PennState

Brief Announcement: SCOT: Fix non-blocking data structures, not memory reclamation

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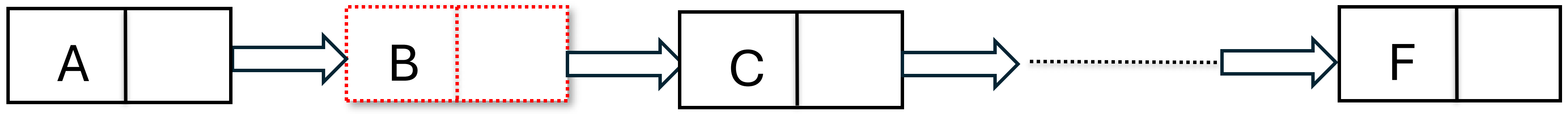
Non-Blocking Data Structures

- Allow multiple threads to operate without mutual exclusion
- *Lock-free* data structures: at least one thread always makes progress
- Require safe memory reclamation (SMR) techniques
    - Epoch-Based Reclamation (EBR) is easy-to-use but has unbounded memory usage
    - Hazard Pointers (HP) is more difficult to use but is *robust*

Limitations of Non-Blocking Data Structures

- Many robust memory reclamation schemes (e.g., HP) fail to support **optimistic traversals** used in many lock-free algorithms:
  - Harris' linked list
  - Natarajan-Mittal tree
  - Many others (skip lists, hash tables, etc)
- Workarounds are sometimes available with performance costs
  - Harris-Michael linked list
  - No such modification for Natarajan-Mittal tree

Problem

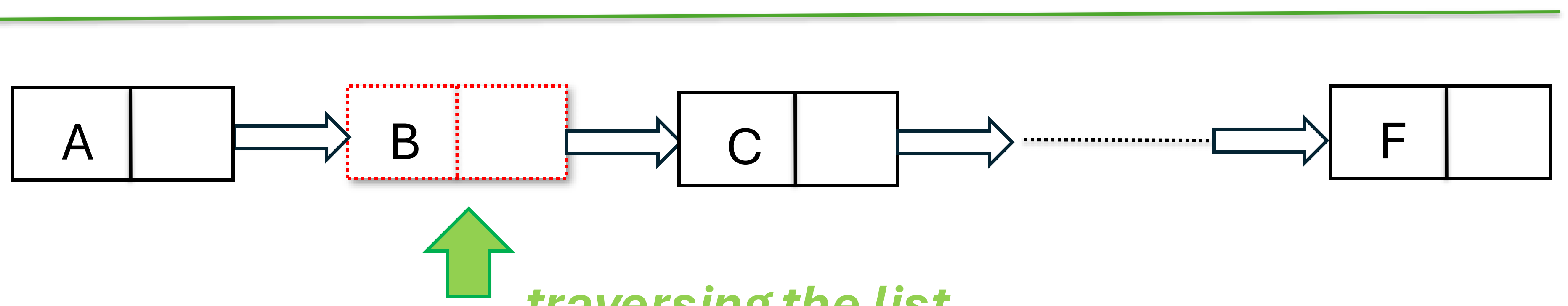


Thread 0: Delete(B) => Node B is marked for logical deletion

… Thread 0 is stalled

Problem

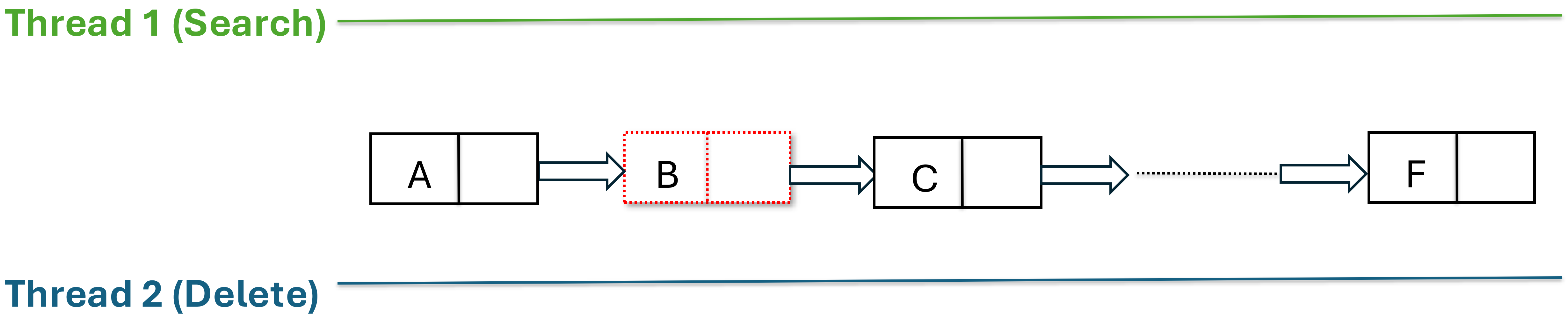
Thread 1 (Search)



traversing the list

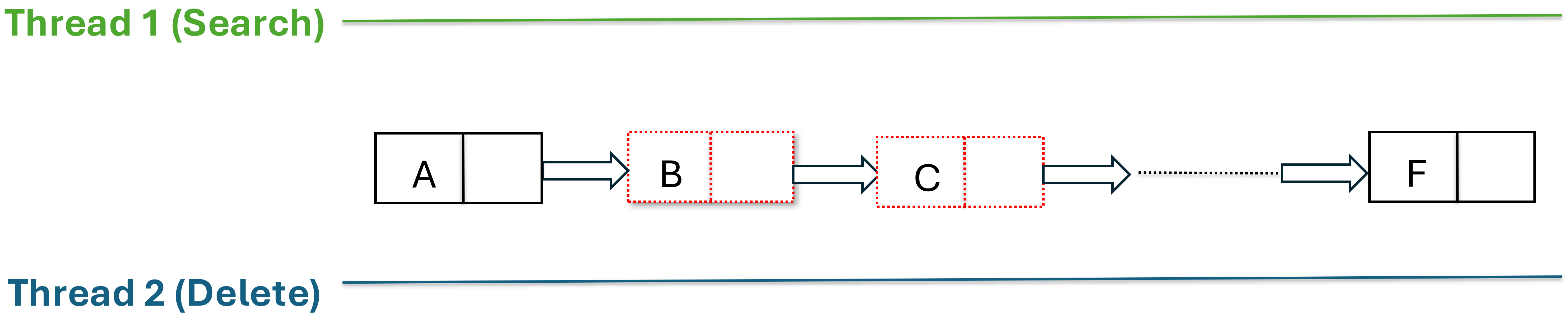
Thread 1: Locate node F

Problem



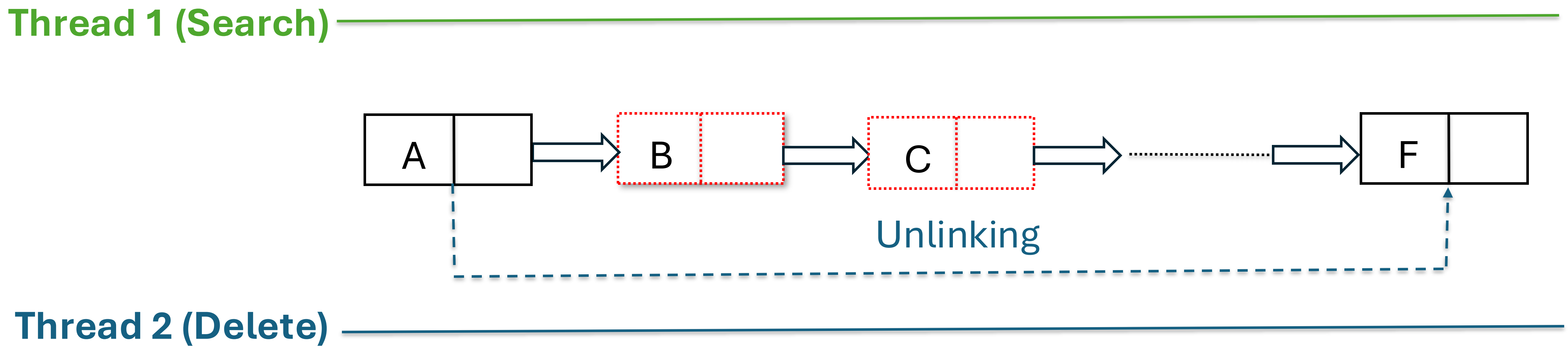
Thread 2: Delete(C)

Problem



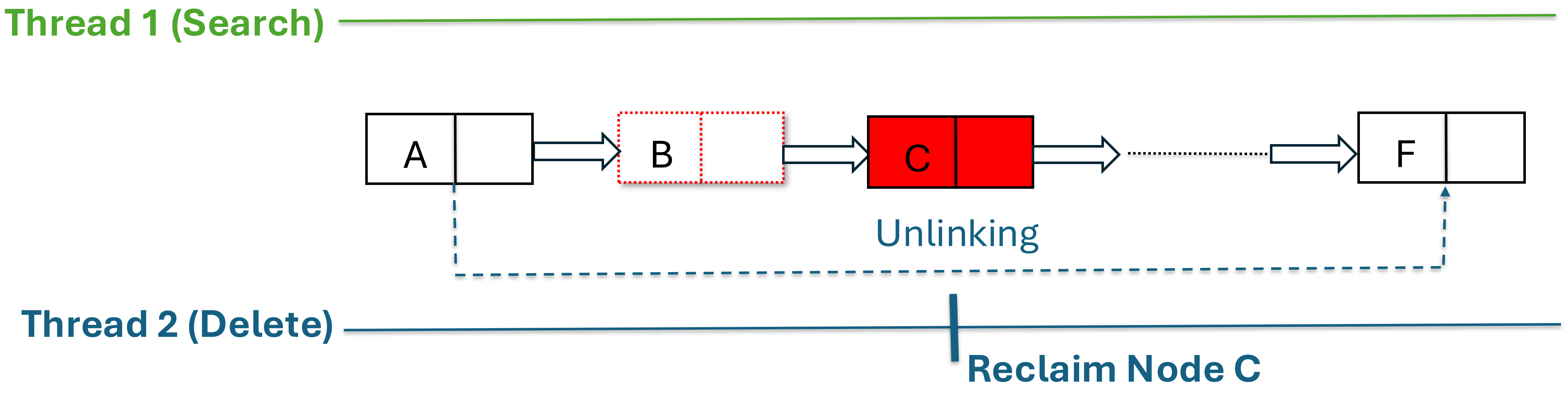
Thread 2: Node C is marked for logical deletion

Problem



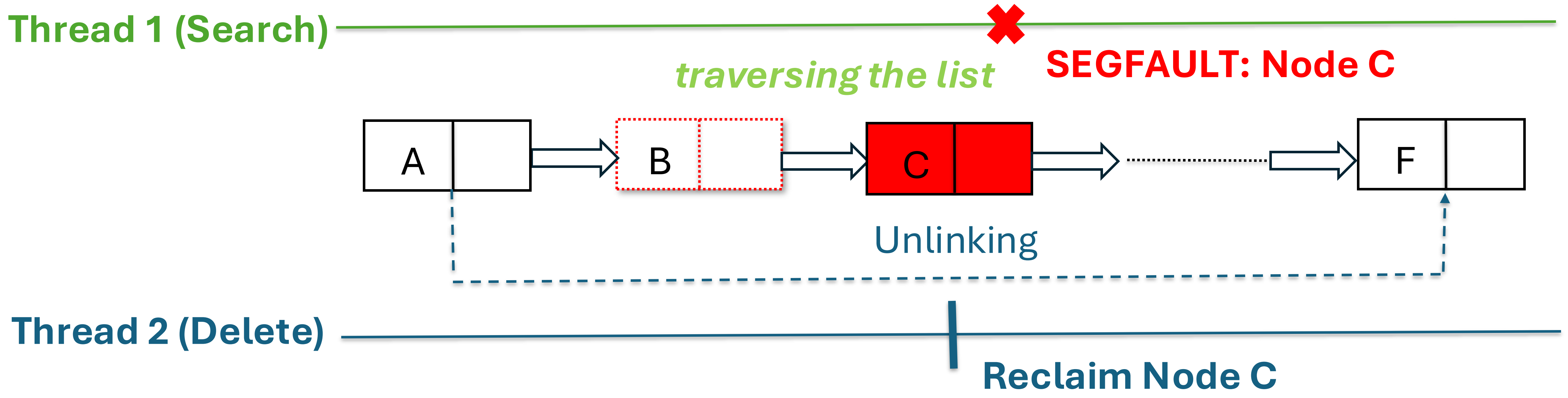
Thread 2 unlinks the entire chain of nodes between Node A and Node F (assuming *all* consecutive nodes in the chain are logically deleted)

Problem



Node C is Reclaimed by Thread 2 and returned to the OS

Problem

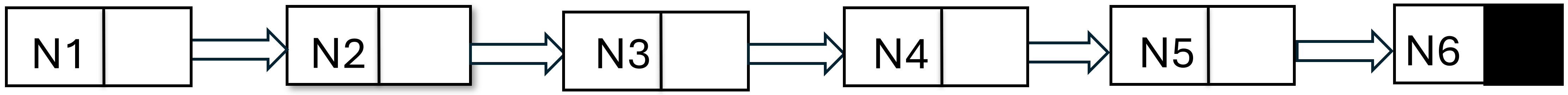


Thread 1 fails when accessing Node C

Safe Concurrent Optimistic Traversals (SCOT)

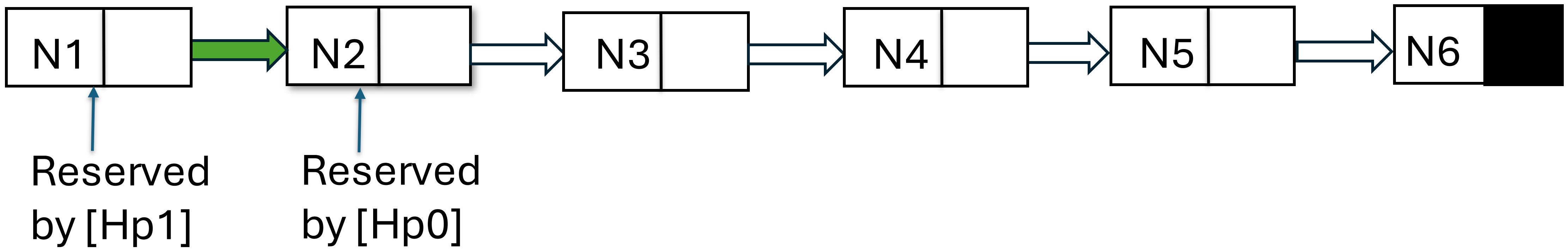
- Instead of fixing the SMR → fix the **data structure**
  - Resolves the robustness vs. applicability dilemma, ERA Theorem [PODC ’23]
- Redesign traversals to add **local validation**

SCOT: Harris' Linked List



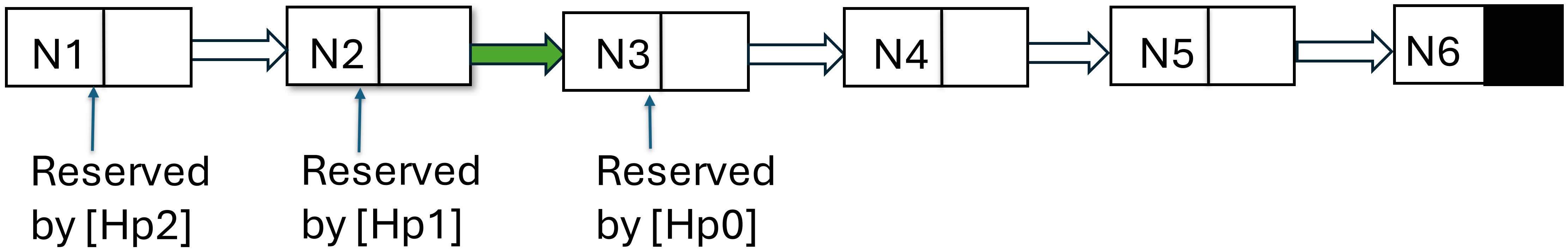
Initial State: List Contains Nodes N1-N6

SCOT: Harris' Linked List



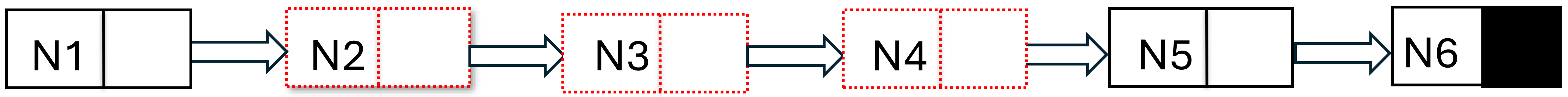
Hp0: protects next
Hp1: protects curr
Hp2: protects prev (not available at the very beginning)

SCOT: Harris' Linked List



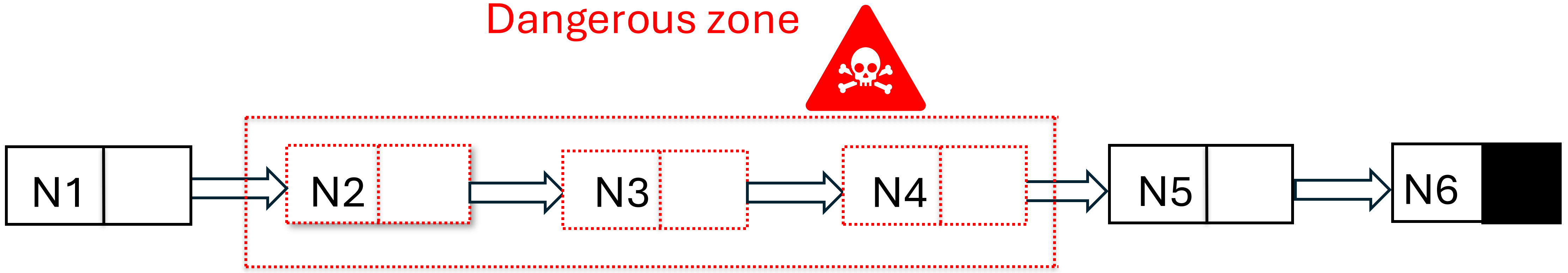
Moving hazard pointers when moving to the next iteration:
curr (N1) [Hp1] -> prev [Hp2]
next (N2) [Hp0] -> curr [Hp1]
(new) next (N3) [Hp0]

SCOT: Harris’ Linked List



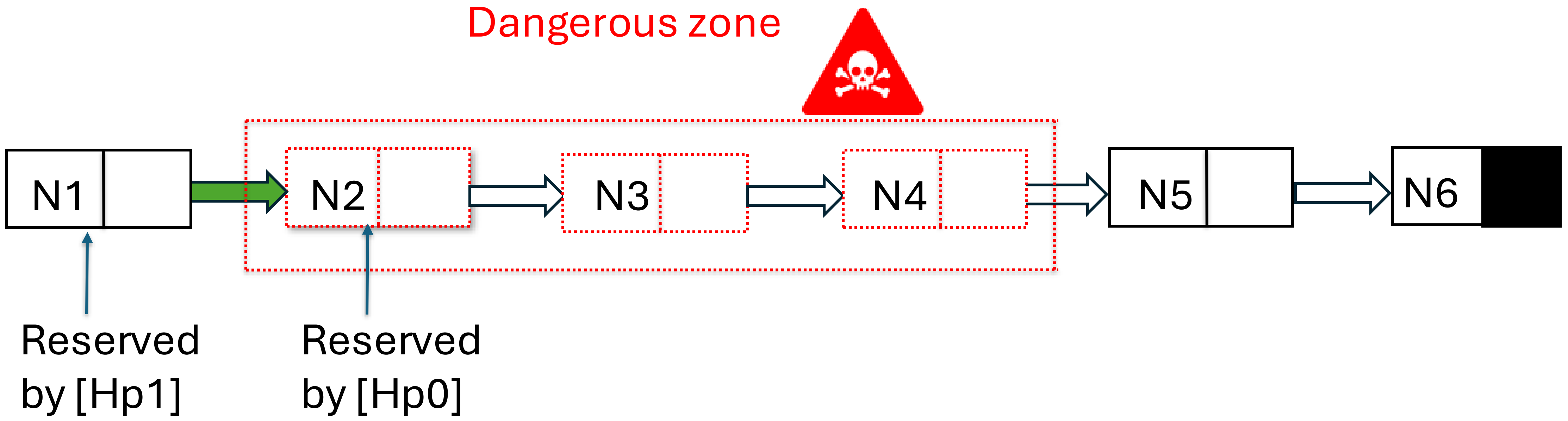
Node N2-N4 are logically deleted

SCOT: Harris' Linked List



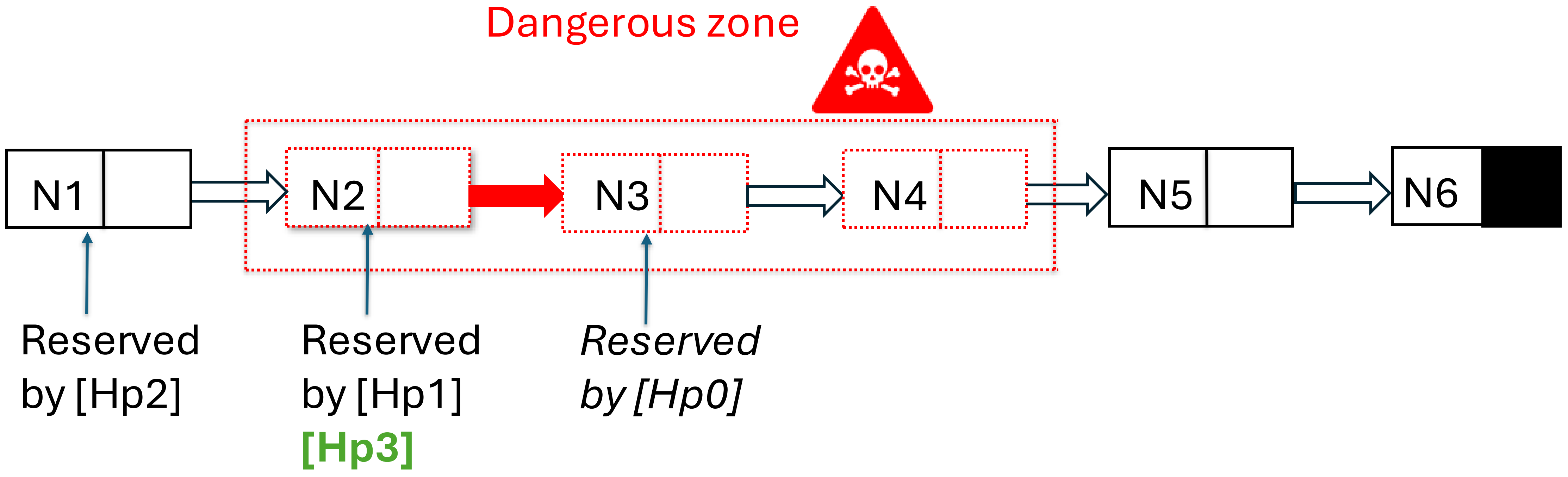
Need to be careful while traversing the dangerous zone

SCOT: Harris’ Linked List



N1 and N2 protected by hazard pointers’ reservations

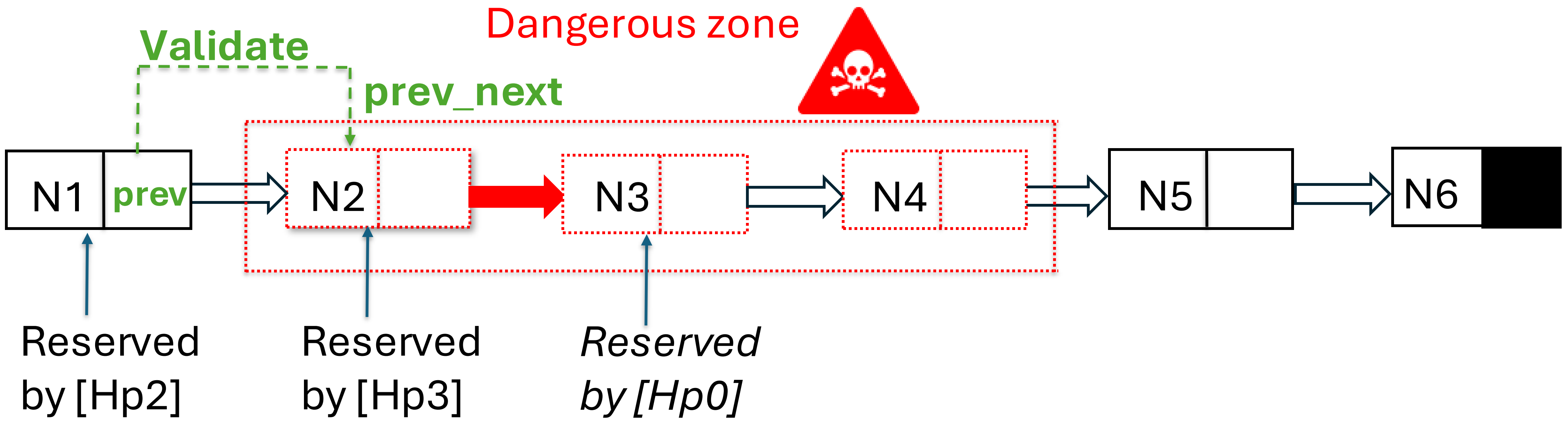
SCOT: Harris' Linked List



Next destination N3
N1 is the last safe node and protected by Hp2
N2 is the first unsafe node protected by **Hp3**

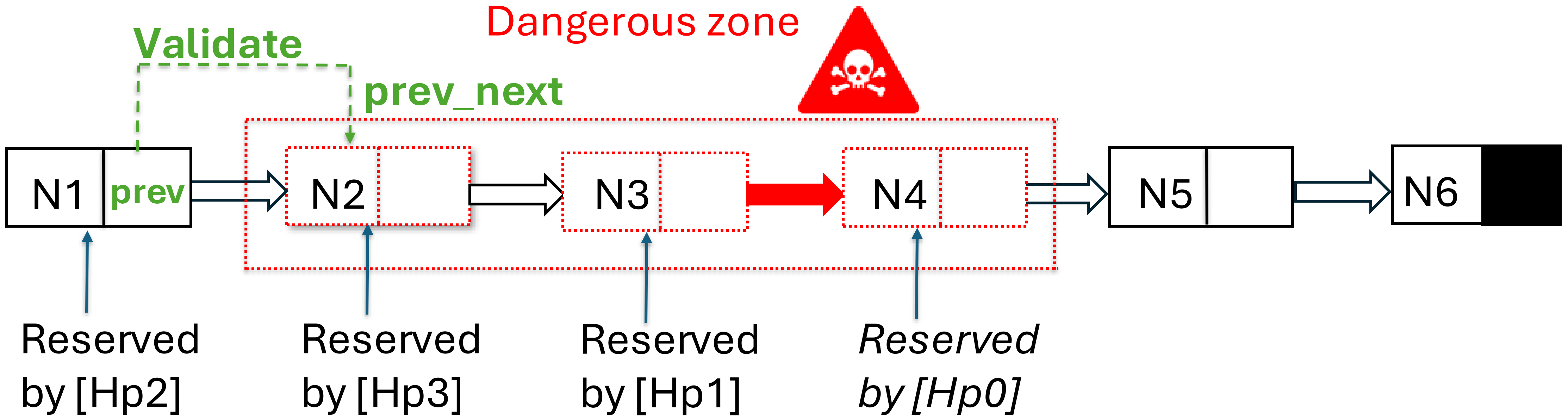
Hp3 is an extra hazard pointer which protects the 1st unsafe node
Hp2 protects the last safe node

SCOT: Harris' Linked List



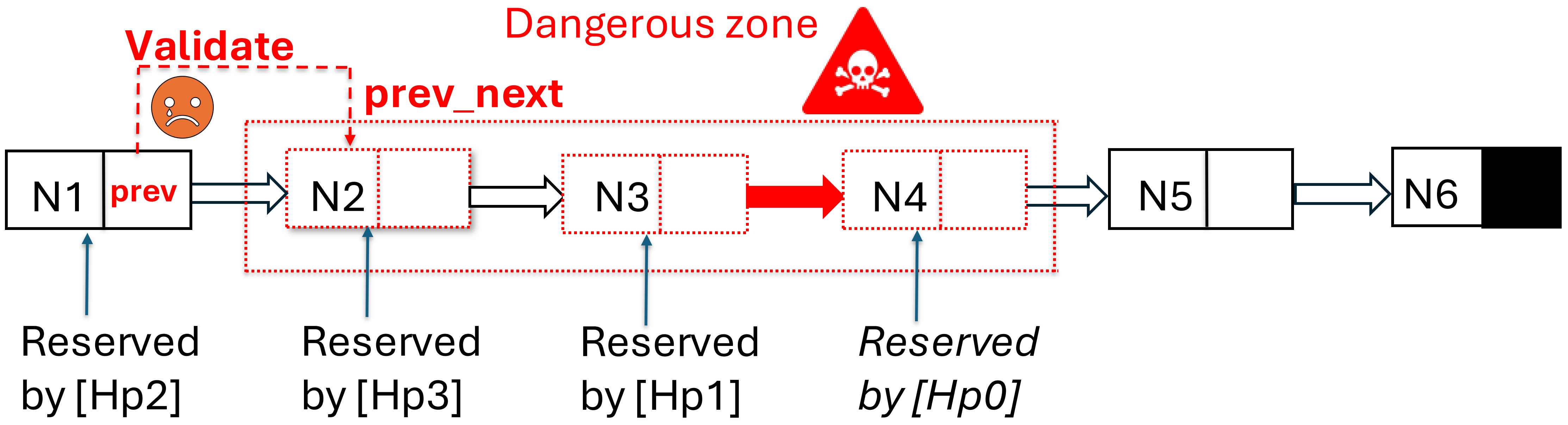
Validate (*prev = prev_next) after reserving N3 (Hp0)

SCOT: Harris' Linked List



Validate (*prev = prev_next) after reserving N4 (Hp0)

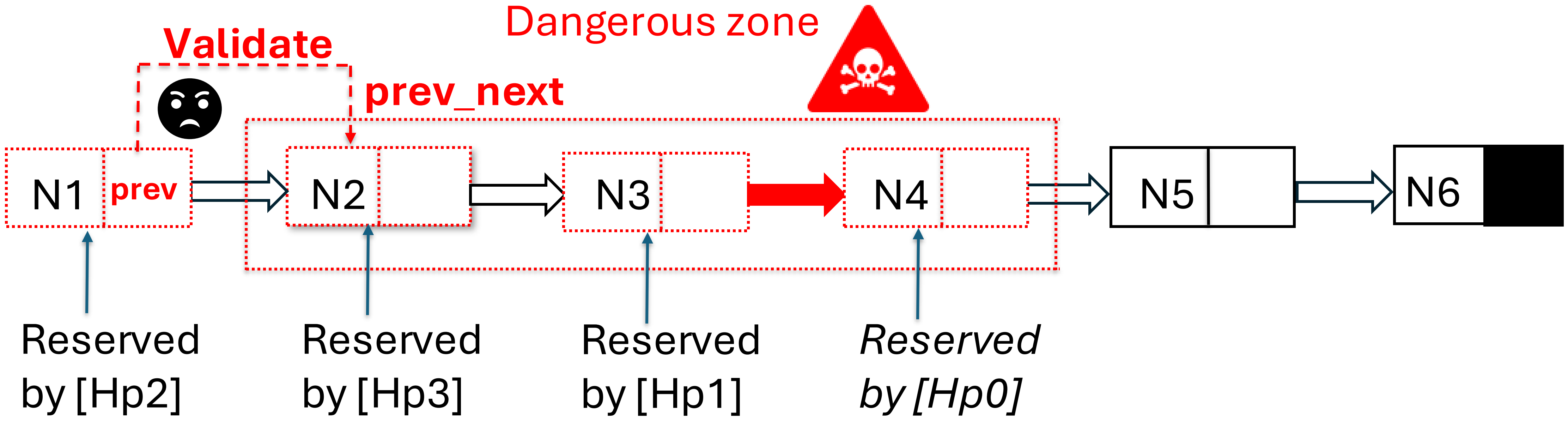
SCOT: Recovery



What if (*prev = prev_next) validation fails due to a new node being inserted or the chain of logically deleted nodes being already eliminated by a concurrent thread?

We start from the last safe node (N1)

SCOT: Recovery

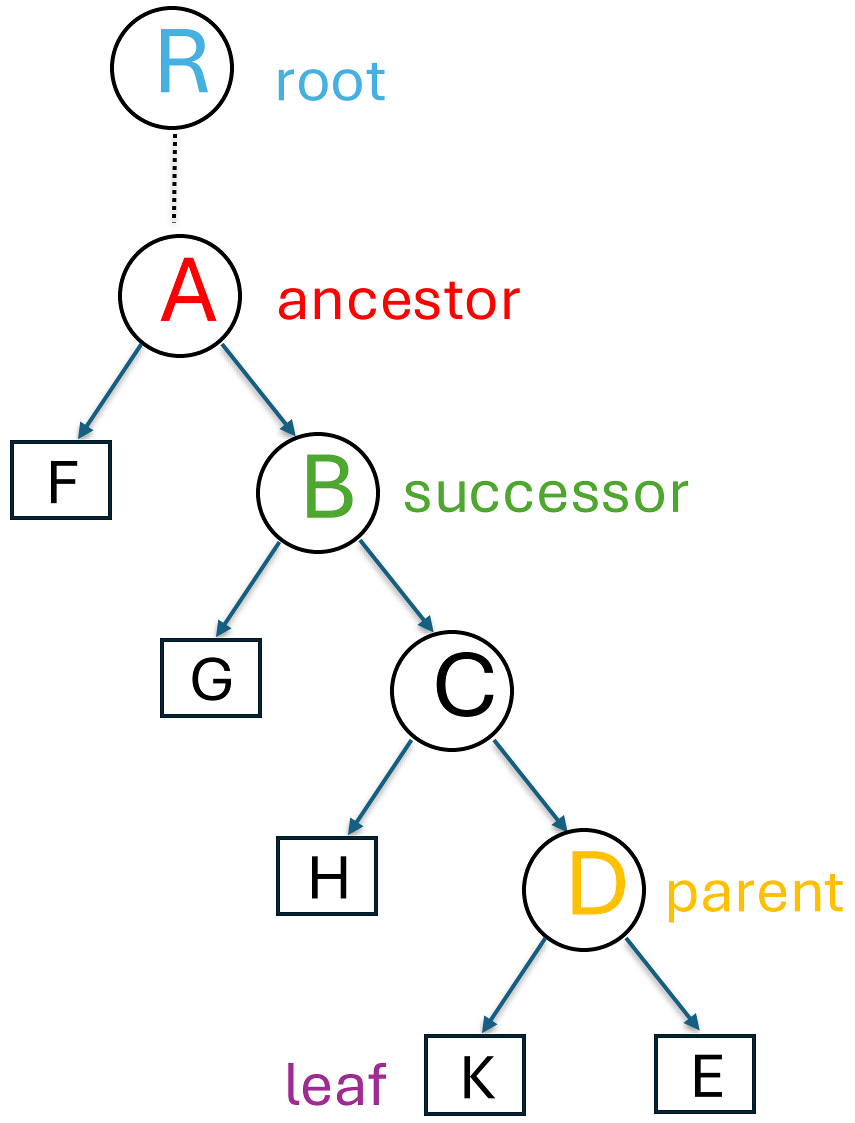


What if the last safe node (N1) is also logically deleted?

We start from the beginning

Note: There are still practical fall-backs (for IBR, Hyaline-1S) in the paper

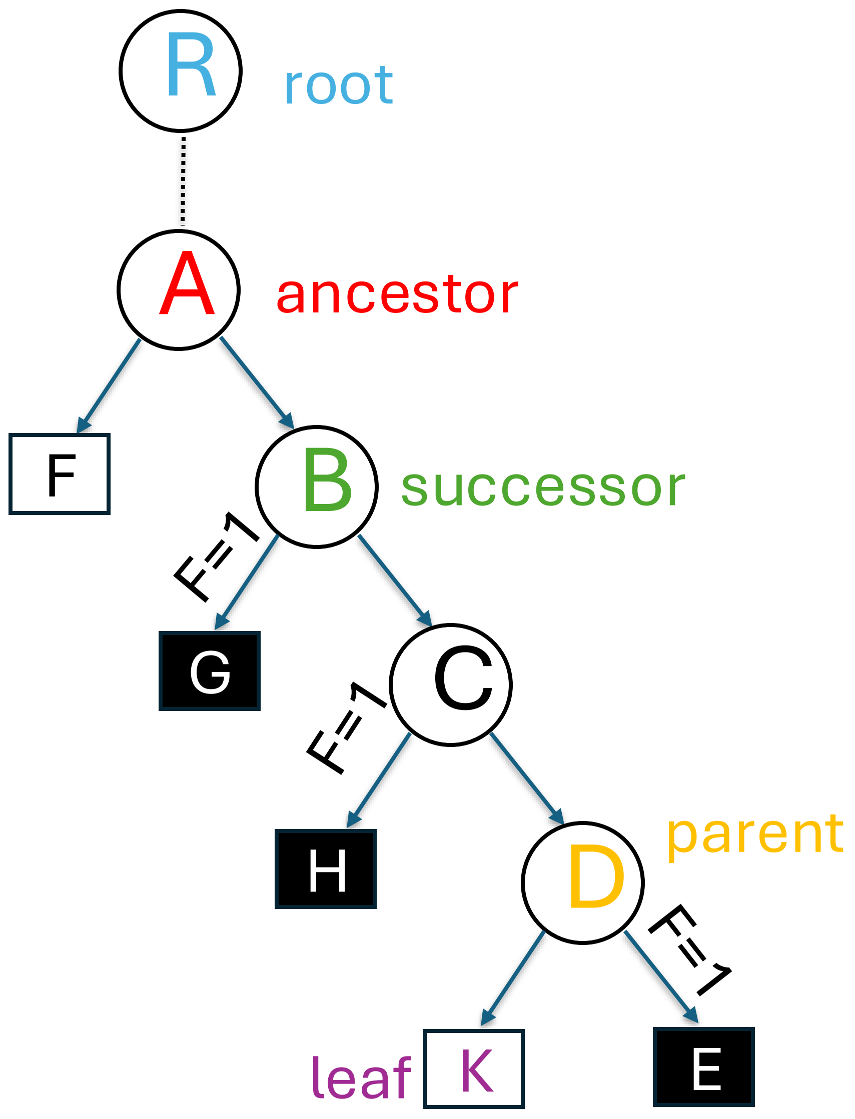
SCOT: Natarajan-Mittal Tree



Leaf nodes contain actual keys

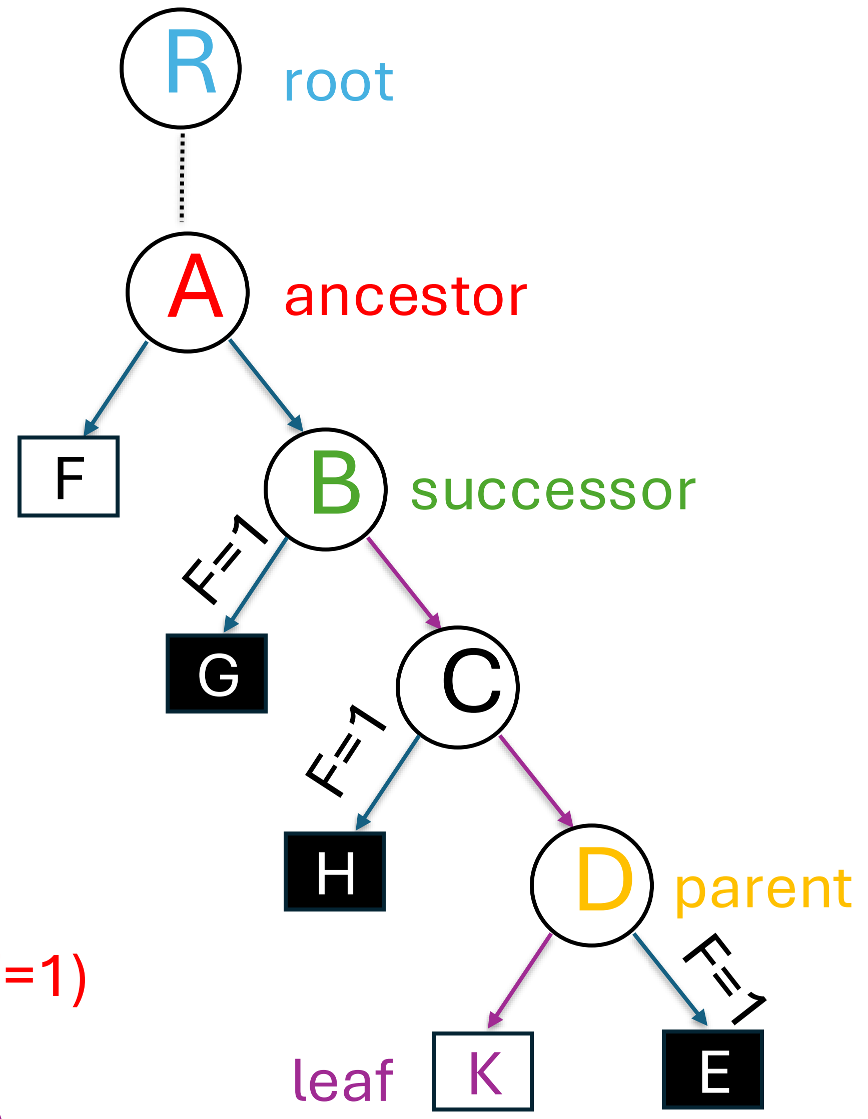
Keys in Internal nodes are used for traversal

SCOT: Natarajan-Mittal Tree



When leaf nodes G, H, E are deleted (flagged, F=1)

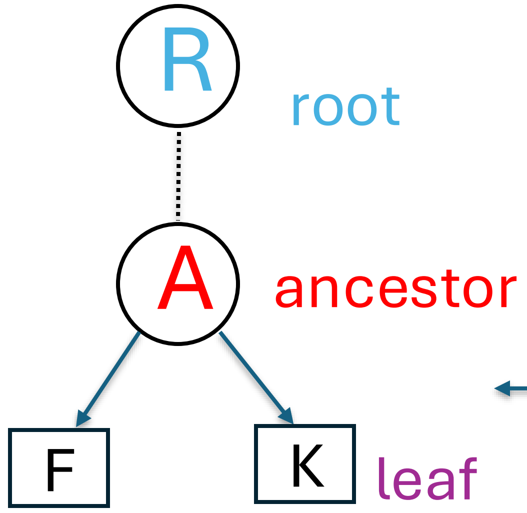
SCOT: Natarajan-Mittal Tree



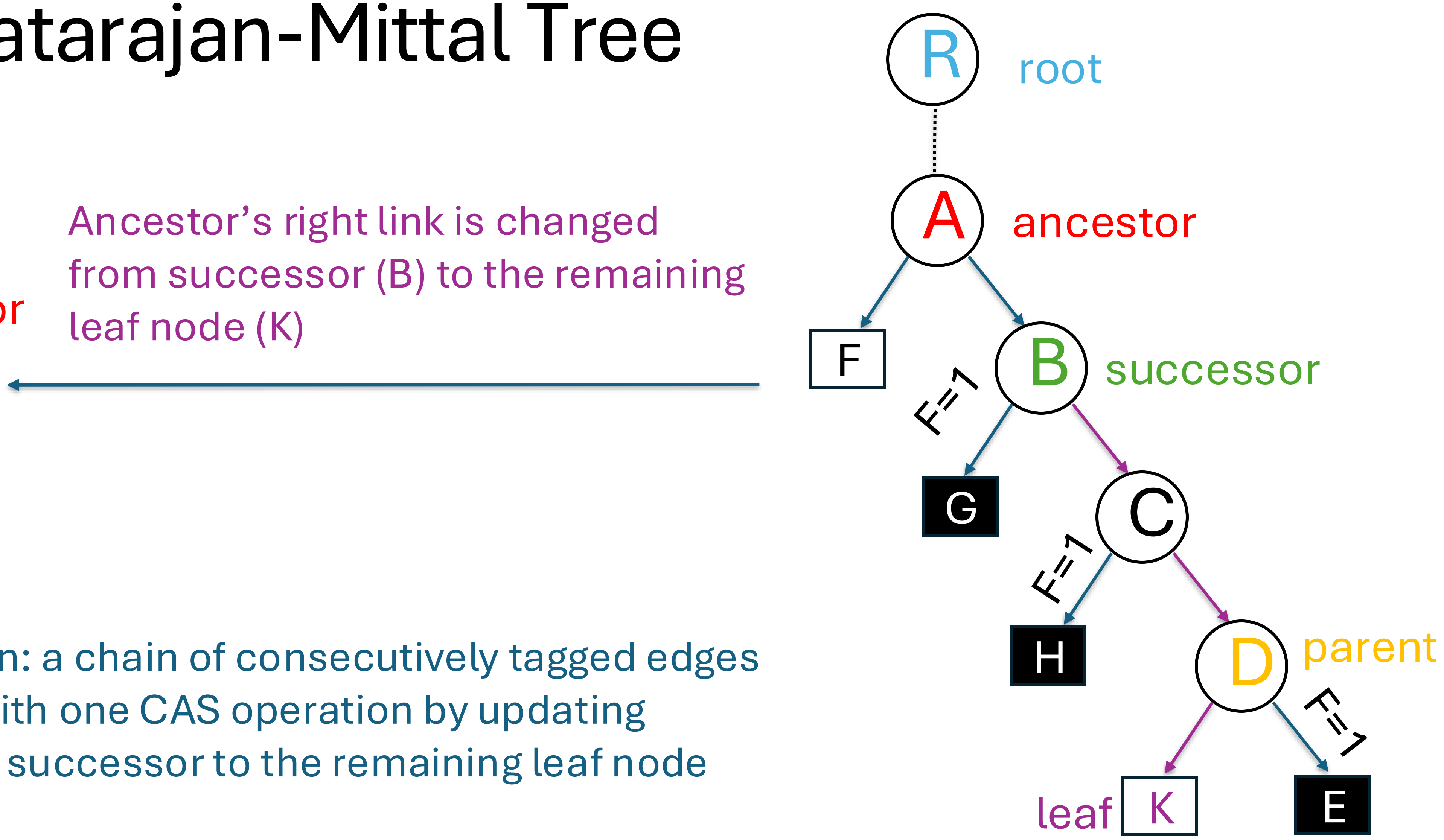
When leaf nodes G, H, E are deleted (flagged, F=1)

siblings (B-C, C-D, D-K) are getting tagged (T=1)

SCOT: Natarajan-Mittal Tree



Ancestor's right link is changed from successor (B) to the remaining leaf node (K)



A crucial observation: a chain of consecutively tagged edges can be eliminated with one CAS operation by updating ancestor's link from successor to the remaining leaf node

successor node is the last untagged node

SCOT: Natarajan-Mittal Tree

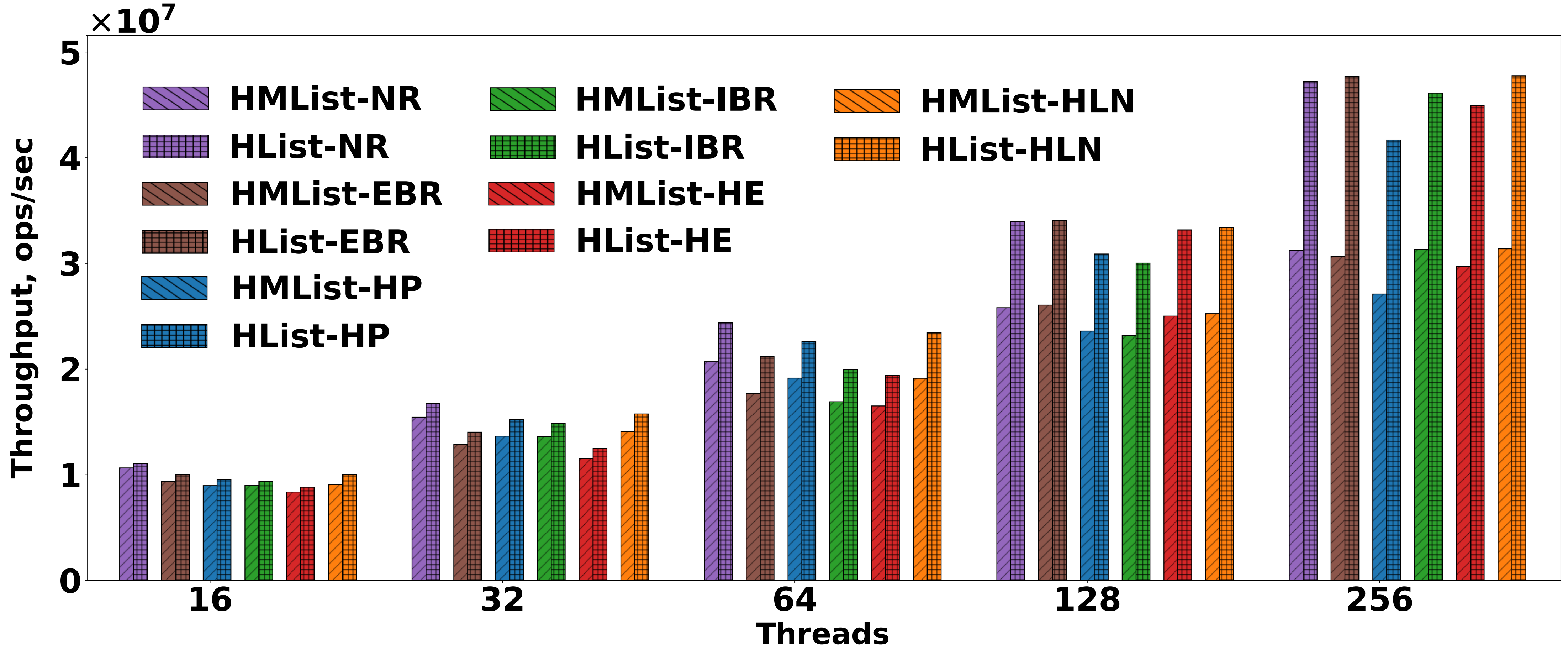
- We allocate 5 hazard pointers to protect nodes in the underlying search procedure: current, leaf, parent, successor, and ancestor. The current node points to the lowest node that is currently considered
- After each HP reservation of the current node, if the corresponding node is flagged or tagged, we need verify that ancestor still points to successor
- If ancestor points to some other node or successor becomes tagged, we need to restart from the very beginning

Evaluation Setup

- AMD EPYC 9754, 128 cores, 256 hardware threads, 384 GiB of RAM
- SMR Schemes
  - No-Reclamation (**NR**) baseline which leaks memory
  - Epoch-Based Reclamation (**EBR**)
  - Hazard Pointers (**HP**): TPDS ’04
  - Hazard Eras (**HE**): SPAA ’17
  - Interval-Based Reclamation (**IBR**): PPoPP ’18
  - Hyaline-1S (**HLN**): PODC ’19, PLDI ’21

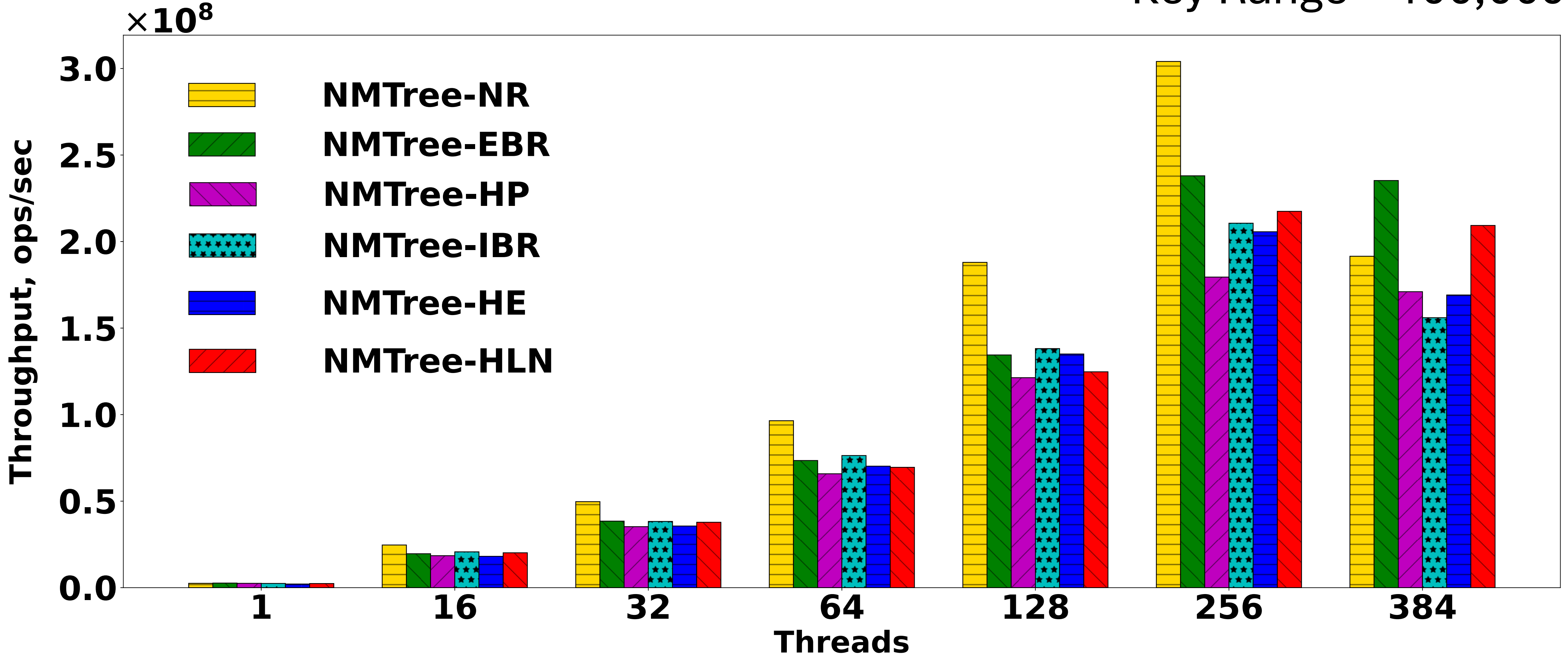
Evaluation: Harris vs. Harris-Michael list

Key Range = 512



Evaluation: Natarajan-Mittal tree

Key Range = 100,000



Code Availability

- Code is open-source and available at:

  https://github.com/rusnikola/scot

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Thank You! Questions?