Programming Languages

2nd edition

Tucker and Noonan

Chapter 11
Memory Management

C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do it blows your whole leg off.

B. Stroustrup

Contents

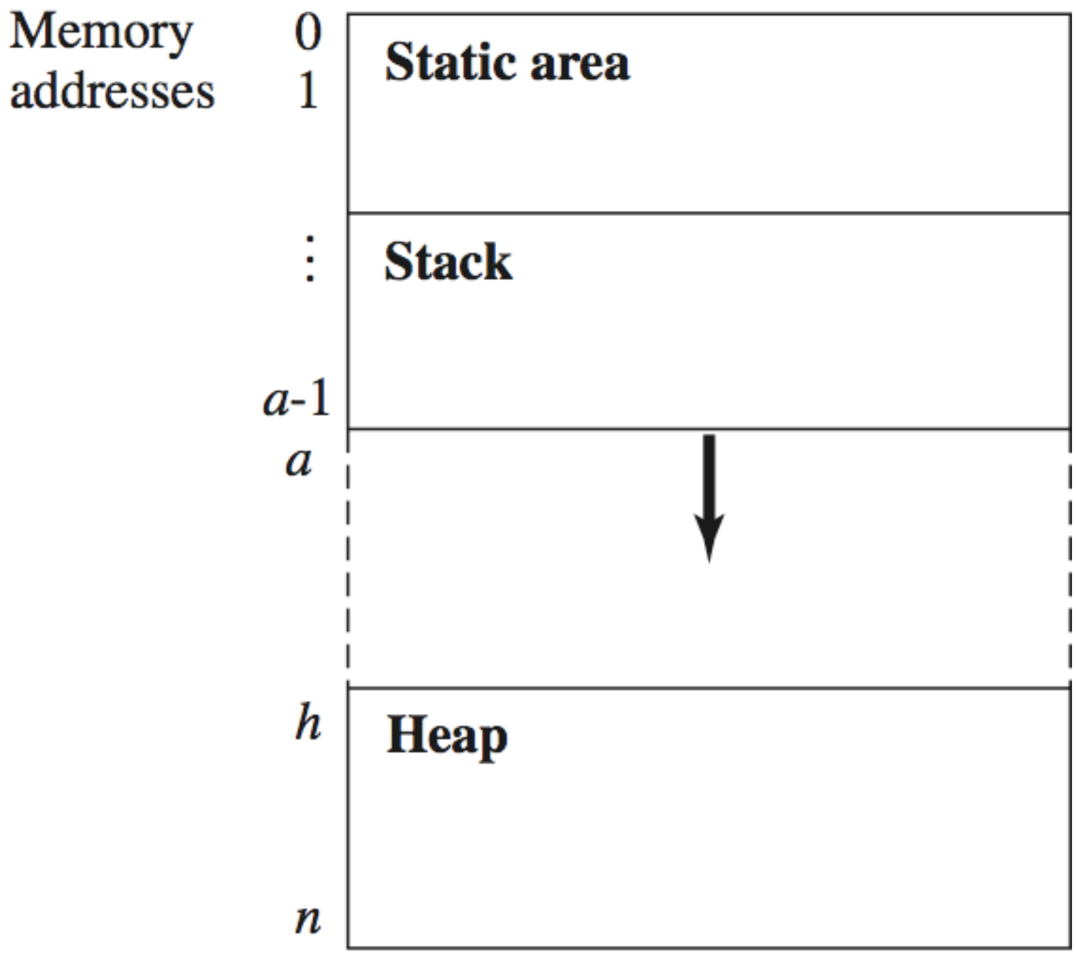
11.1 The Heap

The major areas of memory:

Static area: fixed size, fixed content
allocated at compile time
Run-time stack: variable size, variable content
center of control for function call and return
Heap: fixed size, variable content
dynamically allocated objects and data structures

The Structure of Run-Time Memory (x86 architecture)

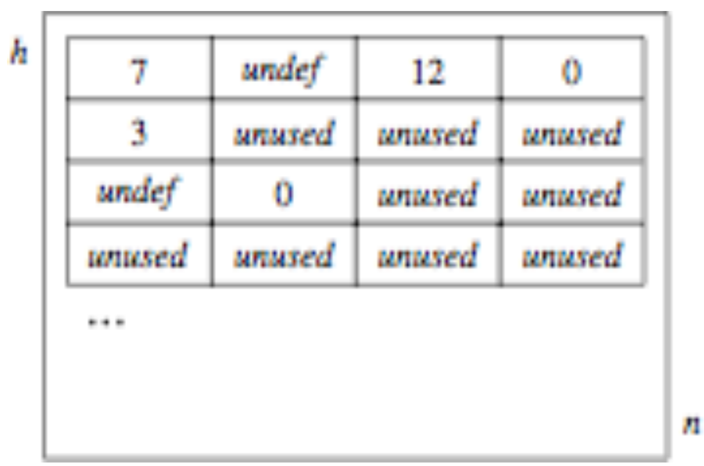
Fig 11.1

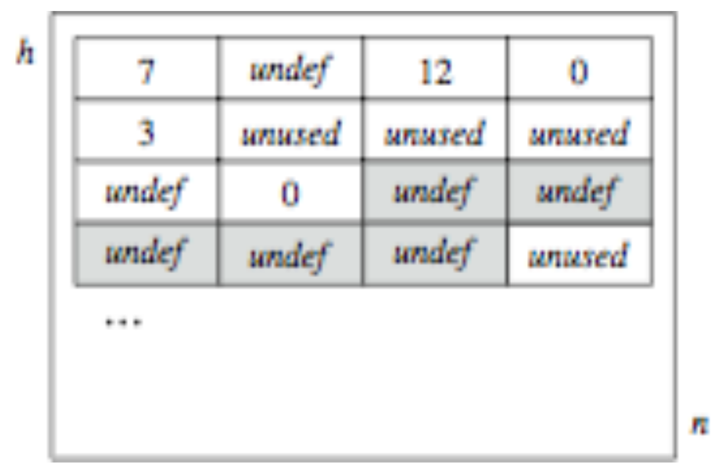


Allocating Heap Blocks

In some languages, the function *new* allocates a block of heap space to the program.

E.g., new(5) returns the address of the next block of 5 words available in the heap:





Stack and Heap Overflow

Stack overflow occurs when the top of stack, *a*, would exceed its (fixed) limit, *h*.

Heap overflow occurs when a call to *new* occurs and the heap does not have a large enough block available to satisfy the call.

11.2 One Implementation of Dynamic Arrays

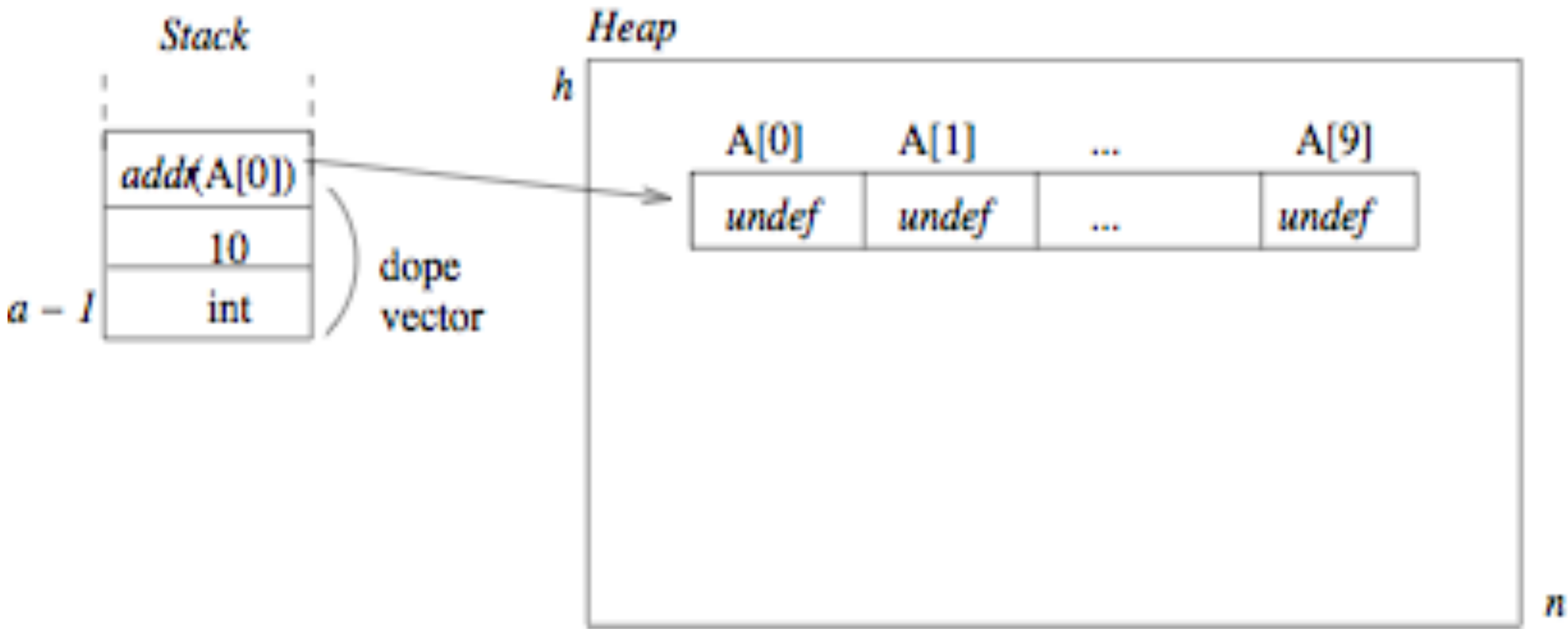
Consider the declaration `int A[n];`

Its meaning is:

1. Compute *addr*(A[0]) = *new(*n*)*.
2. Push *addr*(A[0]) onto the stack.
3. Push n onto the stack.
4. Push int onto the stack.

Step 1 creates a heap block for A.
Steps 2-4 create the dope vector for A in the stack.

Stack and Heap Allocation for int A[10]; Fig 11.3



Array References

The meaning of an *ArrayRef* ar for an array declaration ad is:

1. Compute *addr*(ad[ar.index]) = *addr*(ad[0])+ar.index-1
2. If *addr*(ad[0])≤*addr*(ad[ar.index])<*addr*(ad[0])+ad.size, return the value at *addr*(ad[ar.index])
3. Otherwise, signal an index-out-of-range error.

E.g., consider the *ArrayRef* A[5]. The value of A[5] is addressed by *addr*(A[0])+4.

Note: this definition includes run-time range checking.

Array Assignments

The meaning of an *Assignment* as is:

1. Compute *addr*(ad[ar.index])=*addr*(ad[0])+ar.index-1
2. If

   addr(ad[0])≤*addr*(ad[ar.index])<*addr*(ad[0])+ad.size

   then assign the value of as.source to *addr*(ad[ar.index]).
3. Otherwise, signal an index-out-of-range error.

E.g., The assignment A[5]=3 changes the value at heap address *addr*(A[0])+4 to 3, since

ar.index=5 and *addr*(A[5])=*addr*(A[0])+4.

11.3 Garbage Collection

Garbage is a block of heap memory that cannot be accessed by the program.

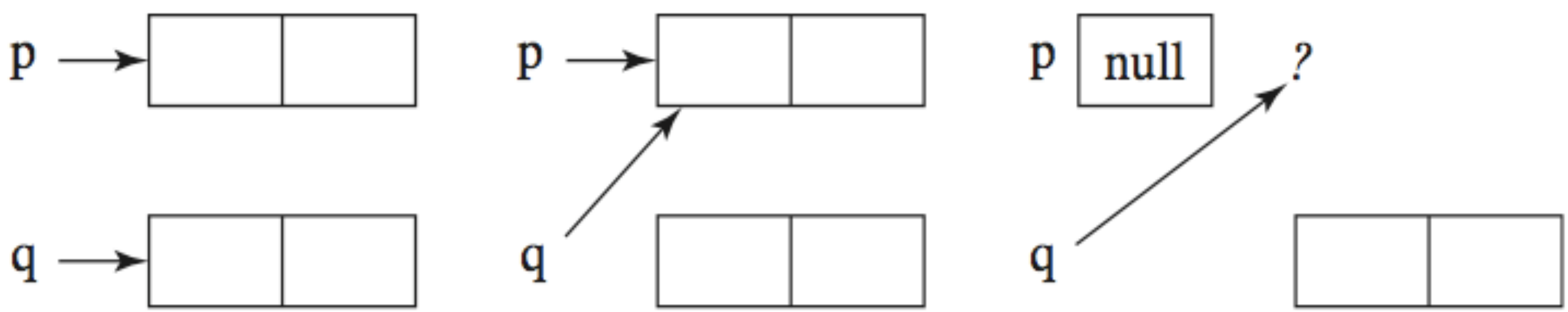
Garbage can occur when either:

1. An allocated block of heap memory has no reference to it (an "orphan"), or
2. A reference exists to a block of memory that is no longer allocated (a "widow").

Garbage Example (Fig 11.4)

```
class node {
    int value;
    node next;
}
node p, q;
```

```
p = new node();
q = new node();
q= p;
delete p;
```



(a) (b) (c)

Garbage Collection Algorithms

Garbage collection is any strategy that reclaims unused heap blocks for later use by the program.

Three classical garbage collection strategies:

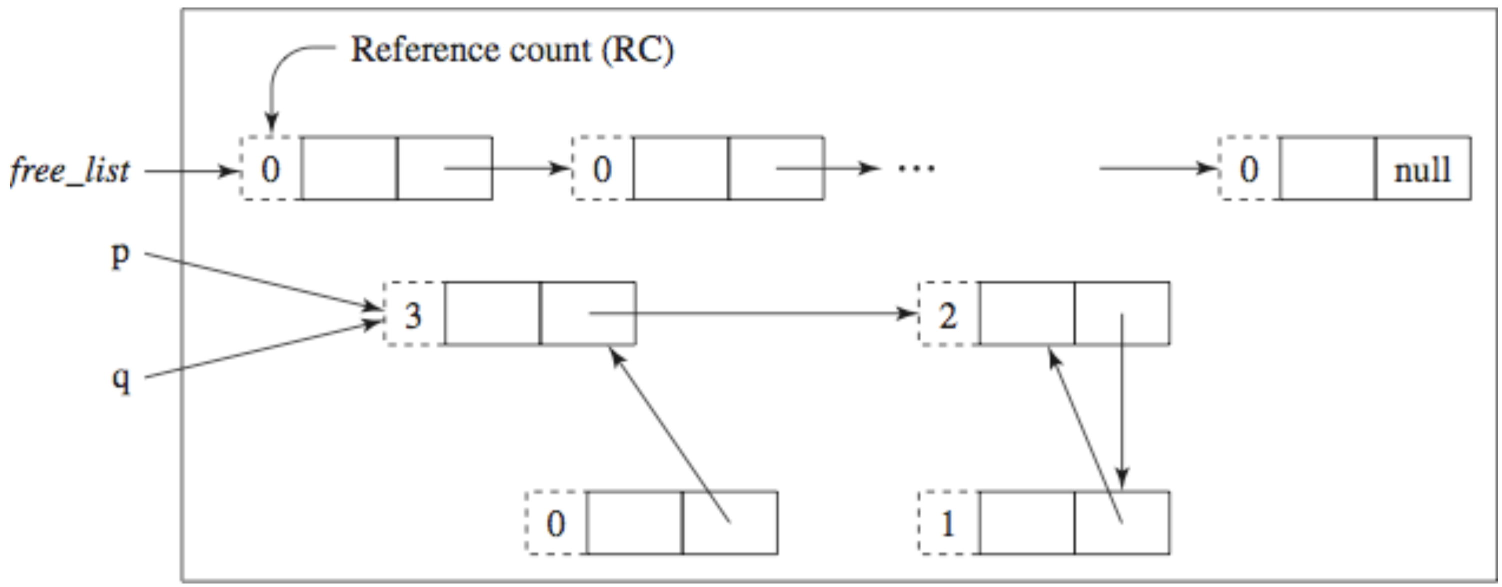
- *Reference Counting - occurs whenever a heap block is allocated, but doesn't detect all garbage.*
- *Mark-Sweep - Occurs only on heap overflow, detects all garbage, but makes two passes on the heap.*
- *Copy Collection - Faster than mark-sweep, but reduces the size of the heap space.*

11.3.1 Reference Counting

The heap is a chain of nodes (the *free_list)*.

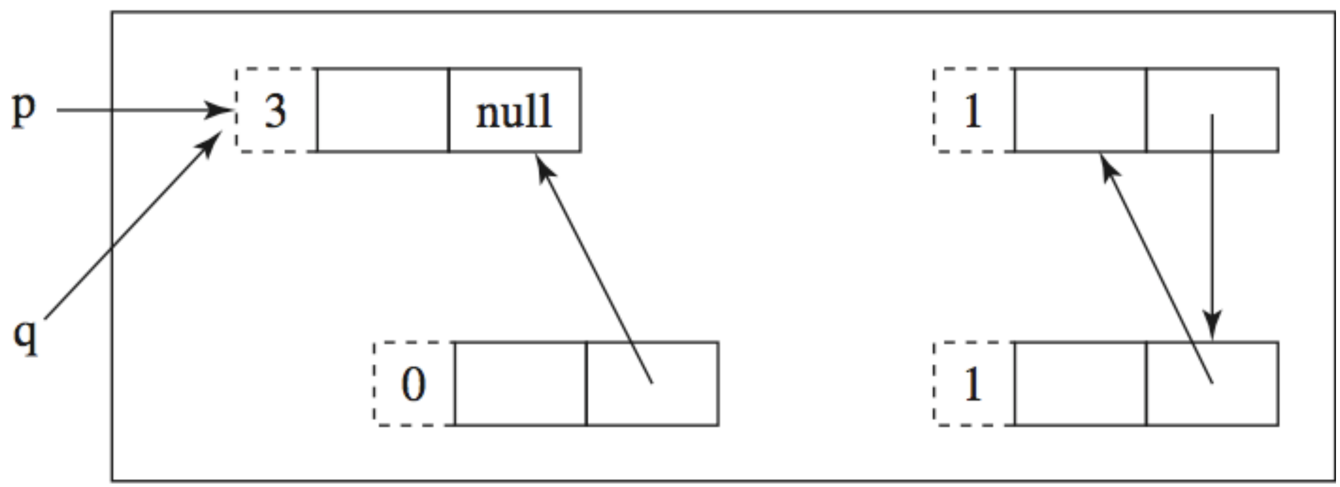
Each node has a reference count (RC).

For an assignment, like q = p, garbage can occur:



But not all garbage is collected...

Since q's node has RC=0, the RC for each of its descendents is reduced by 1, it is returned to the free list, and this process repeats for its descendents, leaving:



Note the orphan chain on the right.

11.3.2 Mark-Sweep

Each node in the *free_list* has a mark bit (MB) initially 0.

Called only when heap overflow occurs:

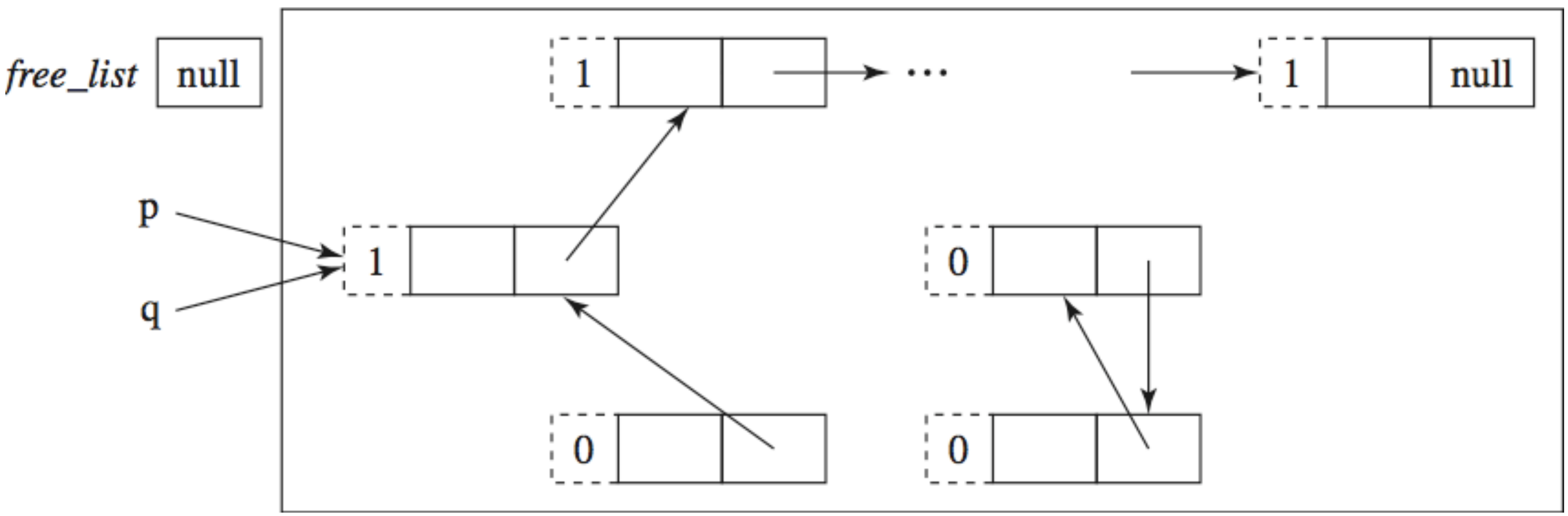
Pass I: Mark all nodes that are (directly or indirectly) accessible from the stack by setting their MB=1.

Pass II: Sweep through the entire heap and return all unmarked (MB=0) nodes to the free list.

Note: all orphans are detected and returned to the free list.

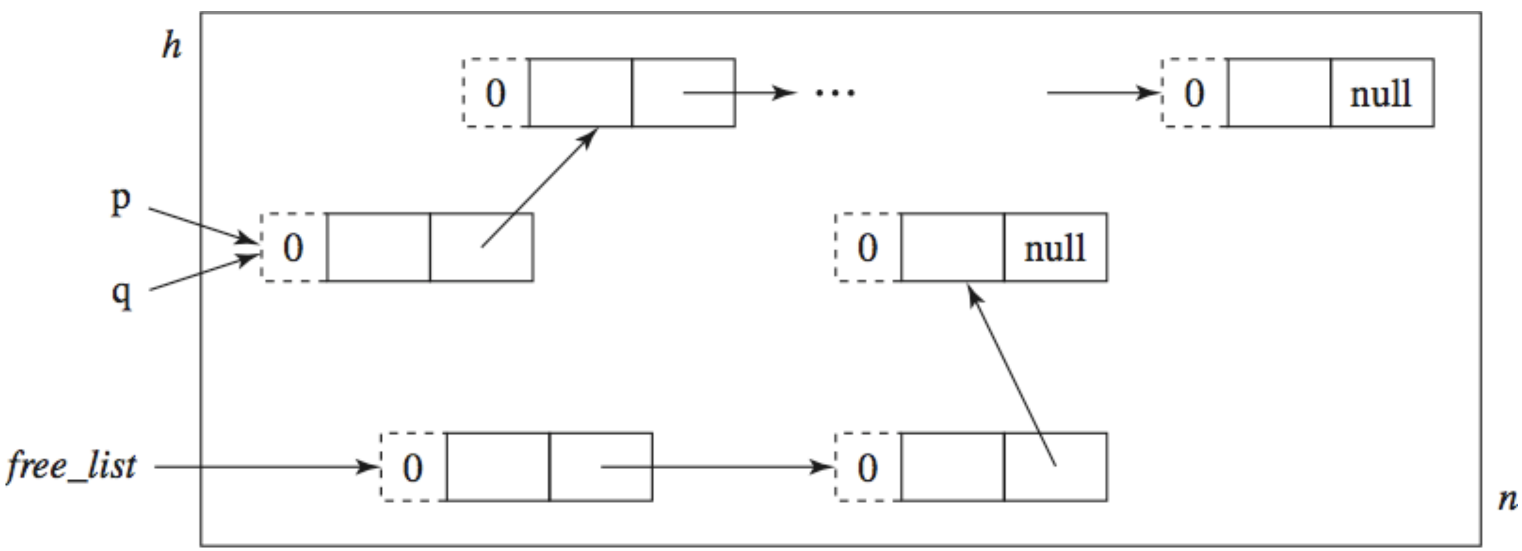
Heap after Pass I of Mark-Sweep

Triggered by `q=new node()` and *free_list* = null.
All accessible nodes are marked 1.



Heap after Pass II of Mark-Sweep

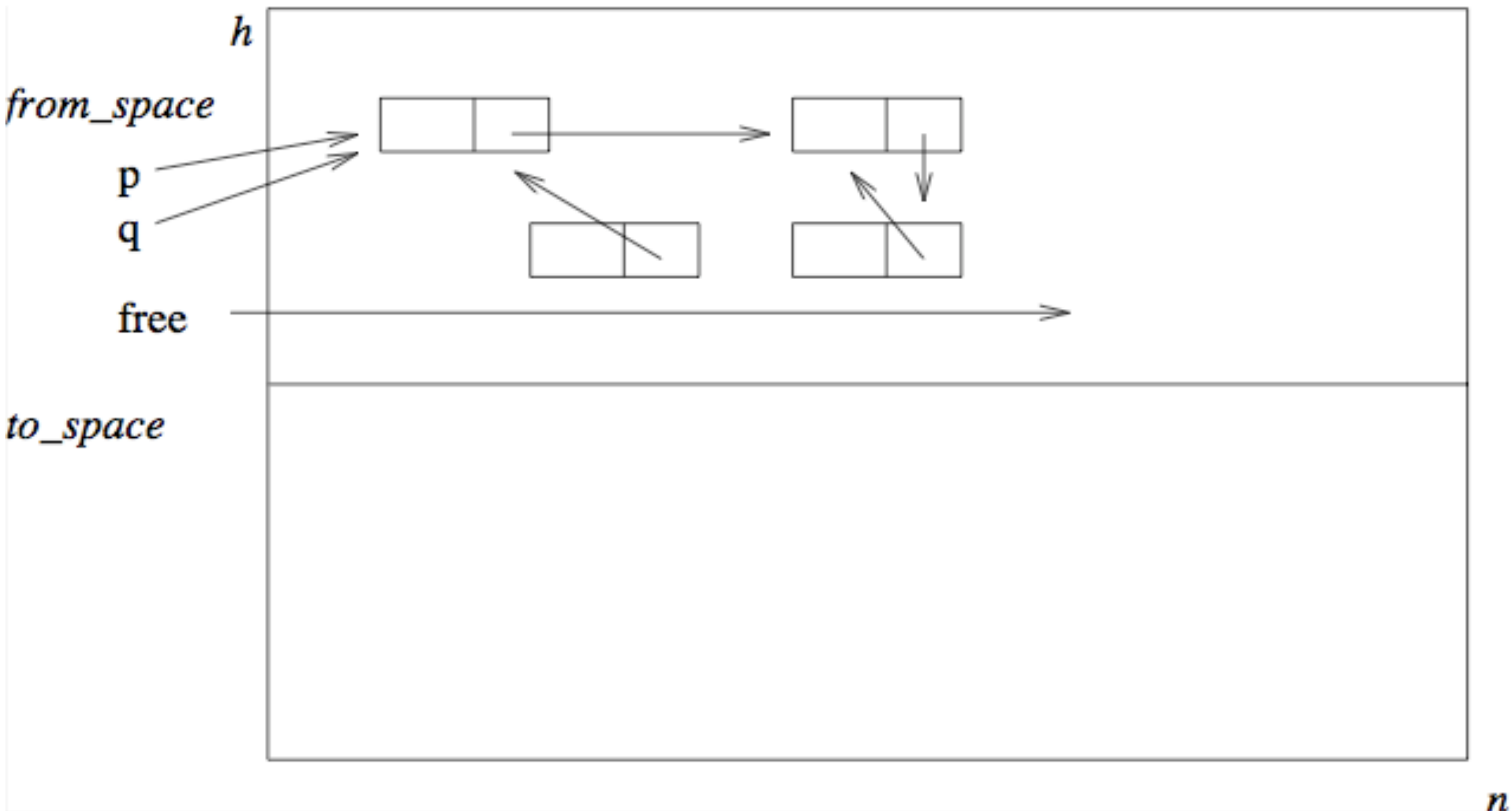
Now *free_list* is restored and
the assignment q=new node() can proceed.



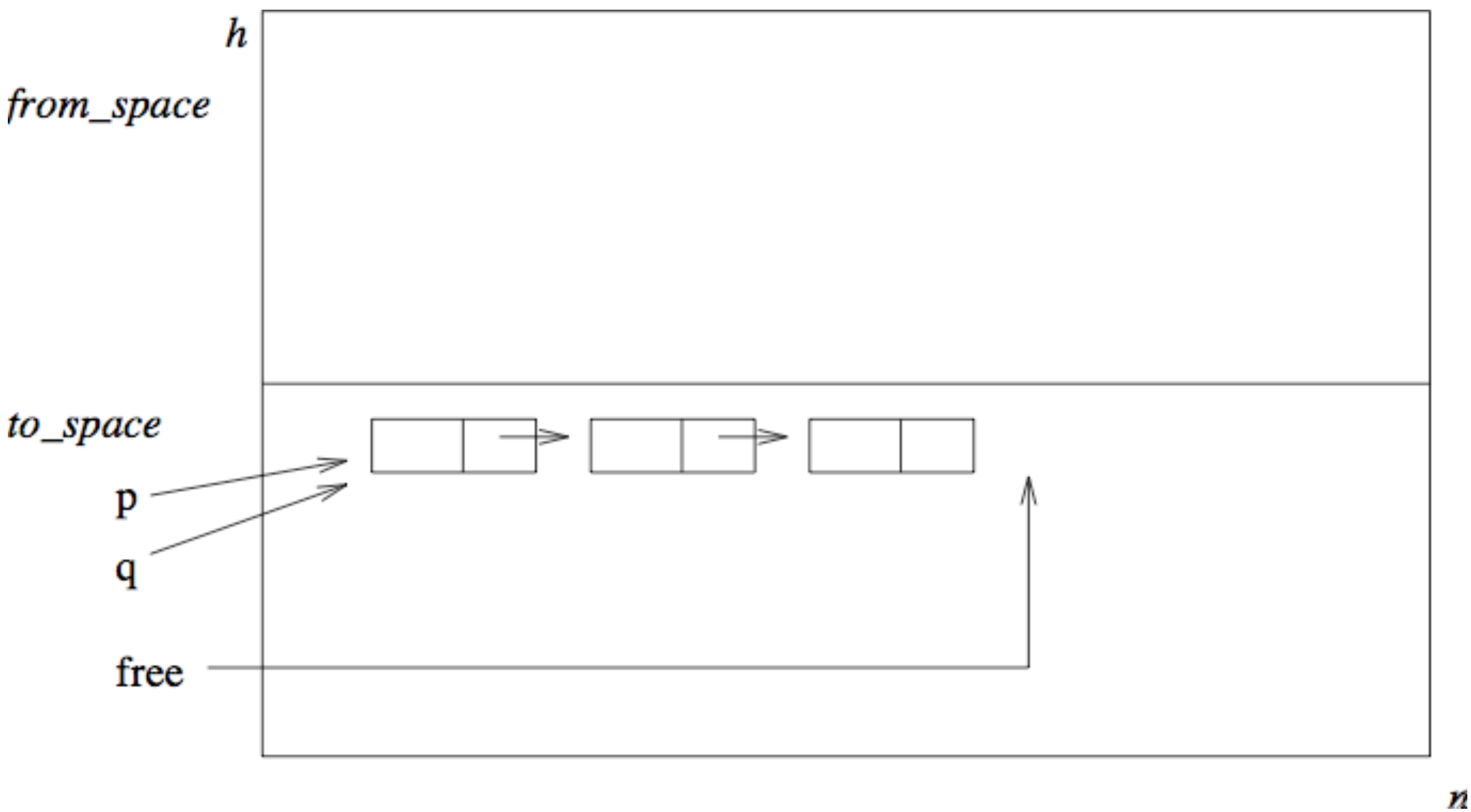
11.3.3 Copy Collection

Heap partitioned into two halves; only one is active.

Triggered by q=new node() and *free_list* outside the active half:



Accessible nodes copied to other half



Note: The accessible nodes are packed, orphans are returned to the free_list, and the two halves reverse roles.

Garbage Collection Summary

- Modern algorithms are more elaborate.
  - *Most are hybrids/refinements of the above three.*
- In Java, garbage collection is built-in.
  - *runs as a low-priority thread.*
  - *Also,* `System.gc` *may be called by the program.*
- Functional languages have garbage collection built-in.
- C/C++ default garbage collection to the programmer.