CSCI-344
Programming Language Concepts (Section 3)

Lecture 31

Copying Garbage Collection

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Where we are

Done:

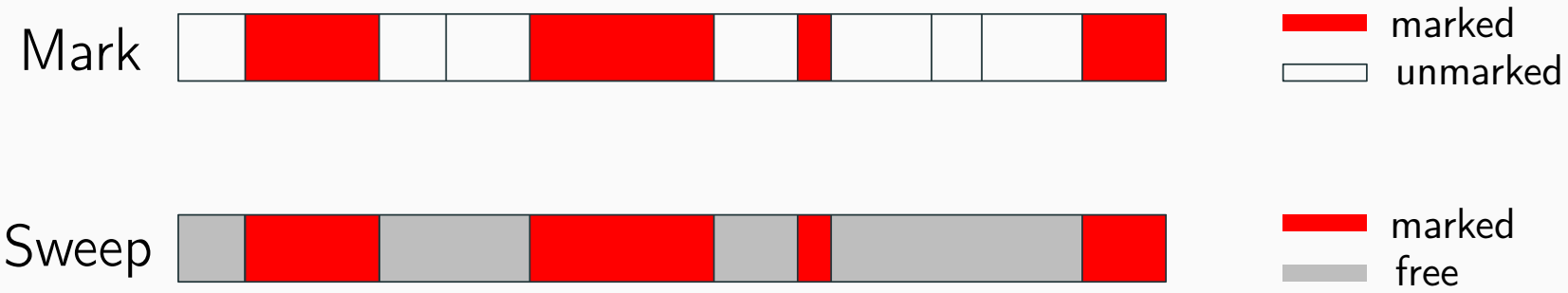
- Garbage Collection
  - Reference counting
  - Mark-and-Sweep Garbage Collection

This session:

- Copying Garbage Collection
- Quantitative aspects

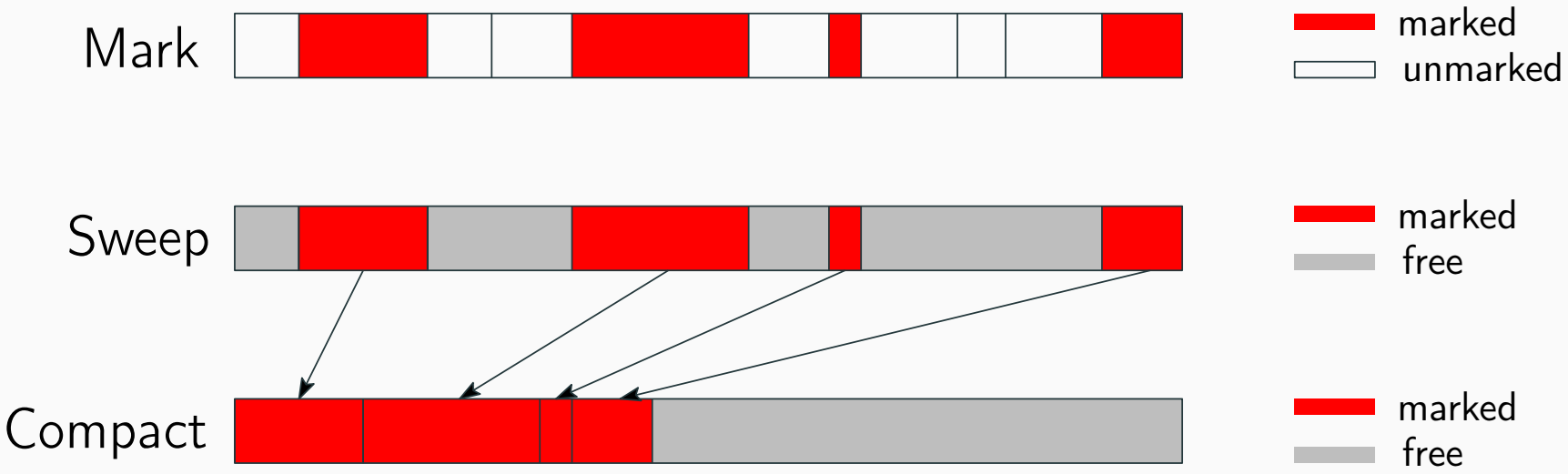
Mark-Compact Garbage Collection

- Mark-Sweep Disadvantage: Fragmentation
- Memory objects are not moved: space can become fragmented
- Makes is difficult to allocate large objects
  - although space is still available overall



Mark-Compact Garbage Collection

- Mark-Sweep Disadvantage: Fragmentation
- Memory objects are not moved: space can become fragmented
- Makes is difficult to allocate large objects
  - although space is still available overall
- Compaction moves live objects together to reclaim contiguous empty space



Mark-Compact Garbage Collection

Pros

- Solves the fragmentation problem
- Does not change the original ordering of the memory objects

Cons

- Several passes over data is required:

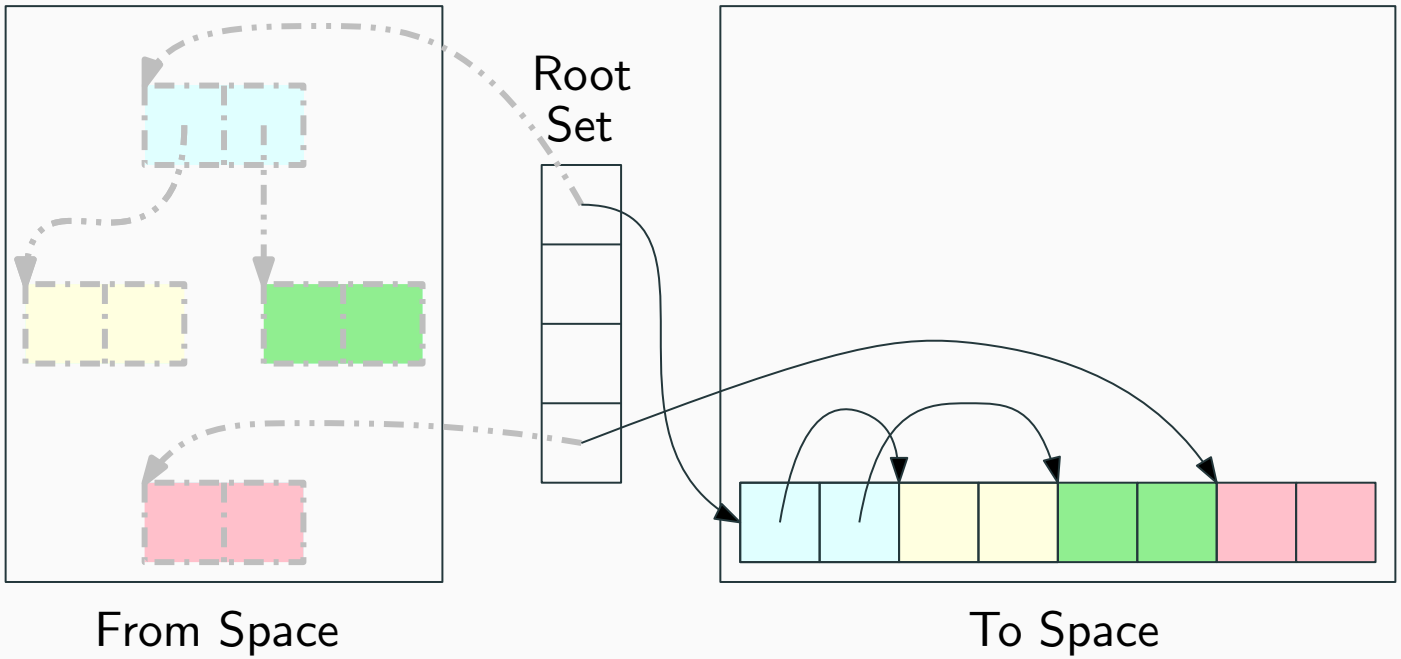
1. Marking phase
2. Compute the new locations that the objects will be moving to
3. Update pointers to refer to objects new locations
4. Actually move the objects

- Significantly slower than mark-sweep if a large portion of data needs compaction

Copying Garbage Collection

- Traverses the heap similar to marking phase
- Instead of marking objects it moves reachable objects
  - from current heap (“from”-space)
  - to new area (“to”-space)
- When all reachable objects have been moved, from-space and to-space switch roles
- Copying garbage collection trades space for time

Copying Garbage Collection



Allocation

Mark-Sweep Garbage Collection

- Maintains a segregated free list
- Free list is divided into several size classes
- Memory objects are allocated from the appropriate size class using a first-fit algorithm

Copying Garbage Collection

- Use bump pointer allocation (pointer increment)
- Allocator maintains a pointer to the start of available memory
- Increments pointer by the allocation size requested by the program
- Bump pointer allocation is much faster than free-list allocation

Cheney's Algorithm

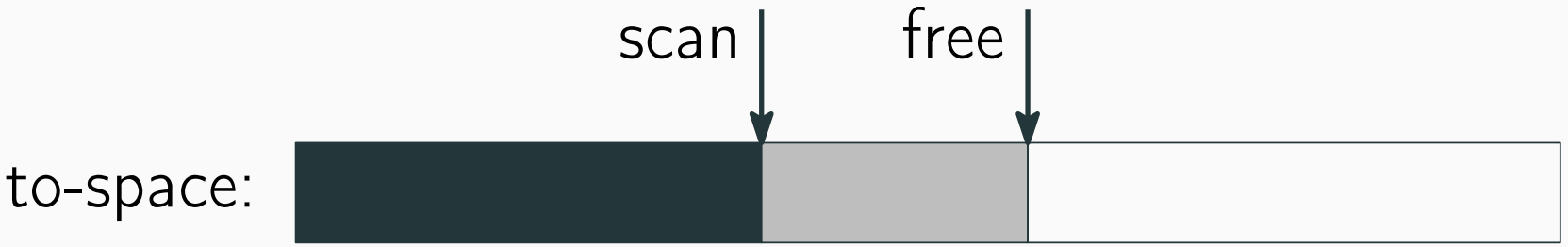
Copy all reachable objects with breadth-first traversal:

1) Copy objects that are reachable from the root to to-space
2) Scan to-space and fix pointers to from-space
   - Copy objects if not yet copied
   - When an object is copied, install a forwarding pointer on the old version of object
   - Update the pointer slot
3) Garbage collection completes when all objects in to-space scanned

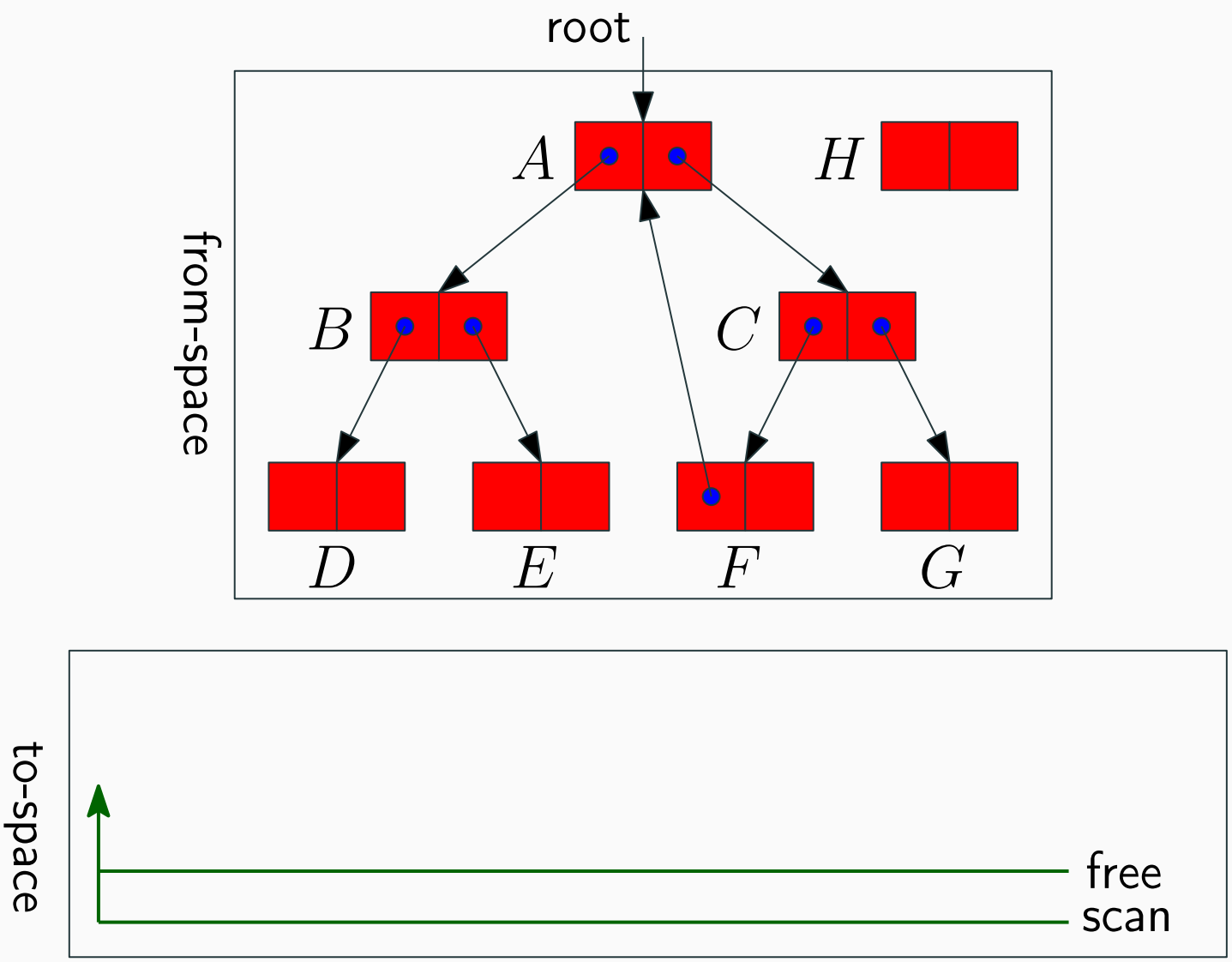
Cheney's Algorithm

A memory object has three different states:

- **White:** still in from-space
- **Gray:** is copied to to-space but still references objects in the from-space
- **Black:** is in the to-space and only references objects in the to-space



Cheney's Algorithm



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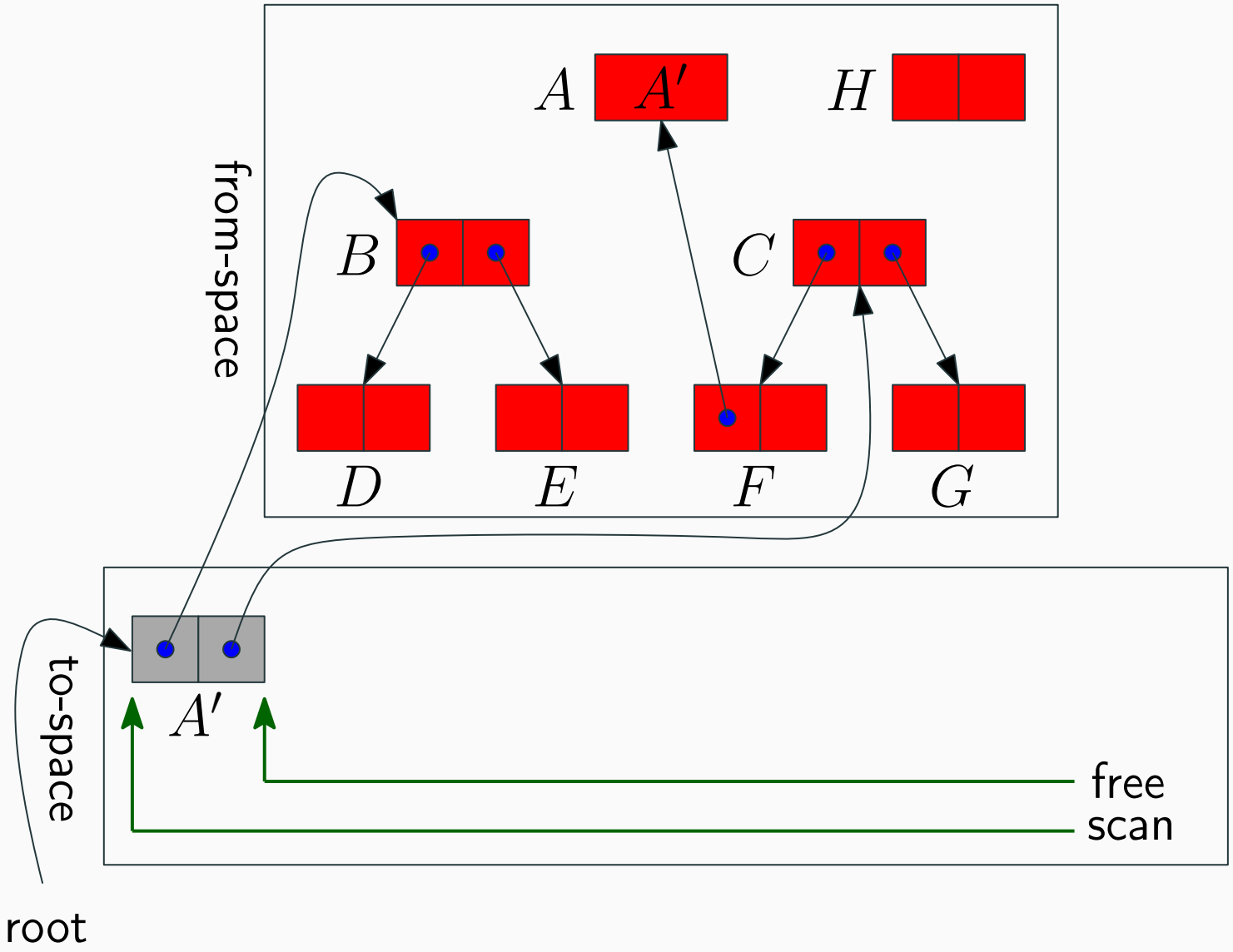

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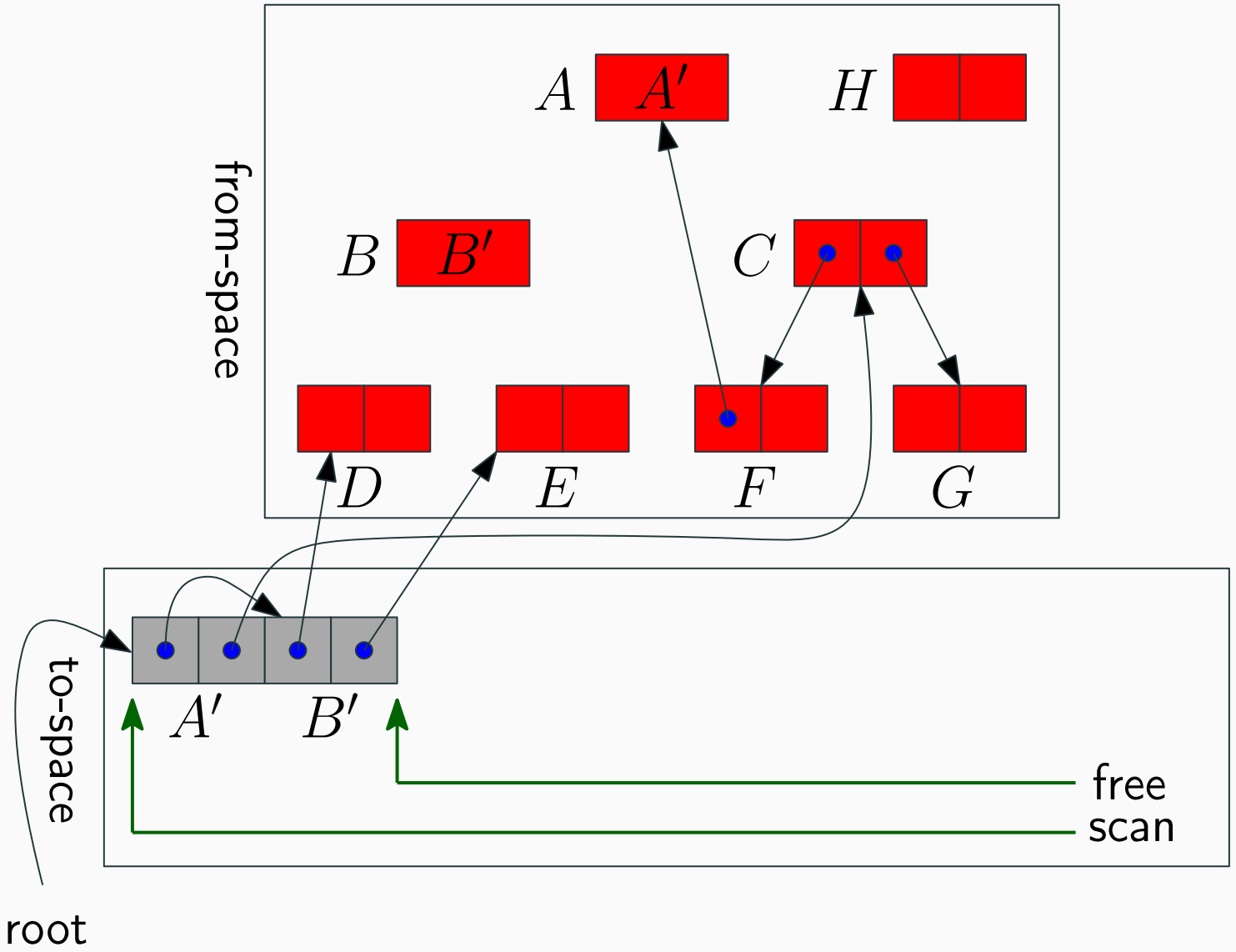

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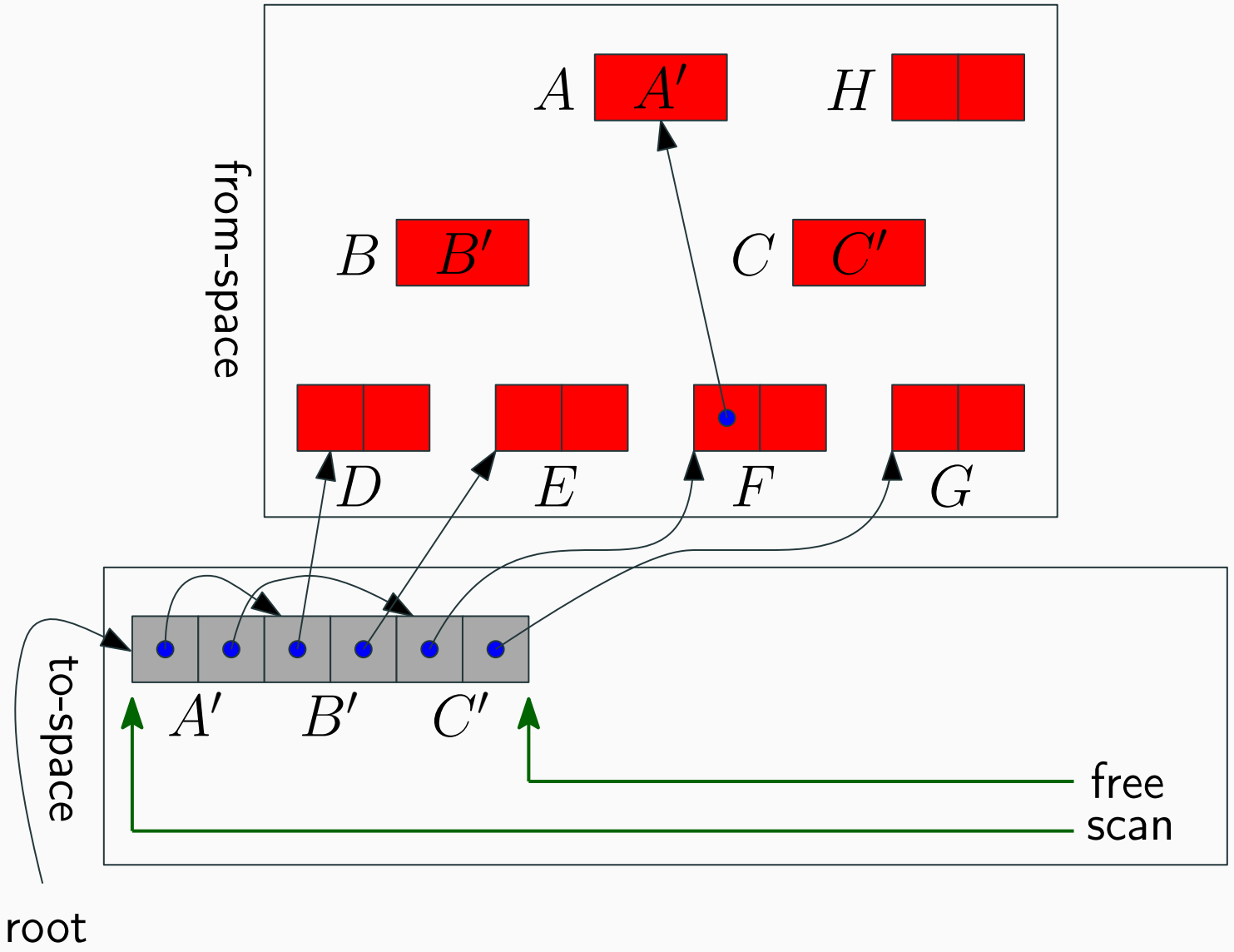

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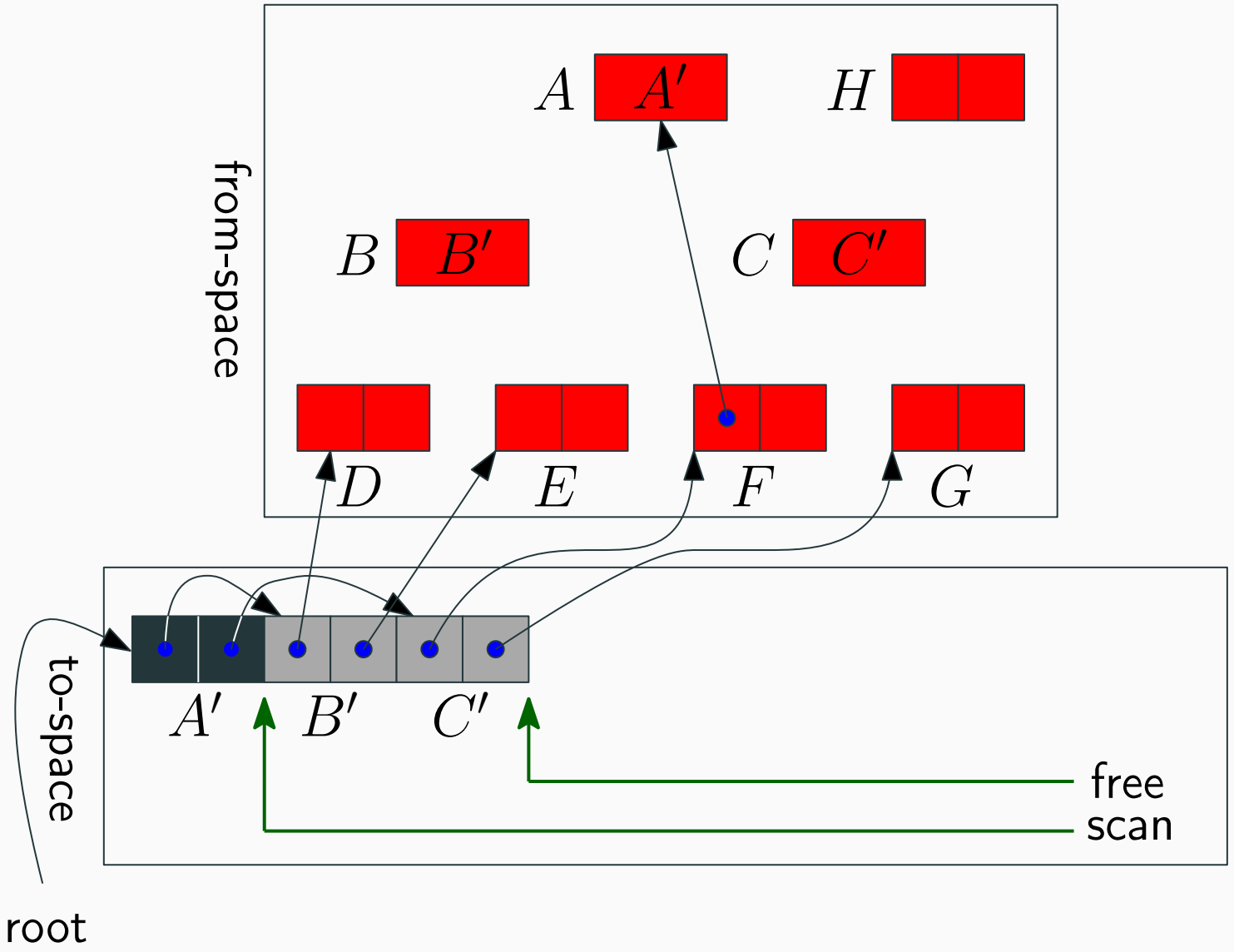

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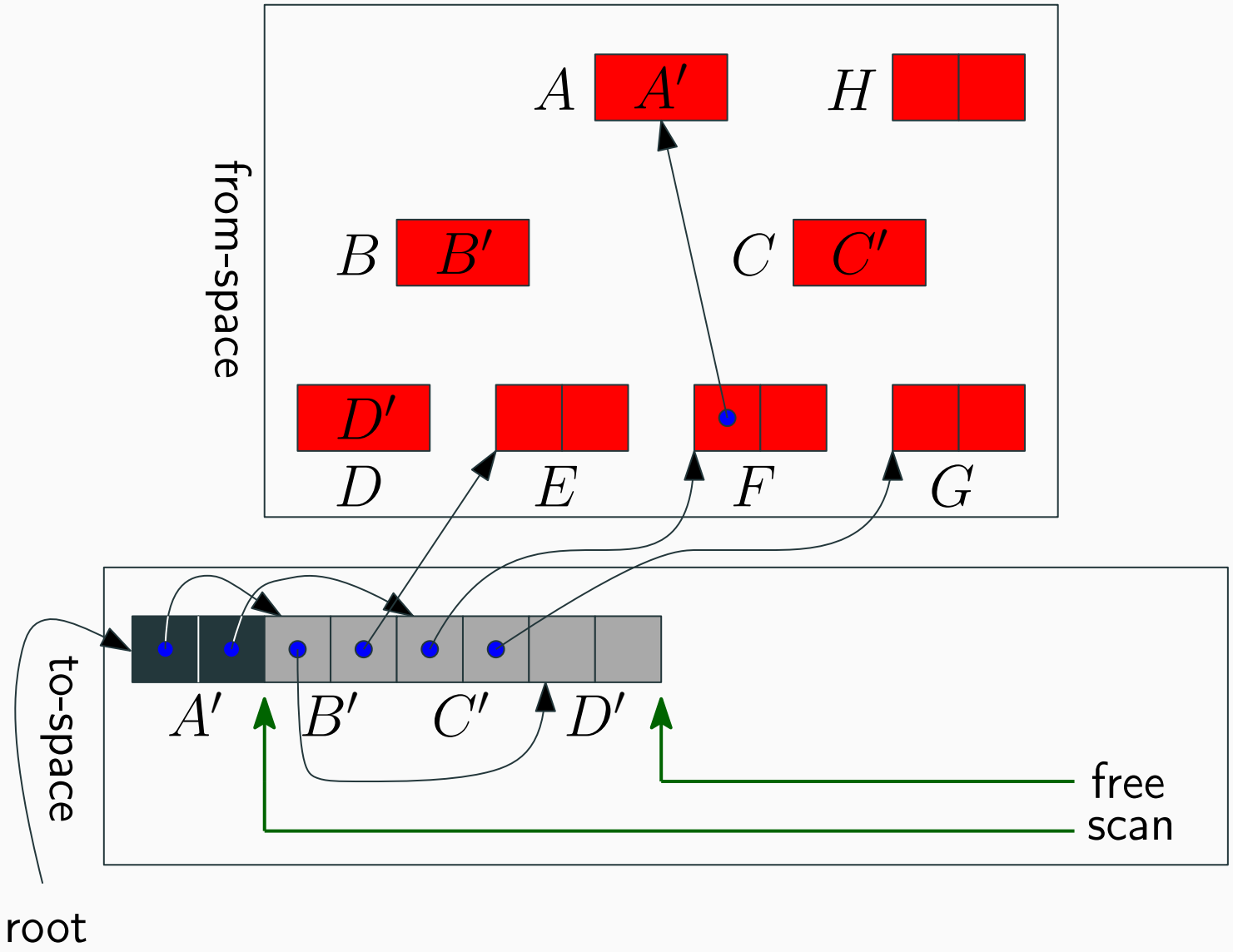

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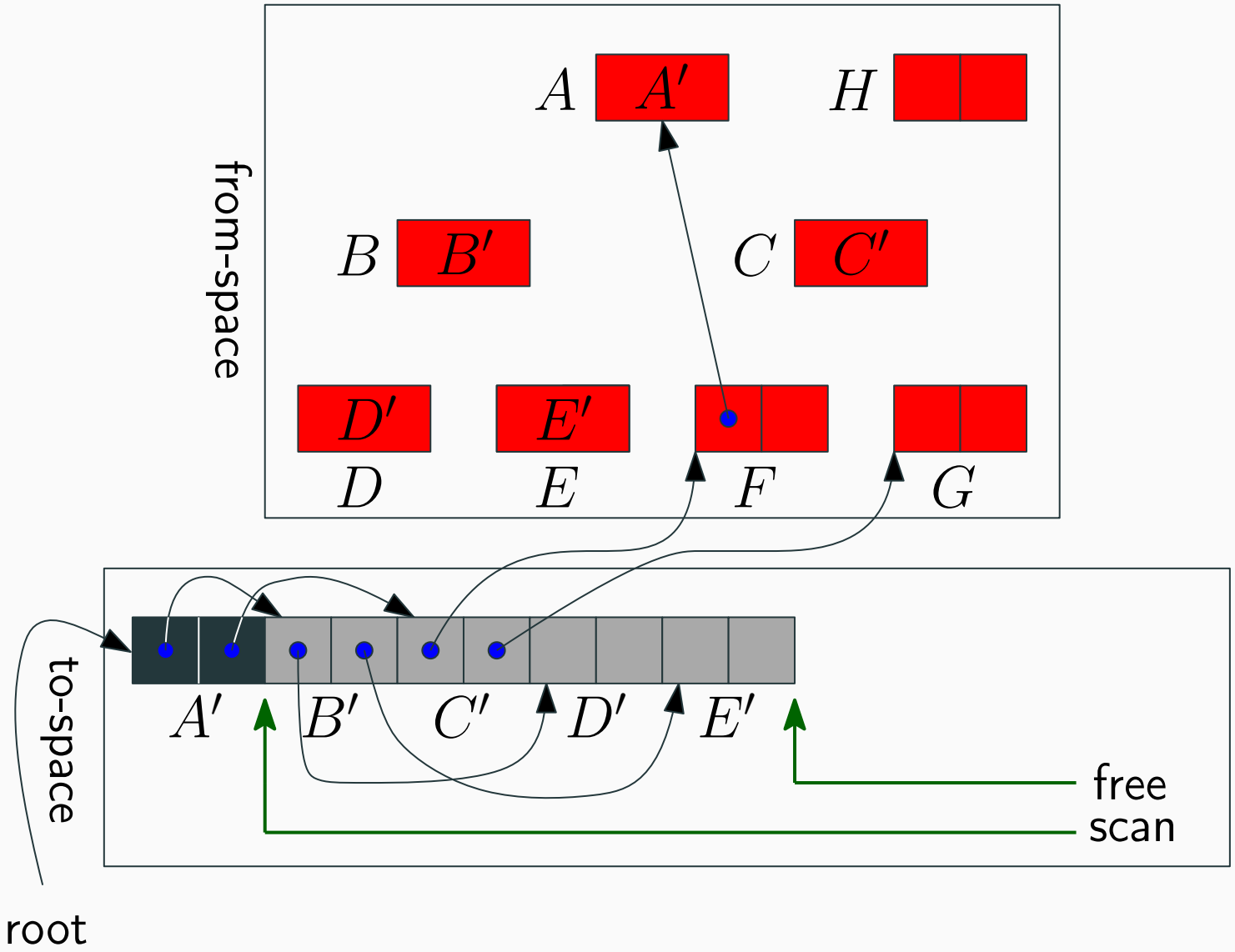

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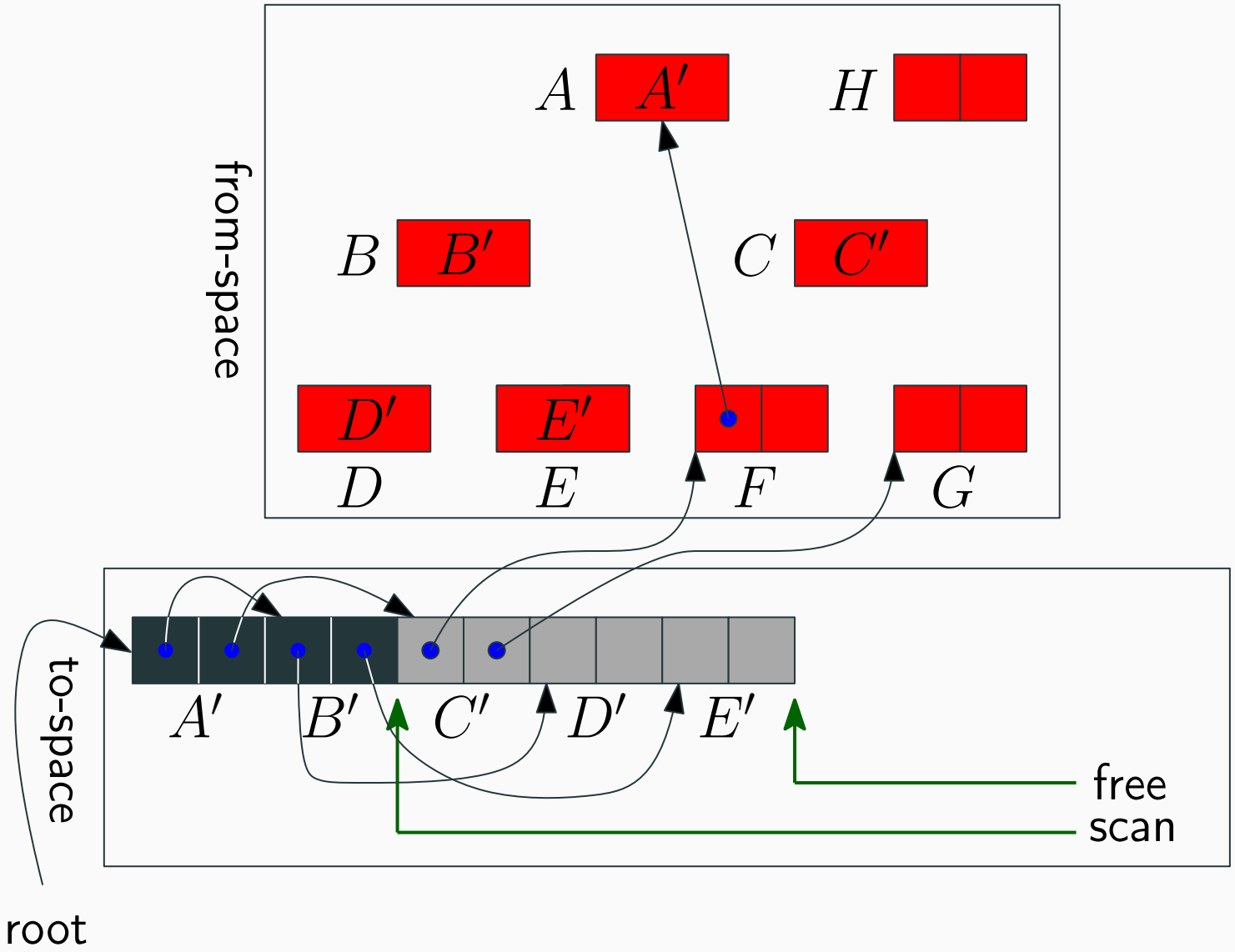

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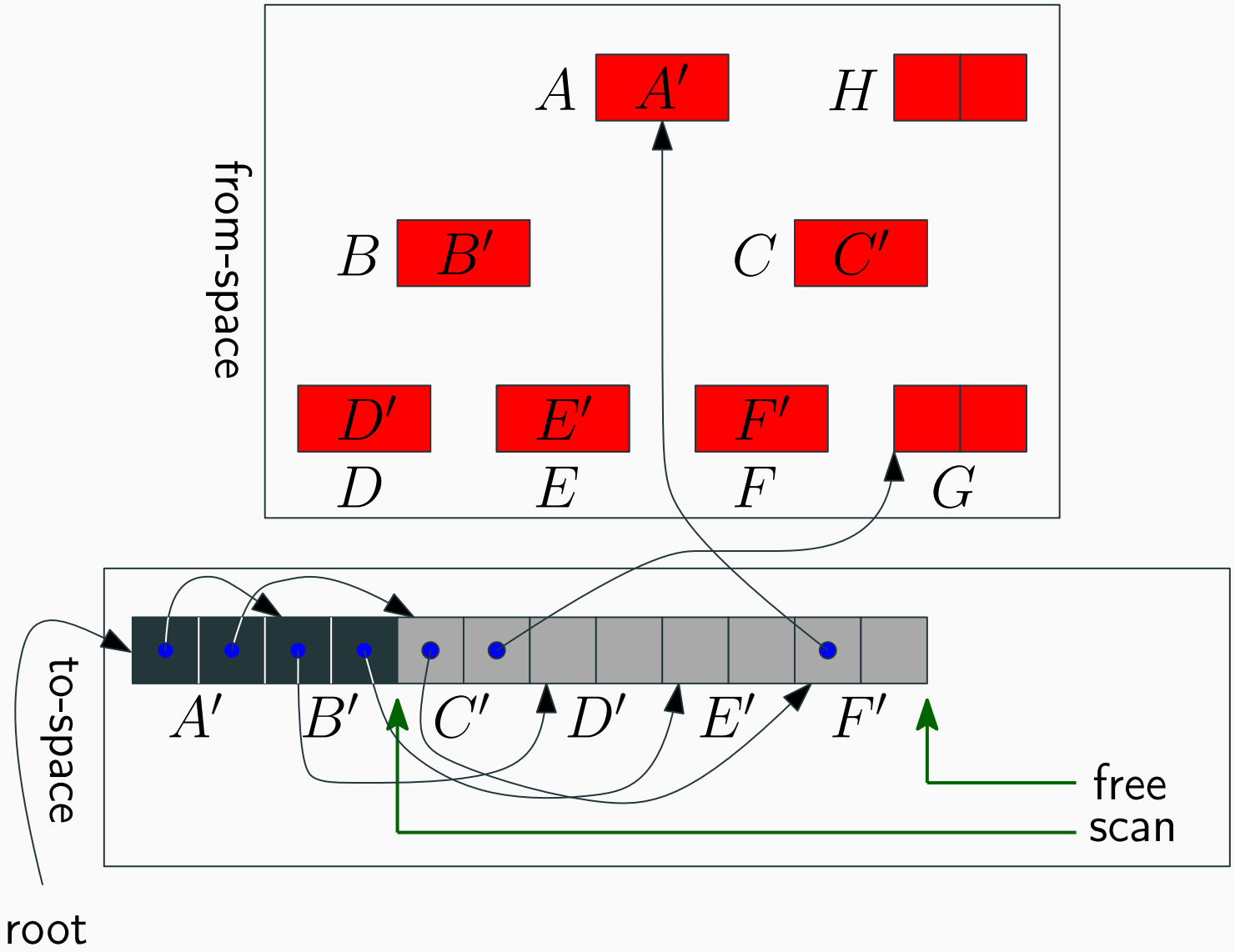

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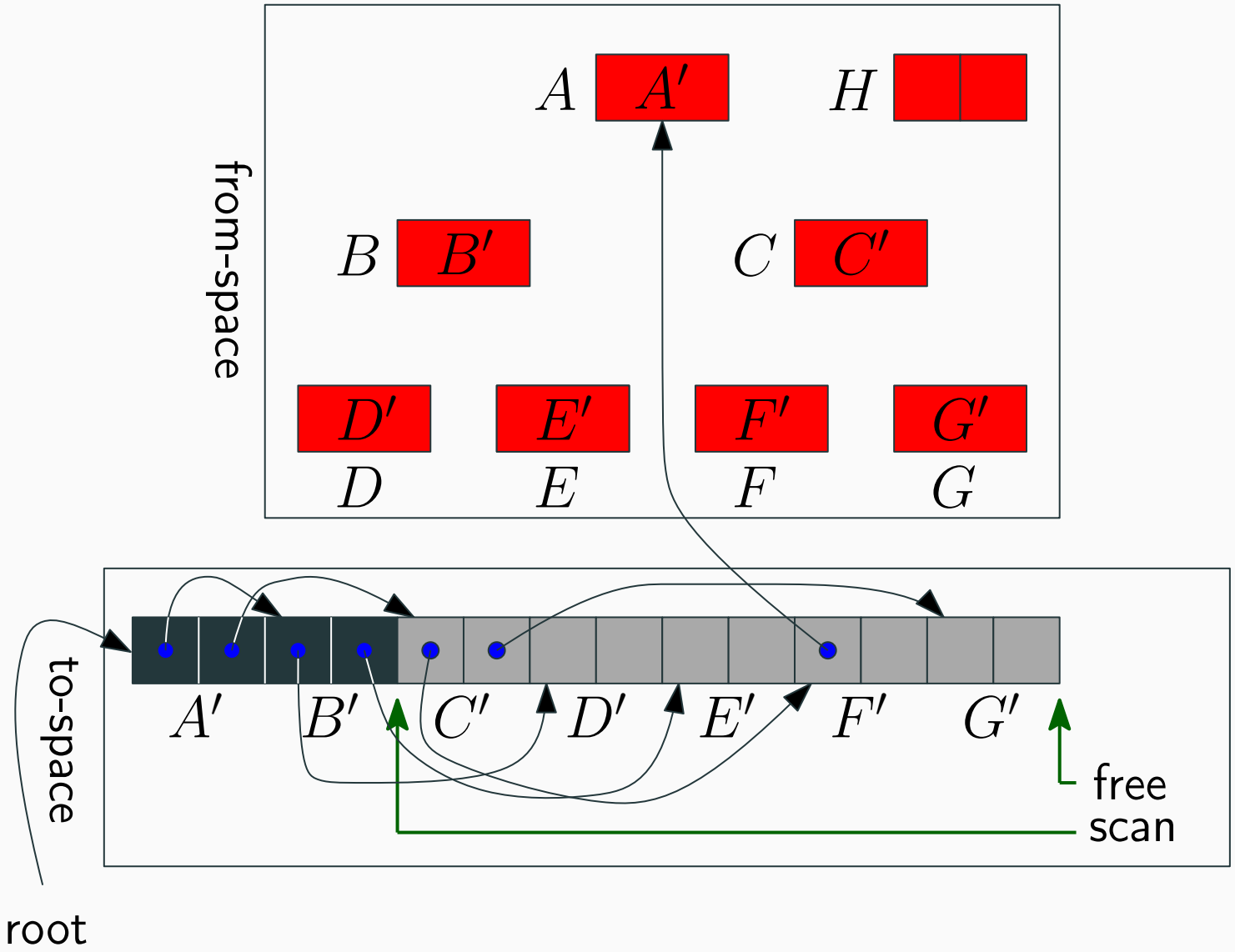

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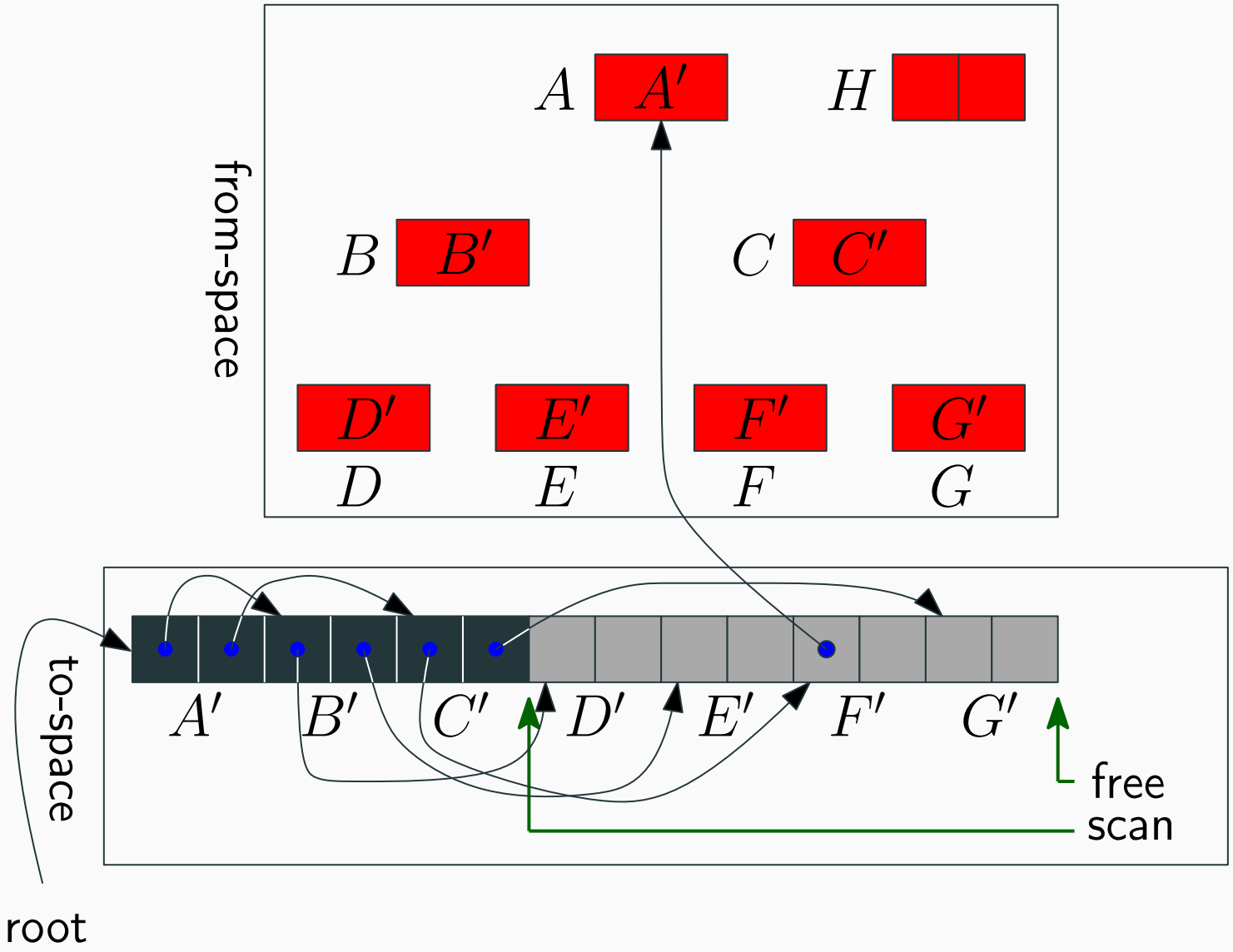

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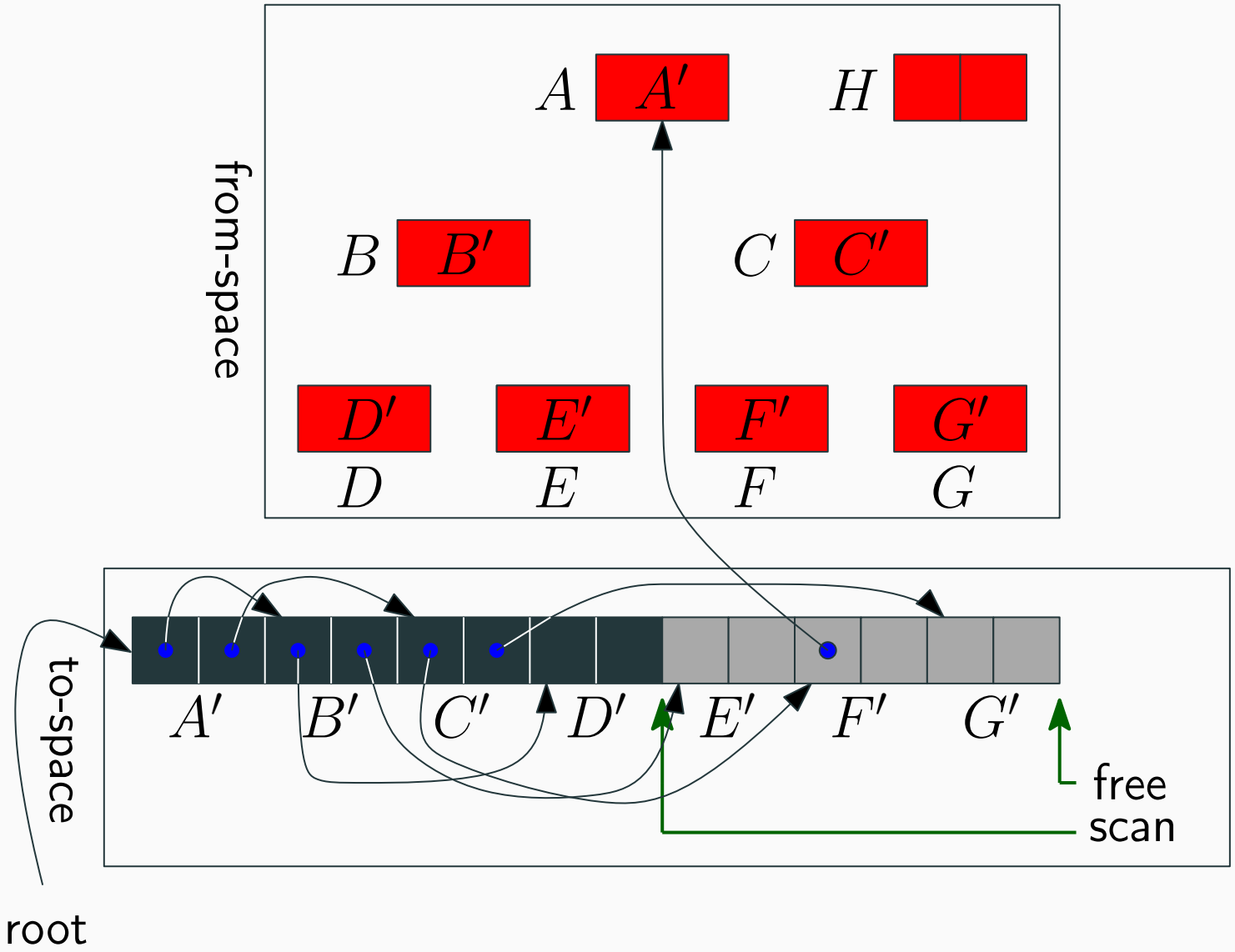

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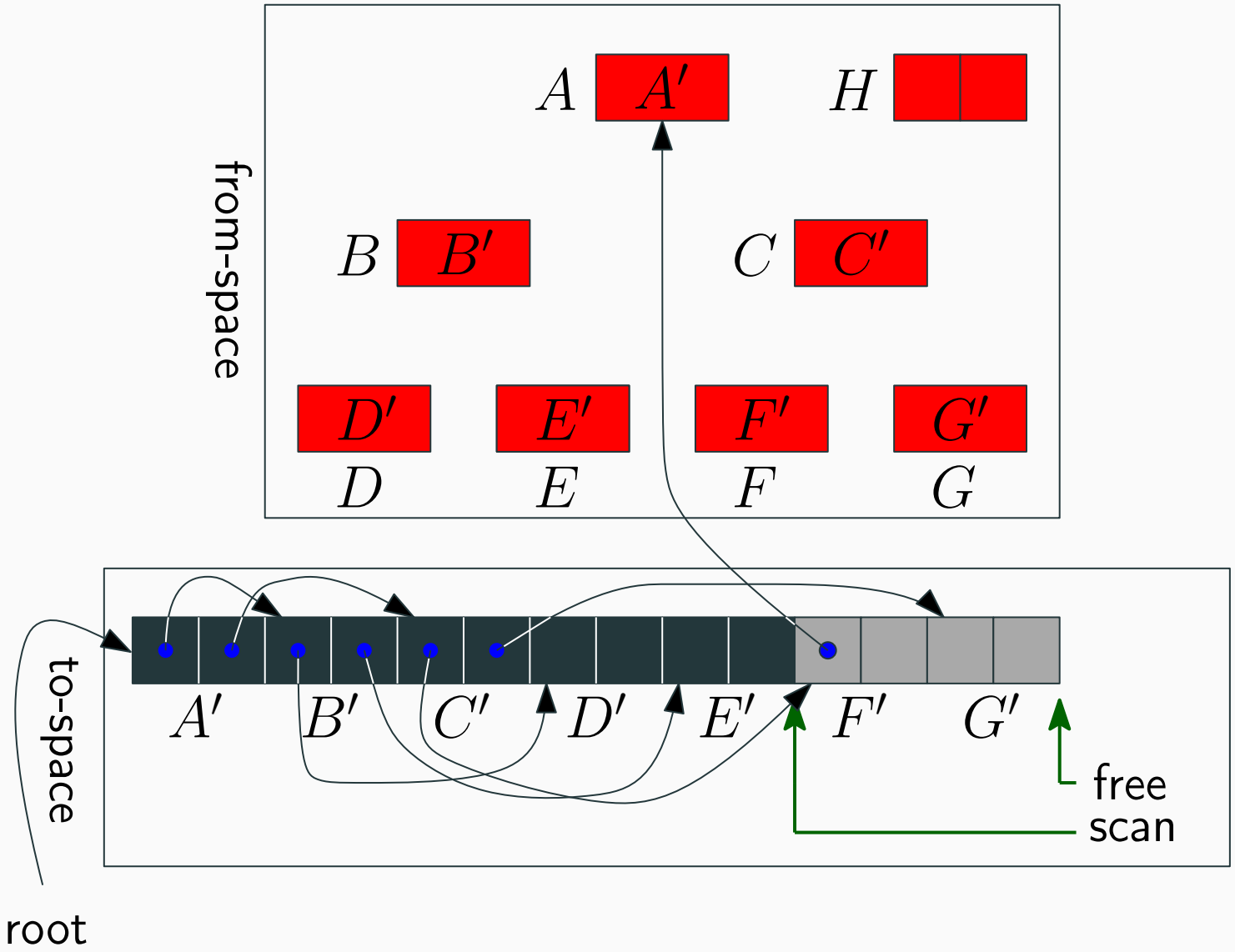

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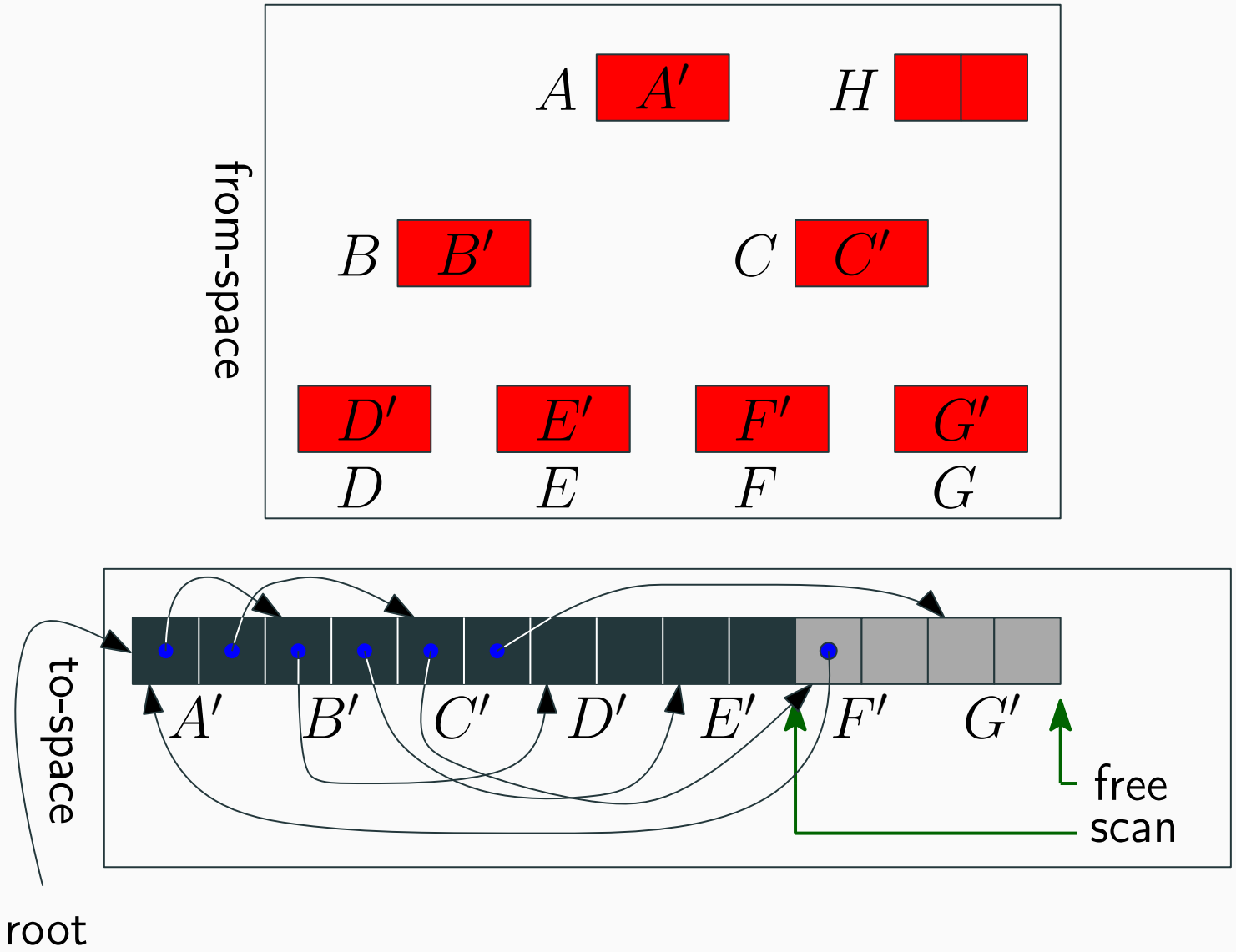

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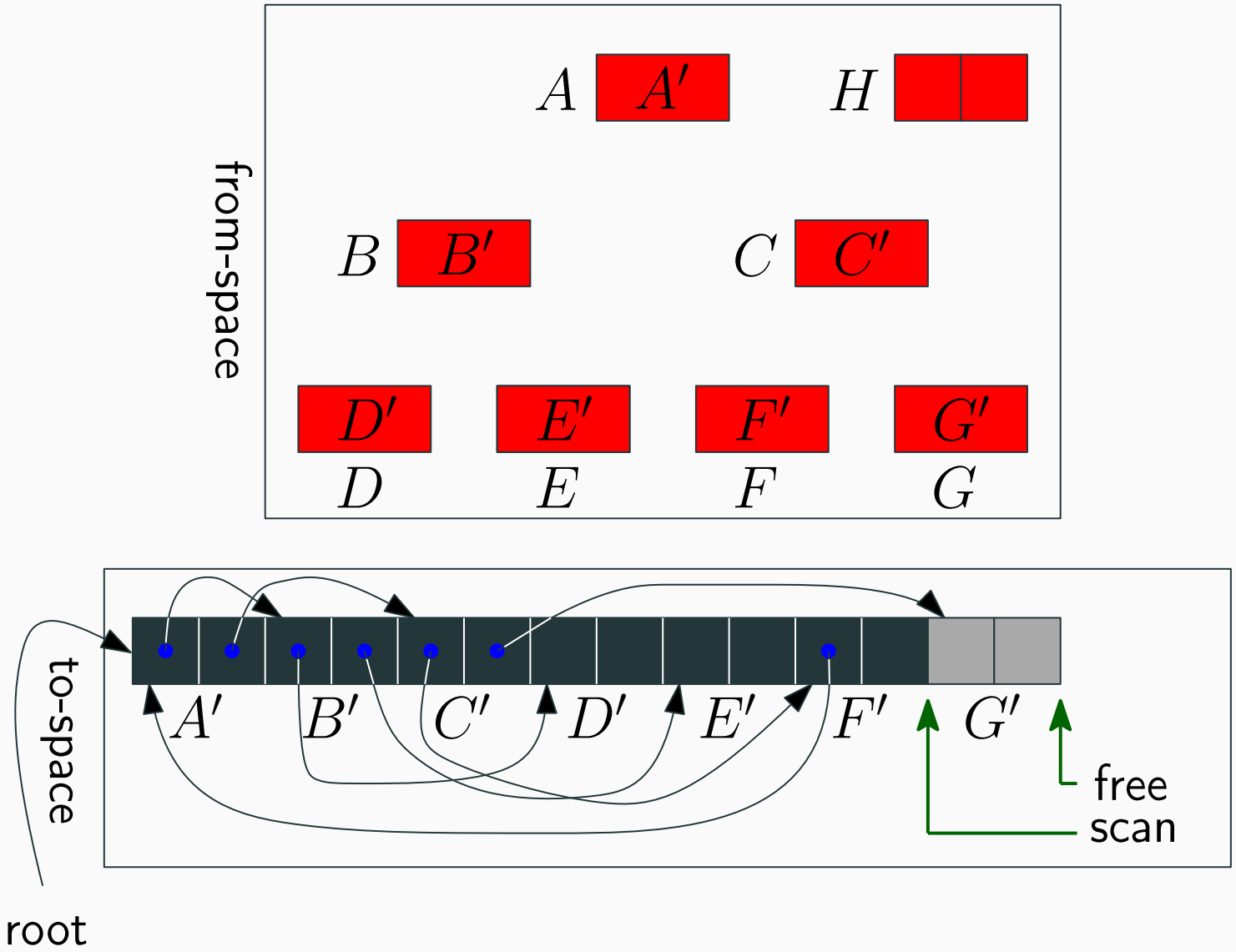

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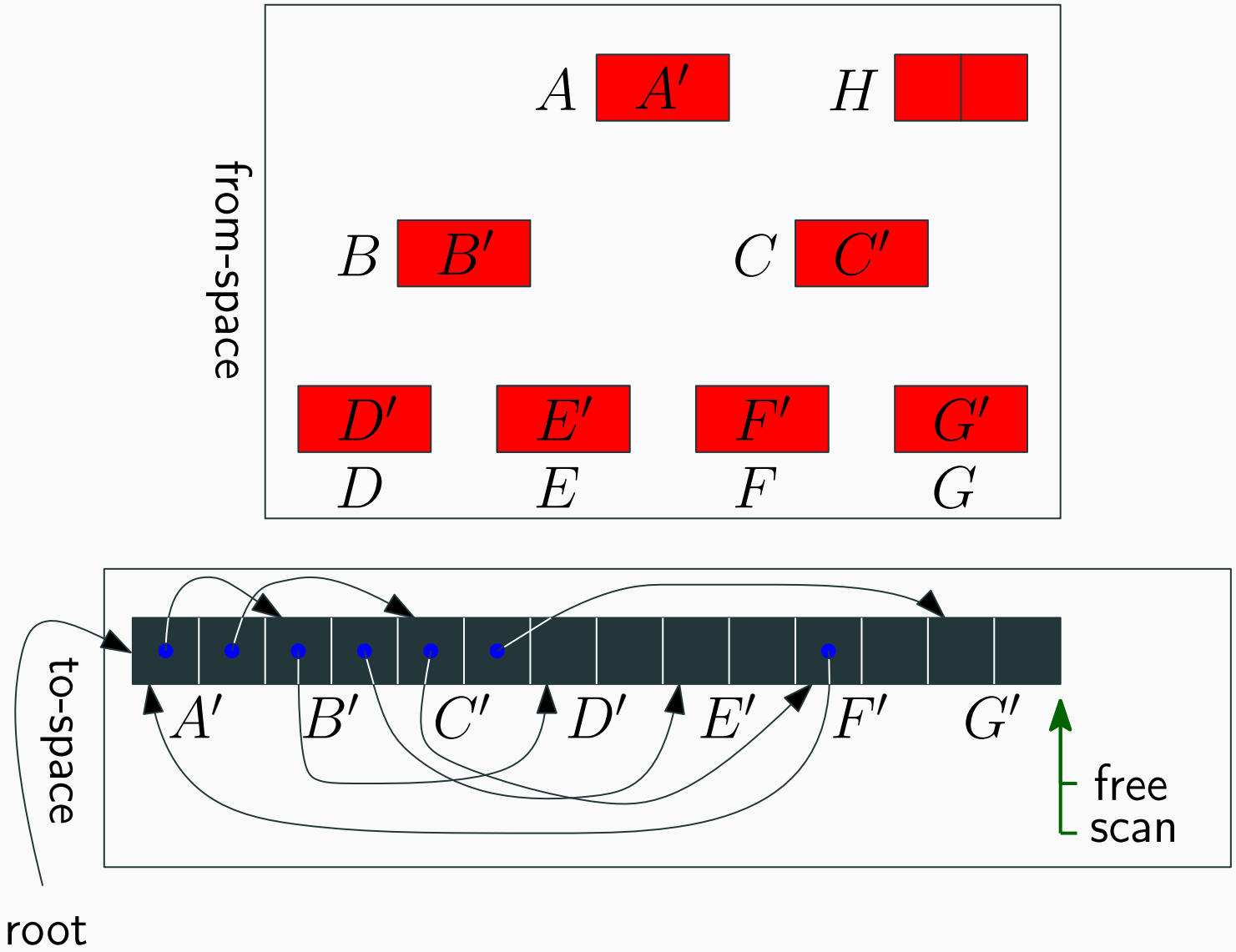

Copying Garbage Collection

Pros

- Contiguous free memory space
- Object creation is cheap: bump allocation
- Only live objects are inspected

Cons

- Stop-the-world garbage collector
- Breath first traversal may mix locality patterns
- All pointers are updated
- Half of the heap is useless
- Objects with long life span are copied over and over again

Quantitative Aspects

- Amount of live data: L
- Size of the heap: H
- Ratio of heap size to live data: $\gamma = \frac{H}{L}$
- Live ratio $\frac{1}{\gamma}$: fraction of the heap occupied by live objects
- γ too small:
  - too few allocation between collections
  - overhead of collection can get very high

Comparison

	Ref. counting	Mark-Sweep	Mark-Compact	Copying
Defragmentation			✓	✓
Time Overhead	$O(\text{ptr manip})$	$O(H)$	$O(H) + O(L)$	$O(L)$
Space Required	L	L	L	$2 \times L$
Passes over memory	-	2	2-4	1

Correct Heap Size

- How should the heap grow?
- Start out with a fairly small heap, enlarge it in response to the growth of live data
- After a collection, if γ is smaller than some criterion, the collector increases H by asking the operating system for more memory
- Simple rule of thumb: maintain a roughly constant γ
- Mark-and-sweep collectors perform very well when $\gamma > 2$
- Copying collectors do better with $\gamma > 3$

Summary

This Lecture

- The last lecture of PLC!

Next Lecture

- There are no more lectures ☺