Garbage Collection

CS4410: Spring 2013

Modern Languages

- Represent all records (tuples, objects, etc.) using pointers.
  - Makes it possible to support *polymorphism*.
  - e.g., ML doesn't care whether we pass an integer, two-tuple, or record to the identity function: they are all represented with 1 word.
  - Price paid: lots of loads/stores…
- By default, allocate records on the heap.
  - Programmer doesn't have to worry about lifetimes.
  - Compiler may determine that it's safe to allocate a record on the stack instead.
  - Uses a garbage collector to safely reclaim data.
  - Because pointers are *abstract*, has the freedom to re-arrange the data in the heap to support compaction.

Allocation in SML/NJ

- Reserve two registers:
  - allocation pointer (like stack pointer)
  - limit pointer
- To allocate a record of size n:
  - checks that limit-alloc > n. If not, invokes garbage collector.
  - Adds n+1 to the alloc pointer, returns old value of alloc pointer as result.
  - Extra word holds meta-data (e.g., size.)
  - Actually, amortizes the limit check across a bunch of allocations (just as we amortize stack pointer adjustment.)
  - Result: 3-5 instructions to allocate a record.

Garbage Collection:

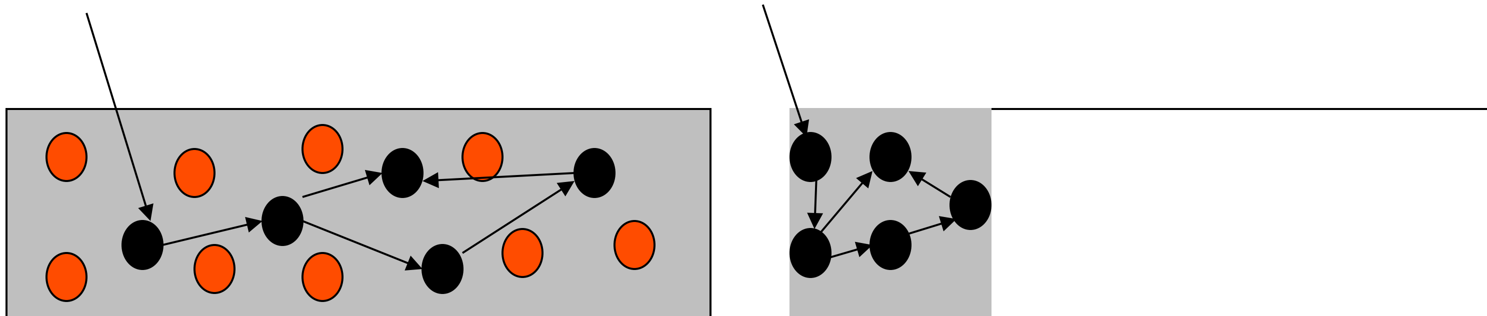
- Starting from stack, registers, & globals (roots), determine which objects in the heap are reachable following pointers.
- Reclaim any object that isn't reachable.
- Requires being able to distinguish pointer values from other values (e.g., ints).
  - SML/NJ uses the low bit:
    1 it's a scalar, 0 it's a pointer.
  - In Java, we use put the tag bits in the meta-data.
  - For BDW collector, we use heuristics:
    (e.g., the value doesn't point into an allocated object.)

Mark/Sweep Traversal:

- Reserve a mark-bit for each object.
- Starting from roots, mark all accessible objects.
- Stick accessible objects into a queue or stack.
  - queue: breadth-first traversal
  - stack: depth-first traversal
- Loop until queue/stack is empty:
  - remove marked object (say x).
  - if x points to an (unmarked) object y, then mark y and put it in the queue.
- Run through all objects:
  - If they haven't been marked, put them on the free list.
  - If they have been marked, clear the mark bit.

Copying Collection:

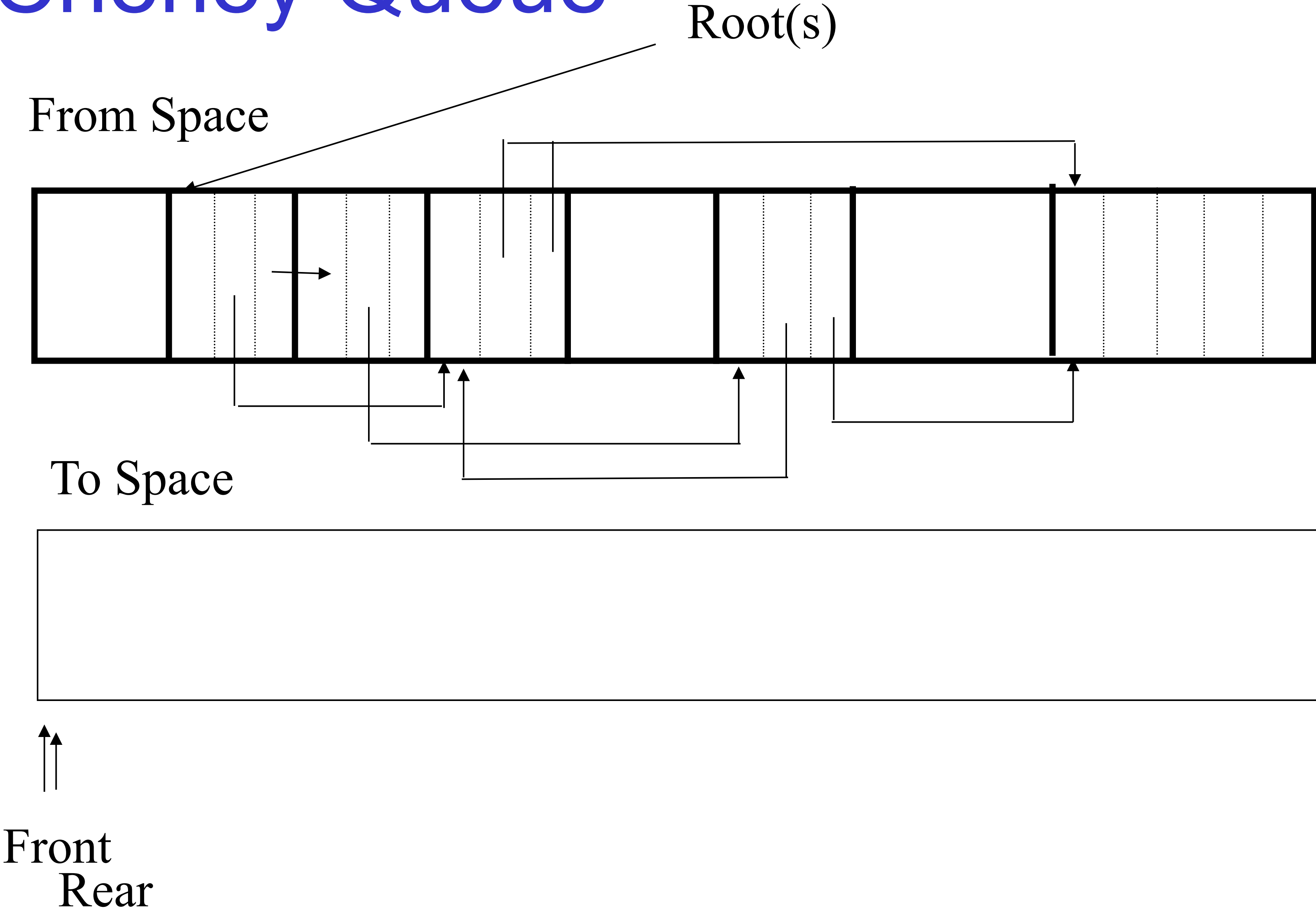
- Split data segment into two pieces.
- Allocate in 1st piece until it fills up.
- Copy the reachable data into the 2nd area, compressing out the holes corresponding to garbage objects.



Algorithm: Queue-Based

- Initialize front/rear to beginning of to-space.
  - A trick for representing the queue using the to-space.
- Enqueue the items pointed to by roots.
  - Copy the objects into to-space (bump rear pointer).
  - Place a *forwarding pointer* in the old copy that points to the new copy.
- While queue is not empty:
  - Dequeue a word (i.e., bump front pointer).
  - If the word is a pointer to an unforwarded object, then enqueue the object and set its forwarding pointer.
  - If the word is a pointer to a forwarded object, overwrite the word with the address of the new copy.

Cheney Queue



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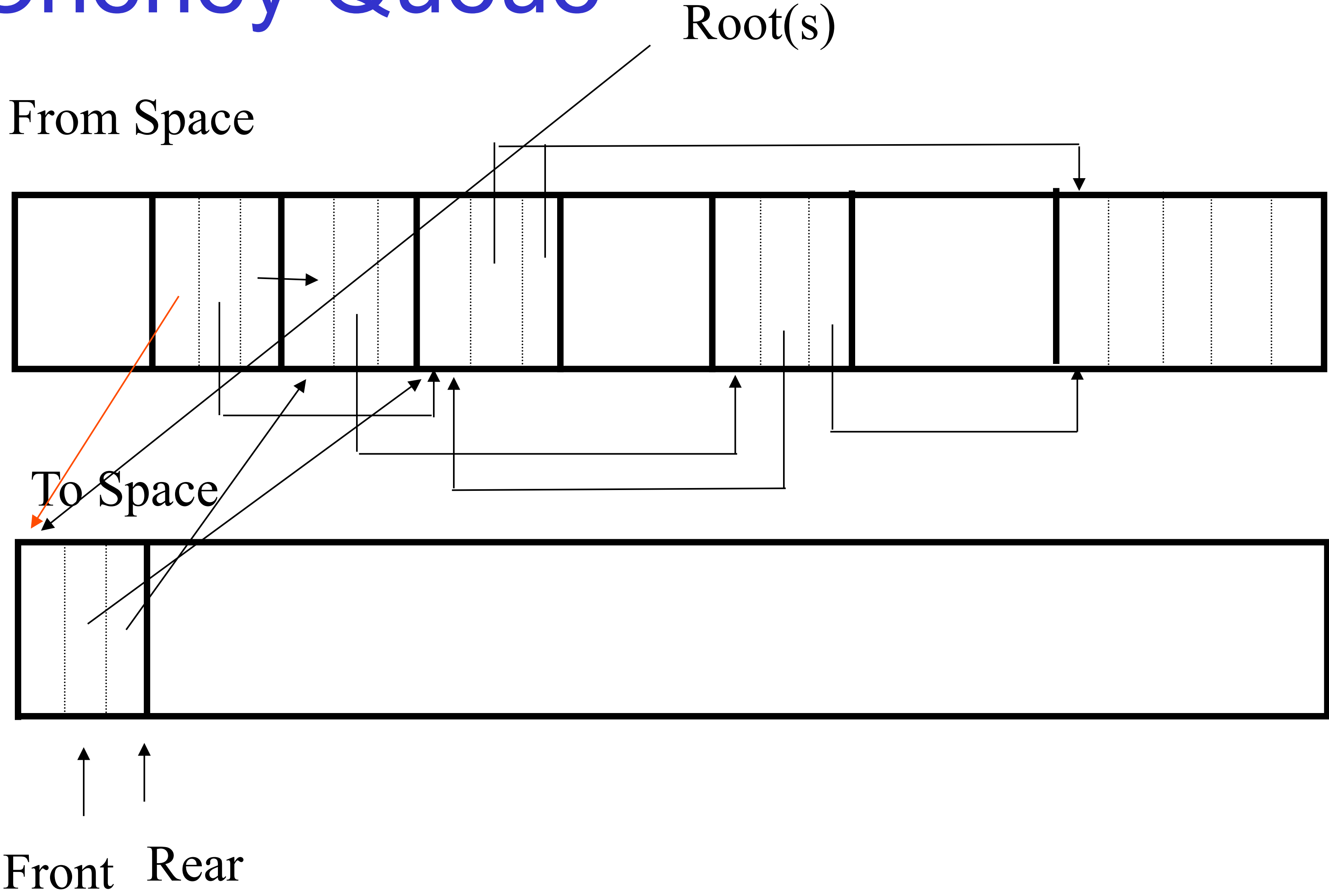

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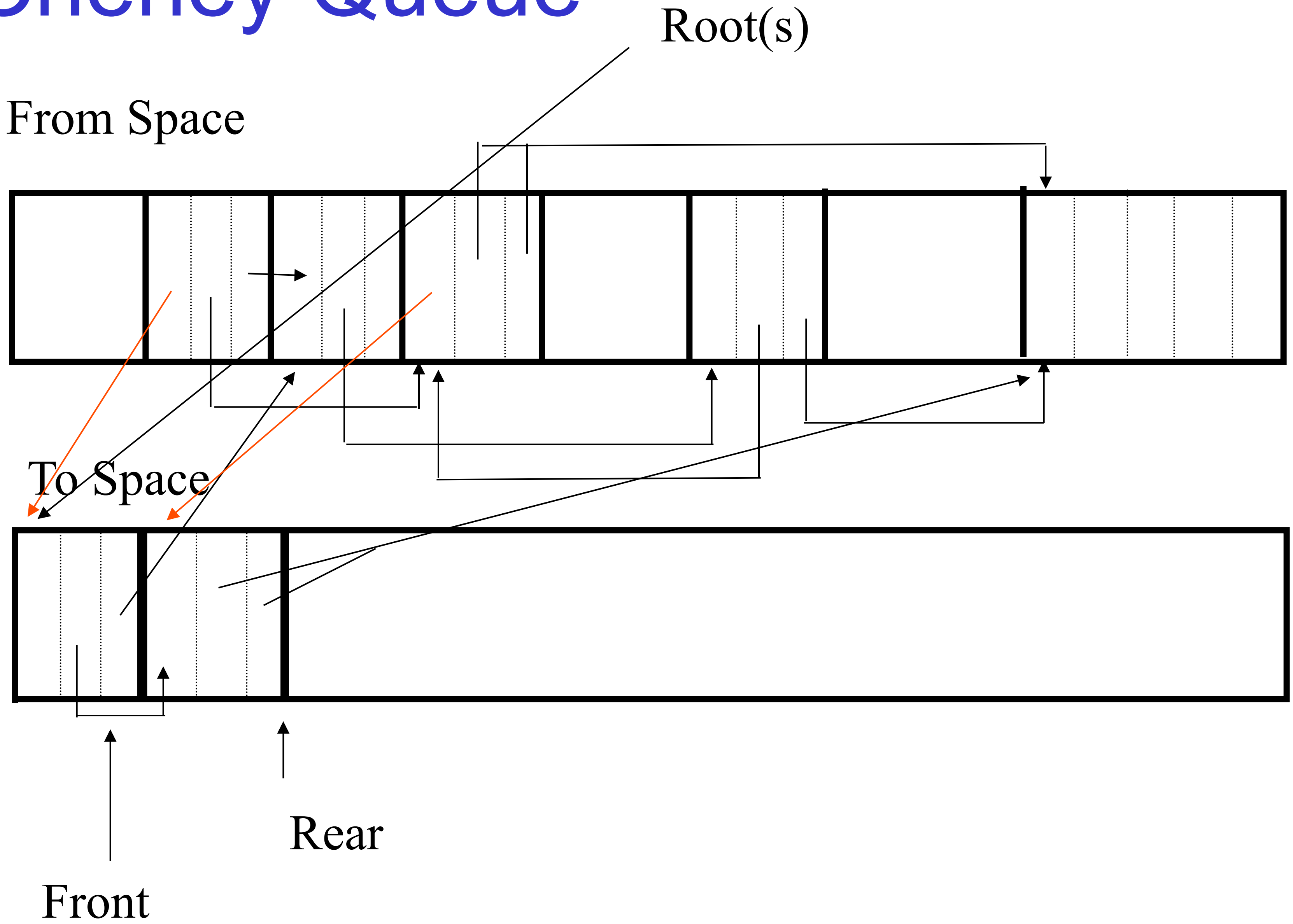

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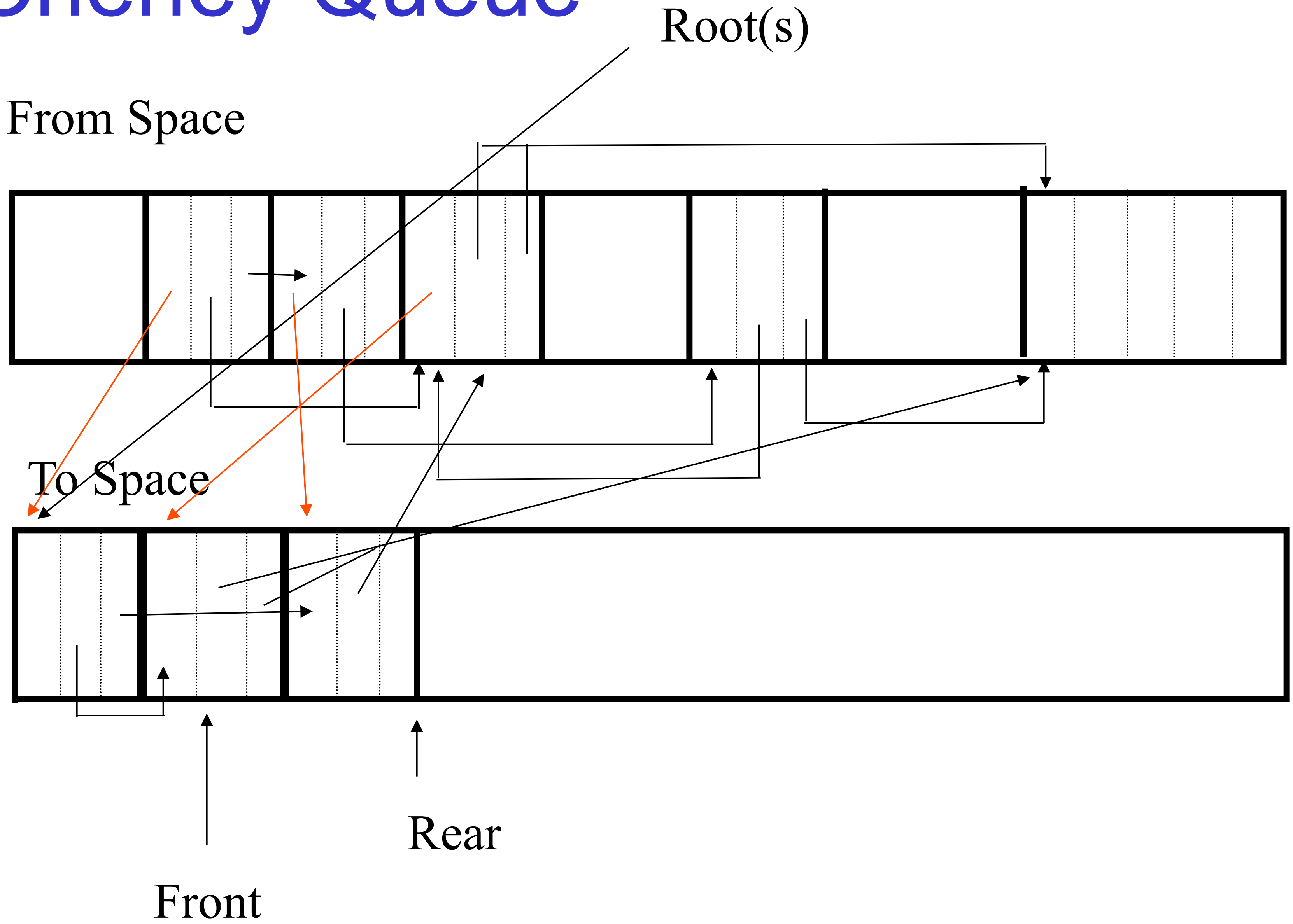

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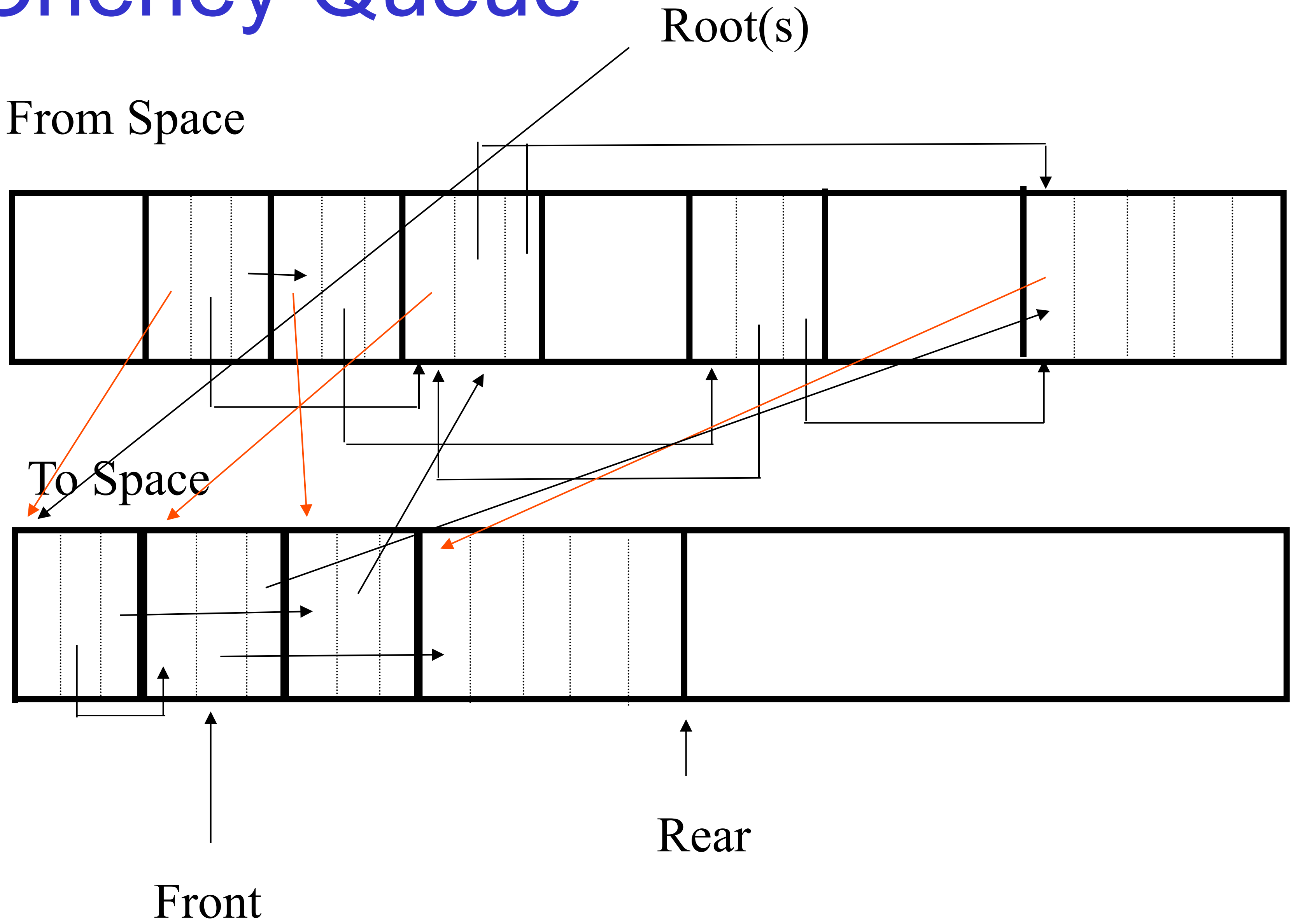

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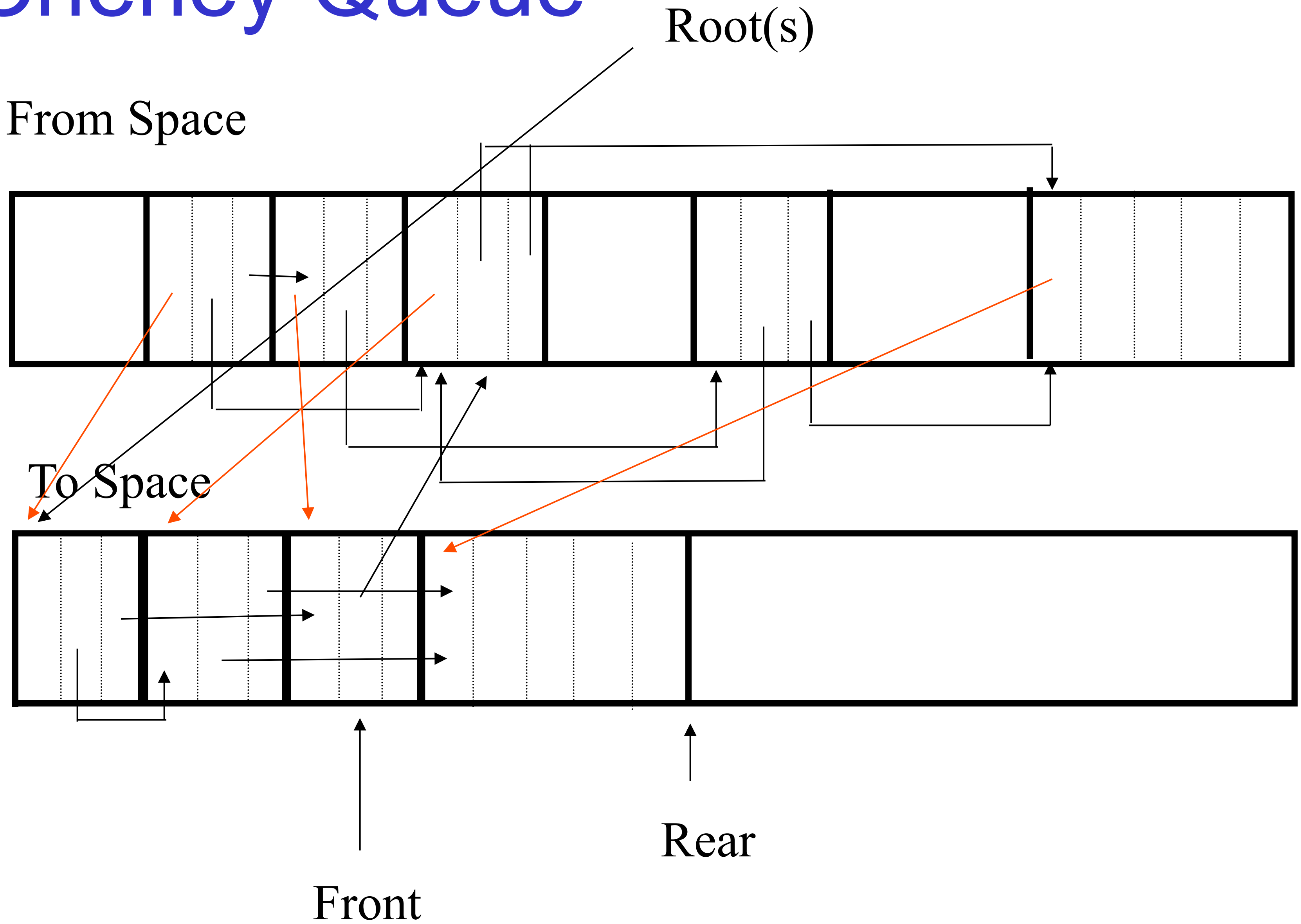

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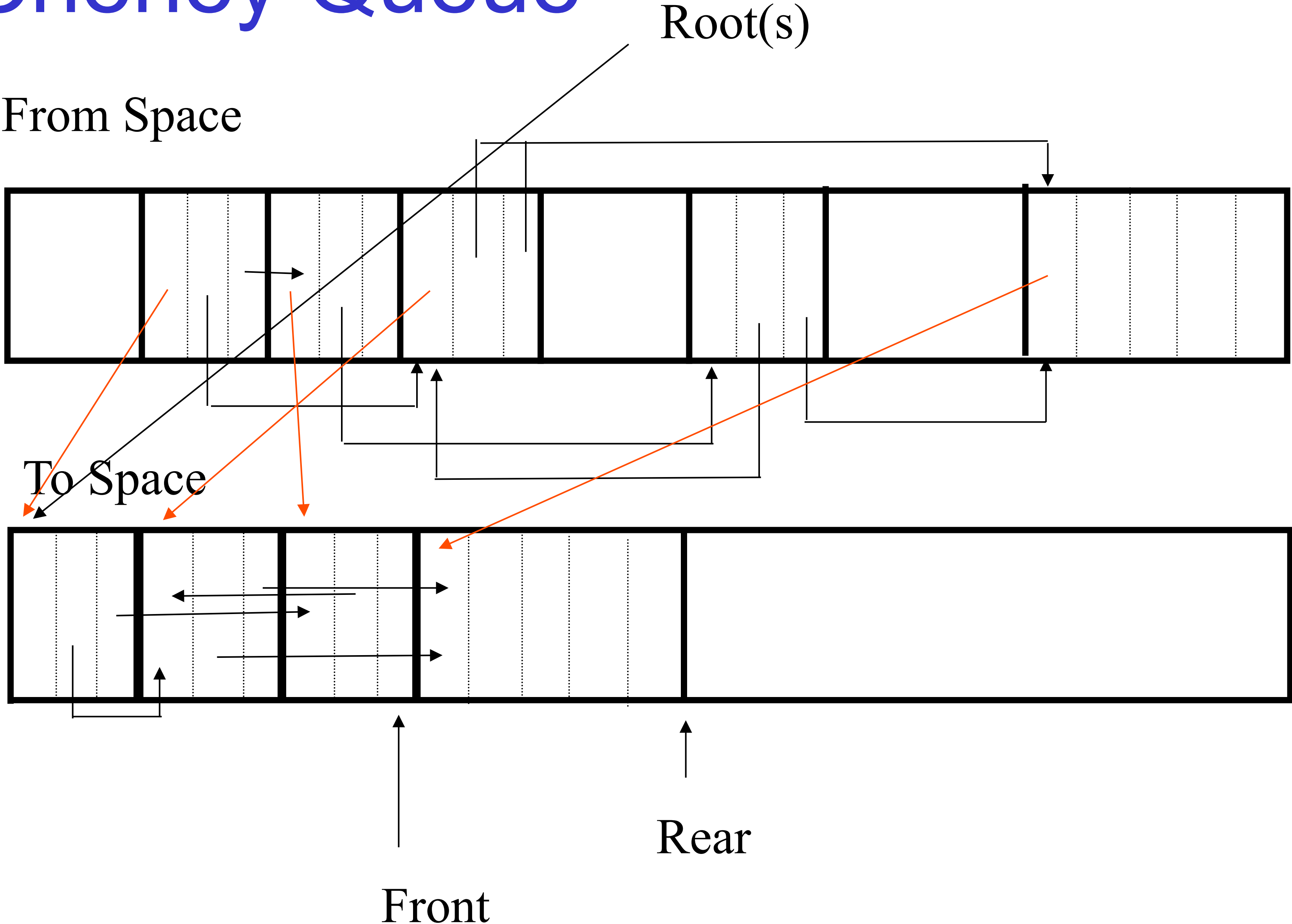

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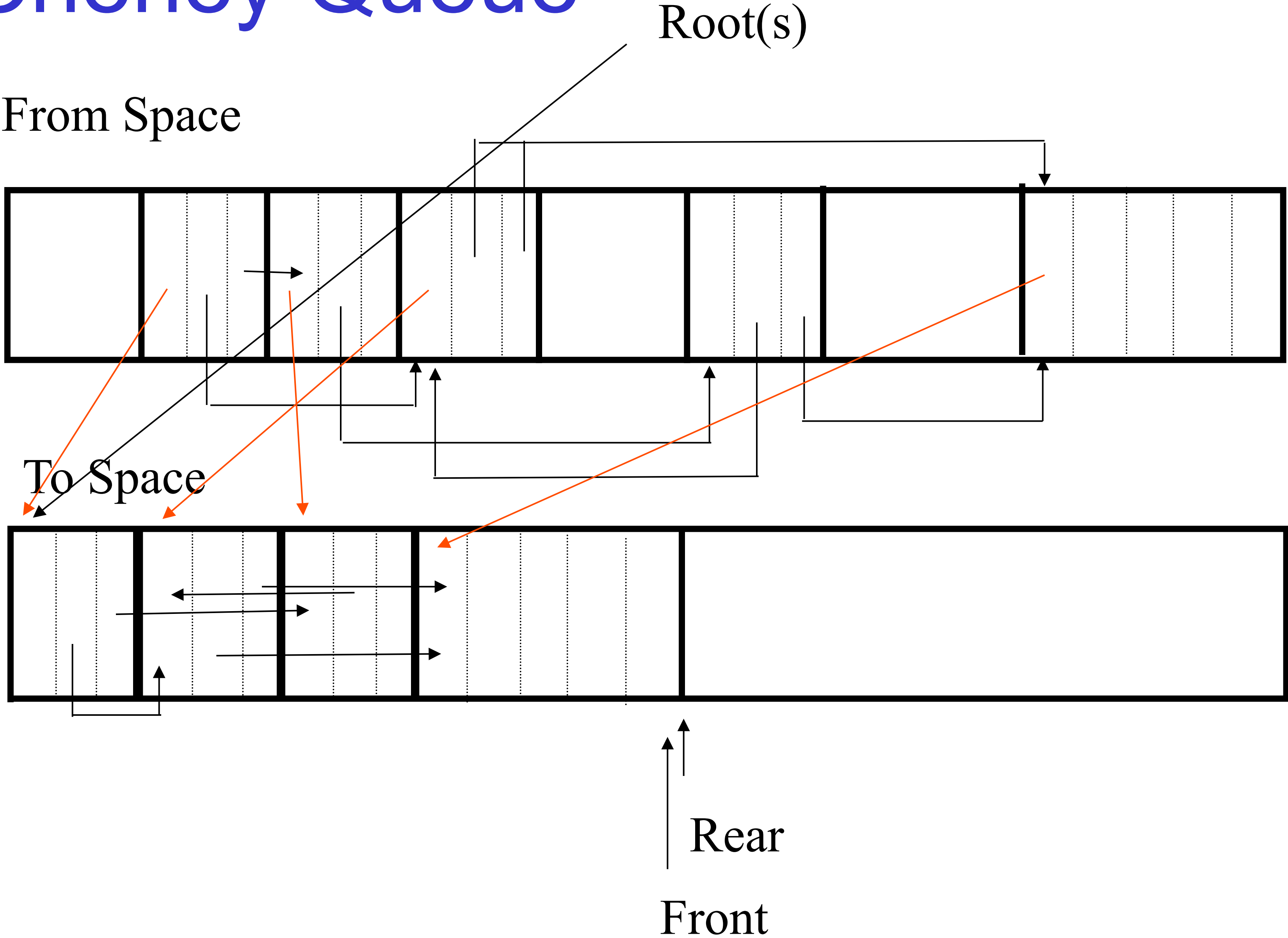
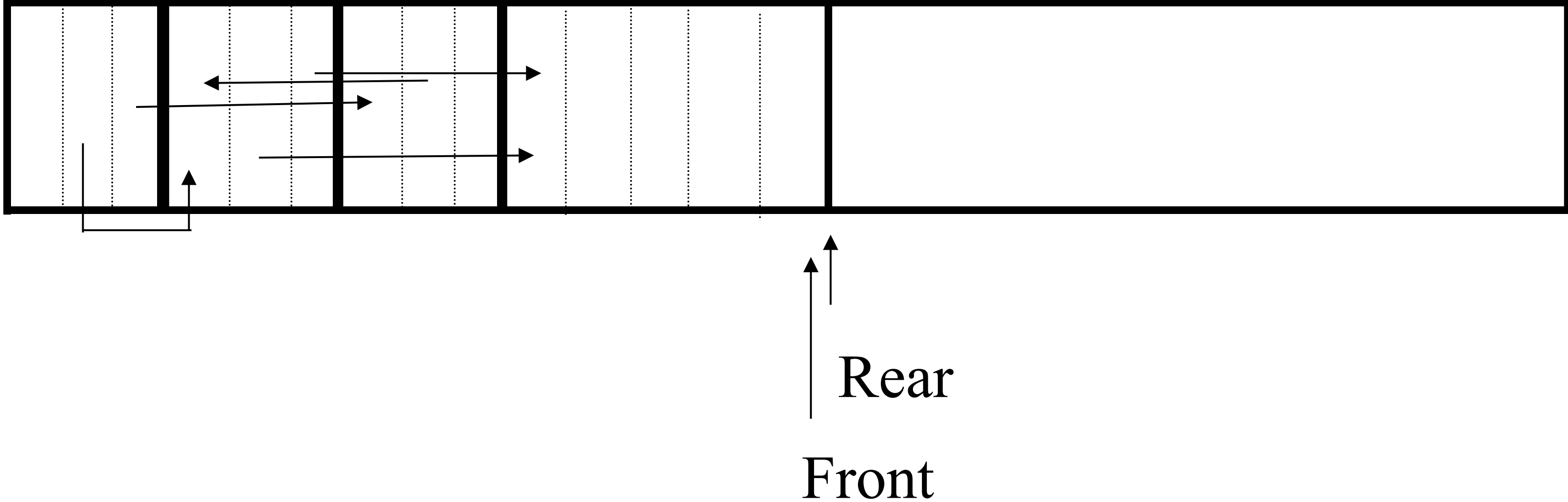


Cheney Queue

Root(s)

From Space

To Space



Pros and Cons:

- Pros:
  - Fast, bump-pointer allocation.
  - Cost of GC is proportional to live data (not all of memory).
  - Compaction happens for free.
- Cons:
  - Long pauses.
  - Memory cut in half.
  - Lots of memory traffic.

Reality:

- Techniques such as *generational* or *incremental* collection can greatly reduce latency.
  - A few millisecond pause times.
- Large objects (e.g., arrays) can be copied in a "virtual" fashion without doing a physical copy.
- Some systems use a mix of copying collection (young data) and mark/sweep (old data) with support for compaction.
- A real challenge is scaling this to server-scale systems with terabytes of memory…
- Interactions with OS matter a lot: cheaper to do GC than it is to start paging…

Conservative Collectors:

- Work without help from the compiler.
  - e.g., legacy C/C++ code.
  - e.g., your compiler :-)
- Cannot accurately determine which values are pointers.
  - But can rule out some values (e.g., if they don't point into the data segment.)
  - So they must conservatively treat anything that looks like a pointer as such.
  - Two bad things result: leaks, can't move.
  - Further problems if pointers are "hidden".

The BDW Collector

- Based on mark/sweep.
  - performs sweep lazily
- Organizes free lists as we saw earlier.
  - different lists for different sized objects.
  - relatively fast (single-threaded) allocation.
- Most of the cleverness is in finding roots:
  - global variables, stack, registers, etc.
- And determining values aren't pointers:
  - blacklisting, etc.