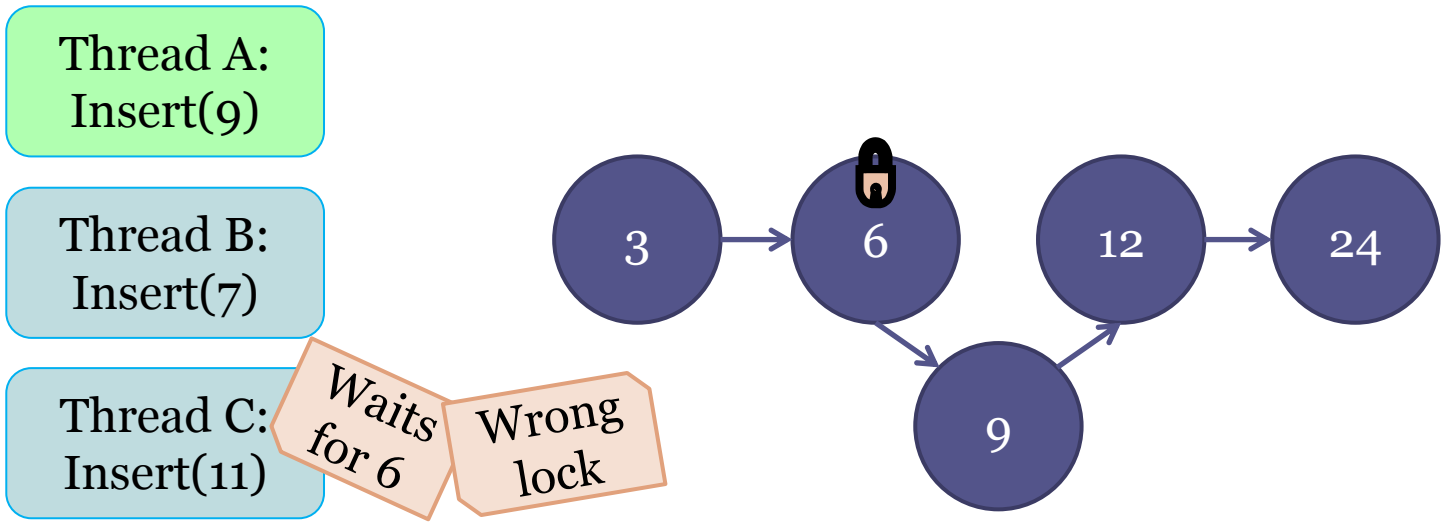

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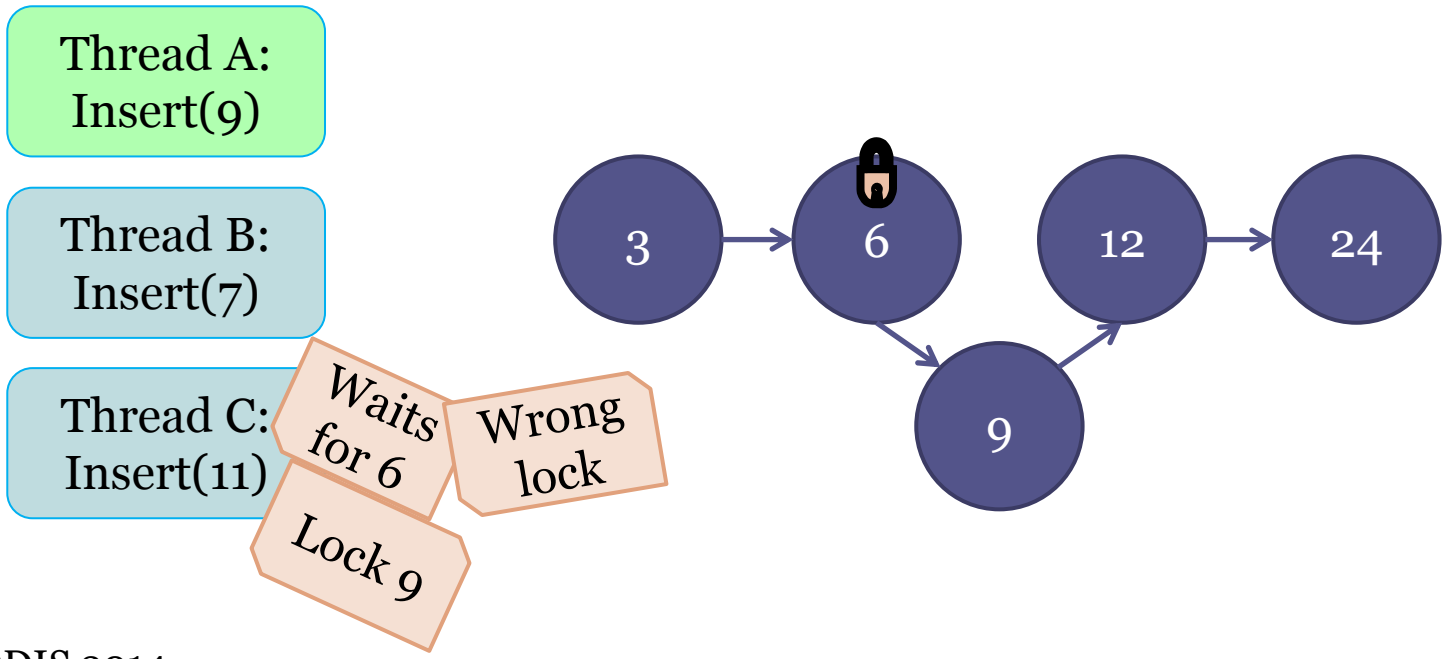

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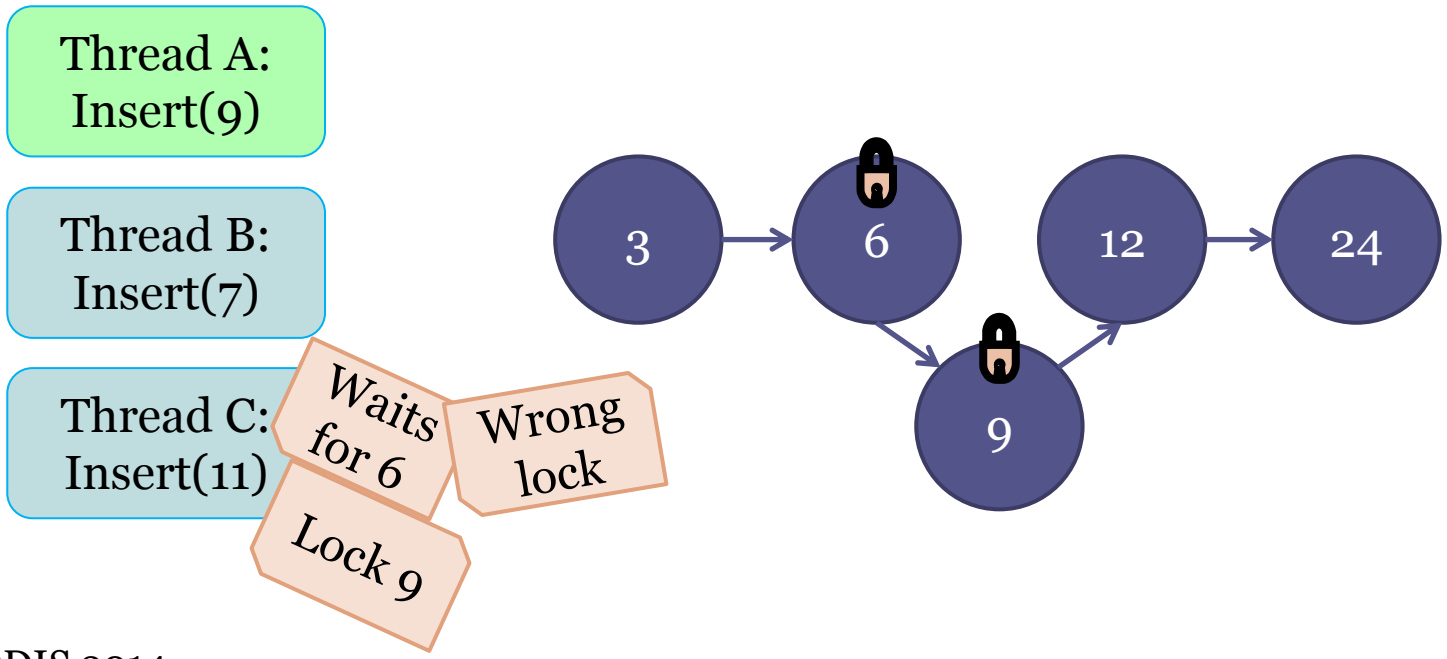

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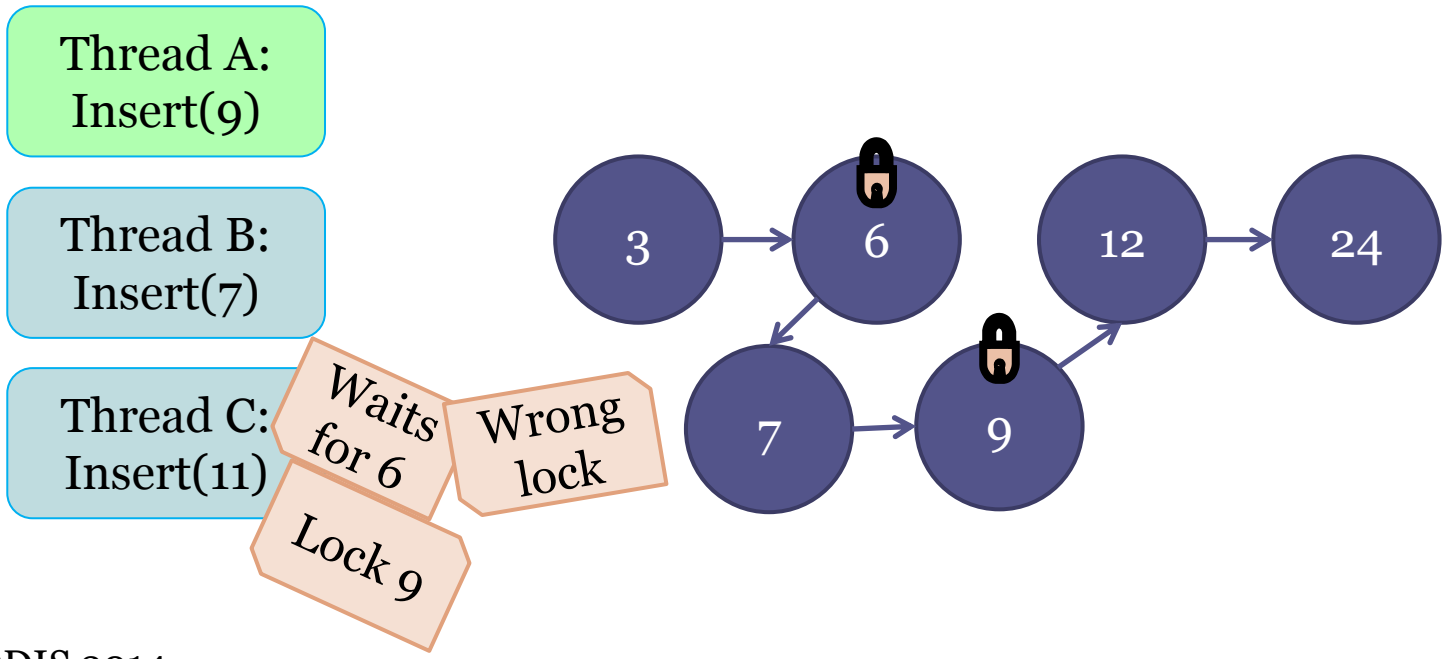

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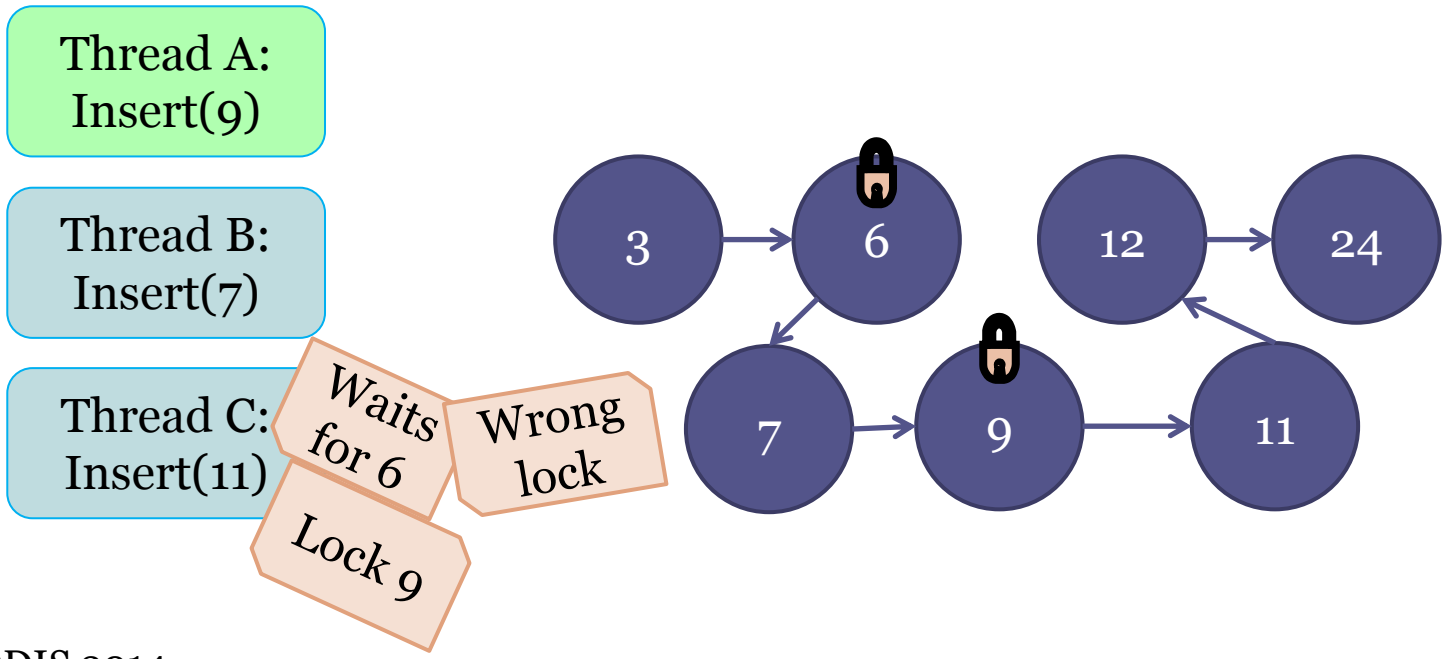

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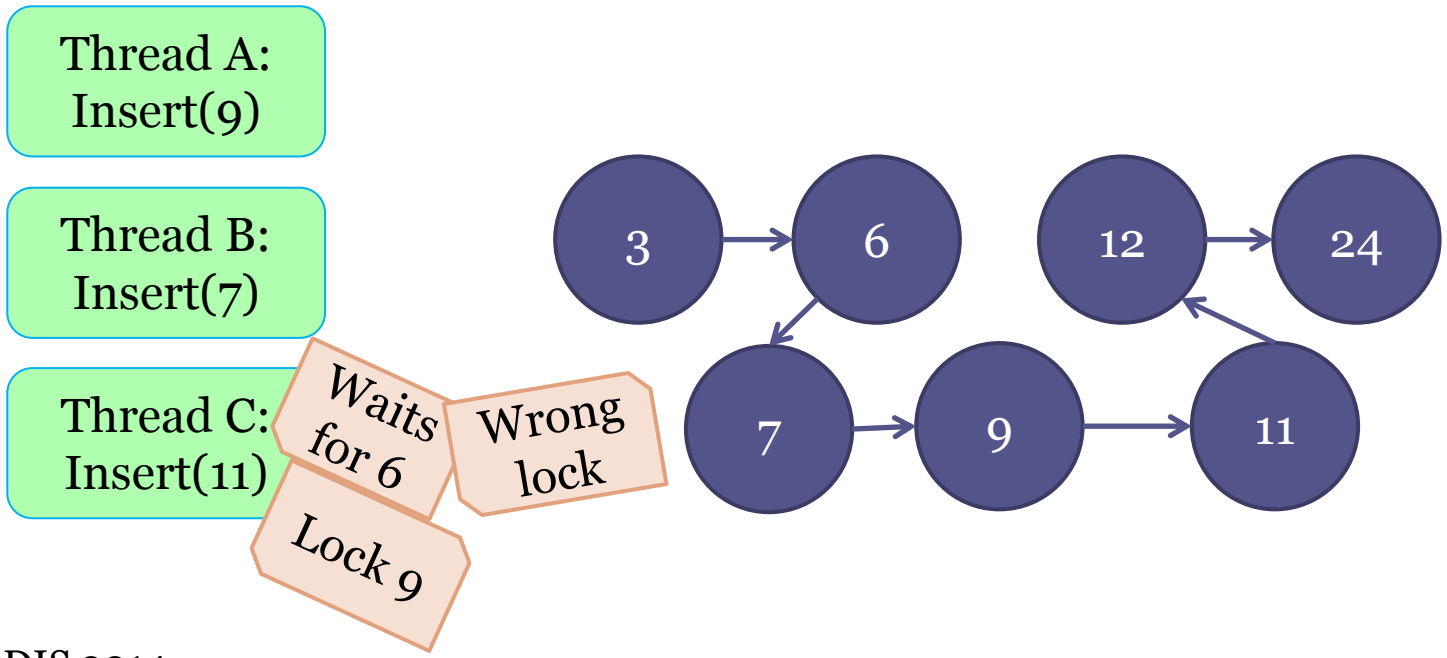

How does on-demand combining work?

No Combining Demand – No Overhead

- If a thread did not observe contention, it is executed without any combining overhead
  - Thread observes contention if it needs to wait to acquire a lock

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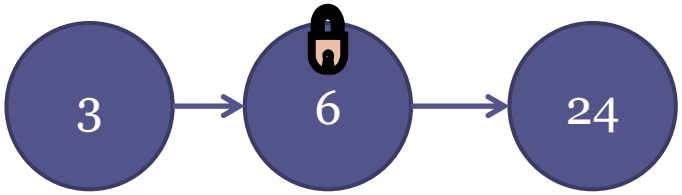

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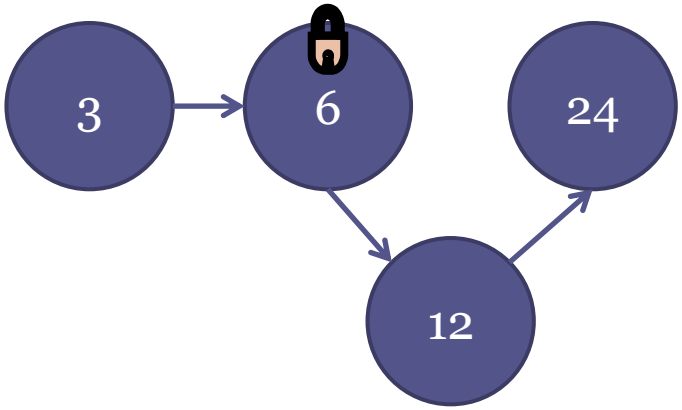

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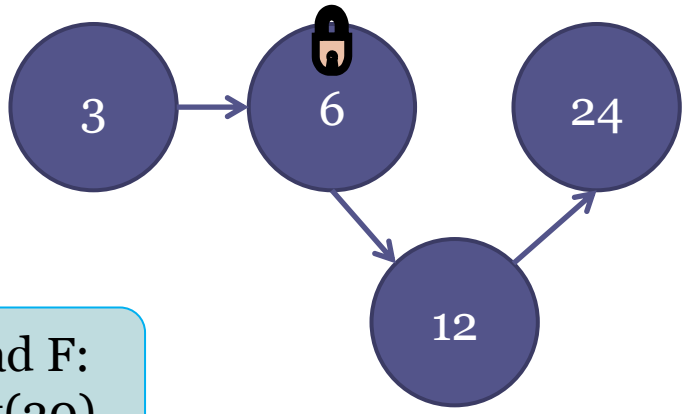

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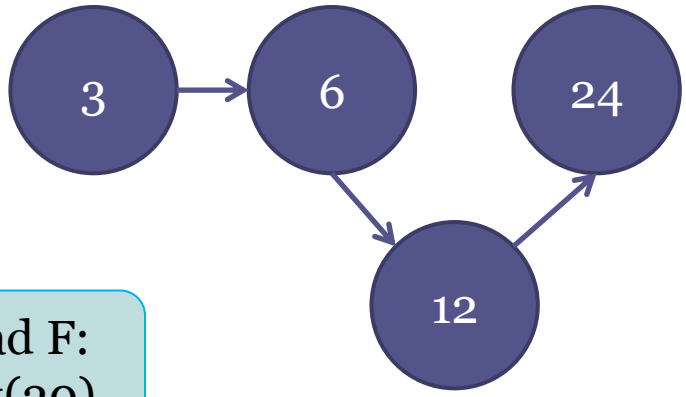
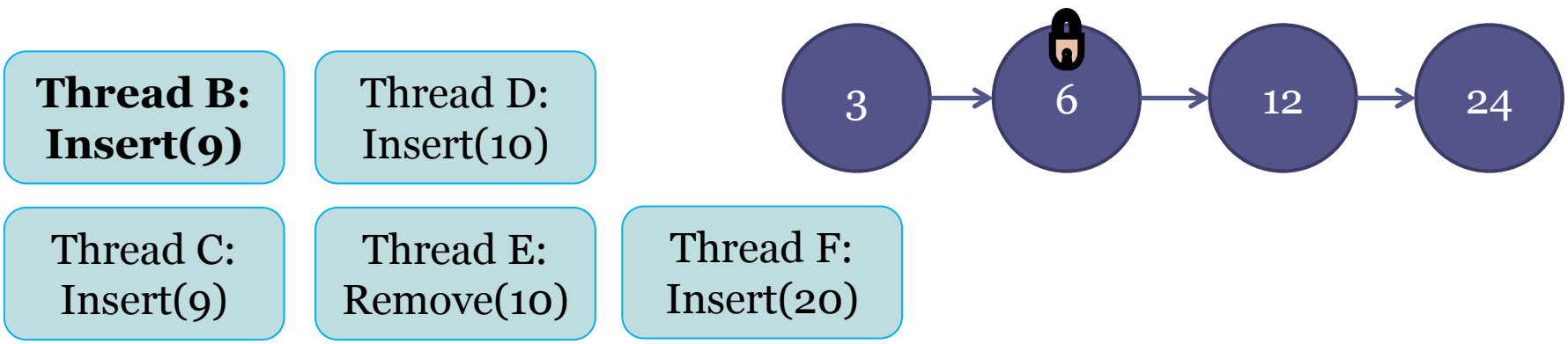


How does the local combining work?

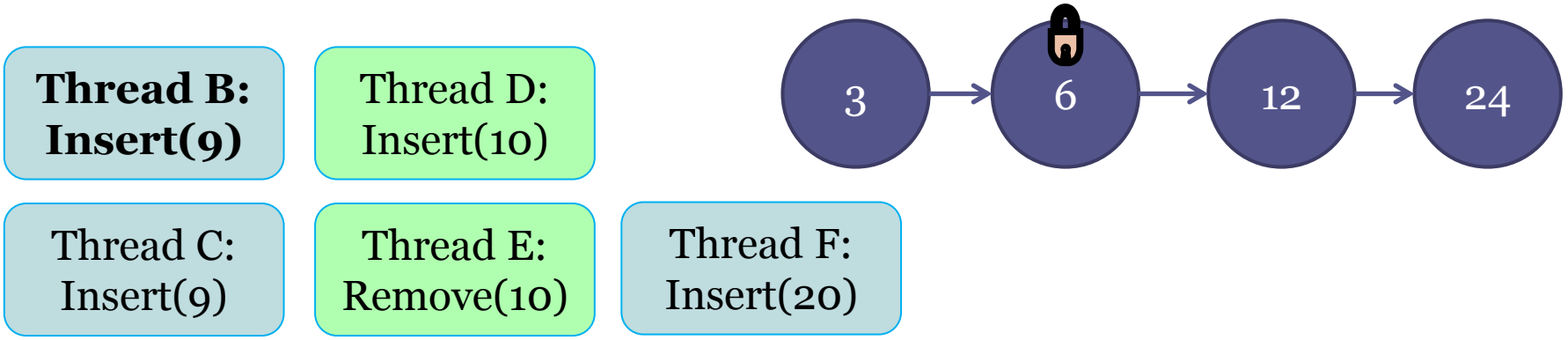
Combine Locally

- A thread that locked after observing contention collects operations of contending threads



Combine Locally

- A thread that locked after observing contention collects operations of contending threads
  - Complementary operations are eliminated



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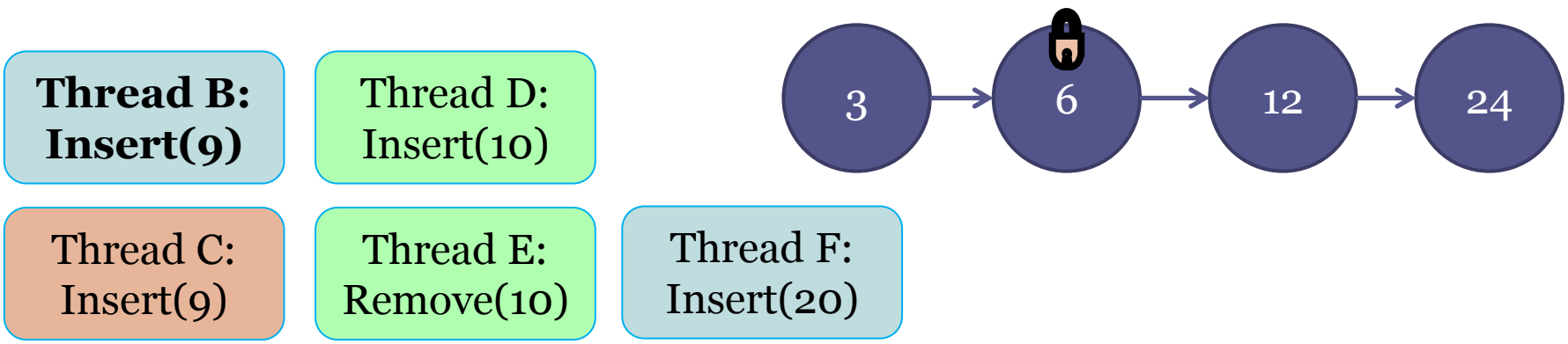

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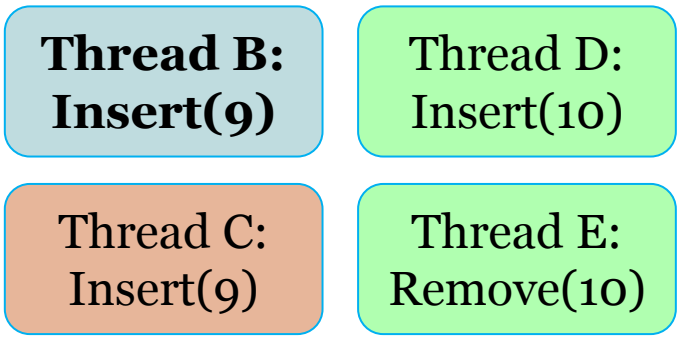

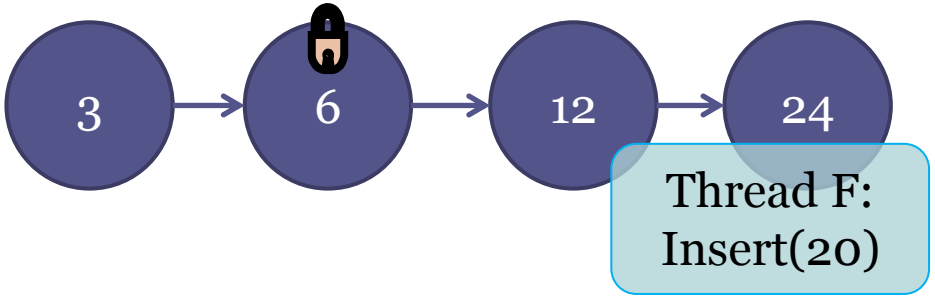

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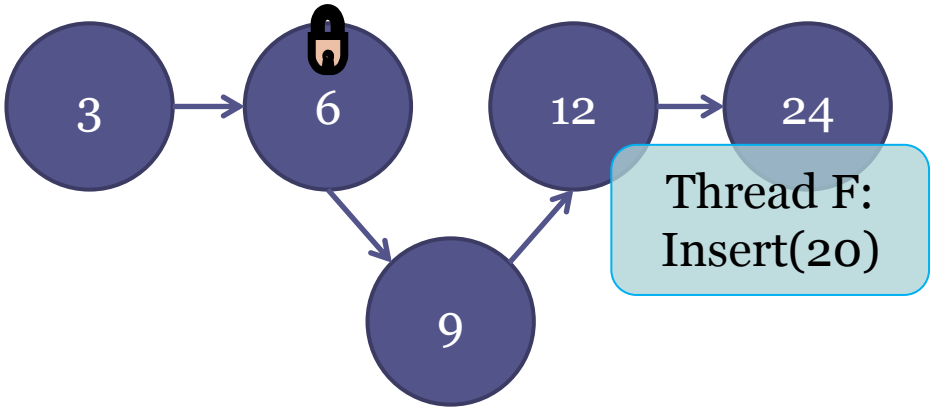

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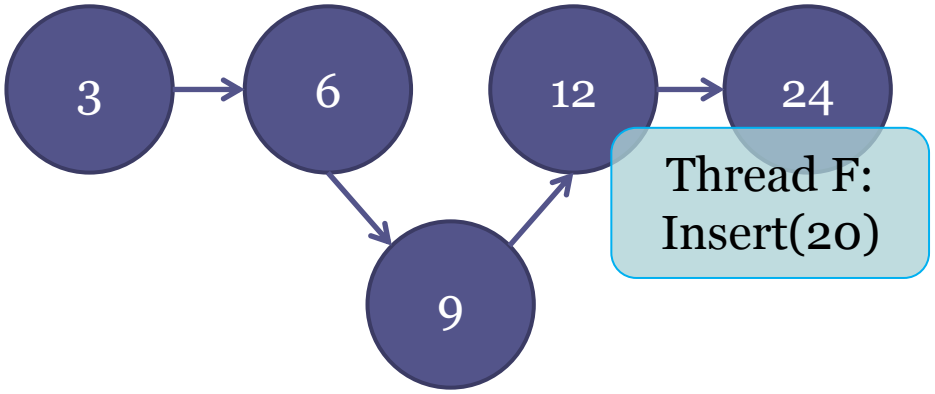

How to handle operations requiring multiple locks?

Operations Requiring Multiple Locks

- LCD is applied independently for each lock
- Operations acquiring multiple locks are split
  - Each sub-operation acquires one lock
  - Each sub-operation may be executed by a different combining thread
- Example: $Remove(k)$

Operations Requiring Multiple Locks

- Example: $Remove(k)$
  - Search for a node p s.t.: $p.key < k \leq next(p).key$
  - Lock p
  - If the key of p's successor is k
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    - Mark the successor
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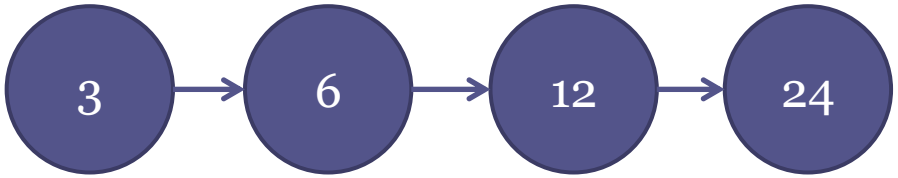

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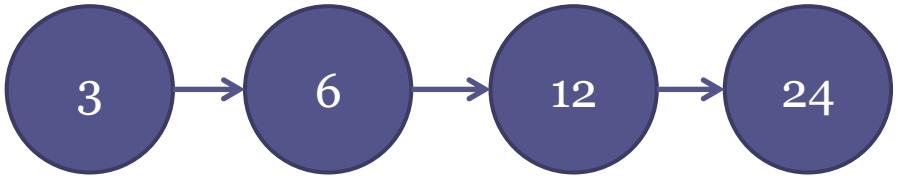

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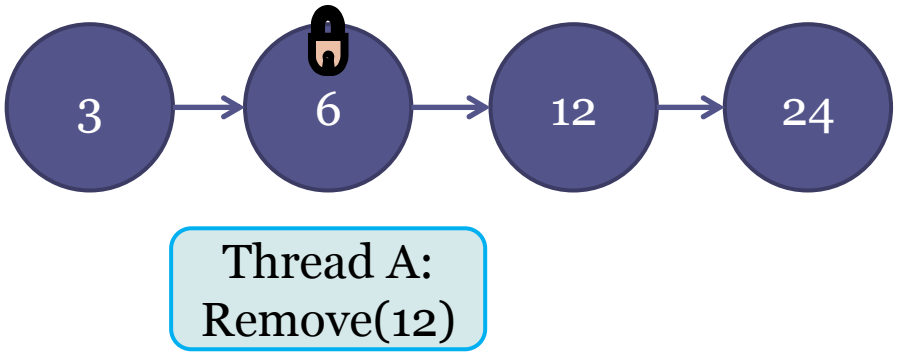

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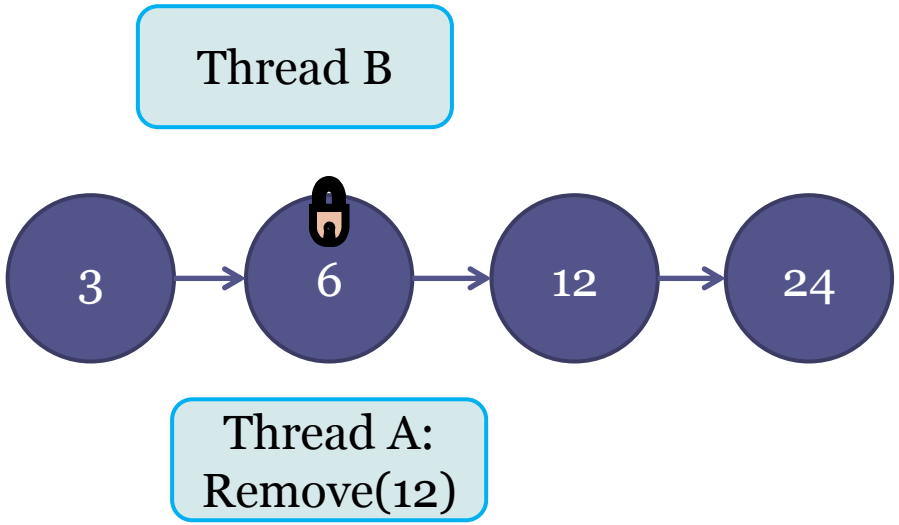

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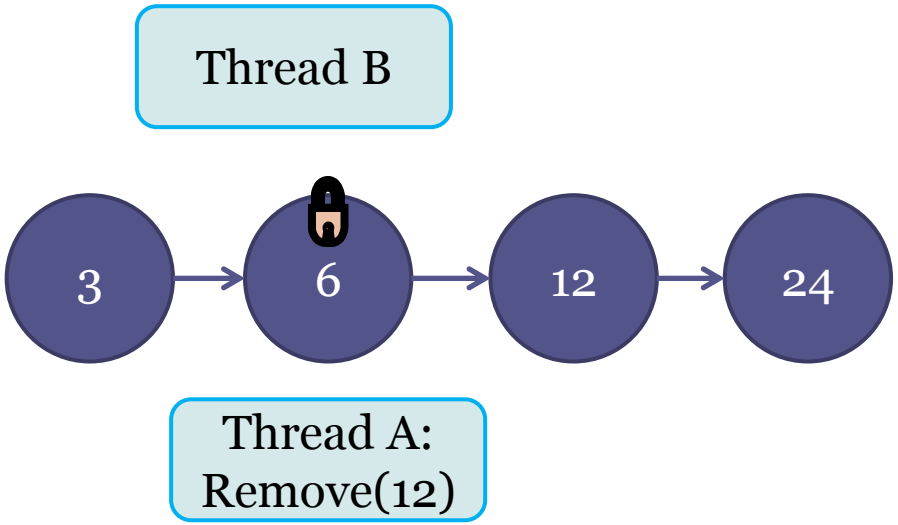

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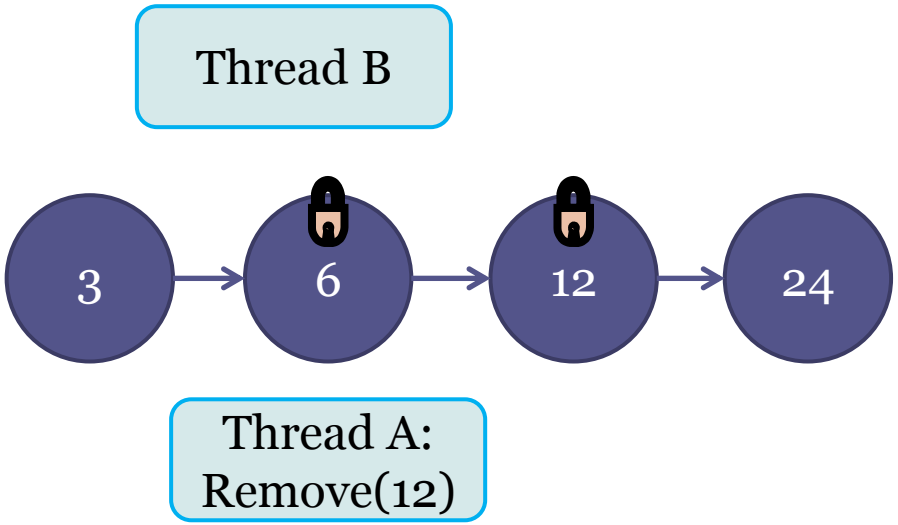

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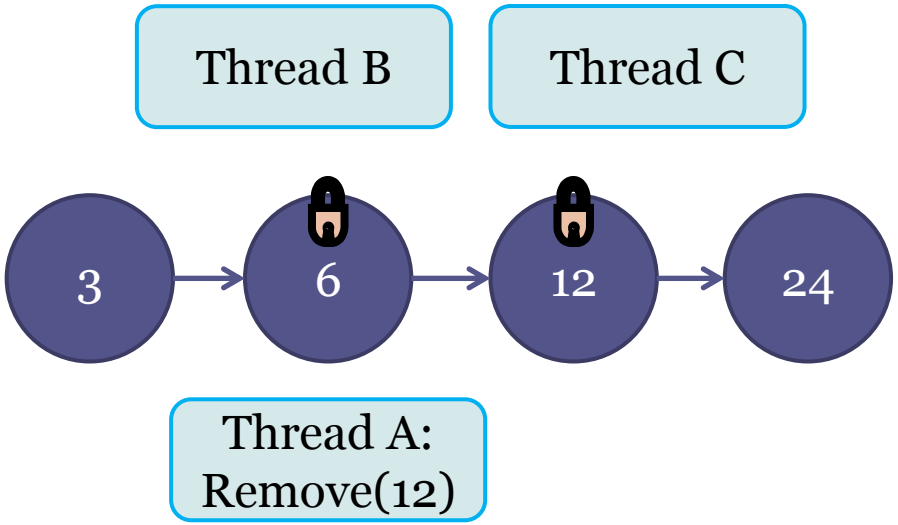

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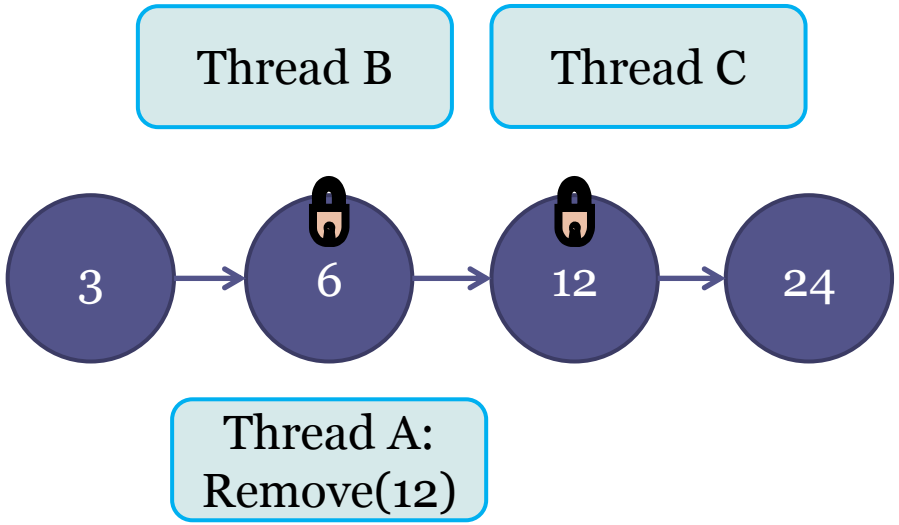

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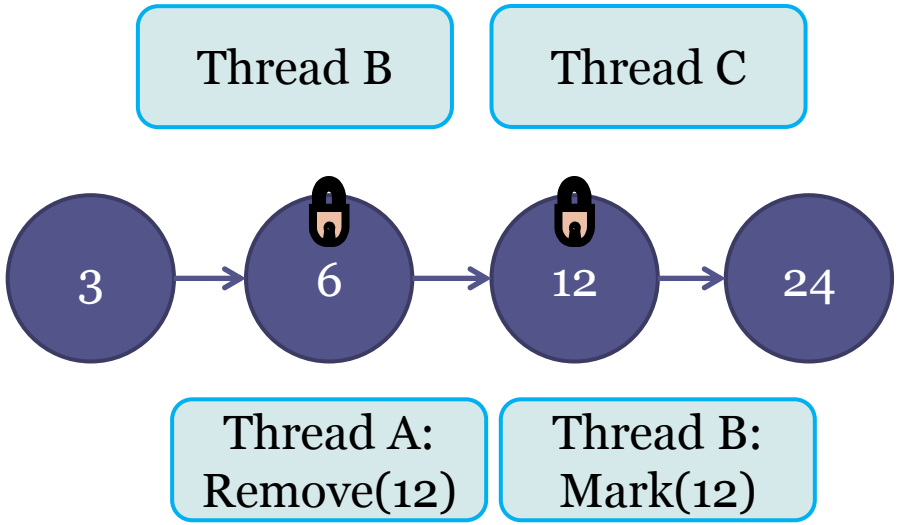

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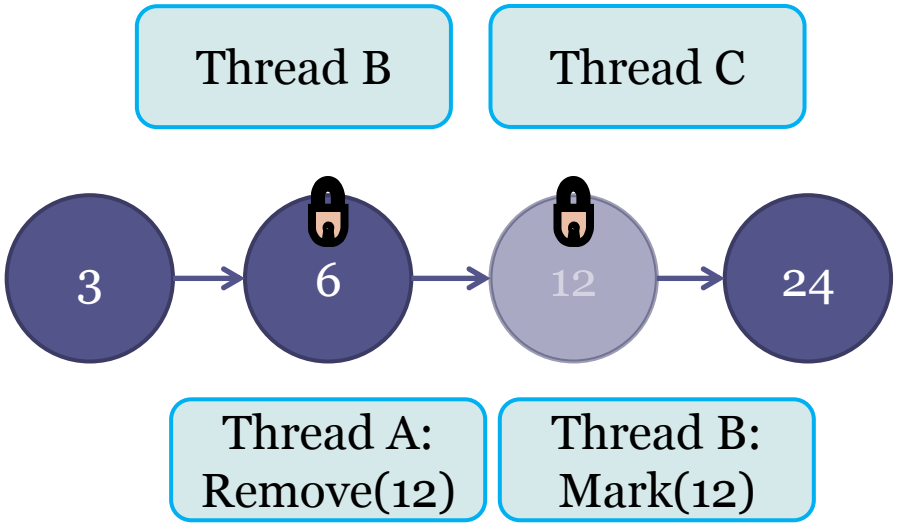

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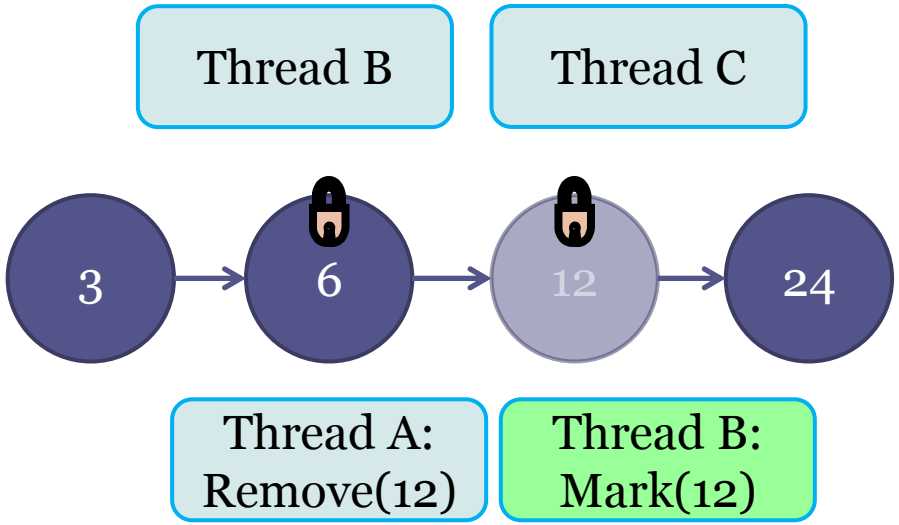

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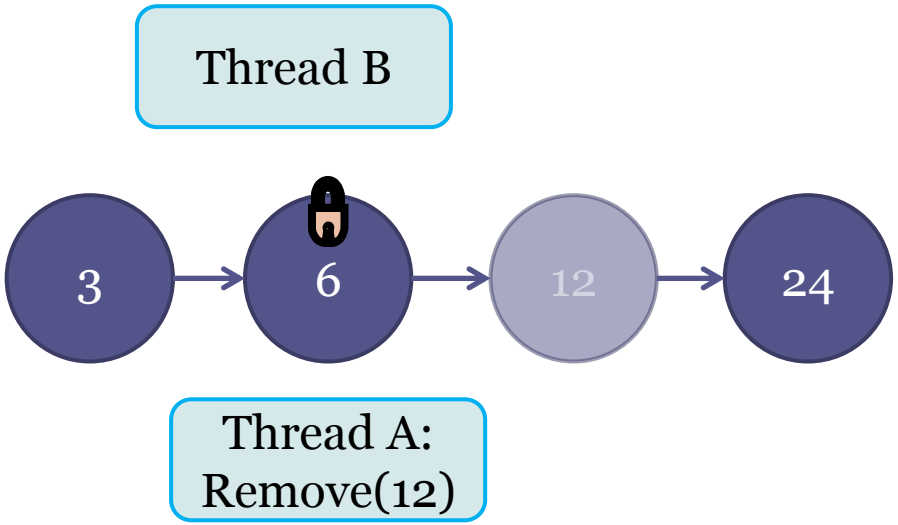

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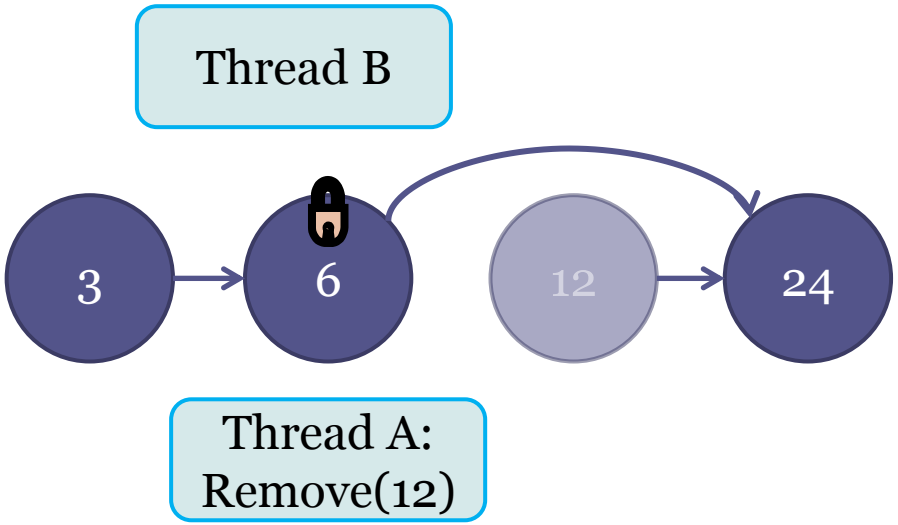

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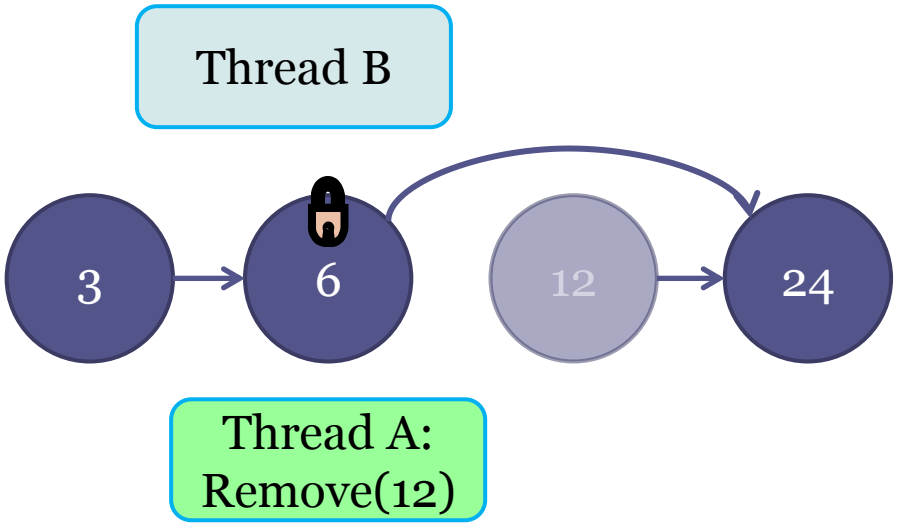


How to integrate LCD with the Java lock?

Java Lock Integration

- Most of the LCD mechanism was integrated into the Java lock
- The Java lock maintains a queue of threads waiting to acquire the lock
- The LCD requires the list of contending threads
  - Which is exactly the list of threads waiting to lock
  - We leverage this queue to the LCD purposes

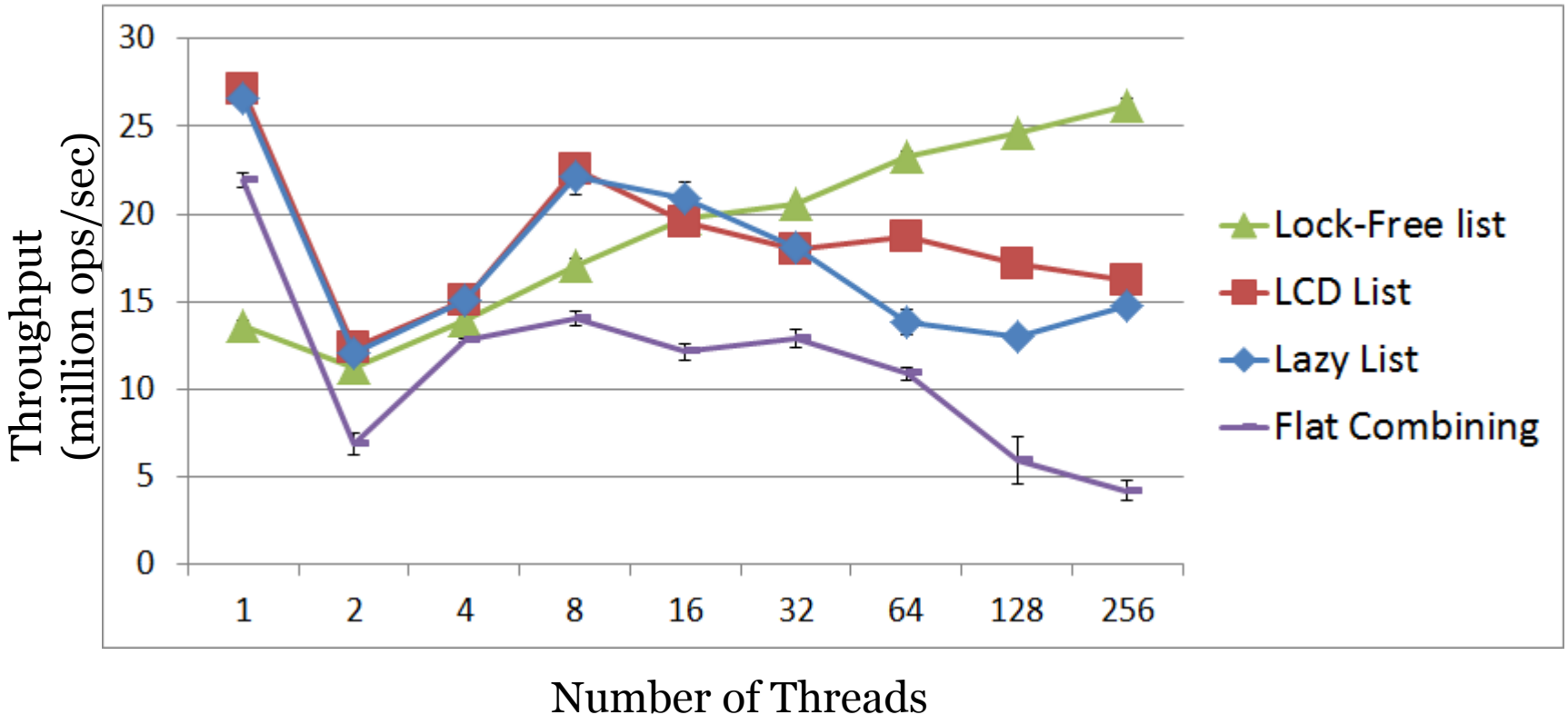
LCD Evaluation

- LCD list was implemented in Java and compared to state-of-the-art algorithms
  - Linked-list algorithms
    - The Lazy List [Heller, Herlihy, Luchangco, Moir, Scherer III, Shavit]
    - The Lock-free List [Harris]
  - Combining algorithms
    - Flat Combining (global lock) [Hendler, Incze, Shavit, Tzafrir]

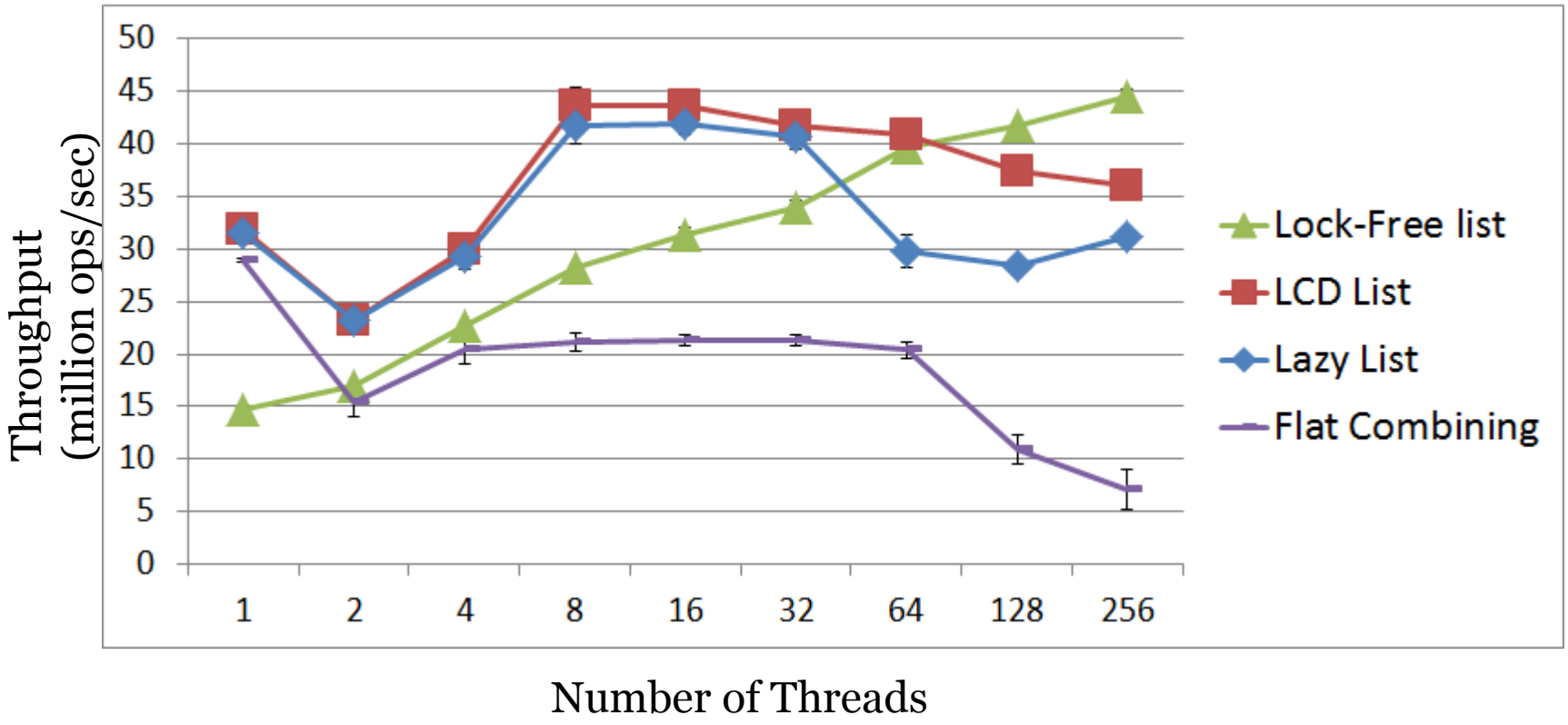
Benchmarks

- Threads randomly chose operation type and key
  - Different workloads for the operation type
    - 0% contains, 50% insert, 50% remove
    - 60% contains, 20% insert, 20% remove
  - Different key ranges
    - 128, 1024
- List was populated to half of its expected size
  - 64, 512
- AMD Opteron machine with 64 h/w threads

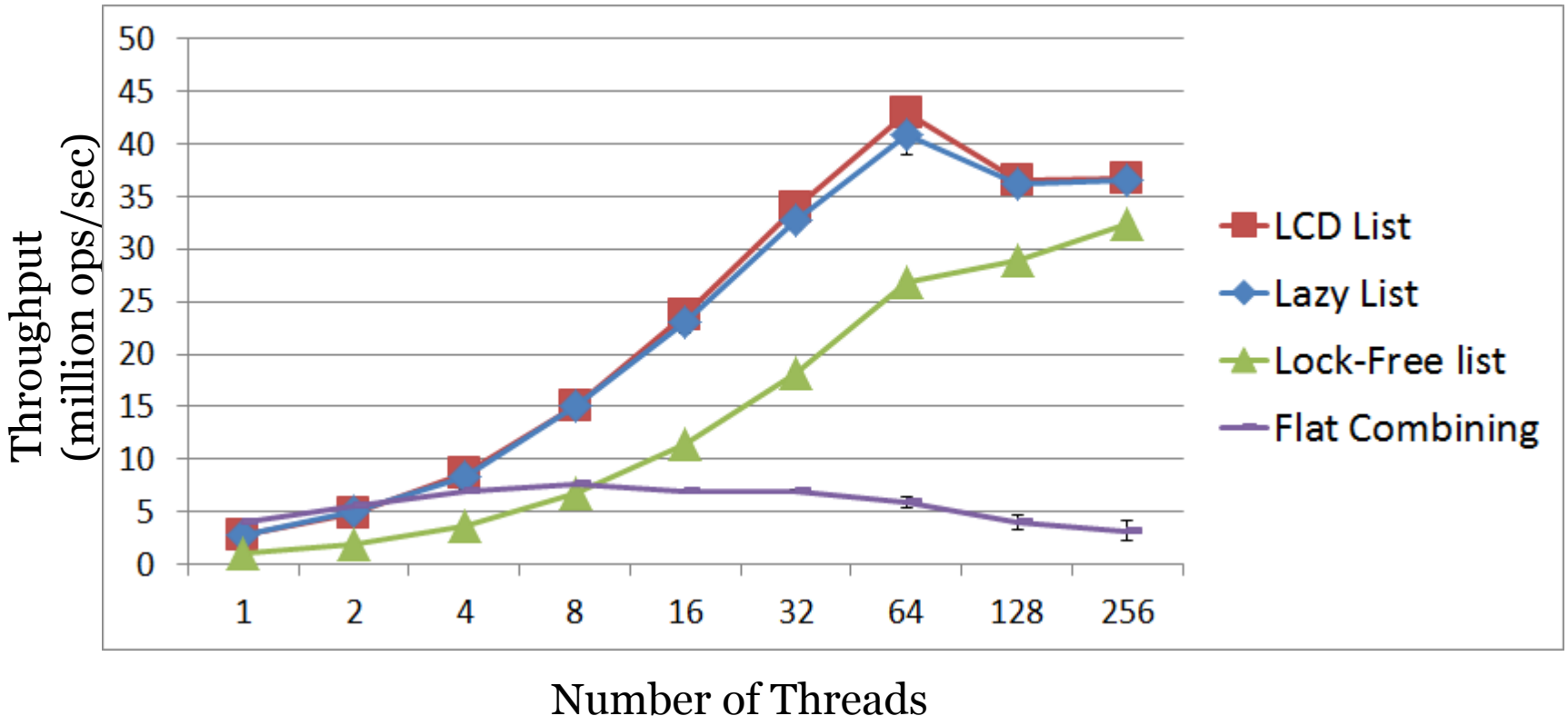
0% contains, 50% insert, 50% remove
Key range: 128



60% contains, 20% insert, 20% remove
Key range: 128



60% contains, 20% insert, 20% remove
Key range: 1024



Summary

- We presented a new combining technique
  - Local
    - Applied independently for contended resources
  - On-demand
    - No overhead if there is no contention
- We demonstrated it on the linked-list
  - And showed it improves performance