CSc 520

Principles of Programming Languages

43: Garbage Collection — Discussion

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Unobrusive Garbage Collection

Unobrusive Garbage Collection

GC Requirements:

batch programs: We want short total GC time.

interactive programs: We want unnoticable GCs.

Unobtrusive GC:

Incremental Collection

- Do a little GC-work every time an object is allocated, or a pointer is changed.

Concurrent Collection

- Run the collector and the program in different processes, or on different processors.

Incremental GC

- Use copying collection, but rather than stop when you run out of memory and then do all the GC work in one shot, do a little bit whenever a pointer variable is referenced or when a new object is allocated.
- We start out by forwarding (copying) the objects pointed to by global variables.
- Then, instead of continuing forwarding recursively, we resume the program.
- Every time a pointer is referenced we check to see whether it is pointing into `from-space`. If it is, we forward that object too.

Incremental GC…

- Even objects which are not explicitly referenced have to be checked, to see if they have become garbage.
  Therefore, every time we allocate a new object we forward k pointers.
  A good value for k has to be determined by experimentation.
- Eventually `scan` will catch up with `next` and we switch `from-space` and `to-space` and start an new cycle.
- Baker's algorithm (on the next slide) is a variant of copying collection.

Incremental GC…

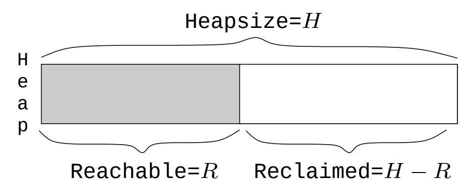
1. Copy and update objects pointed to by global pointers to `to-space`.
2. Resume program.
3. When an object in `from-space` is referenced, first copy it to `to-space`.

   p `:=` $x\uparrow$`.next;`
   $\Downarrow$ `(implemented as)`
   IF $x \in \mathtt{from-space}$ **THEN**
   `copy` x `to to-space;`
   `update` x`, scan, and next;`
   x `:=` x`'s new address in to-space;`
   END;
   p `:=` $x\uparrow$`.next;`
4. Every time NEW is called, k pointers are forwarded.

Cost of Garbage Collection

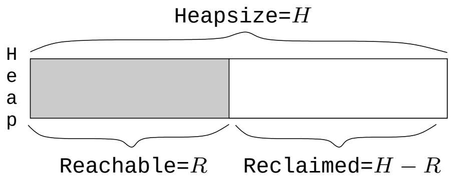
Cost of Garbage Collection

- The size of the heap is H, the amount of reachable memory is R, the amount of memory reclaimed is $H - R$.
- What is the cost of the different GC algorithms?



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

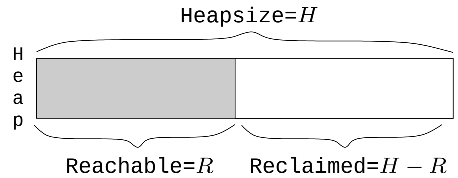
Cost of GC — Mark-and-Sweep



- The mark phase touches all live nodes. Hence, it takes time $c_1 H$, for some constant c_1. $c_1 \approx 10$?
- The sweep phase touches the whole heap. Hence, it takes time $c_2 R$, for some constant c_2. $c_2 \approx 3$?

$$\textit{GC cost} = \frac{c_1 R + c_2 H}{H - R} \approx \frac{10R + 3H}{H - R}$$

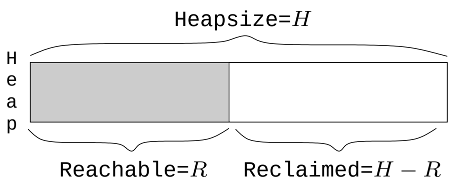
Cost of GC — Mark-and-Sweep…



$$\textit{GC cost} = \frac{c_1 R + c_2 H}{H - R} \approx \frac{10R + 3H}{H - R}$$

- If $H \approx R$ we reclaim very litte, and the cost of GC goes up. In this case the GC should grow the heap (increase H).

Cost of GC — Copying Collection



- The breadth first search phase touches all live nodes. Hence, it takes time $c_3 R$, 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.

$$\textit{GC cost} = \frac{c_3 R}{\frac{H}{2} - R} \approx \frac{10R}{\frac{H}{2} - R}$$

Cost of GC — Copying Collection…

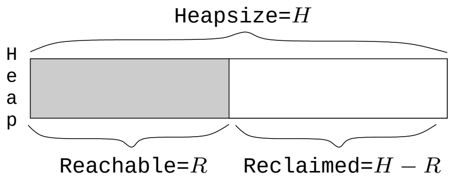
$$\textit{GC cost} = \frac{c_3 R}{\frac{H}{2} - R} \approx \frac{10R}{\frac{H}{2} - R}$$

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

$$\textit{GC cost} = \frac{c_3 R}{\frac{4R}{2} - R} \approx 10.$$

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

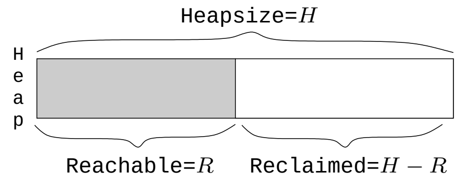
Cost of GC — Generational Collection



- Assume the youngest generation (G_0) has 10% live data, i.e. $H = 10R$.
- Assume we're using copying collection for G_0.

$$\textit{GC cost}_{G_0} = \frac{c_3 R}{\frac{H}{2} - R} = \frac{c_3 R}{\frac{10R}{2} - R} \approx \frac{10R}{4R} = 2.5$$

Cost of GC — Generational Collection. . .



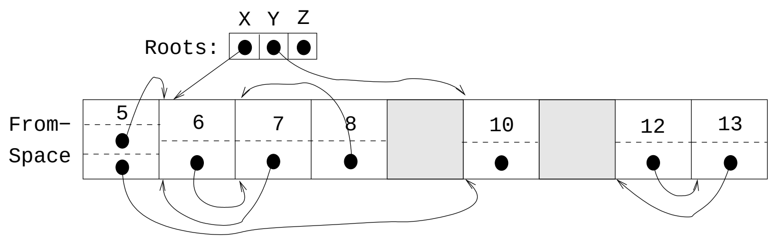
$$\textit{GC cost}_{G_0} = \frac{c_3 R}{\frac{H}{2} - R} = \frac{c_3 R}{\frac{10R}{2} - R} \approx \frac{10R}{4R} = 2.5$$

- If $R \approx 100$ kilobytes in G_0, then $H \approx 1$ megabyte.
- In other words, we've wasted about 900 kilobytes, to get 2.5 instruction/word GC cost (for G_0).

Exam Problem

1. Why is generational collection more appropriate for functional and logic languages (such as LISP and Prolog), than for object-oriented languages (such as Eiffel and Modula-3)?
2. The heap in the figure on the next slide holds 7 objects. All objects have one integer field and one or two pointer fields (black dots). The only roots are the three global variables `X`, `Y`, and `Z`. Free space is shaded. Show the state of `To-Space` after a copying garbage collection has been performed on `From-Space`. Note that several answers are possible, depending on the visit strategy (Depth-First or Breadth-First Search) you chose.

Exam Problem I. . .



Exam Problem. . .

1. Name five garbage collection algorithms!
2. Describe the Deutsch-Schorr-Waite algorithm! When is it used? Why is it used? How does it work?
3. What are the differences between stop-and-copy, **incremental** and concurrent garbage collection? When would we prefer one over the other?

Readings and References

- Read Scott, pp. 395–401.
- Apple's Tiger book, pp. 257–282
- Topics in advanced language implementation, Chapter 4, Andrew Appel, Garbage Collection. Chapter 5, David L. Detlefs, Concurrent Garbage Collection for C++. ISBN 0-262-12151-4.
- Aho, Hopcroft, Ullman. Data Structures and Algorithms, Chapter 12, Memory Management.

Readings and References. . .

- Nandakumar Sankaran, A Bibliography on Garbage Collection and Related Topics, ACM SIGPLAN Notices, Volume 29, No. 9, Sep 1994.
- J. Cohen. Garbage Collection of Linked Data Structures, Computing Surveys, Vol. 13, No. 3, pp. 677–678.