

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

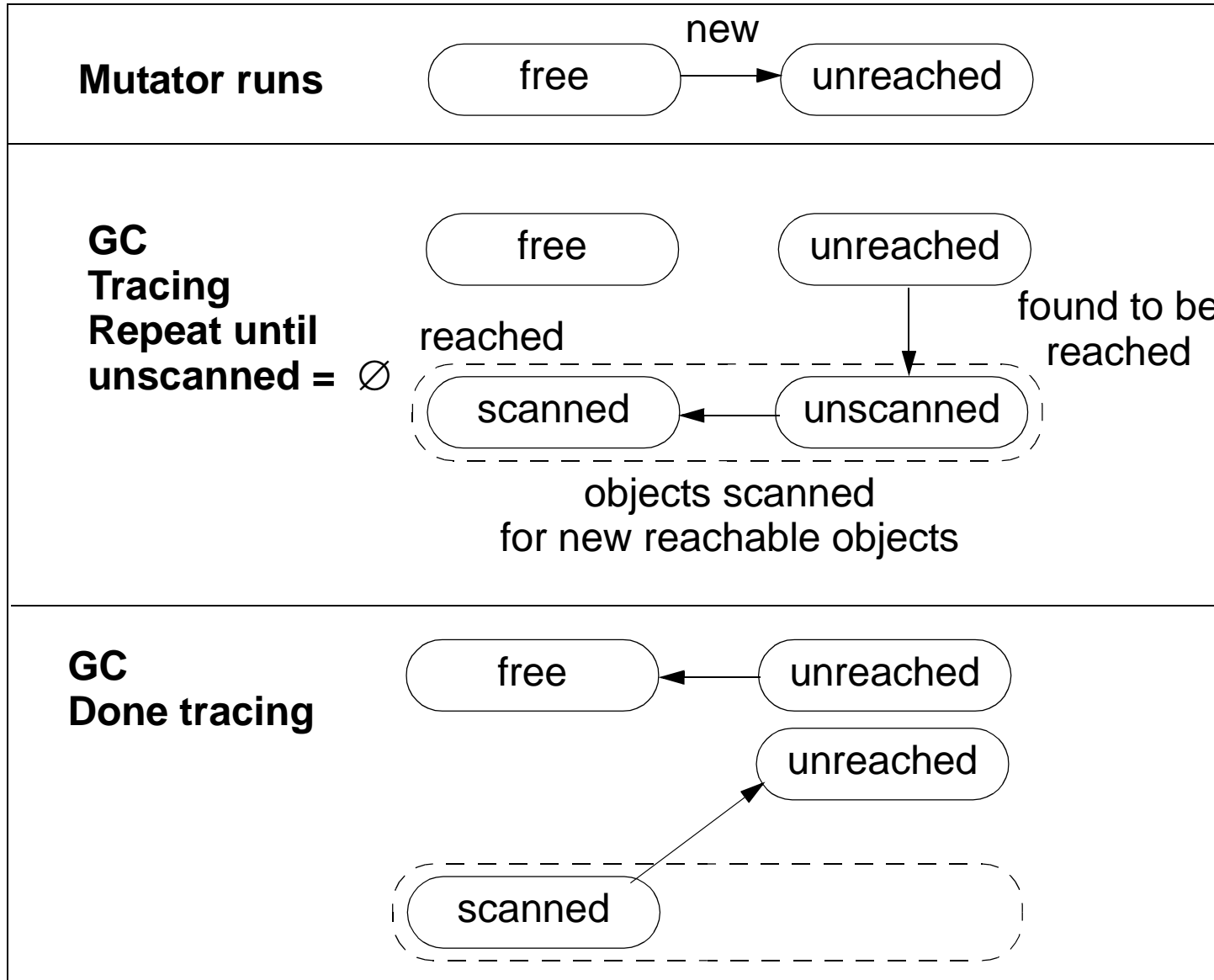
Trace-based GC

- **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 = \emptyset
 - Move objects in root set from Unreached to Unscanned
 - While Unscanned $\neq \emptyset$
 - move object o from Unscanned to Scanned
 - scan o , move newly reached objects from Unreached to Unscanned
 - Free = Free \cup Unreached
 - Unreached = Scanned

Trace-Based GC: Memory Life-Cycle

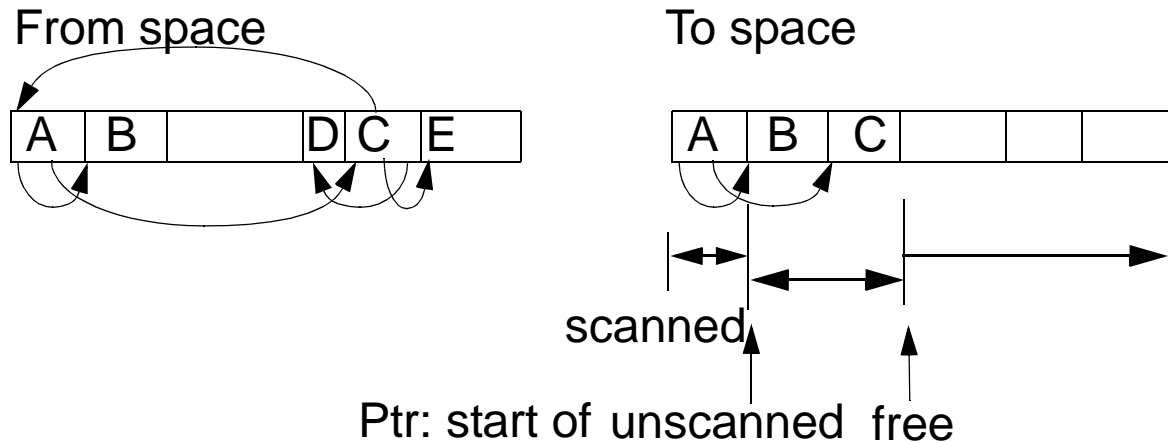


Copying Collector

- **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 \neq 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