Lecture 24

Public Service Announcement: "Hackers@Berkeley is hosting BEARHACK this Saturday at 11AM in the Wozniak Lounge. It's a 24 hour hackathon - there'll be tons of good food (Cheeseboard, sushi & boba!), activities (including massages!), and prizes (including an Occulus Rift).

Administrivia:

- There will be a homework assignment due next Wednesday night (but of course you can do it early!).
- Project 3 to be posted today or tomorrow.

Storage Management

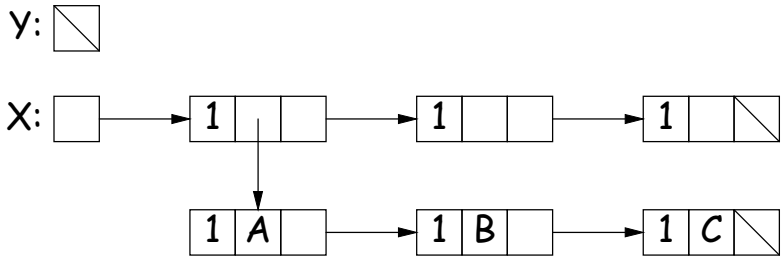
- Java has no means to free dynamic storage.
- However, when no expression in any thread can possibly be influenced by or change an object, it might as well not exist:

```
IntList wasteful ()
{
  IntList c = new IntList (3, new IntList (4, null));
  return c.tail;
  // variable c now deallocated, so no way
  // to get to first cell of list
}
```

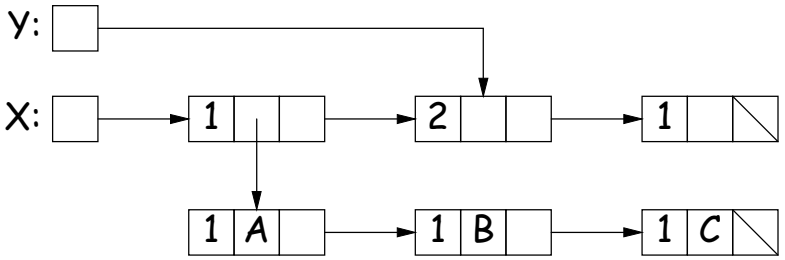
- At this point, Java runtime, like Scheme's, recycles the object `c` pointed to: *garbage collection*.

Garbage Collection: Reference Counting

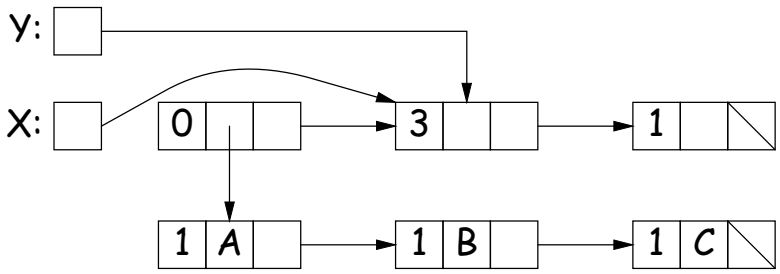
- Idea: Keep count of number of pointers to each object.

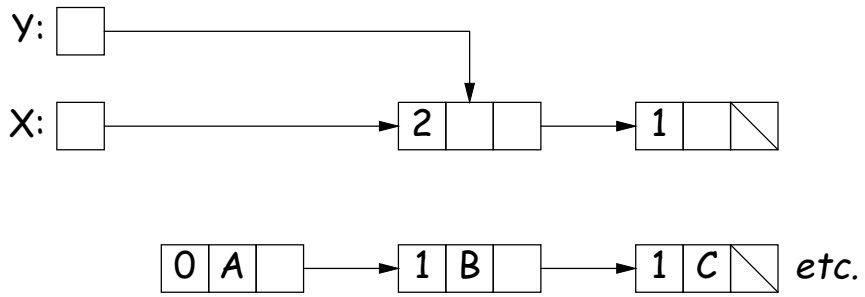



```
Y = X.tail;
```

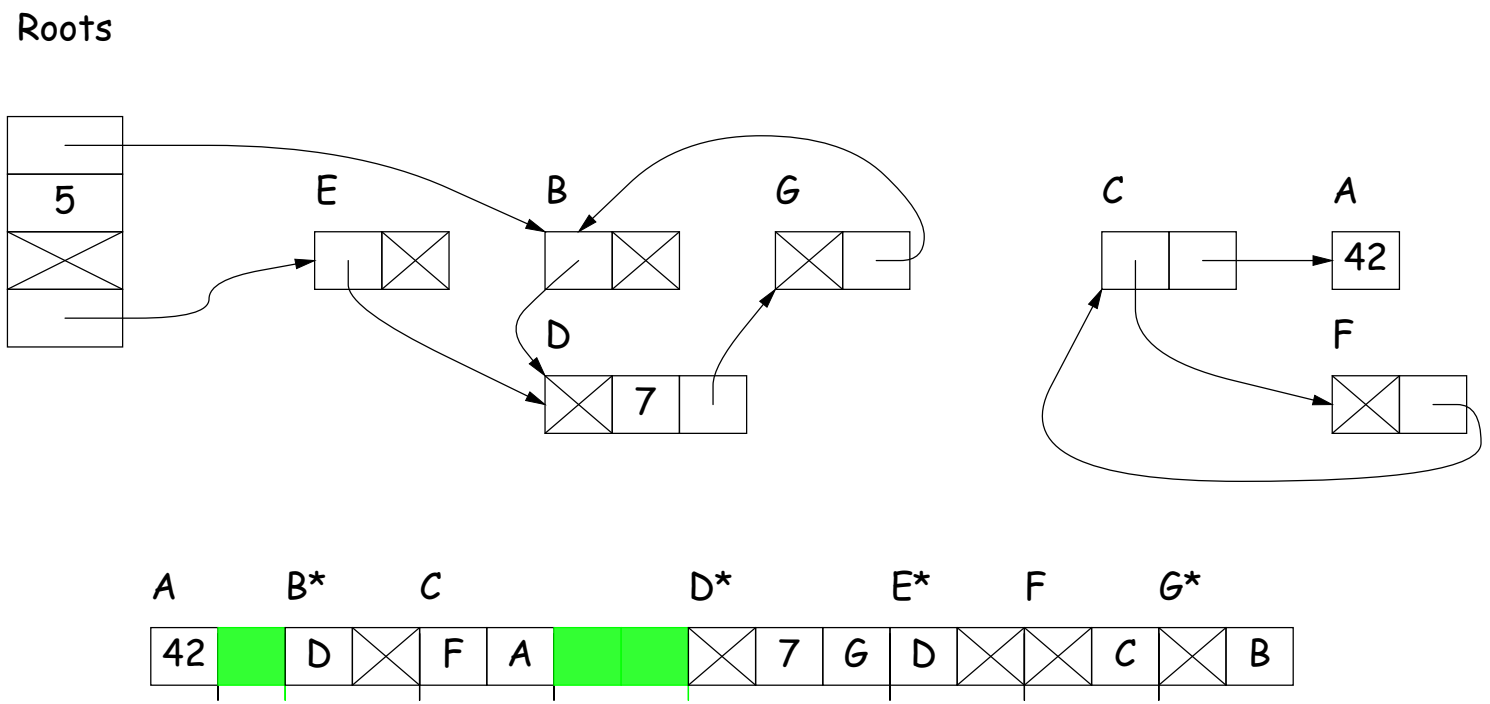



```
X = Y;
```





Garbage Collection: Mark and Sweep



- Start at roots (named variables, static and on stack)
- Perform graph traversal to find and mark all reachable storage.
- Sweep over memory, adding all unmarked storage to free list.

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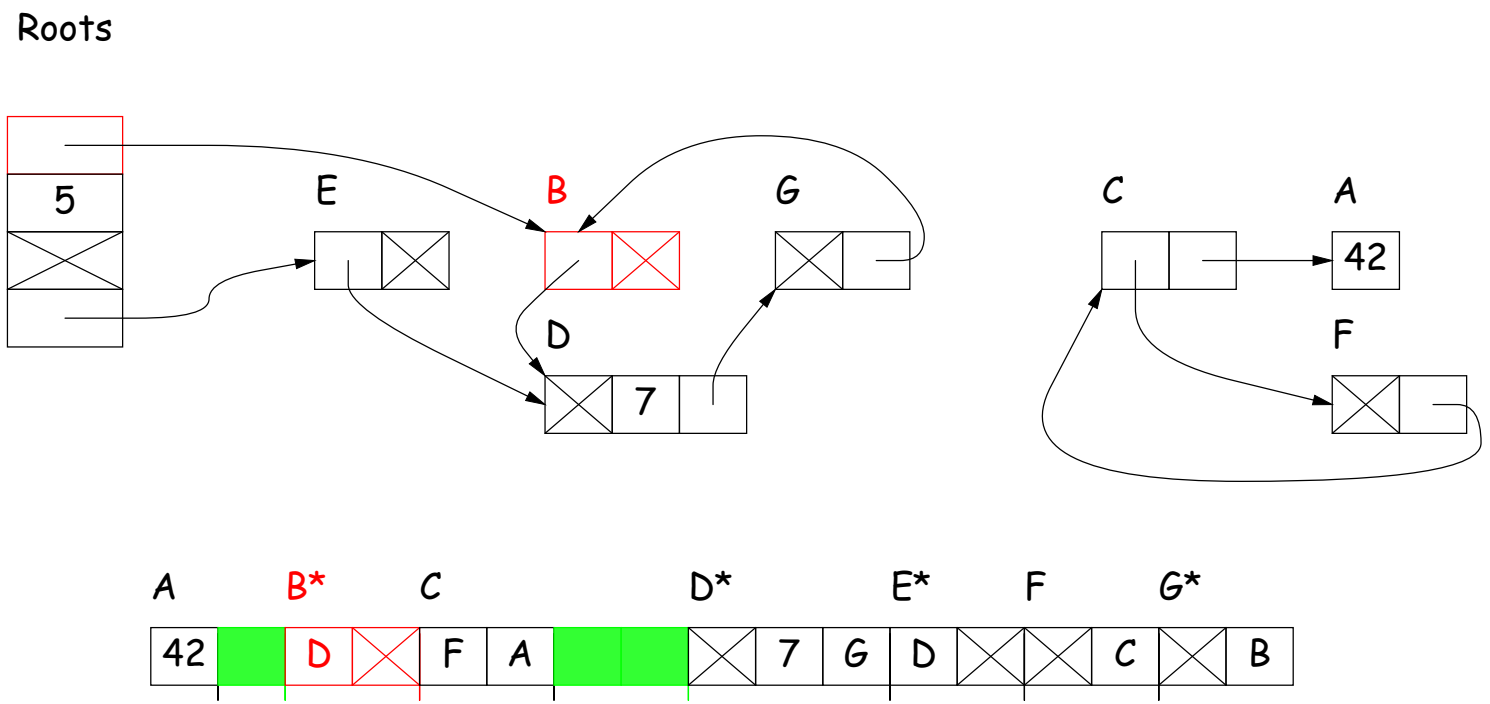

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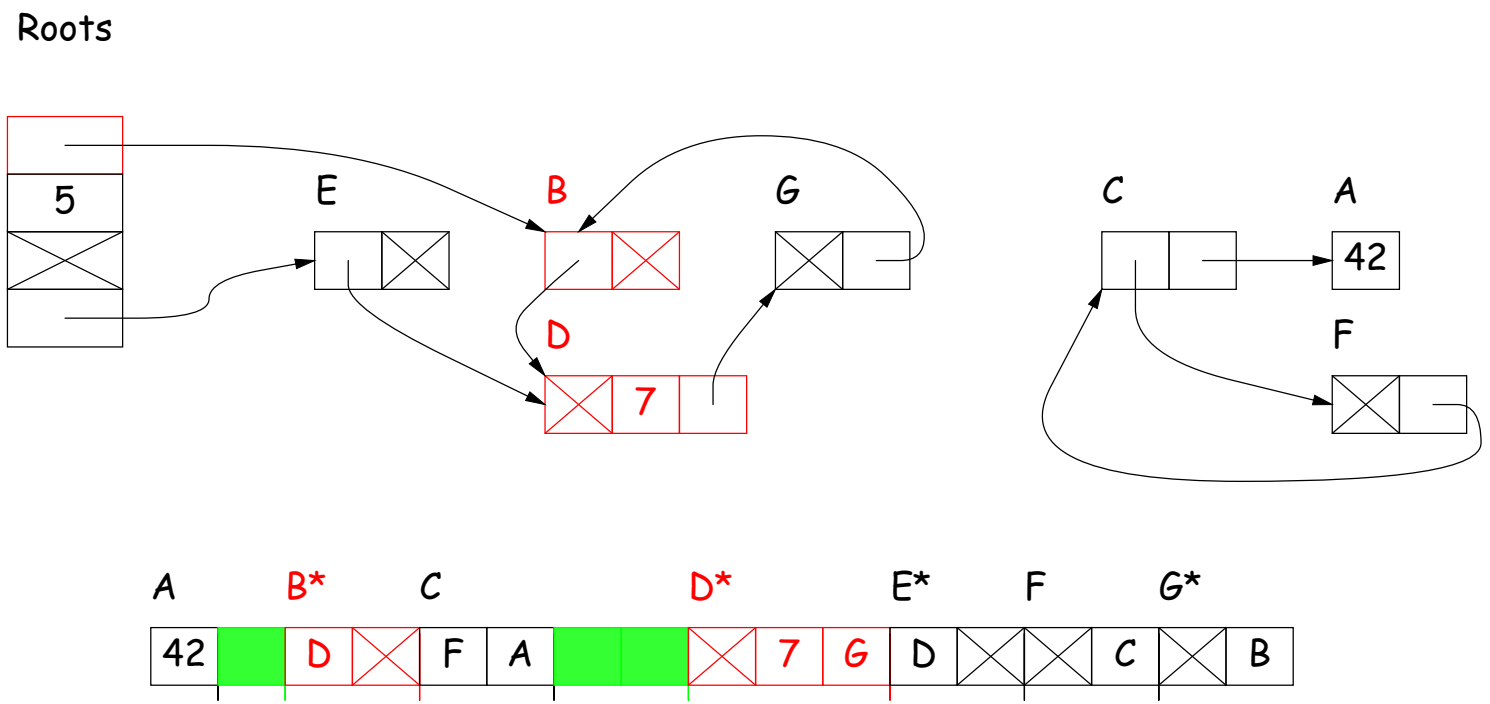

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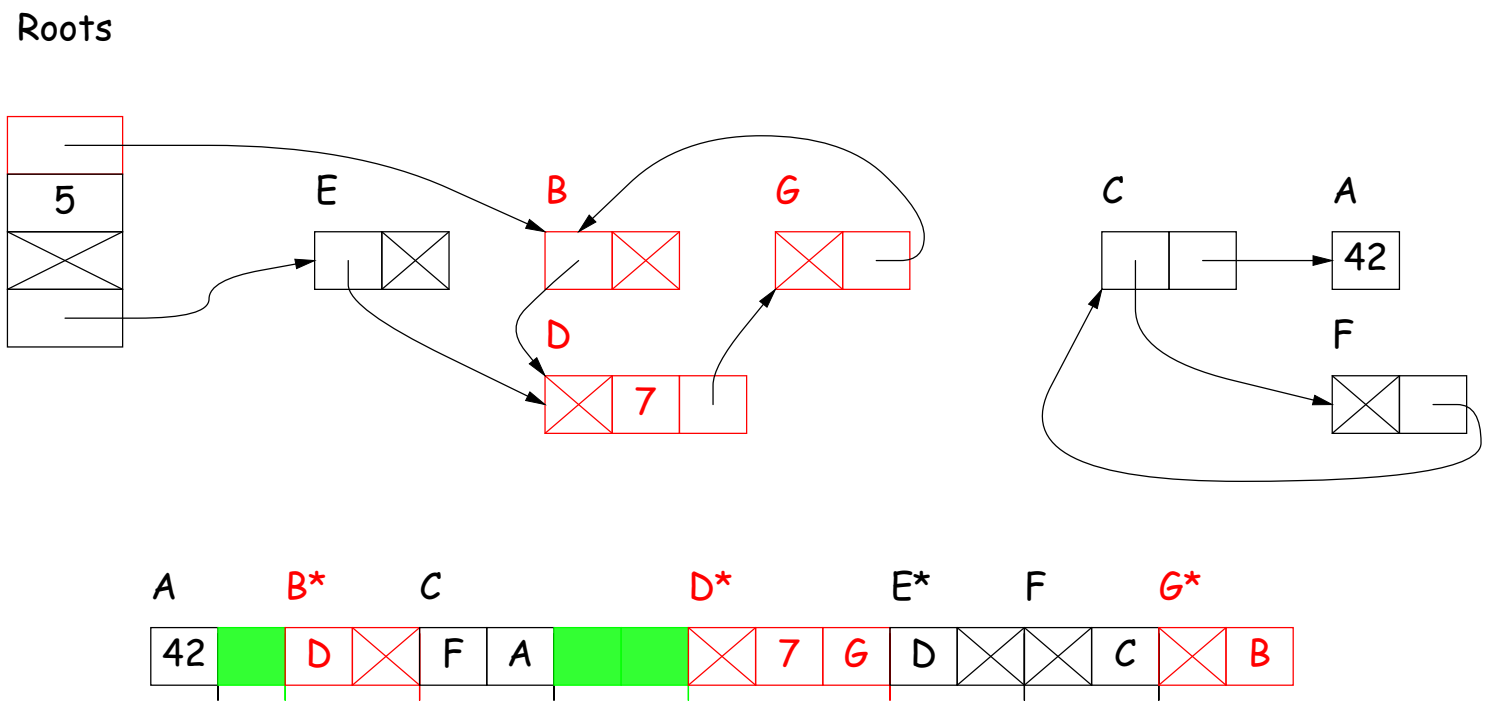

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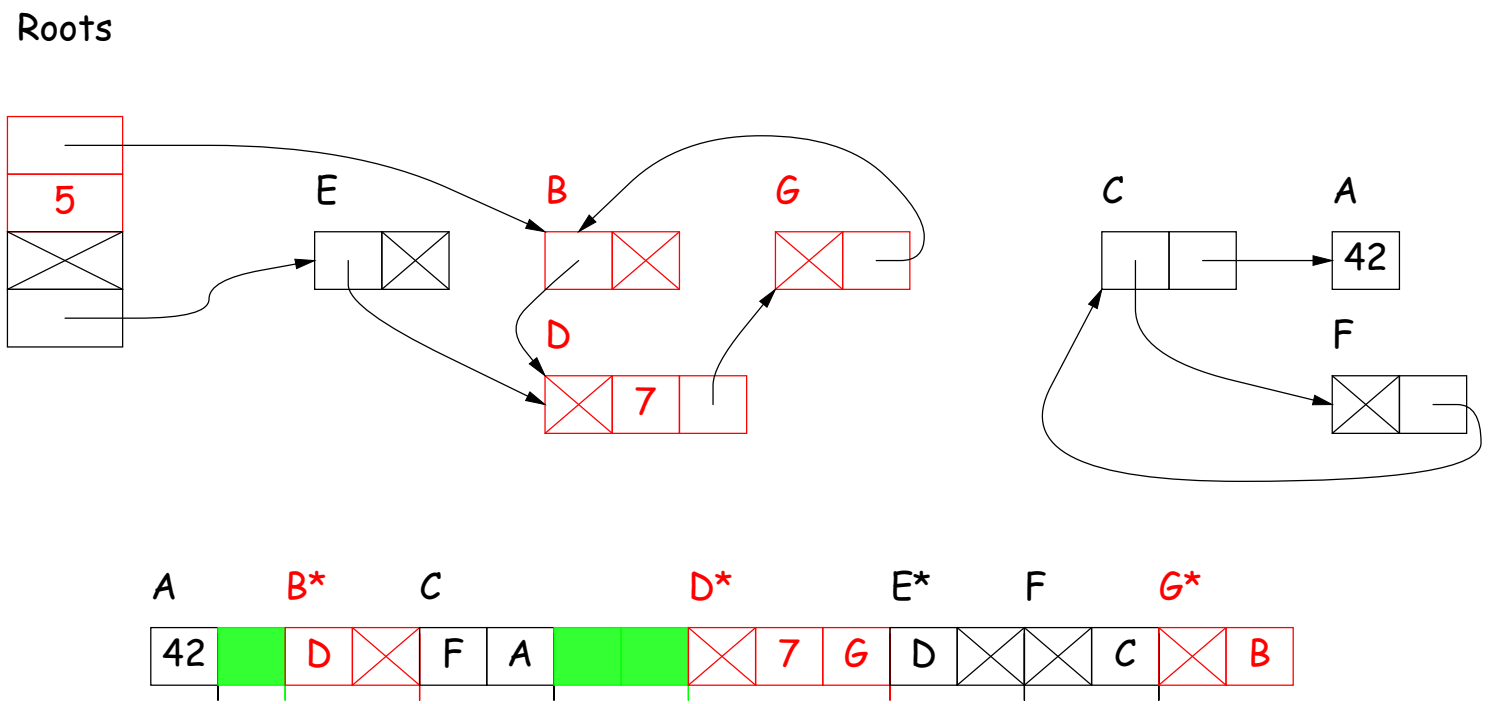

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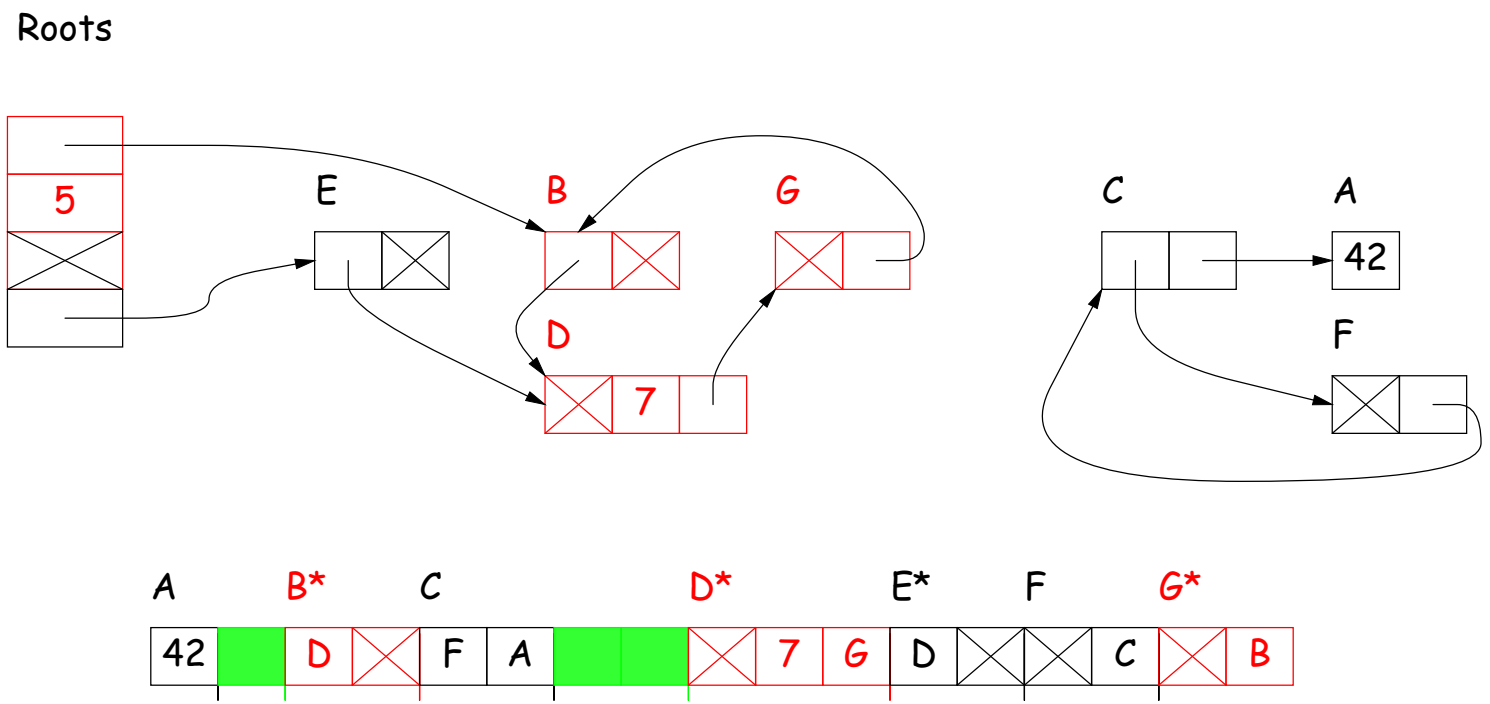

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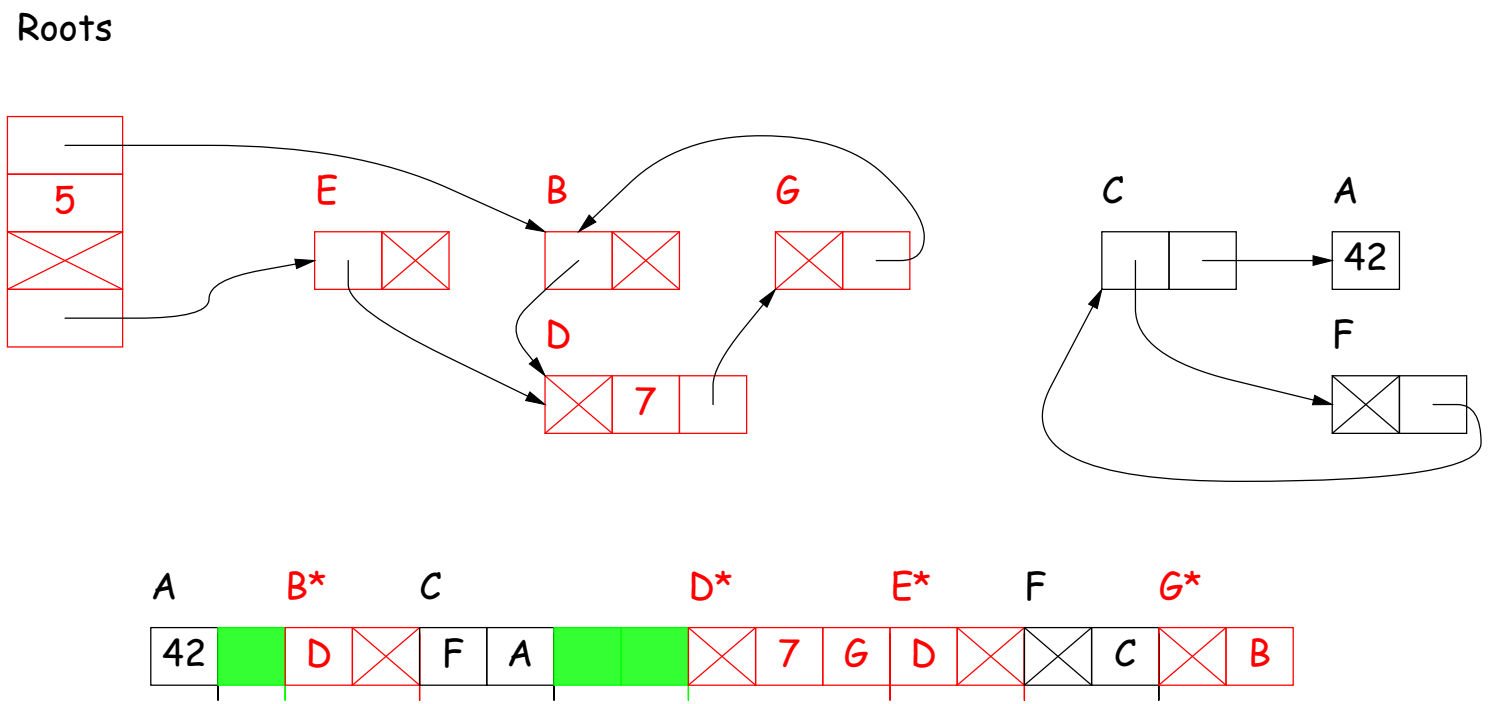

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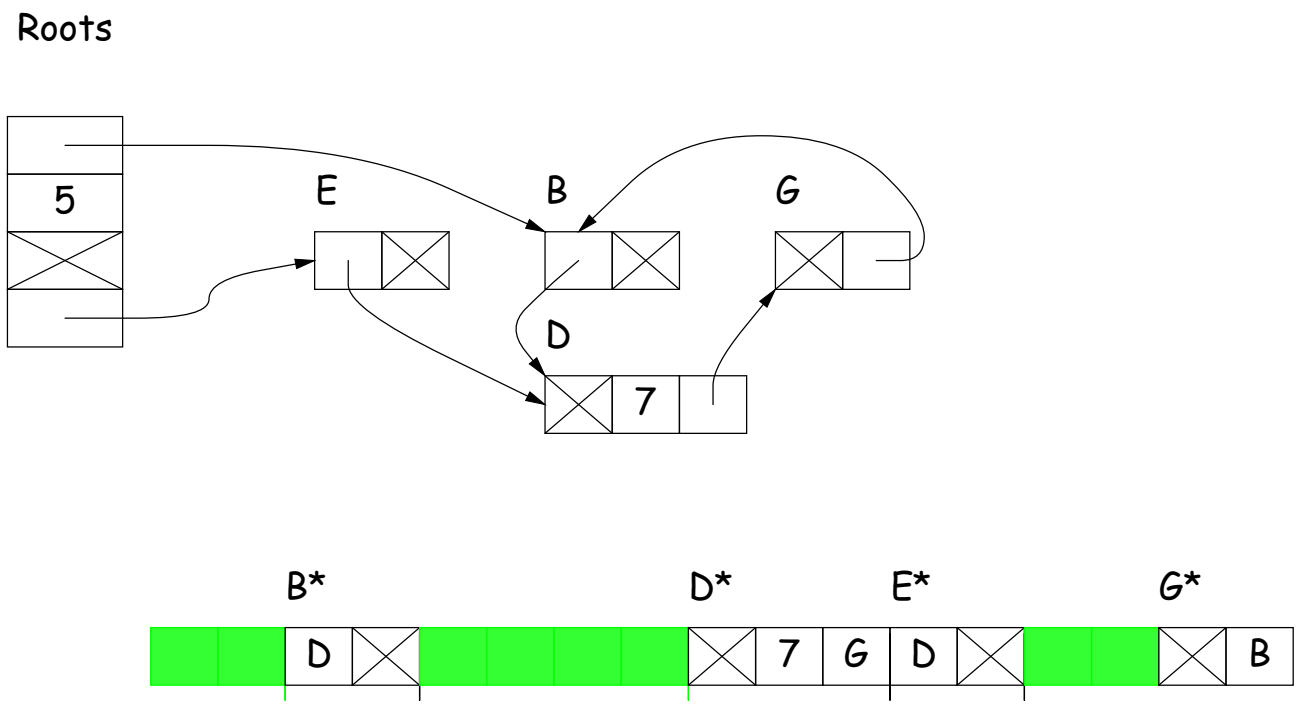

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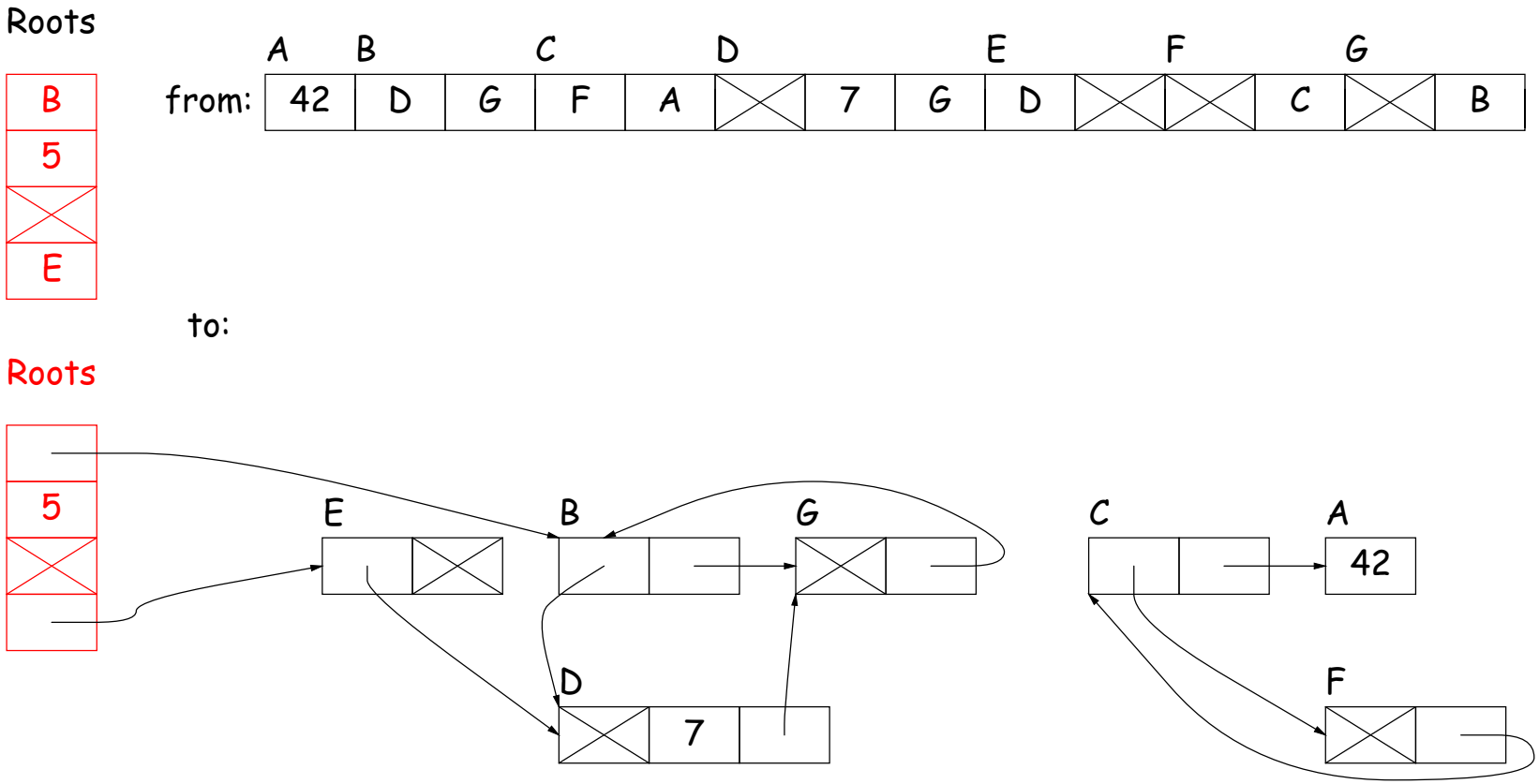
Copying Garbage Collection

- Copy (and move) only reachable (useful) storage from 'from' space to 'to' space.
- The 'from' and 'to' areas are called *semispaces*. Need twice the virtual memory you actually use.
- As you copy, mark 'from' storage as moved, and leave behind a *forwarding pointer* that tells how to translate other references to the old storage.
- At end of algorithm, 'from' and 'to' swap roles, and the old 'from' area is freed *en masse*.
- Copied storage is *compacted* (gaps squeezed out) with possible advantages for memory access.

Copying Garbage Collection, Illustrated



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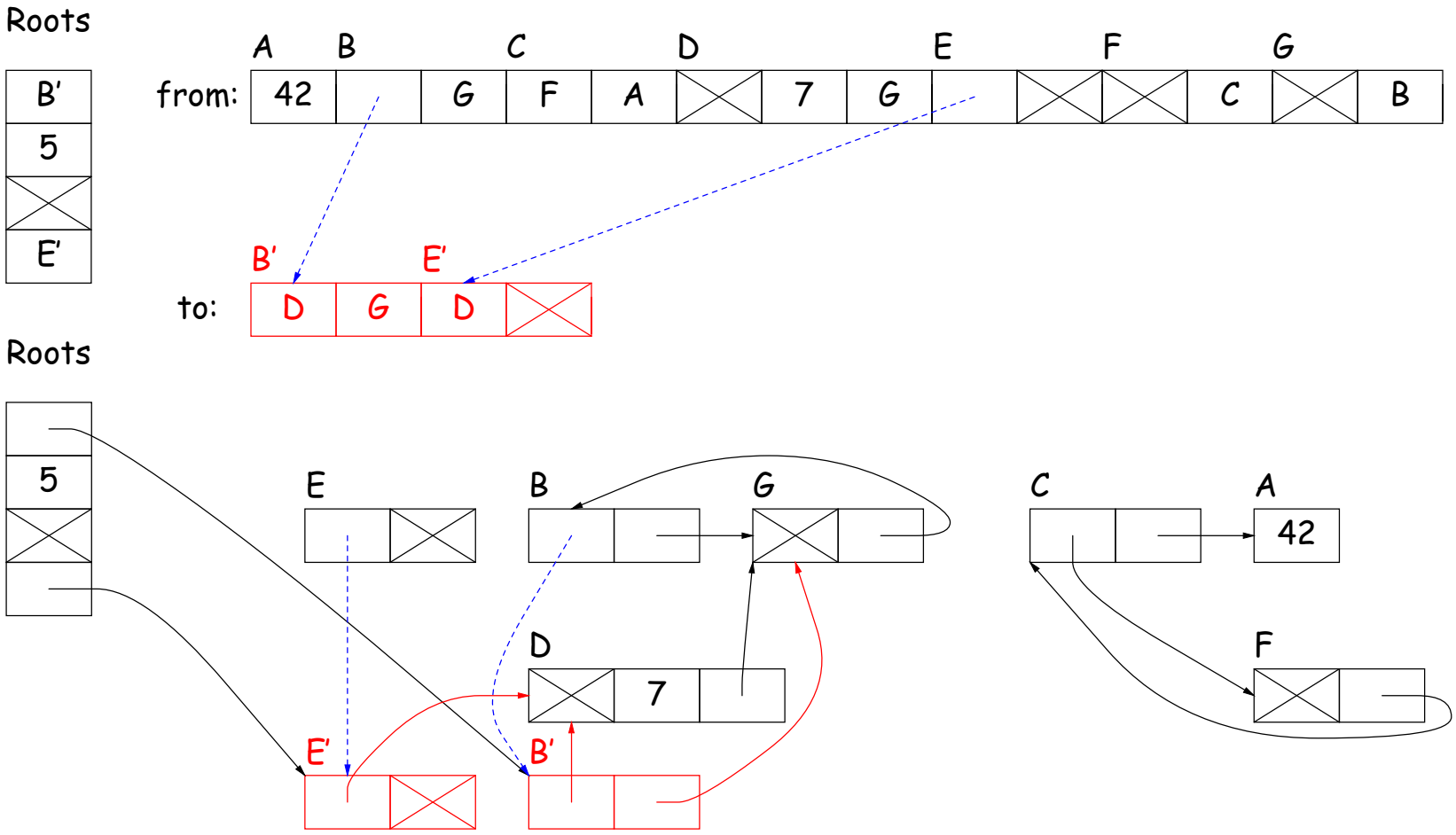

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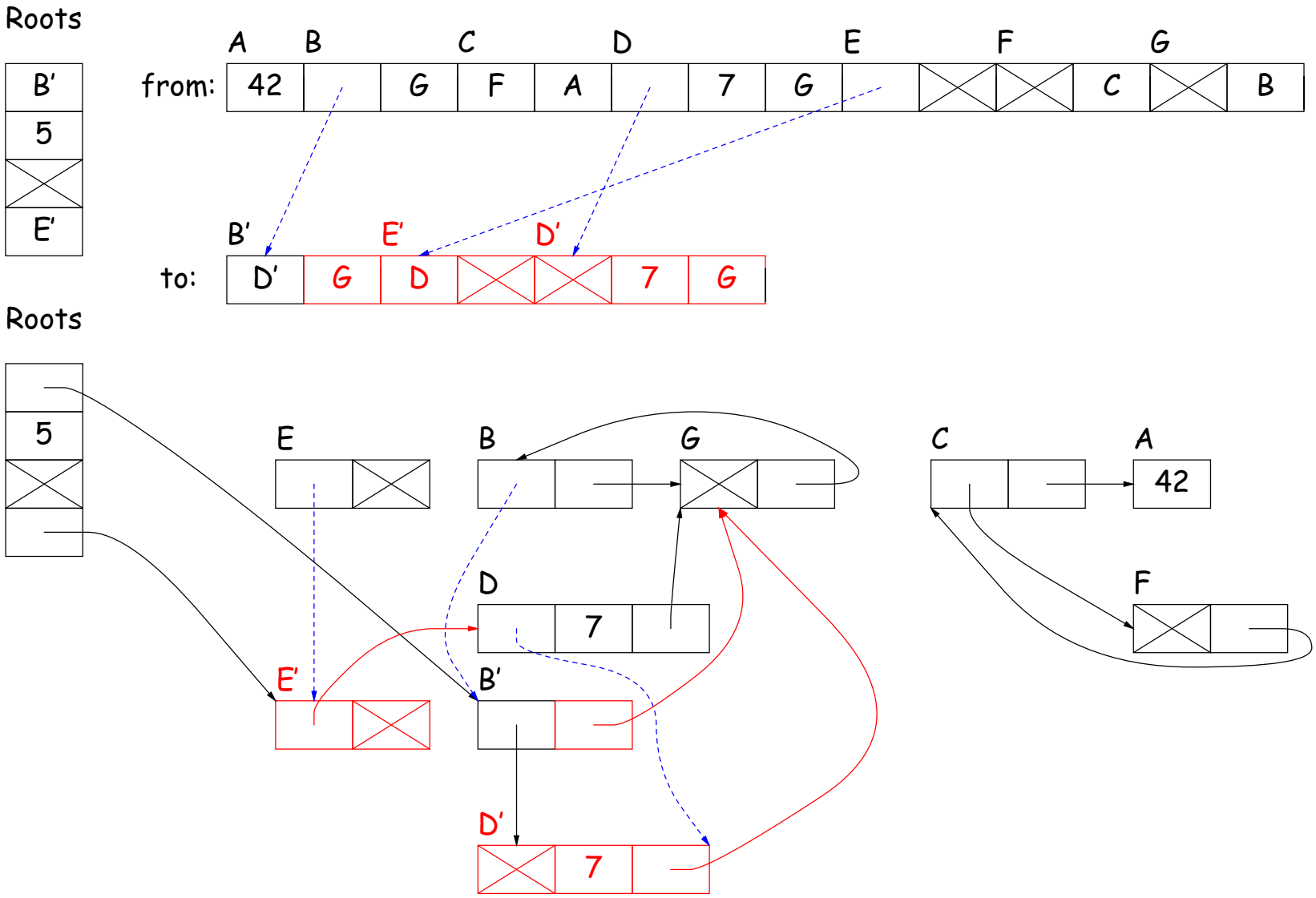

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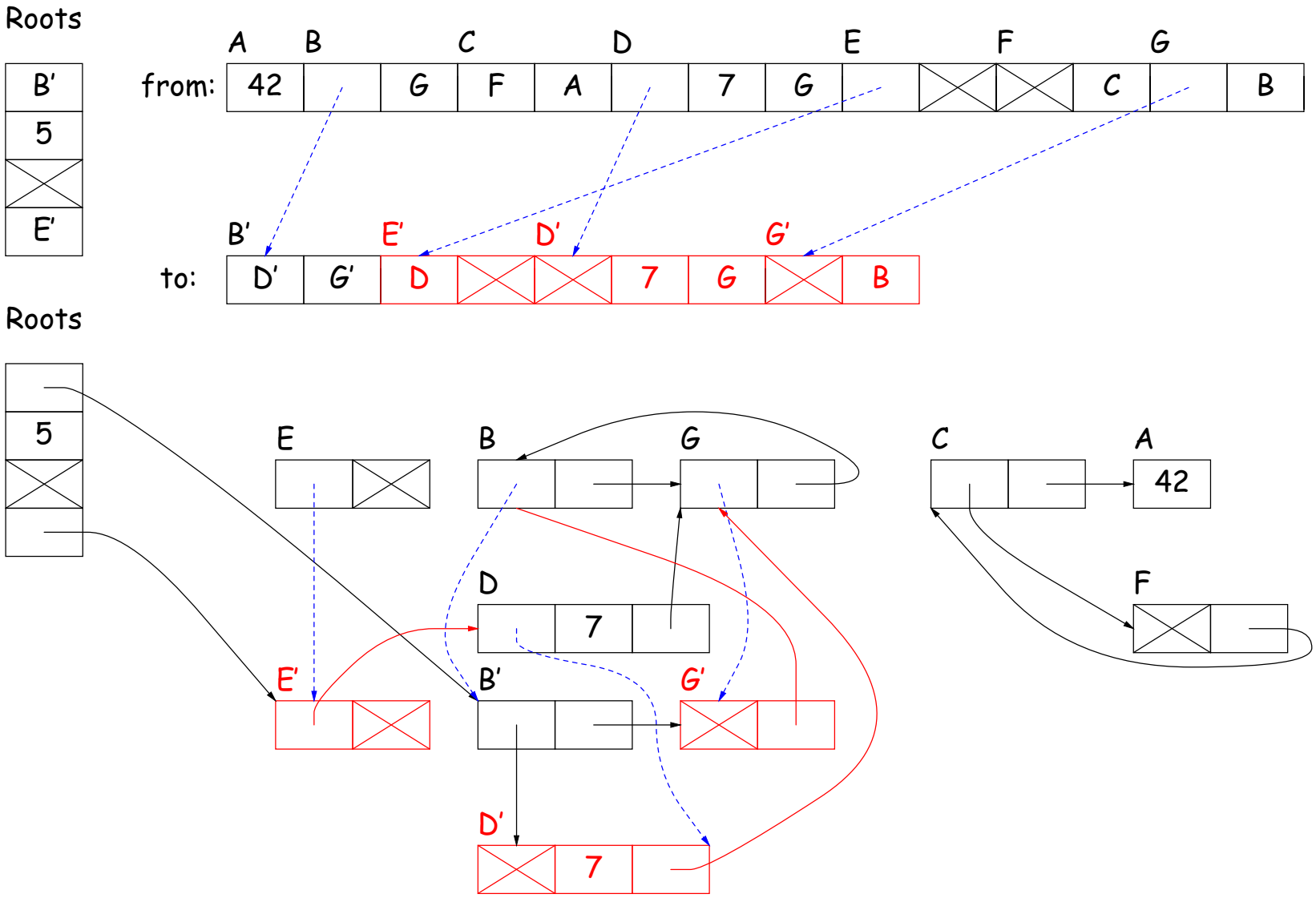

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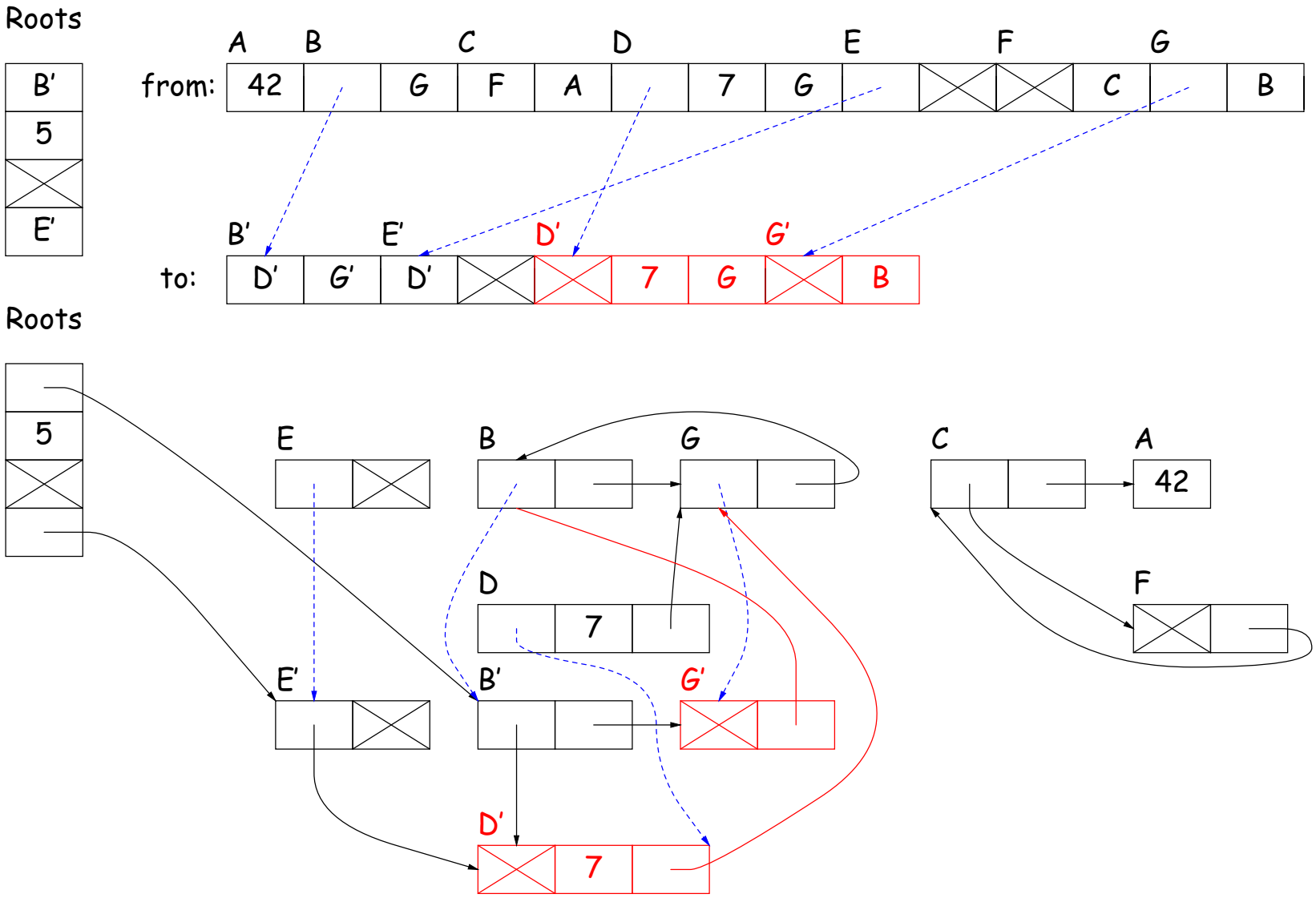

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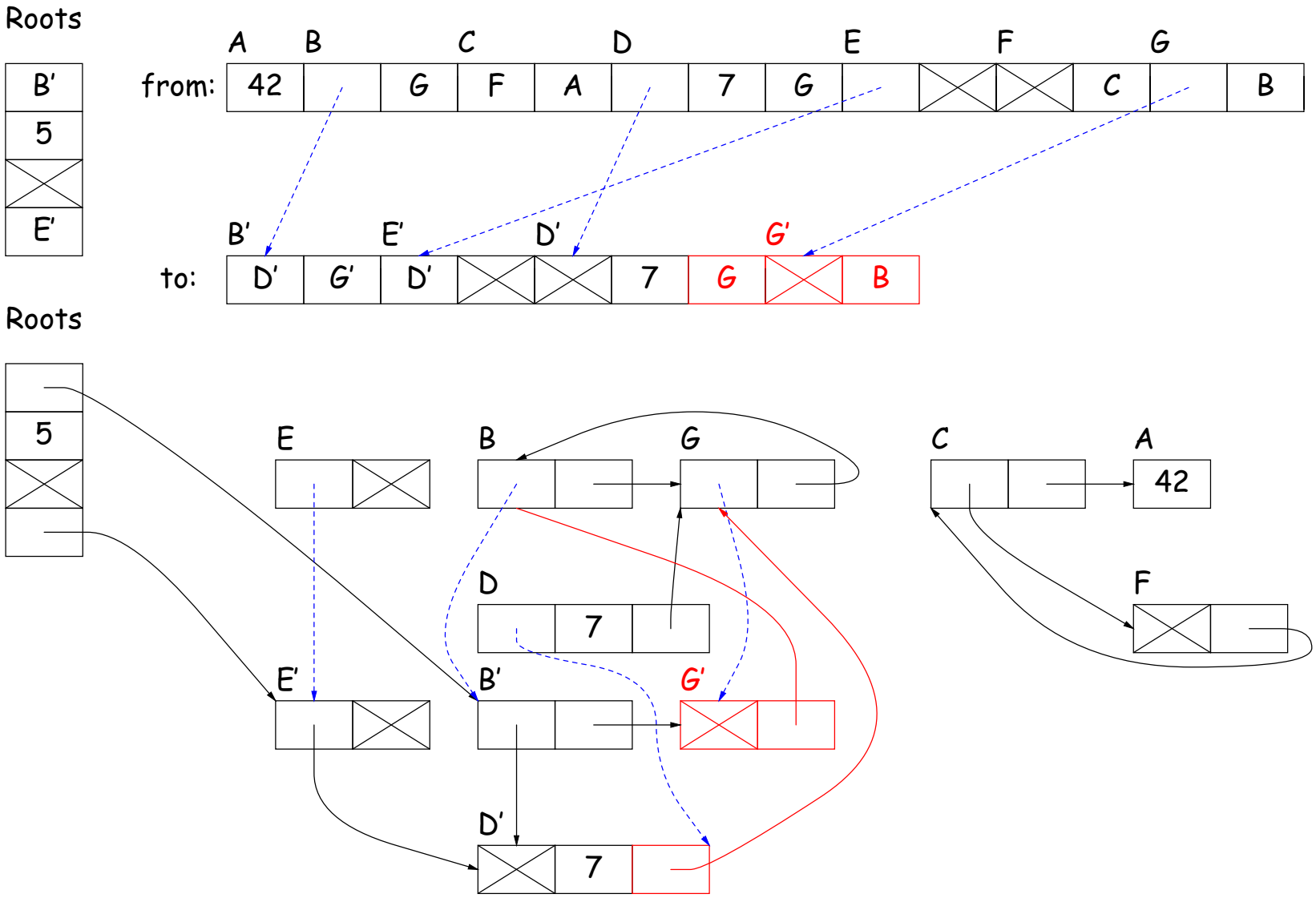

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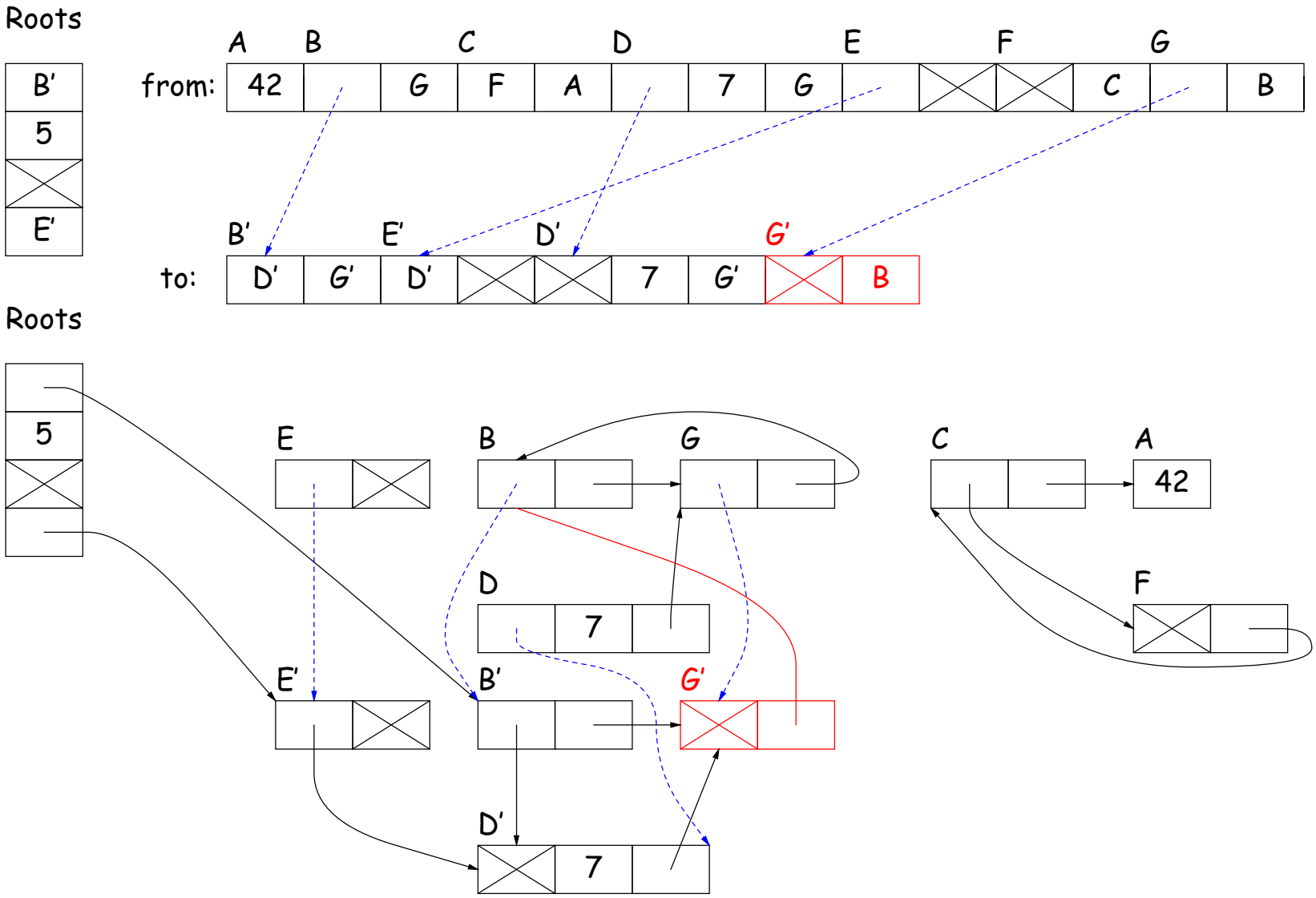

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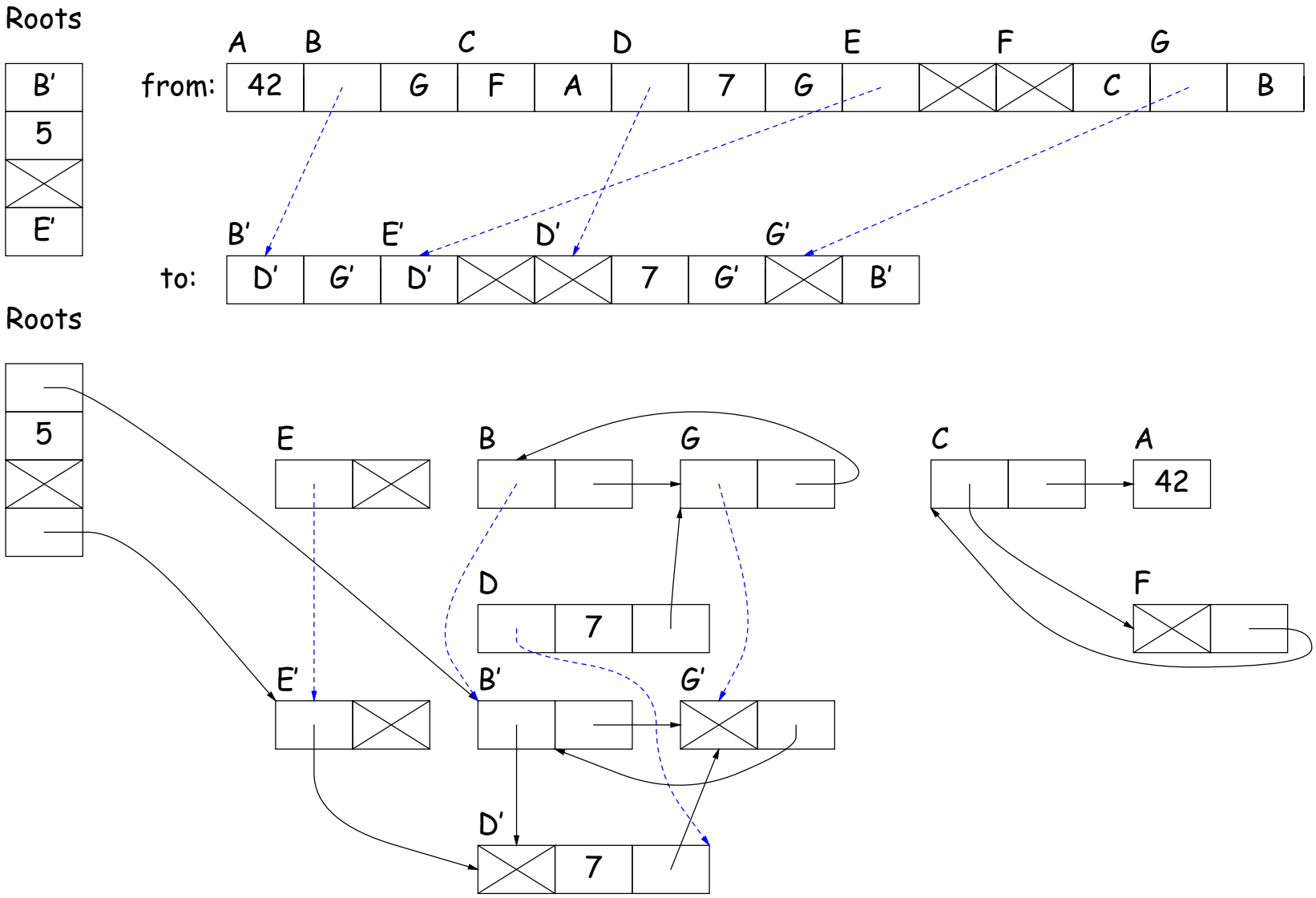

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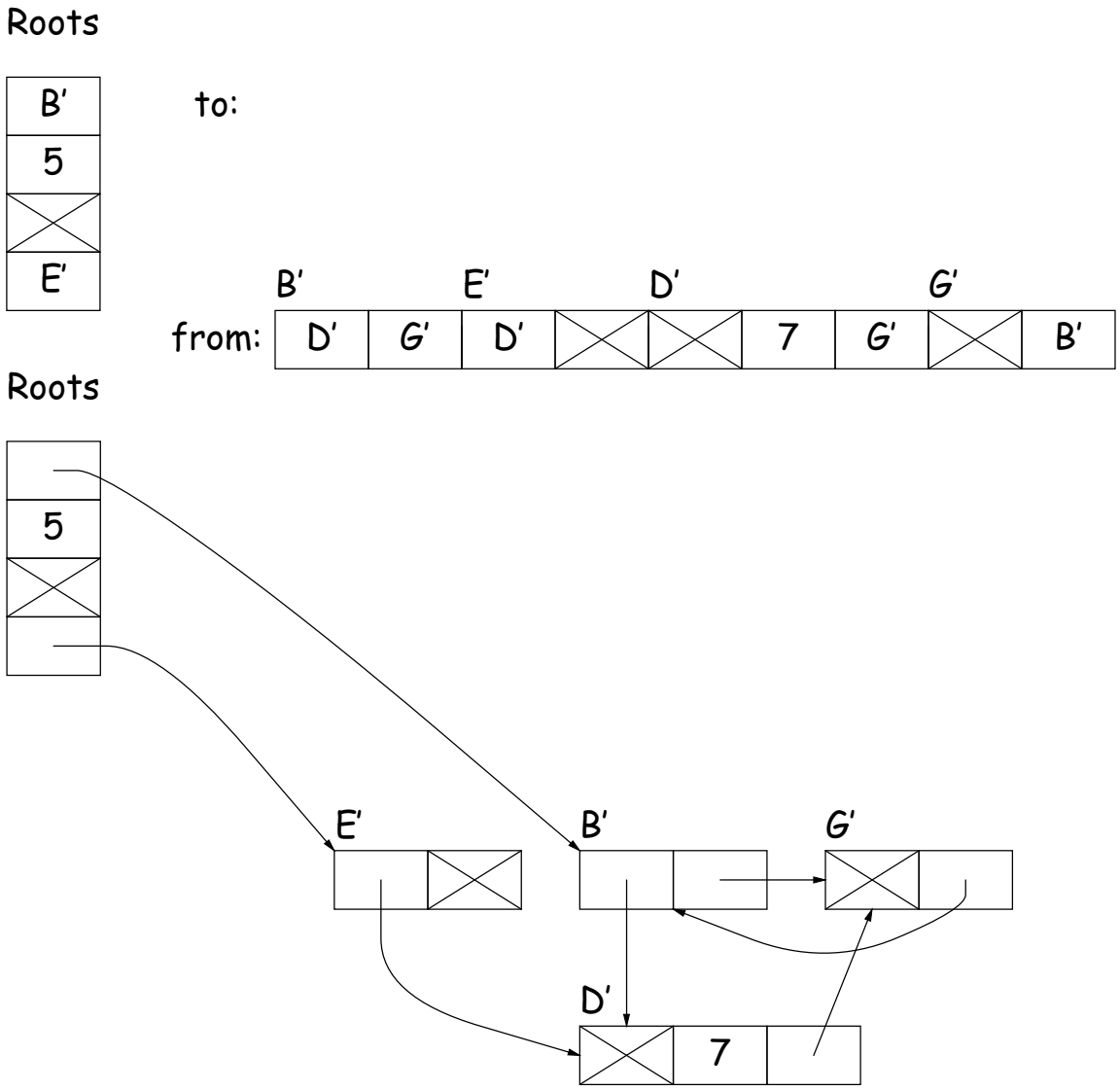


Roots and Other Pointers

- Above methods require that we know locations of roots and of pointer fields in objects.
- Positions of some roots change during execution.
- Compiler keeps tables mapping PC to where roots are.
- Runtime type information (virtual tables) keep information of where pointer fields are.
- Implementation must guarantee that fields are initialized.

Conservative Garbage Collection

- With C, you have none of the needed information.
- But easy to know the addresses of allocated storage, and sizes of allocated objects (allocator keeps them around).
- So, guess that any word that looks like an address of allocated storage is a valid address.
- Do mark-and-sweep on this assumption (look at whole stack and static storage for roots).
- Marks some garbage, but can be surprisingly effective.

Generational Garbage Collection

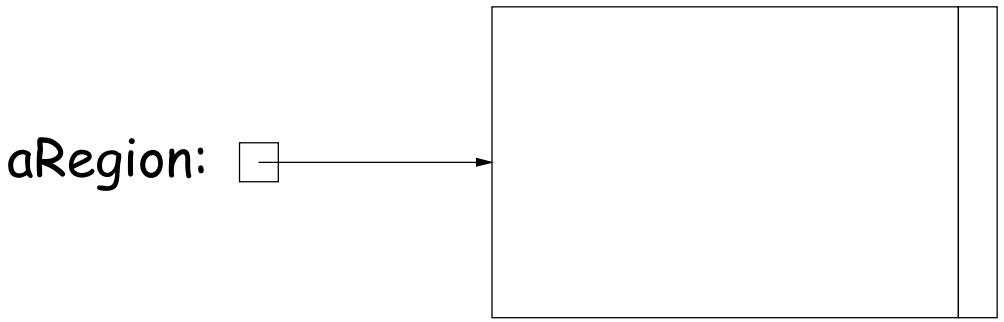
- Heap storage tends to "die young."
- So divide memory into young and old storage, and do copying only on young storage.
- Must add old storage that points to young storage to roots.
- When young storage survives a GC (or two), move it to old storage.
- Every now and then, stop the world and do a full garbage collection.
- This technique significantly speeds up GC.

Region-Based Allocation

- Garbage collection (all forms) does incur overheads, which can be unpredictable,
- While manual freeing is prone to error and inconvenient.
- One compromise is *region-based allocation*.
- Idea:
  - Create a data structure known as a region (or zone, or arena, or various other names).
  - Provides two operations: allocate object, and free *all* objects.
- Thus, to perform calculation that creates lots of temporary heap objects,
  - Create region (a local variable).
  - Allocate all the temporary storage in this region.
  - Delete whole region at end.

Region Implementation

- Simple implementation: allocate storage in big blocks, and allocate objects sequentially in the blocks.
- Freeing all blocks frees all the objects quickly.



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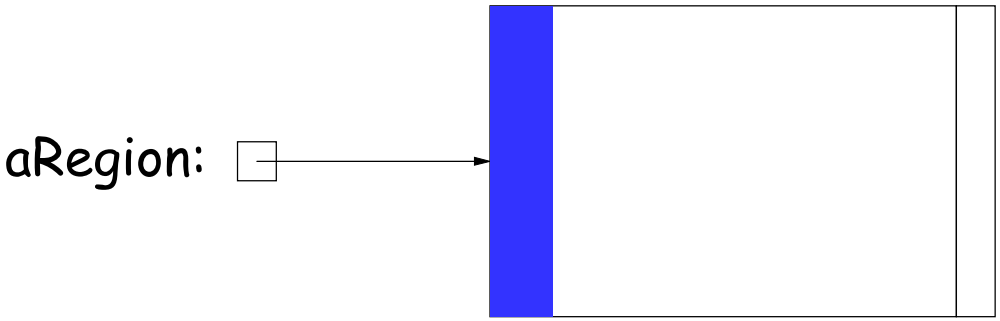


```
x = aRegion.alloc (40);
```

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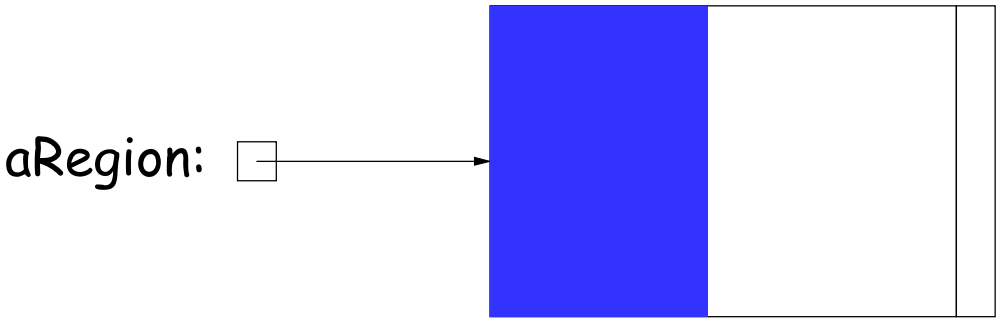


```
x = aRegion.alloc (40);
y = aRegion.alloc (100);
```

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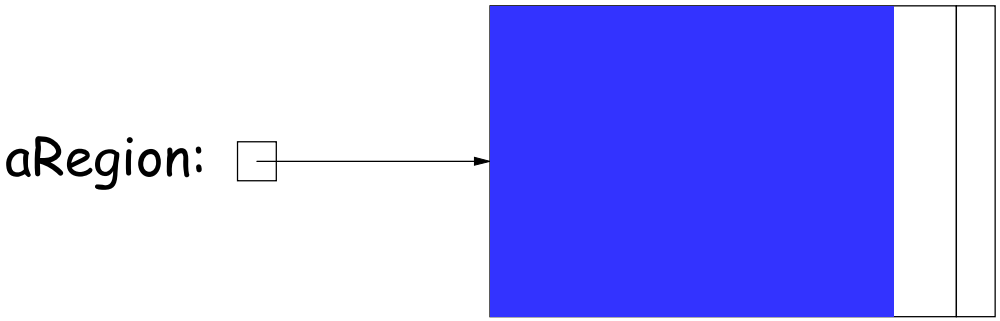


```
x = aRegion.alloc (40);
y = aRegion.alloc (100);
z = aRegion.alloc (120);
```

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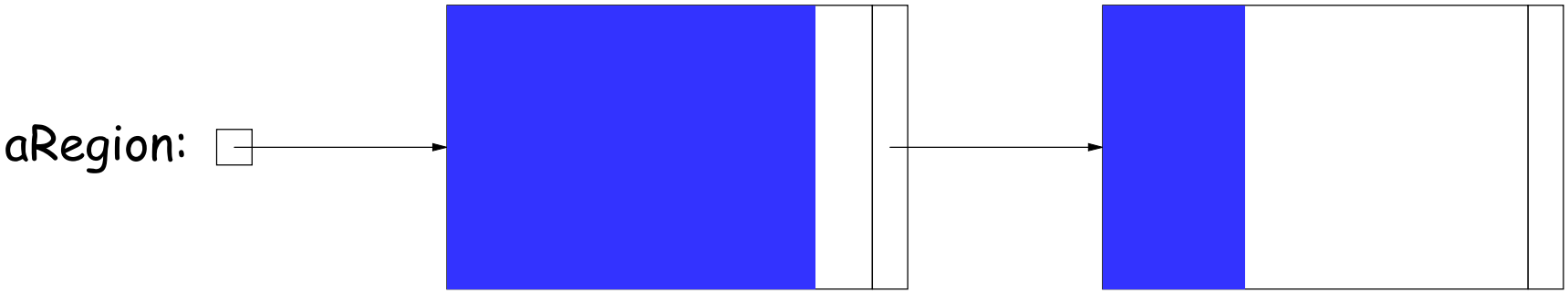


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x = aRegion.alloc (40);
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z = aRegion.alloc (120);
v = aRegion.alloc (100);
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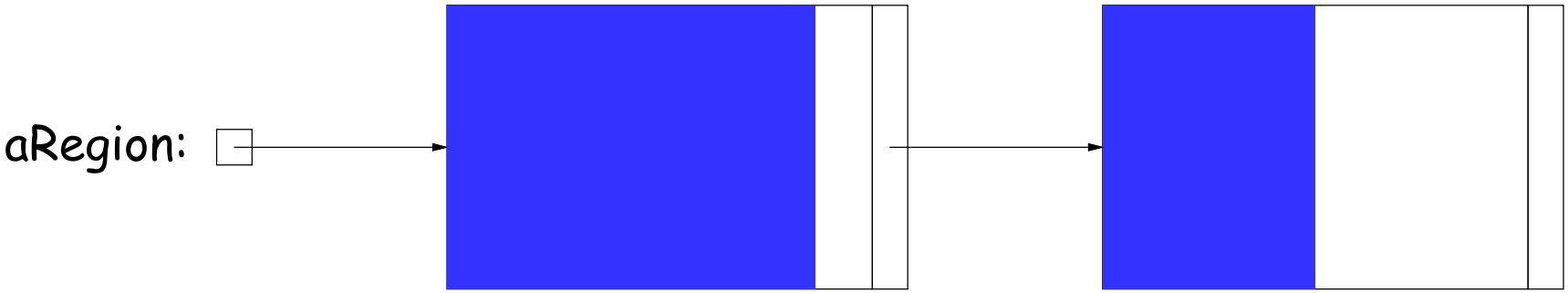


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v = aRegion.alloc (100);
w = aRegion.alloc (50);
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aRegion: 

```
x = aRegion.alloc (40);
y = aRegion.alloc (100);
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aRegion.freeAll ();
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```

- Potential problem: using x, y, z, . . . after freeAll.