CSc 520 — Principles of Programming Languages

9 : Garbage Collection — Copying Collection

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1 Copying Collection

- Even if most of the heapspace is garbage, a mark and sweep algorithm will touch the entire heap. In such cases it would be better if the algorithm only touched the live objects.
- **Copying collection** is such an algorithm. The basic idea is:
  1. The heap is divided into two spaces, the **from-space** and the **to-space**.
  2. We start out by allocating objects in the **from-space**.
  3. When **from-space** is full, all live objects are copied from **from-space** to **to-space**.
  4. We then continue allocating in **to-space** until it fills up, and a new GC starts.

2 Copying Collection...

- An important side-effect of **copying collection** is that we get automatic compaction – after a collection **to-space** consists of the live objects in a contiguous piece of memory, followed by the free space.
- This sounds really easy, but ···:
  - We have to traverse the object graph (just like in mark and sweep), and so we need to decide the order in which this should be done, depth-first or breadth-first.
  - DFS requires a stack (but we can, of course, use pointer reversal just as with mark and sweep), and BFS a queue. We will see later that encoding a queue is very simple, and hence most implementations of copying collection make use of BFS.

3 Copying Collection...

- This sounds really easy, but ···
  - An object in **from-space** will generally have several objects pointing to it. So, when an object is moved from **from-space** to **to-space** we have to make sure that we change the pointers to point to the new copy.

4 Copying Collection...

- Mark-and-sweep touches the entire heap, even if most of it is garbage. Copying collection only touches live cells.
- Copying collection divides the heap in two parts: **from-space** and **to-space**.
- **to-space** is automatically compacted.
- How to traverse object graph: BFS or DFS?
- How to update pointers to moved objects?

Algorithm:

1. Start allocating in **from-space**.
2. When **from-space** is full, copy live objects to **to-space**.
3. Now allocate in **to-space**.

5 Copying Collection...

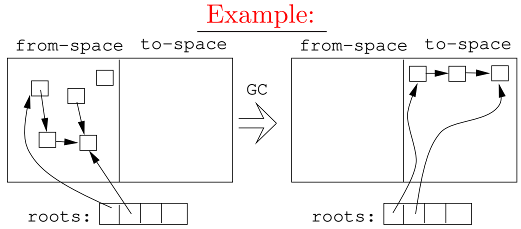
Traversing the Object Graph:

- Most implementations use BFS.
- Use the **to-space** as the queue.

Updating (Forwarding) Pointers:

- When an object is moved its new address is stored **first** in the old copy.

Example:

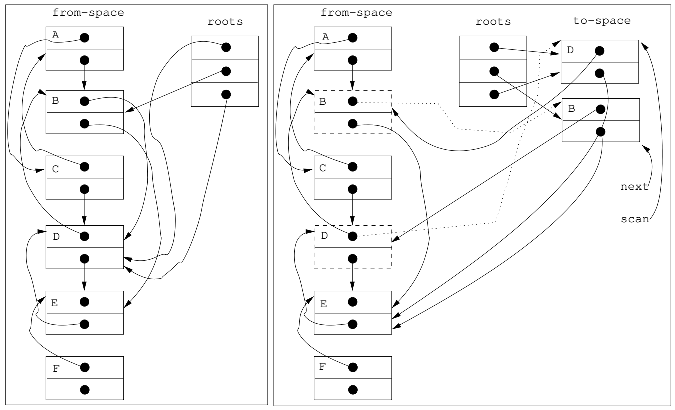


6 Copying Collection Algorithm

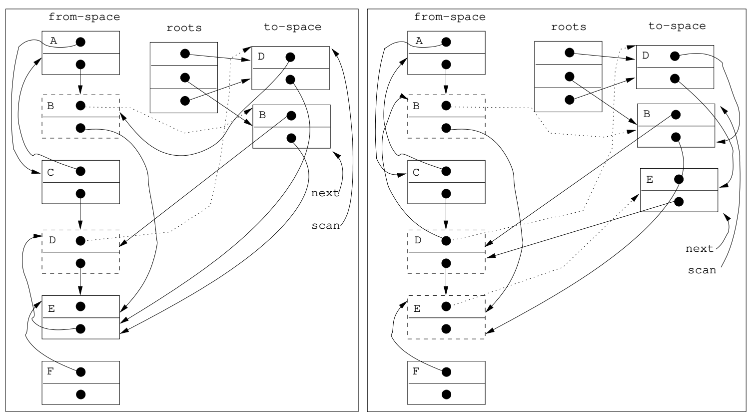
1. `scan := next := ` **ADDR**`(to-space)`
   - [`scan` $\cdots$ `next`] hold the BFS queue.
   - Objects above `scan` point into `to-space`. Objects between `scan` and `next` point into **from-space**.
2. Copy objects pointed to by the root pointers to `to-space`.
3. Update the root pointers to point to `to-space`.
4. Put each object's new address first in the original.
5. Repeat (recursively) with all the pointers in the new `to-space`.
   (a) Update `scan` to point past the last processed node.
   (b) Update `next` to point past the last copied node.

   Continue while `scan < next`.

7 Copying Collection Example... (A)



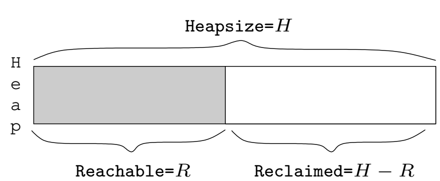
8 Copying Collection Example... (B)



Cost of Garbage Collection

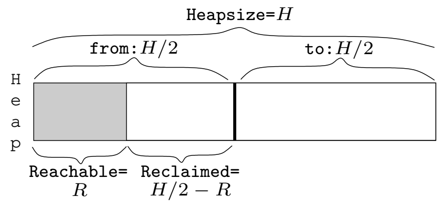
9 Cost of Garbage Collection

- The size of the heap is H, the amount of reachable memory is R, the amount of memory reclaimed is $H - R$.



$$
\begin{aligned}
\textit{amortized GC cost} &= \frac{\textit{time spent in GC}}{\textit{amount of garbage collected}} \\
&= \frac{\textit{time spent in GC}}{H - R}
\end{aligned}
$$

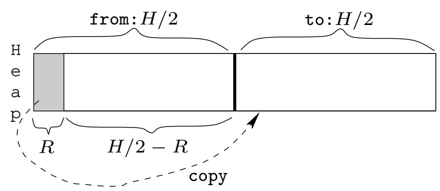
10 Cost of GC — Copying Collection



- The breadth first search phase touches all live nodes. Hence, it takes time c_3R, for some constant c_3. $c_3 \approx 10$?
- The heap is divided into a from-space and a to-space, so each collection reclaims $\frac{H}{2} - R$ words.

$$GC\ cost = \frac{c_3R}{\frac{H}{2} - R} \approx \frac{10R}{\frac{H}{2} - R}$$

11 Cost of GC — Copying Collection...



- If there are few live objects ($H \gg R$) the GC cost is low.
- If $H = 4R$, we get

  $$GC\ cost = \frac{c_3R}{\frac{4R}{2} - R} \approx 10.$$

  This is expensive: 4 times as much memory as reachable data, 10 instruction GC cost per object allocated.

12 Readings and References

- **Read Scott, pp. 387–388.**