Lecture 14

Introduction to Garbage Collection

I Why is Automatic GC Important and Hard?

II Reference Counting

III Basic Trace-Based GC

Readings: Chapter 7.4-7.6.4

I. Why Automatic Memory Management?

- **Perfect**

	live	dead
not deleted	✓	–––
deleted	–––	✓

- **Manual management**

	live	dead
not deleted		
deleted		

- **Assume for now the target language is Java**

What is Garbage?

When is an Object not Reachable?

- **Mutator (the program)**
  - New / malloc: (creates objects)
  - Store p in a pointer variable or field in an object
  - Load
  - Procedure calls
- **Important property**
  - once an object becomes unreachable, stays unreachable!

How to Find Unreachable Objects?

II. Reference Counting

- **Free objects as they transition from "reachable" to "unreachable"**
- **Keep a count of pointers to each object**
- **Zero reference -> not reachable**
  - When the reference count of an object = 0
    - delete object
    - subtract reference counts of objects it points to
    - recurse if necessary
- **Not reachable -> zero reference?**
- **Cost**
  - overhead for each statement that changes ref. counts

III. Why is Trace-Based GC Hard?

- **Reasons**
  - Requires complementing the reachability set - that's a large set
  - Interacts with resource management: memory

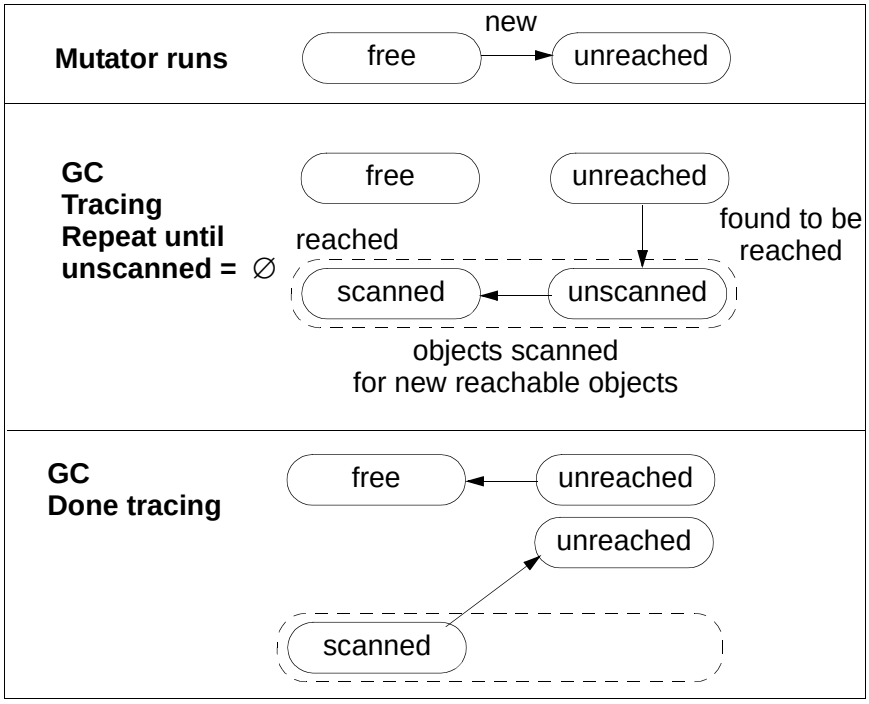
Trace-based GC

- **Reachable objects**
  - Root set: (directly accessible by prog. without deref'ing pointers)
    - objects on the stack, globals, static field members
  - + objects reached transitively from ptrs in the root set.
- **Complication due to compiler optimizations**
  - Registers may hold pointers
  - Optimizations (e.g. strength reduction, common subexpressions) may generate pointers to the middle of an object
  - Solutions
    - ensure that a "base pointer" is available in the root set
    - compiler writes out information to decipher registers and compiler-generated variables (may restrict the program points where GC is allowed)

Baker's Algorithm

- **Data structures**
  - Free: a list of free space
  - Unscanned: a work list
  - Unreached: a list of allocated objects
  - Scanned: a list of scanned objects
- **Algorithm**
  - Scanned = ∅
  - Move objects in root set from Unreached to Unscanned
  - While Unscanned ≠ ∅
    - move object o from Unscanned to Scanned
    - scan o, move newly reached objects from Unreached to Unscanned
  - Free = Free ∪ Unreached
  - Unreached = Scanned

Trace-Based GC: Memory Life-Cycle

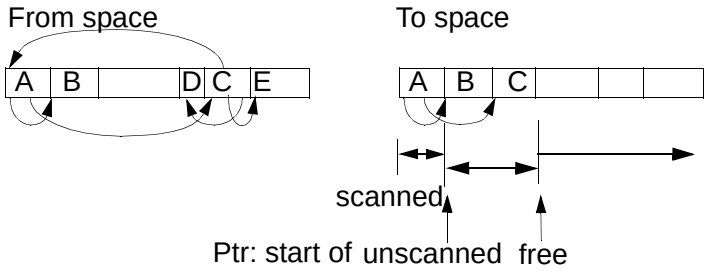


Copying Collector

- **To improve data locality**
  - place all live objects in contiguous locations
- **Memory separated into 2 (semi-)spaces: From and To**
  - Allocate objects in one
  - When (nearly) full, invoke GC,
    which copies reachable objects to the other space.
  - Swap the roles of semi-spaces and repeat

Copying Collector (cont)

- **Algorithm**



  - UnScanned = Free = Start of To space
  - Copy root set of objects space after Free, update Free;
  - While UnScanned ≠ Free
    - scan o, object at UnScanned
    - copy all newly reached objects to space after Free, update Free
    - update pointers in o
    - update UnScanned

Frequency of GC

- **How many objects?**
  - Language dependent, for example, Java:
    - all non-primitive objects are allocated on the heap
    - all elements in an array are individually allocated
    - “Escape” analysis is useful
      -- object escapes if it is visible to caller
      -- allocate object on the stack if it does not escape
- **How long do objects live?**
  - Objects die young
- **Cost of reachability analysis: depends on reachable objects**
  - Less frequent: faster overall, requires more memory

Conclusions

- **Manual GC is error-prone**
  - Memory leaks & dangling pointers
- **Automatic GC: eliminate unreachable objects, not dead objects**
  - May still leak memory, if pointers to unused data exist
- **Reference counting**
  - Delete objects when their reference counts go to 0
  - Expensive
  - Cannot collect circular data structures
- **Trace-based GC**
  - Find all reachable objects, complement to get unreachable
  - 4 states: free, unreached unscanned, scanned
  - Stop-the-world GC: Baker’s algorithm has a long pause time
  - Copying collector improves data locality