CSC 252: Computer Organization
Spring 2022: Lecture 24

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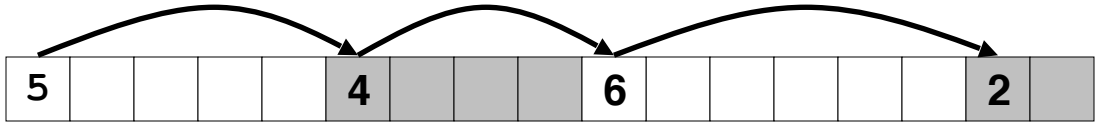
Announcements

- Cache problem set: https://www.cs.rochester.edu/courses/252/spring2022/handouts.html
  - Not to be turned in. Won't be graded.
- Assignment 5 due April 21.

10	11	12	13	14	15	16
				Today		
17	18	19	20	21	22	23
				Due		
24	25	26	27	28	29	30
		Last Lecture				

Keeping Track of Free Blocks

- Method 1: *Implicit list* using length—links all blocks



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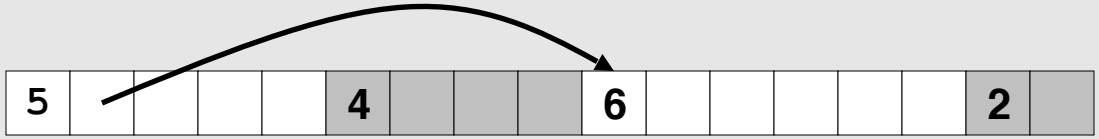
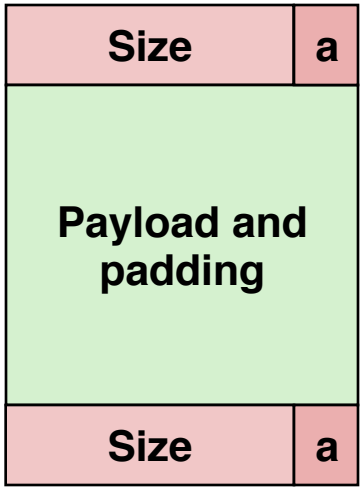


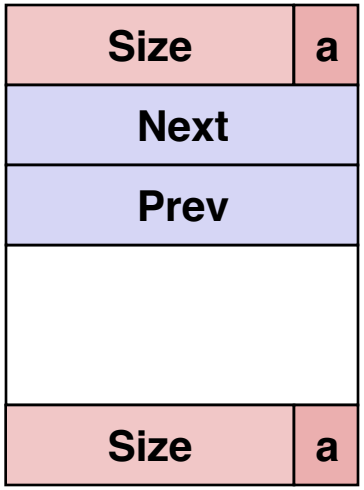
- Method 3: *Segregated free list*
  - Different free lists for different size classes

Explicit Free Lists

Allocated block (same as before)



Free block

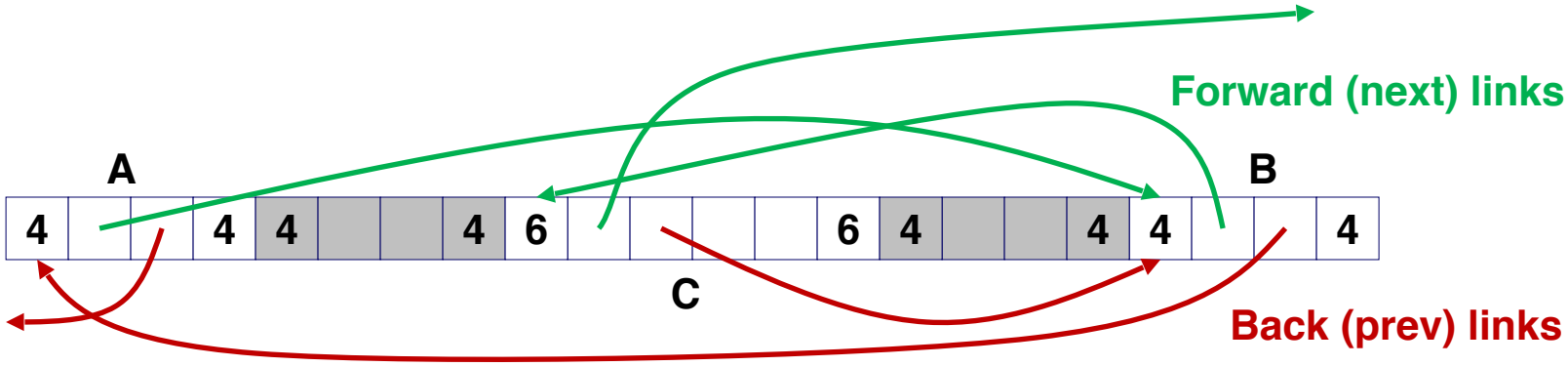


- Maintain list(s) of *free* blocks, not *all* blocks
  - The "next" free block could be anywhere
    - So we need to store forward/back pointers, not just sizes
    - These pointers exist only in free blocks, occupying the would-be payload area, so not really an overhead.
  - Still need boundary tags for coalescing.

Explicit Free Lists

- Logically:

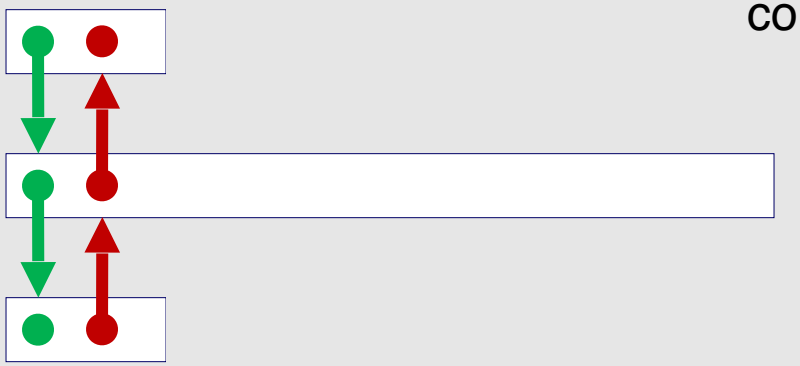
- Physically: blocks can be in any order



Allocating From Explicit Free Lists

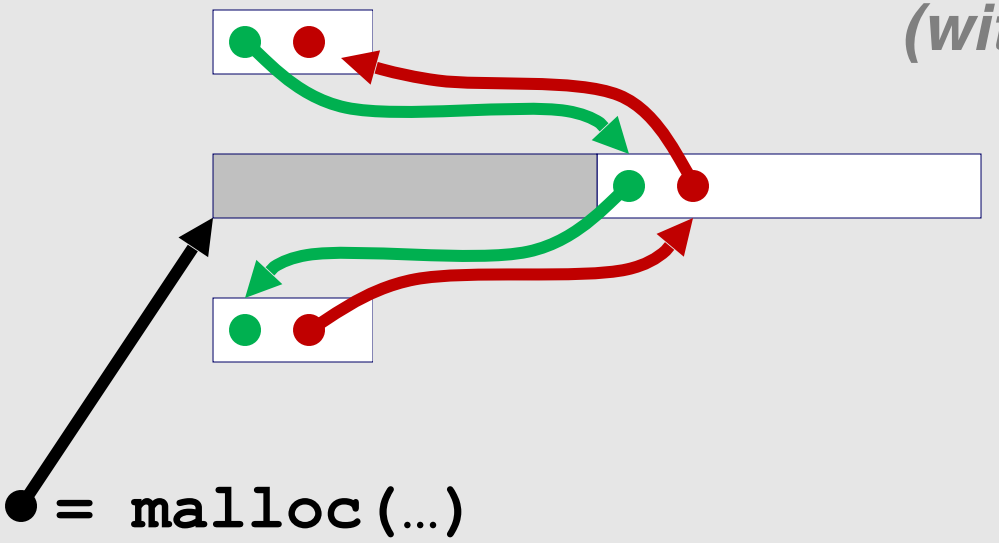
Before

conceptual graphic



After

(with splitting)



Freeing With Explicit Free Lists

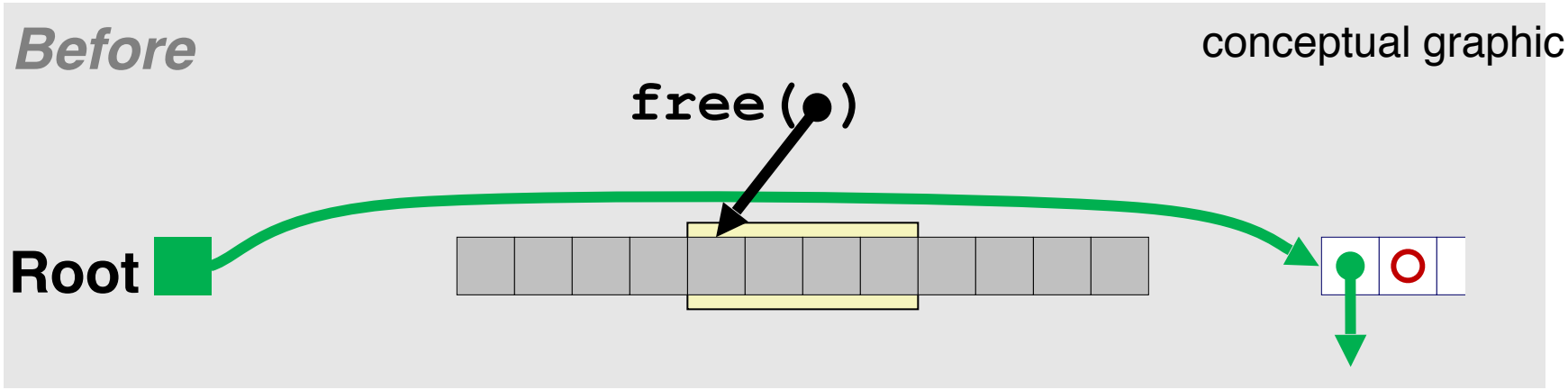
- *Insertion policy*: Where in the free list do you put a newly freed block?
- LIFO (last-in-first-out) policy
  - Insert freed block at the beginning of the free list
  - *Pro:* simple and constant time
  - *Con:* studies suggest fragmentation is worse than address ordered

- Address-ordered policy
  - Insert freed blocks so that free list blocks are always in address order:

    addr(prev) < addr(curr) < addr(next)
  - ***Con:*** requires search
  - ***Pro:*** studies suggest fragmentation is lower than LIFO

Freeing With a LIFO Policy (Case 1)

- Insert the freed block at the root of the list



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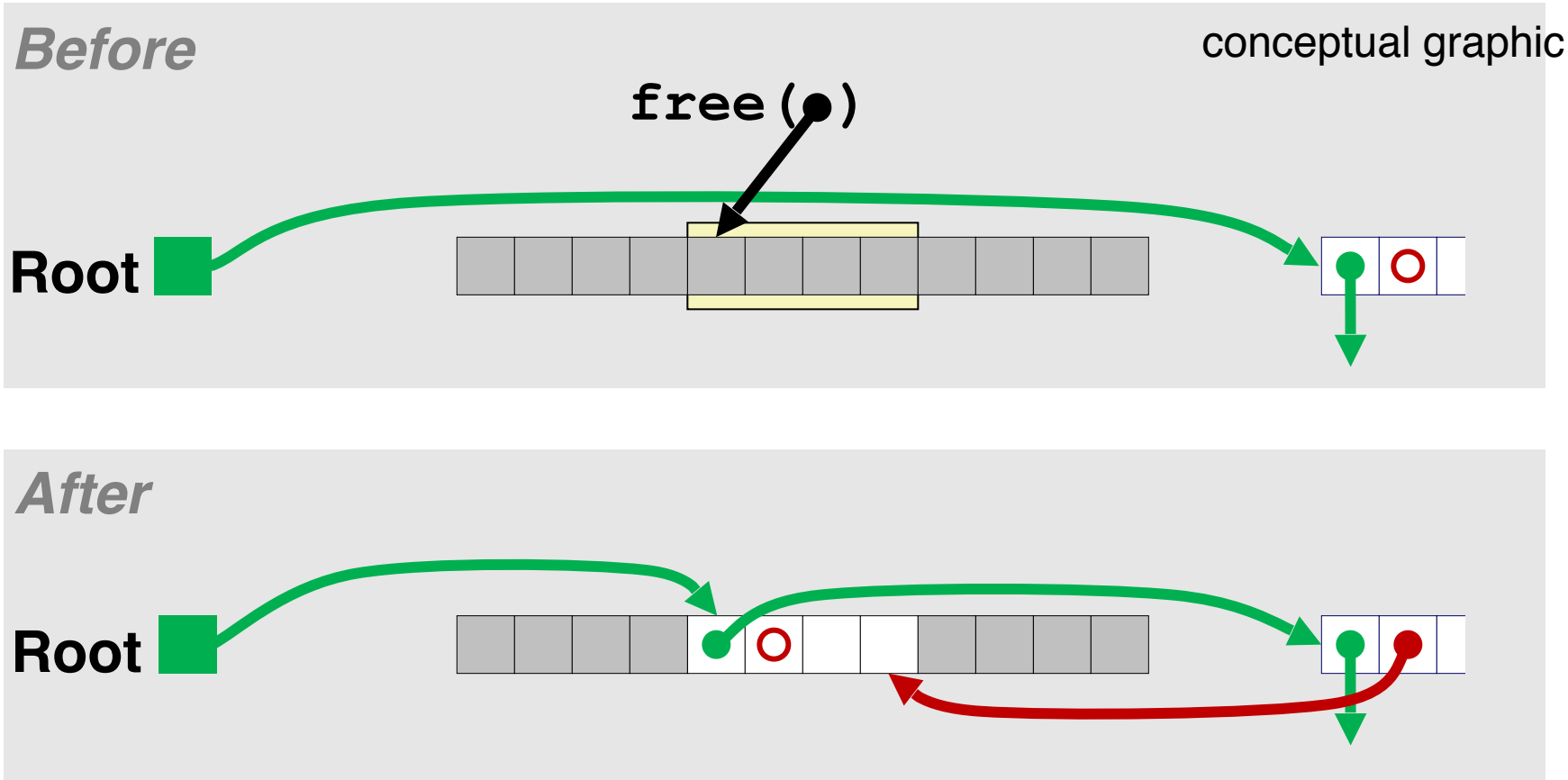
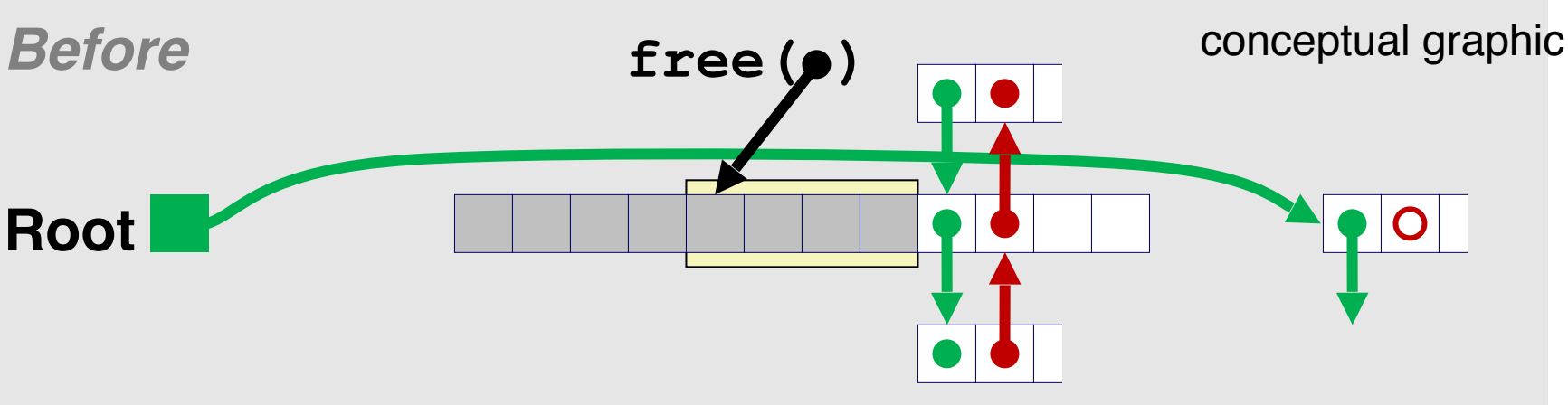


Freeing With a LIFO Policy (Case 2)

- Splice out successor block, coalesce both memory blocks and insert the new block at the root of the list



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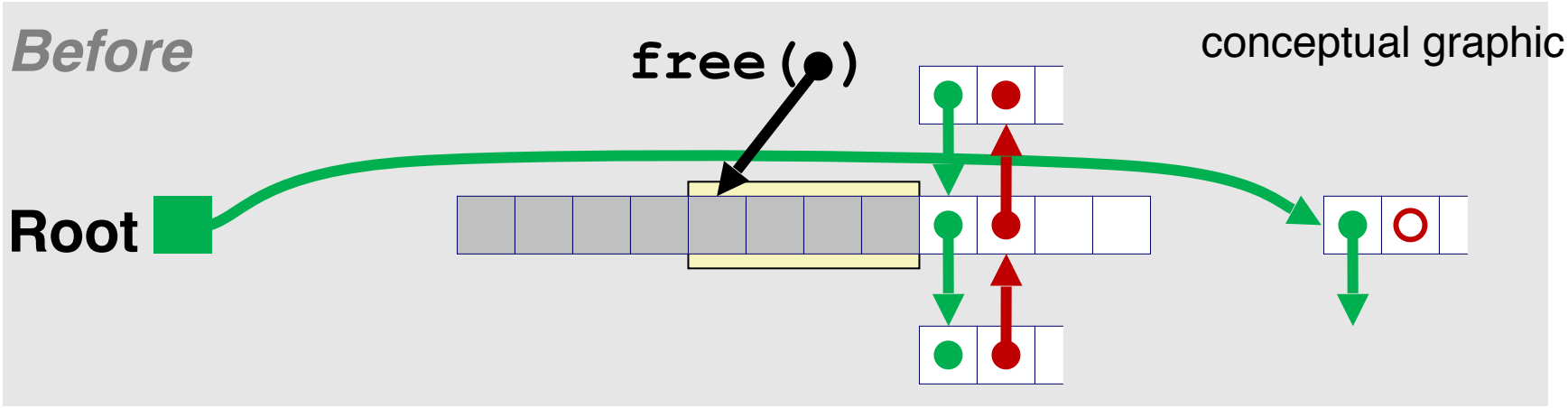

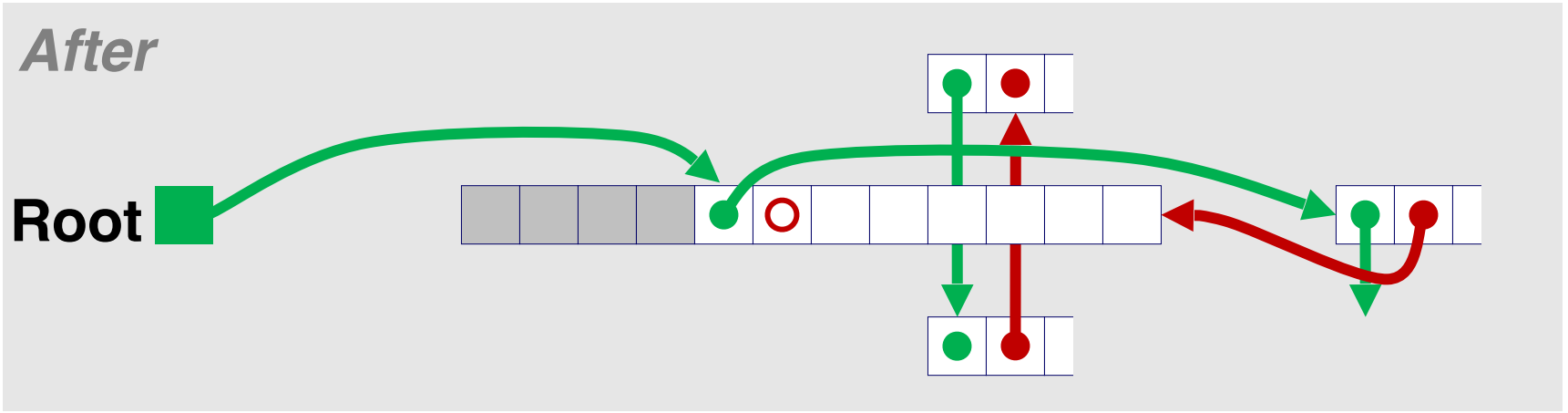

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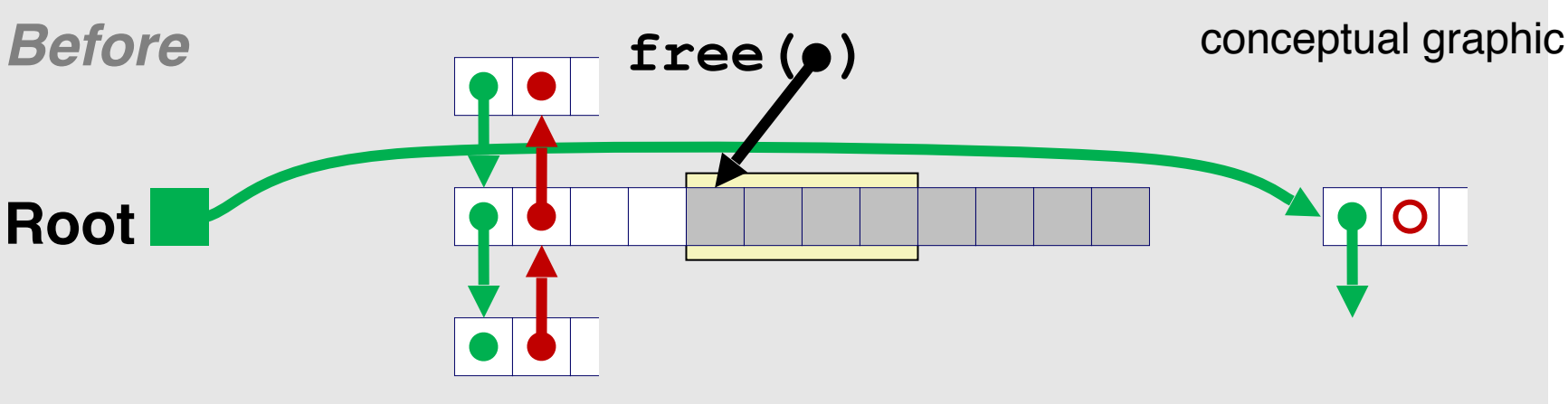

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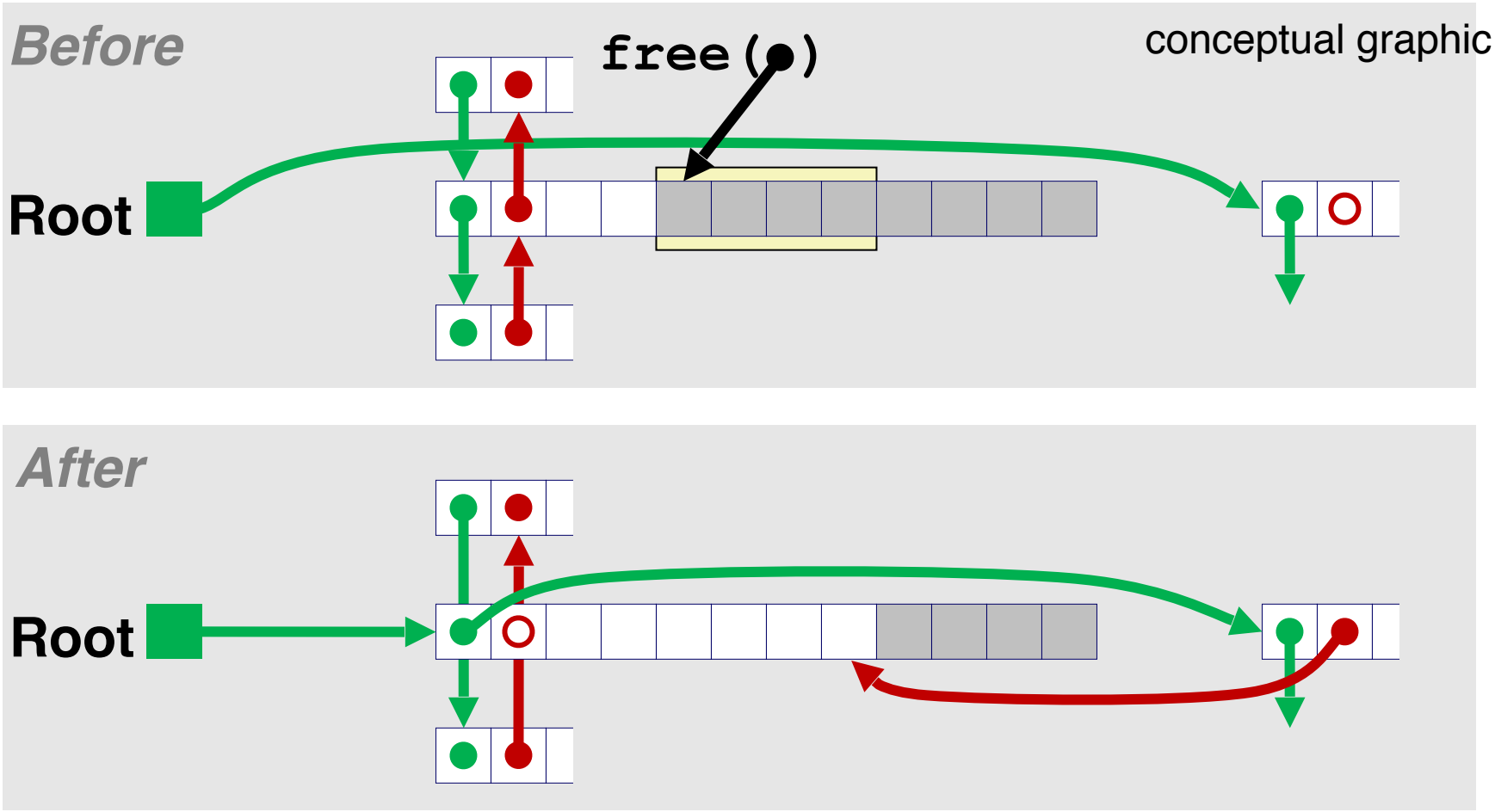
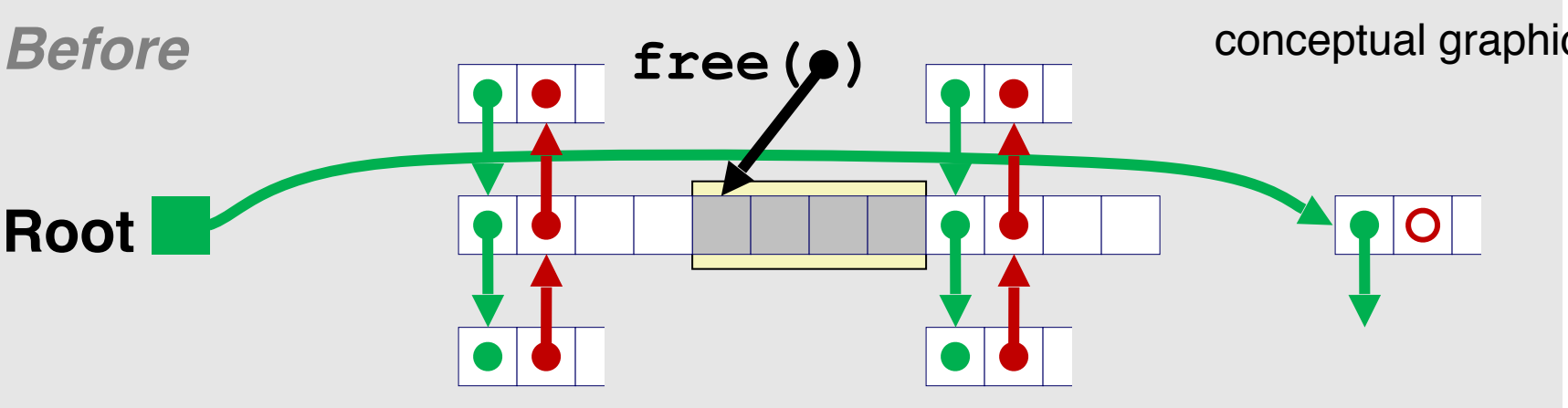


Freeing With a LIFO Policy (Case 4)

- Splice out predecessor and successor blocks, coalesce all 3 memory blocks and insert the new block at the root of the list



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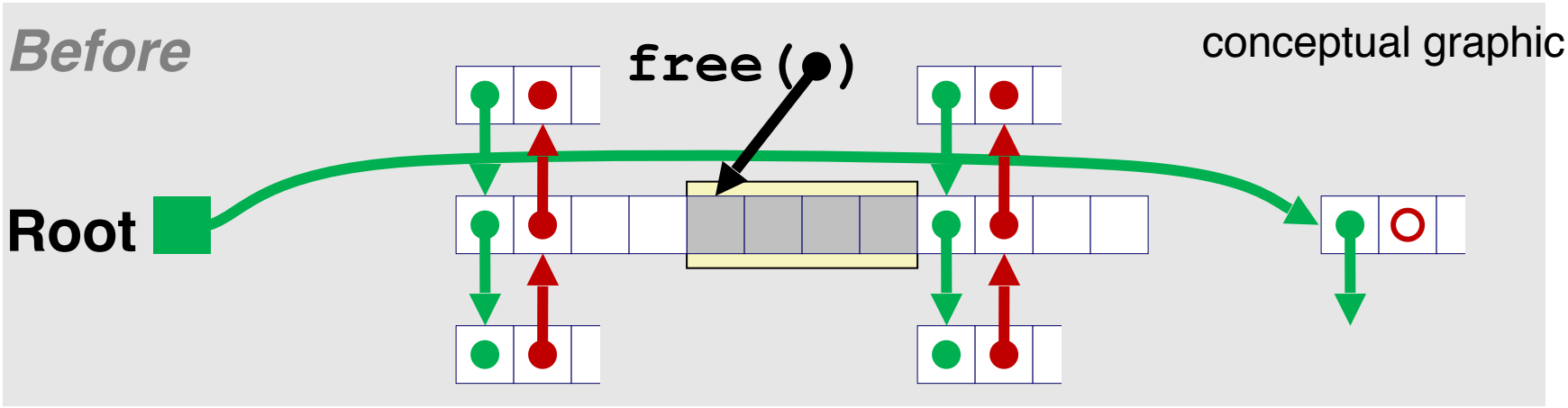
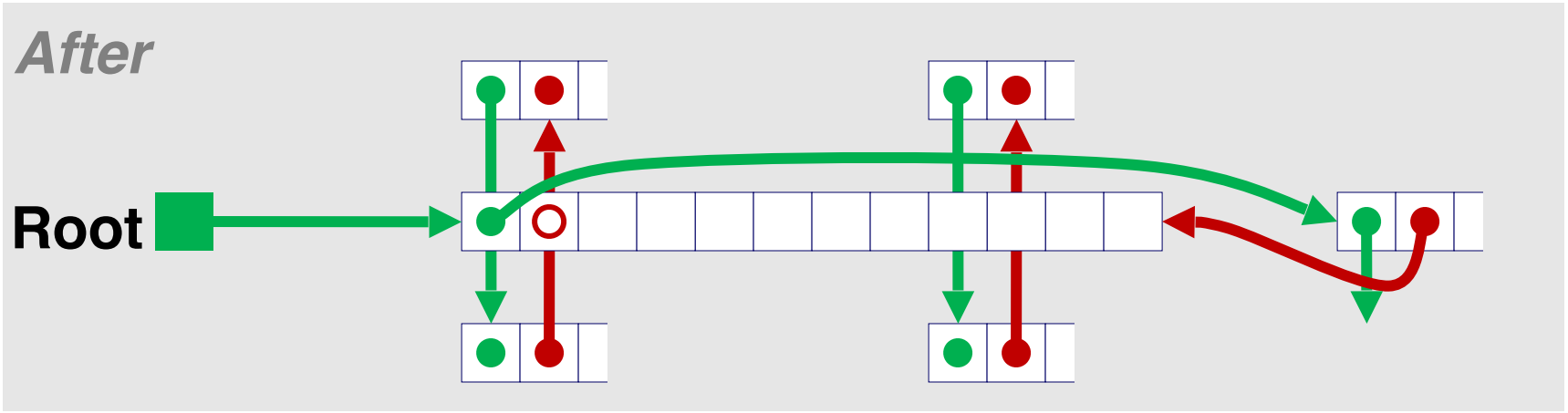


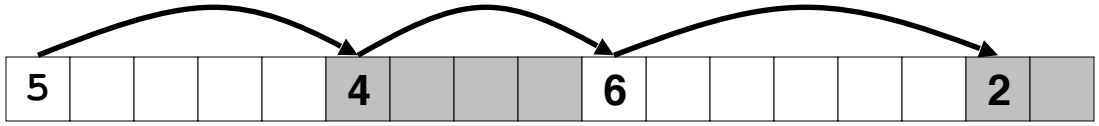


Explicit List Summary

- Comparison to implicit list:
  - Allocate is linear time in number of free blocks instead of all blocks. Much faster when most of the memory is full.
  - Slightly more complicated allocate and free since needs to splice blocks in and out of the list
  - Some extra space for the links in free blocks (2 extra words needed for each block).

Keeping Track of Free Blocks

- Method 1: *Implicit list* using length—links all blocks



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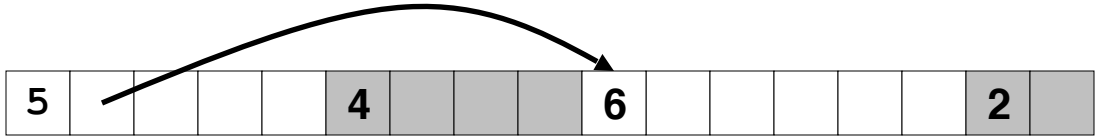

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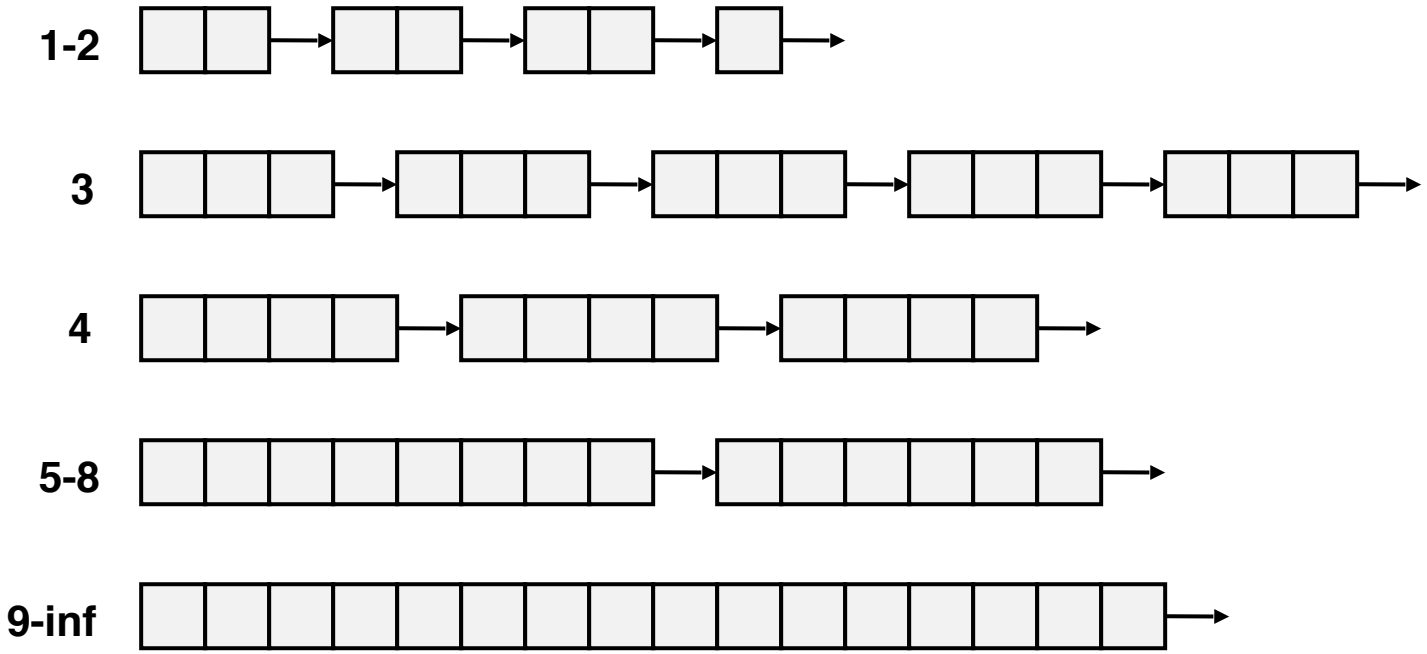
Segregated List (Seglist) Allocators



- Each *size class* of blocks has its own free list
- Organize the Seglist
  - Often have separate classes for each small size
  - For larger sizes: One class for each two-power size (why?)

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  - Remember heap is in VM, so request heap memory in pages
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- To free a block:
  - Coalesce and place on appropriate list

Advantages of Seglist allocators

- Higher throughput
  - Constant time allocation and free for requests that have a dedicated free list (most of the cases)
  - log time for power-of-two size classes (searching the lists)
- Better memory utilization
  - First-fit search of segregated free list approximates a best-fit search of entire heap.
  - Extreme case: Giving each block its own size class is equivalent to best-fit.

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- Common in many dynamic languages:
  - Python, Ruby, Java, JavaScript, Perl, ML, Lisp, Mathematica
- The key: Garbage collection
  - Automatic reclamation of heap-allocated storage—application never has to free

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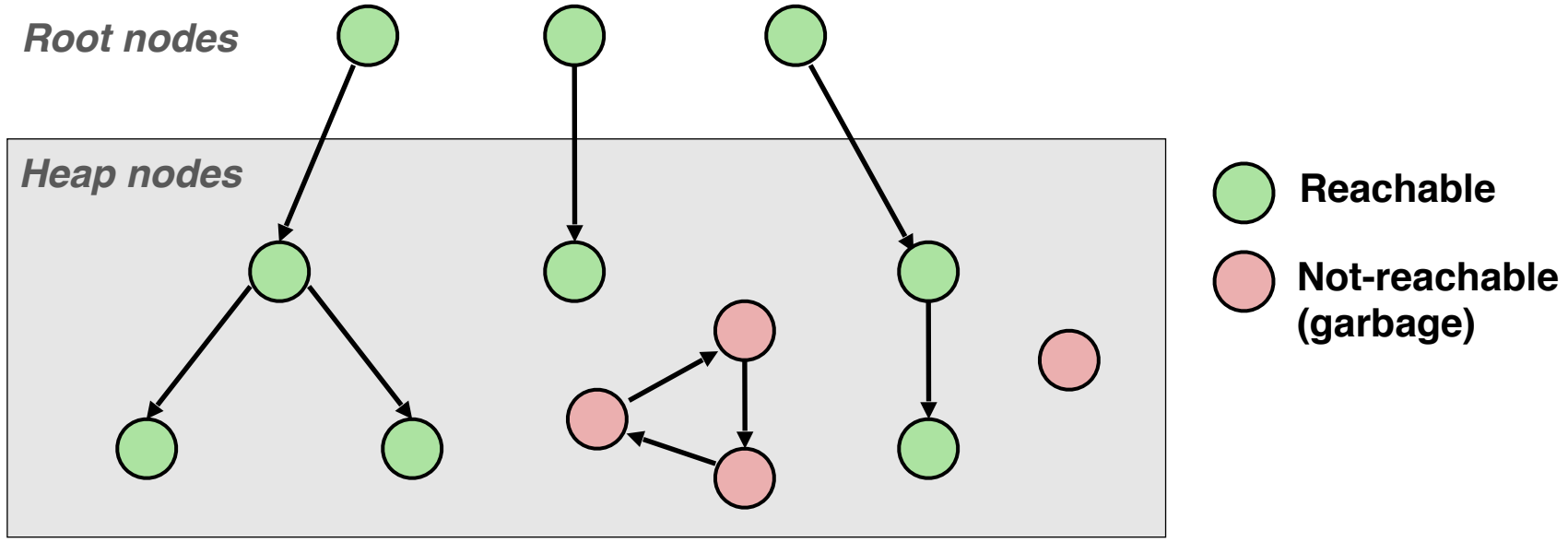
  - But we can tell that certain blocks cannot possibly be used ***if there are no pointers to them***
  - Garbage collection is essentially to obtain all **reachable** blocks and discard unreachable blocks.

Memory as a Graph

- We view memory as a directed graph
  - Each block is a node in the graph
  - Each pointer is an edge in the graph
  - Locations not in the heap that contain pointers into the heap are called ***root*** nodes (e.g. registers, locations on the stack, global variables)

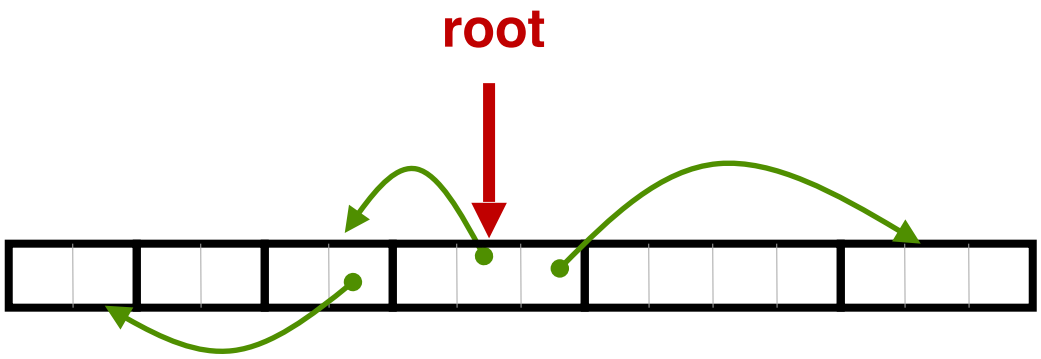


A node (block) is *reachable* if there is a path from any root to that node.

Non-reachable nodes are *garbage* (cannot be needed by the application)

Mark and Sweep Collecting

- Idea:
  - Use extra ***mark bit*** in the header to indicate if a block is reachable
  - *Mark:* Start at roots and set mark bit on each reachable block
  - *Sweep:* Scan all blocks and free blocks that are not marked



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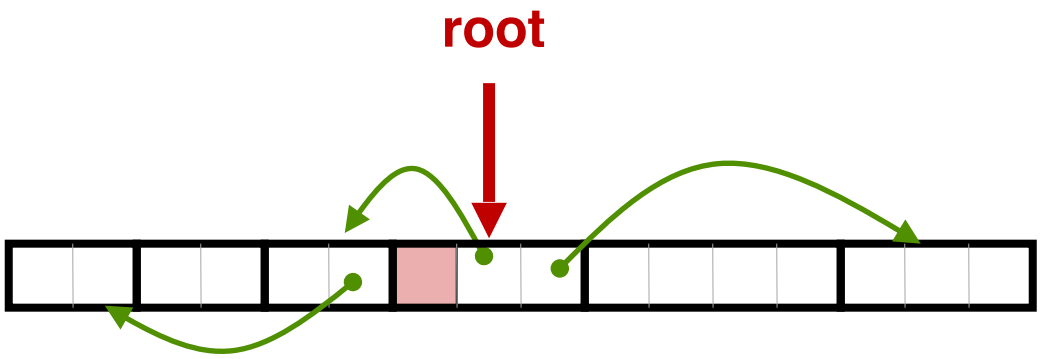

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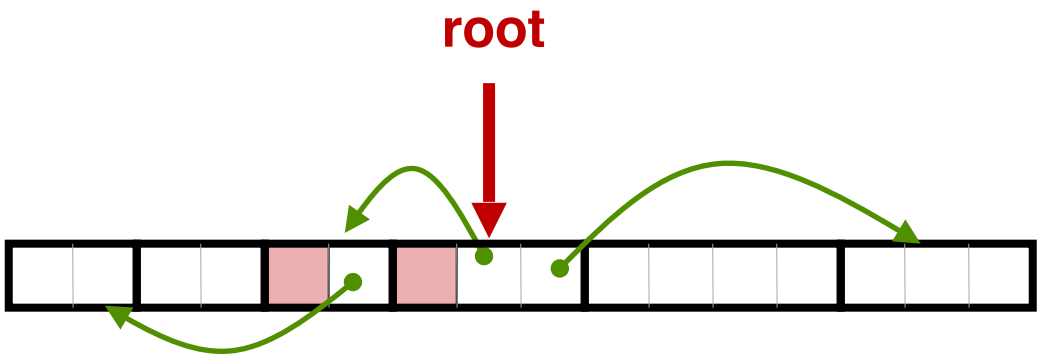

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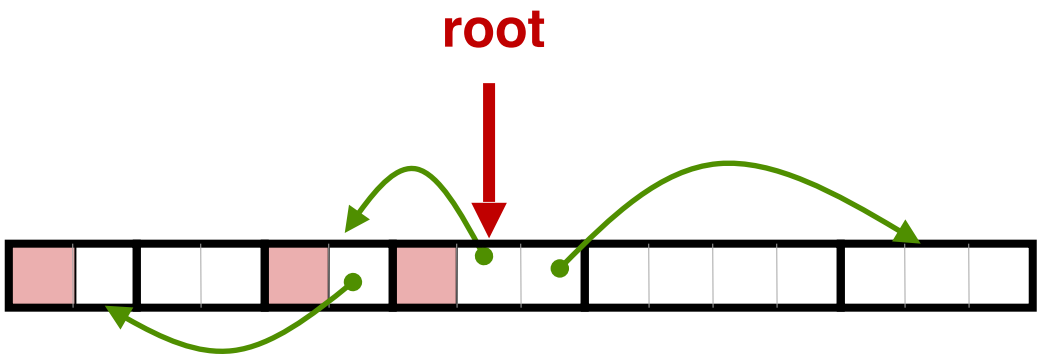

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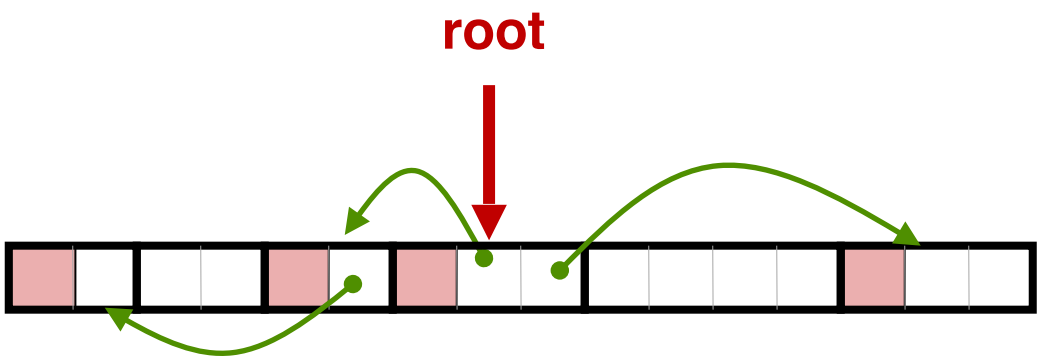

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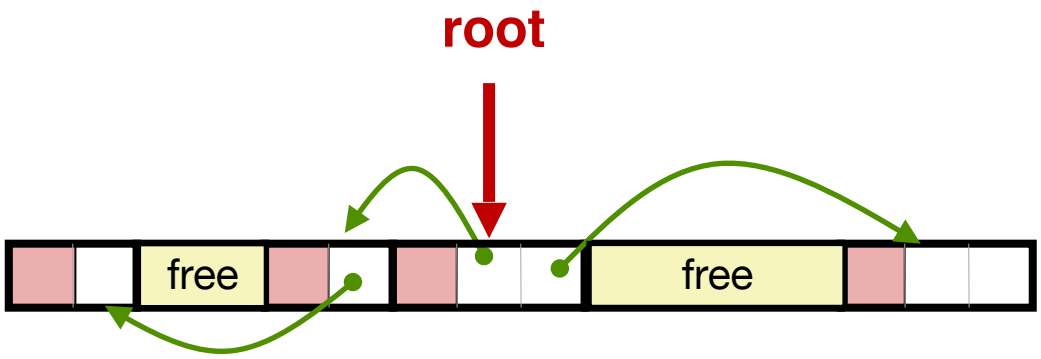

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Mark and Sweep (cont.)

Mark using depth-first traversal of the memory graph

```
ptr mark(ptr p) {
   if (!is_ptr(p)) return;          // do nothing if not pointer
   if (markBitSet(p)) return;       // check if already marked
   setMarkBit(p);                   // set the mark bit
   for (i=0; i < length(p); i++)    // call mark on all words
     mark(p[i]);                    //   in the block
   return;
}
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Sweep using lengths to find next block

```
ptr sweep(ptr p, ptr end) {
   while (p < end) {
      if markBitSet(p)
         clearMarkBit();
      else if (allocateBitSet(p))
         free(p);
      p += length(p);
}
```

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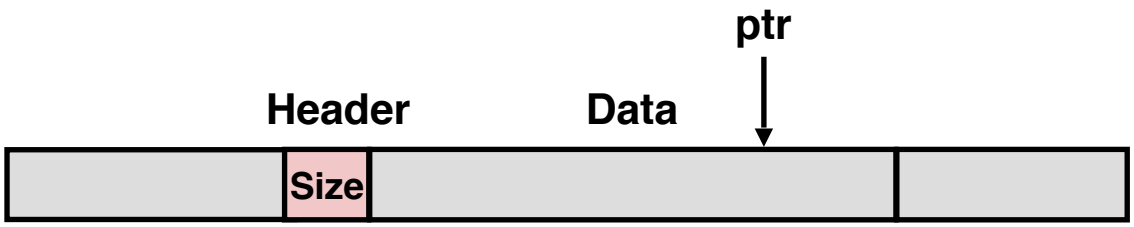

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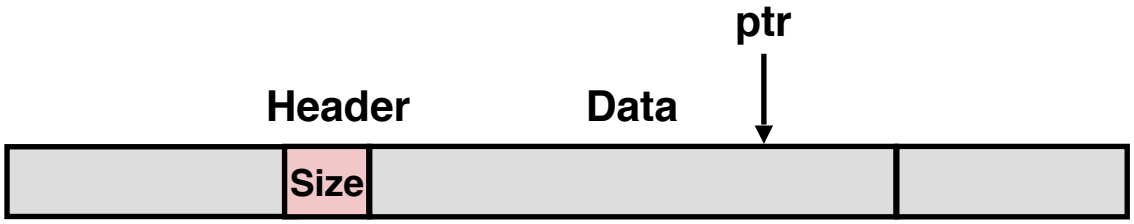

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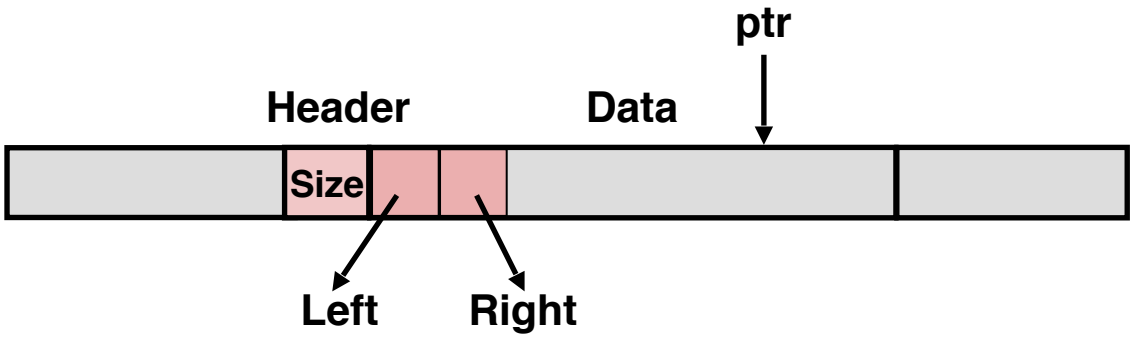

Left: smaller addresses
Right: larger addresses

Potential GC Implementations (in C)

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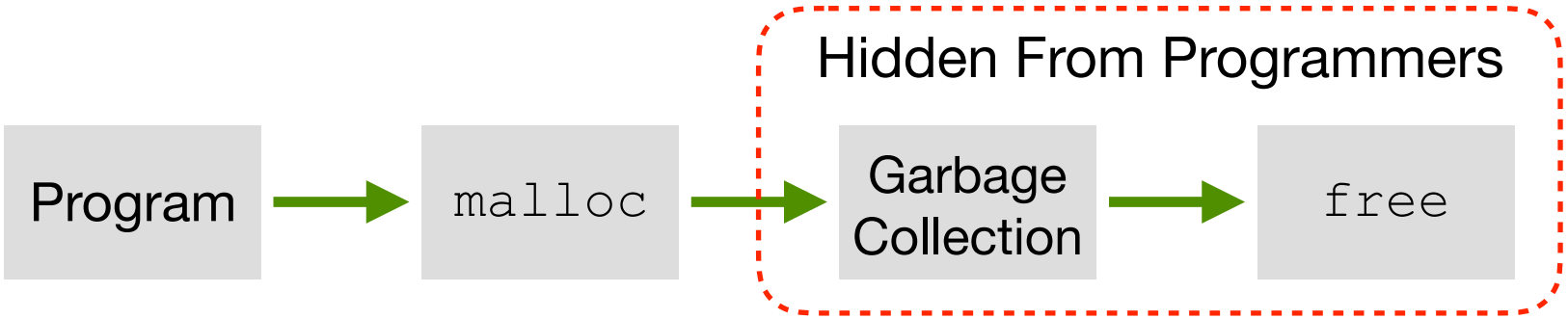

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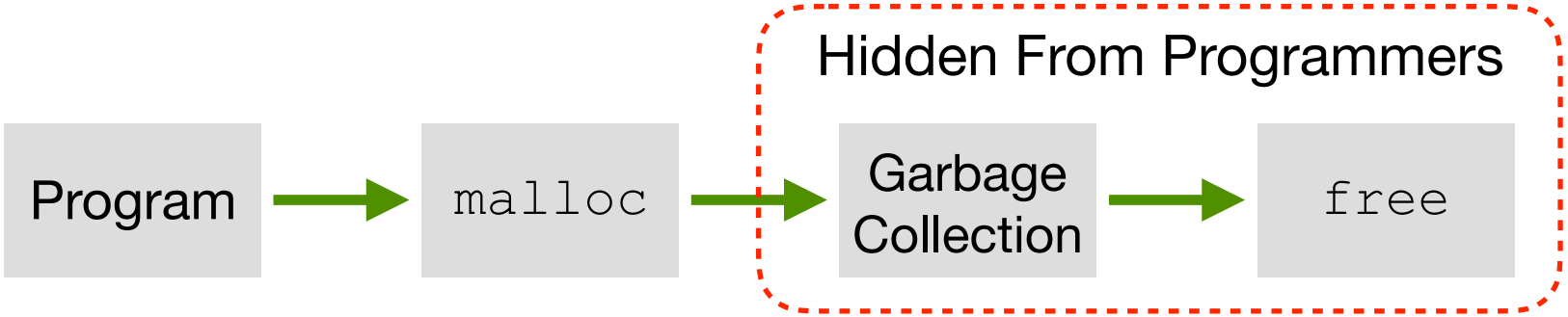

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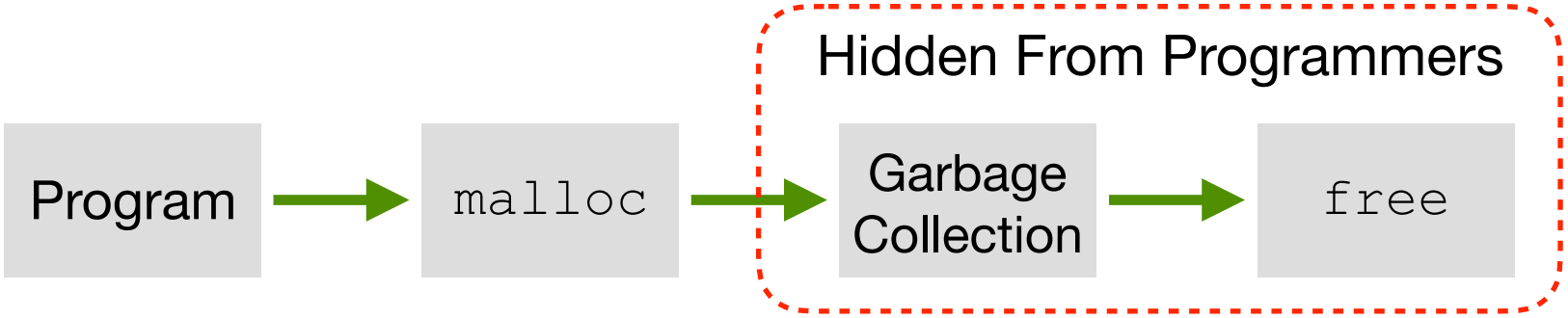

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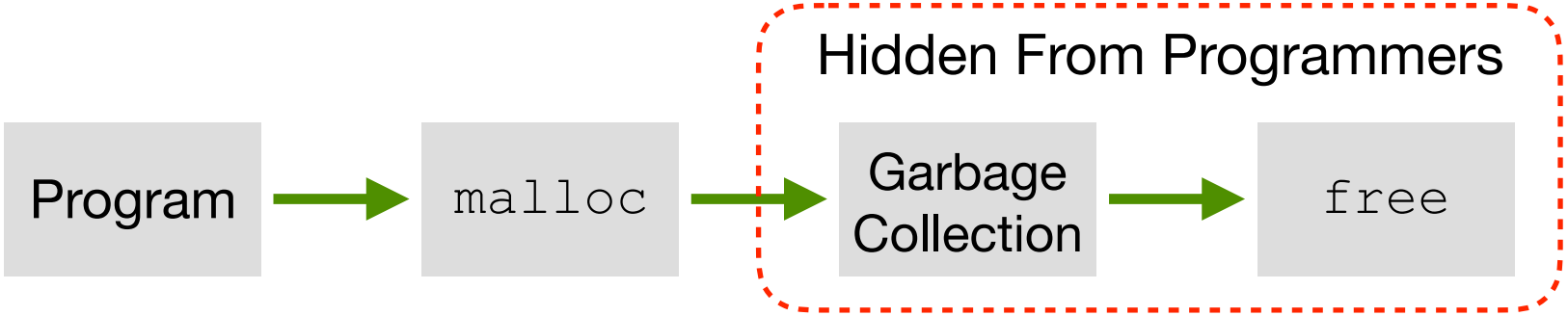

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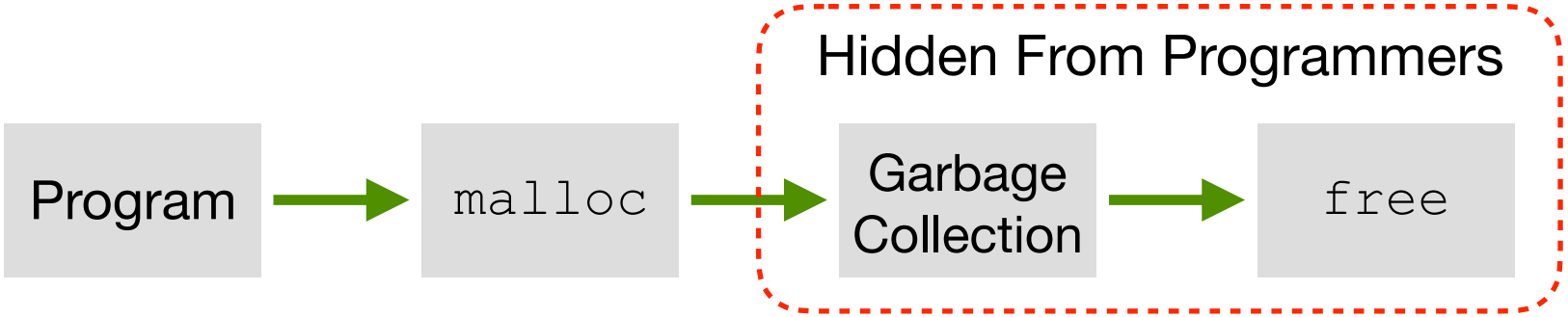

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https://robertovitillo.com/why-you-should-measure-tail-latencies/

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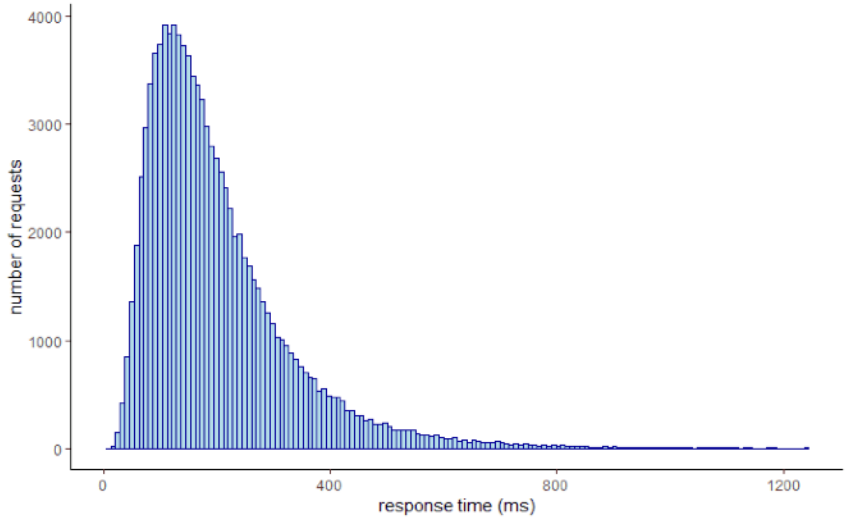

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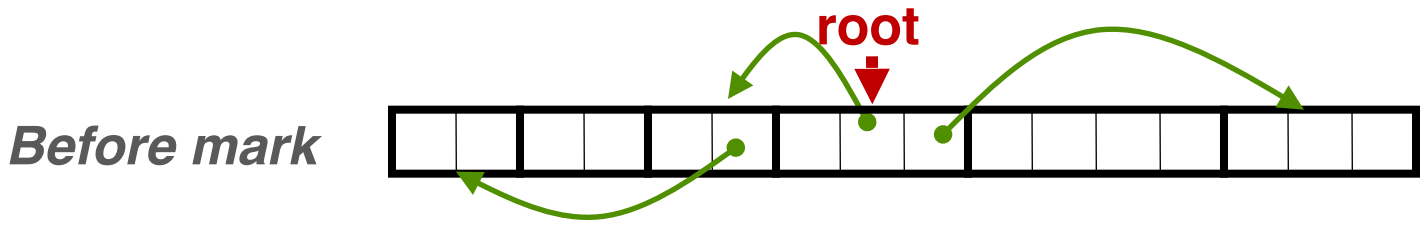

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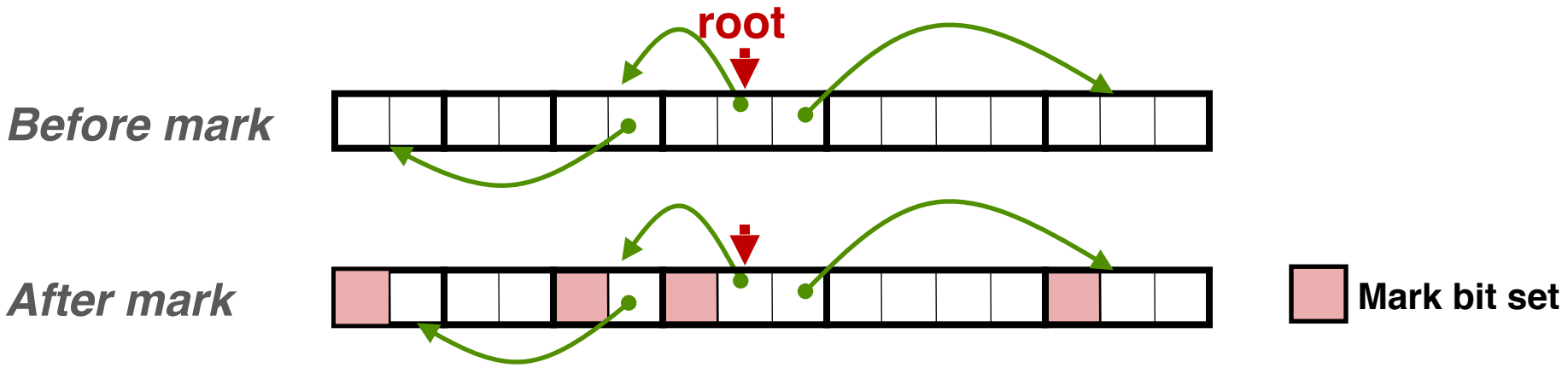

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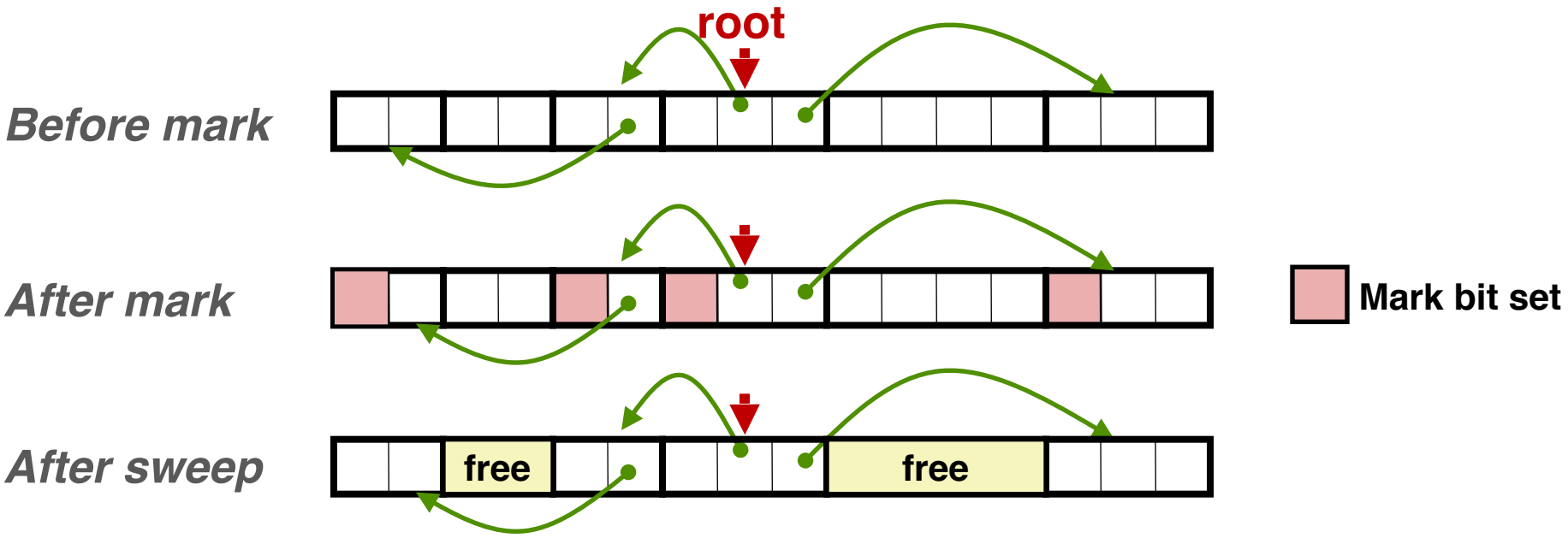

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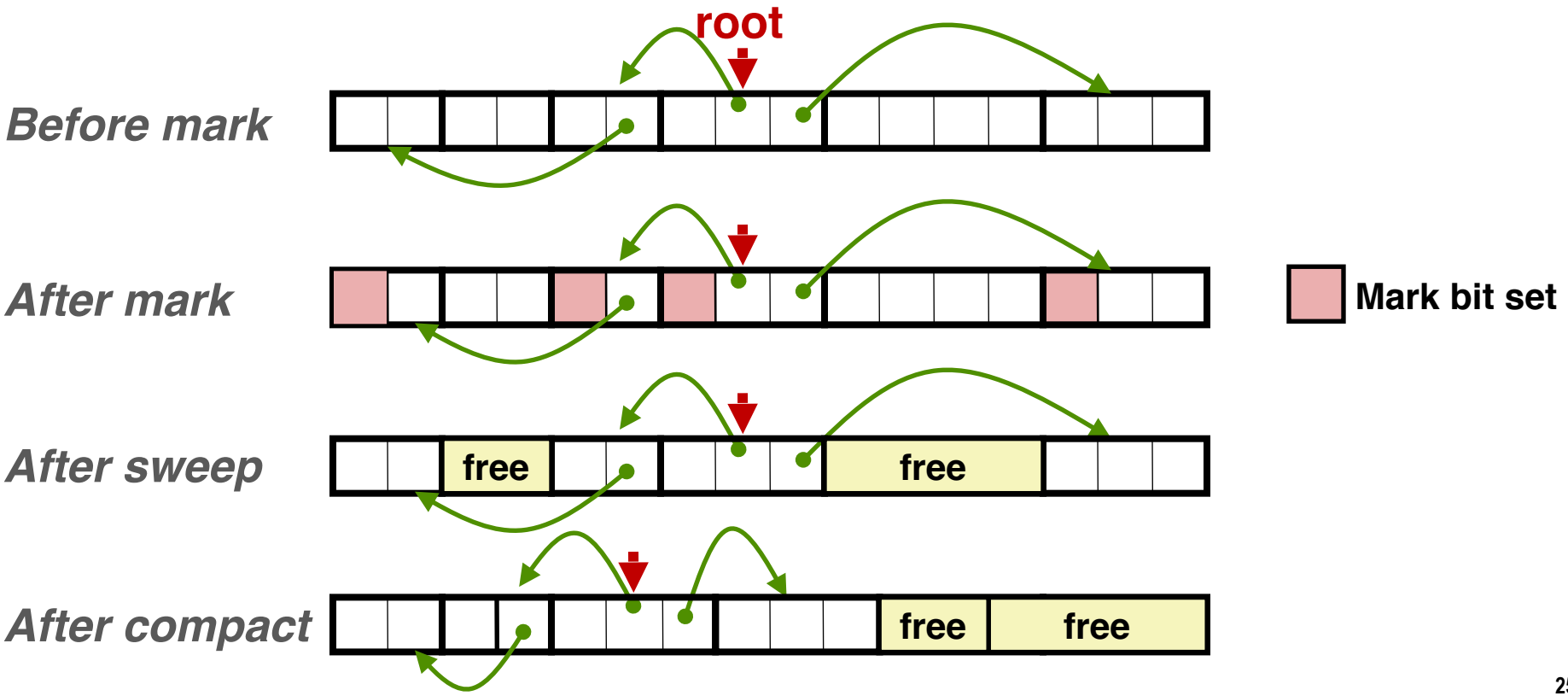

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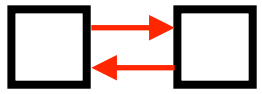

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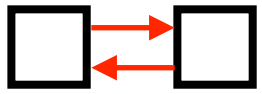


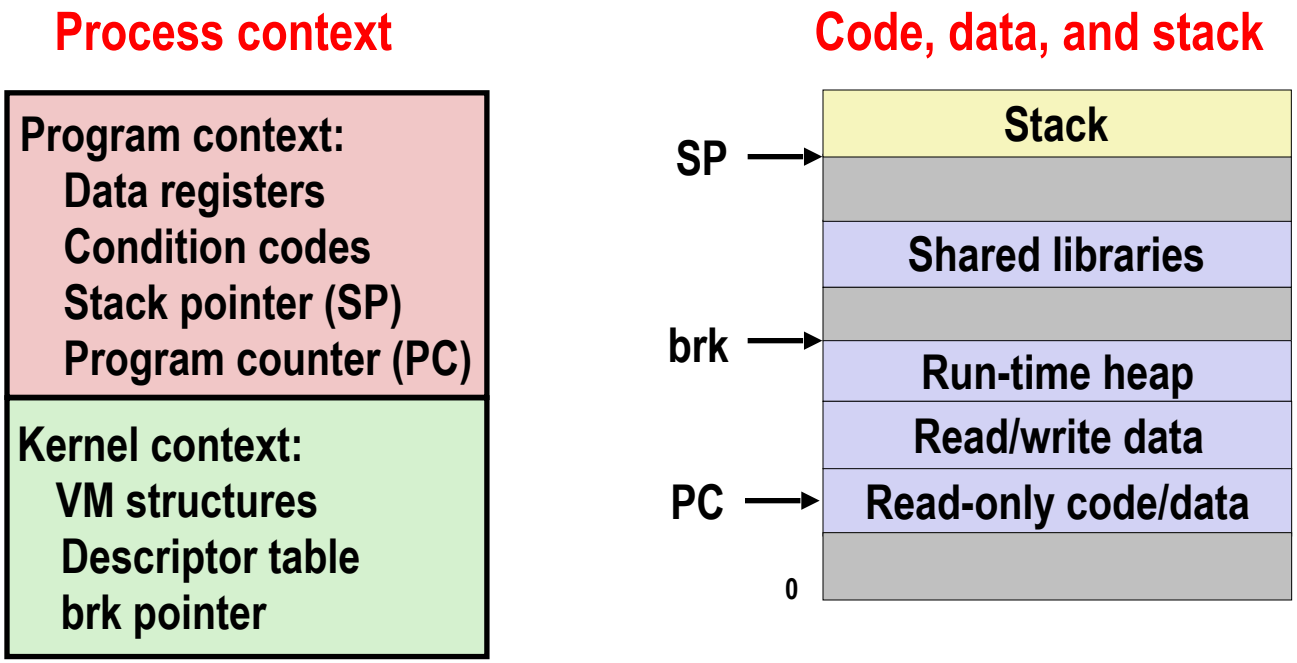
- A heterogeneous approach (RC + tracing) is often used

Today

- From process to threads
  - Basic thread execution model
- Multi-threading programming
- Hardware support of threads
  - Single core
  - Multi-core
  - Hyper-threading
  - Cache coherence

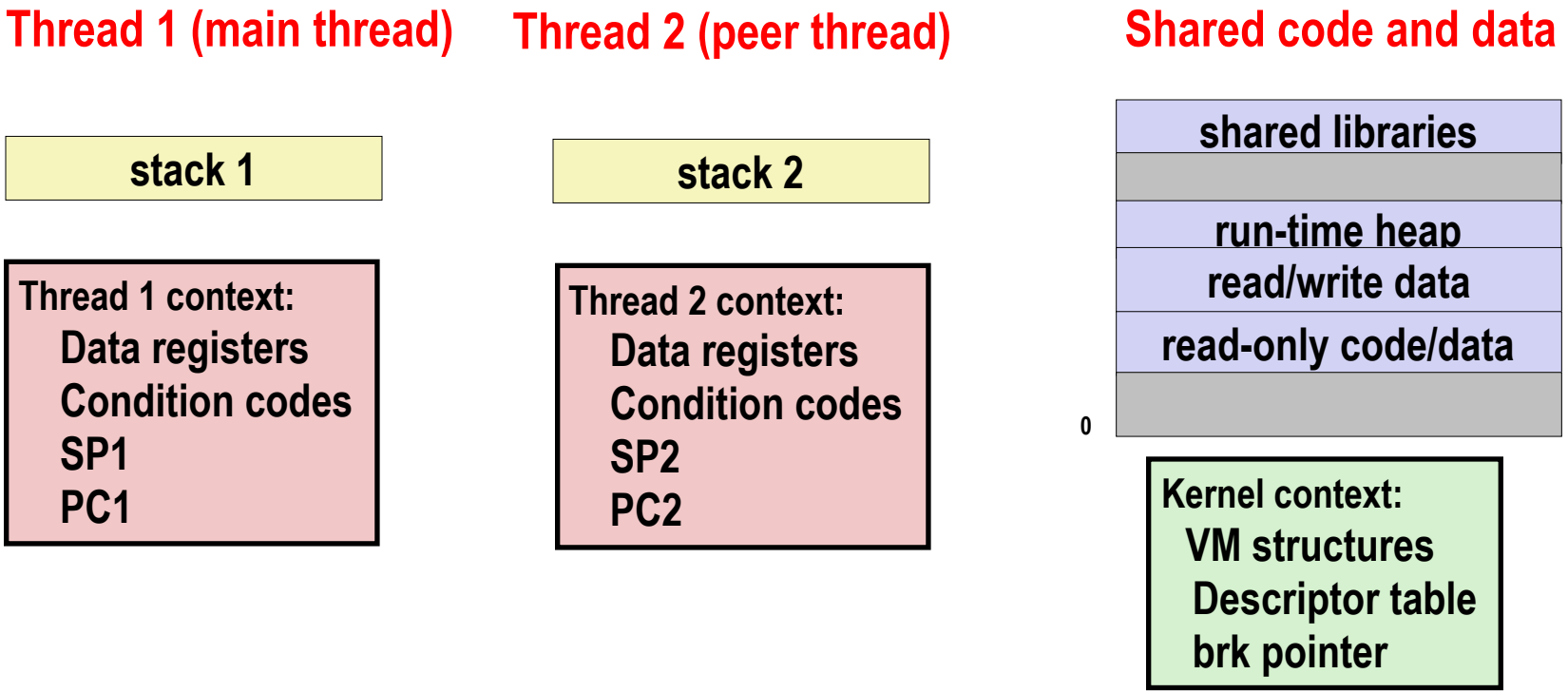
Programmers View of A Process

- Process = process context + code, data, and stack



A Process With Multiple Threads

- Multiple threads can be associated with a process
  - Each thread has its own logical control flow
  - Each thread shares the same code, data, and kernel context
  - Each thread has its own stack for local variables
    - but not protected from other threads
  - Each thread has its own thread id (TID)



Logical View of Threads

- Threads associated with process form a pool of peers
  - Unlike processes which form a tree hierarchy