# Lecture 15

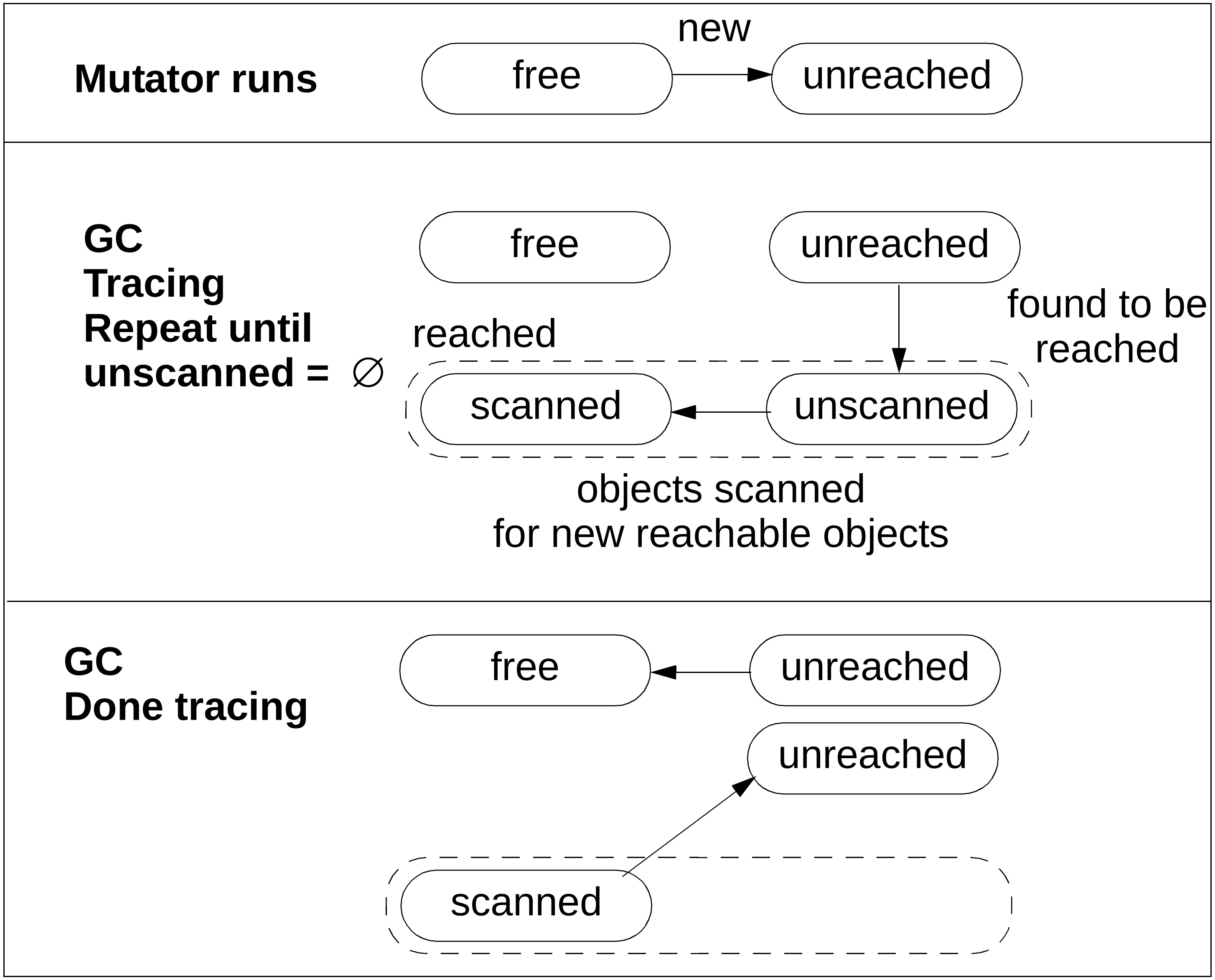
# Advanced Garbage Collection

I Break Up GC in Time (Incremental)

II Break Up GC in Space (Partial)

Readings: Ch. 7.6.4 - 7.7.4

# Trace-Based GC: Memory Life-Cycle



**Mutator runs**

free → new → unreached

**GC**
**Tracing**
**Repeat until**
**unscanned = ∅**

free

unreached → found to be reached → unscanned

reached: scanned ← unscanned

objects scanned
for new reachable objects

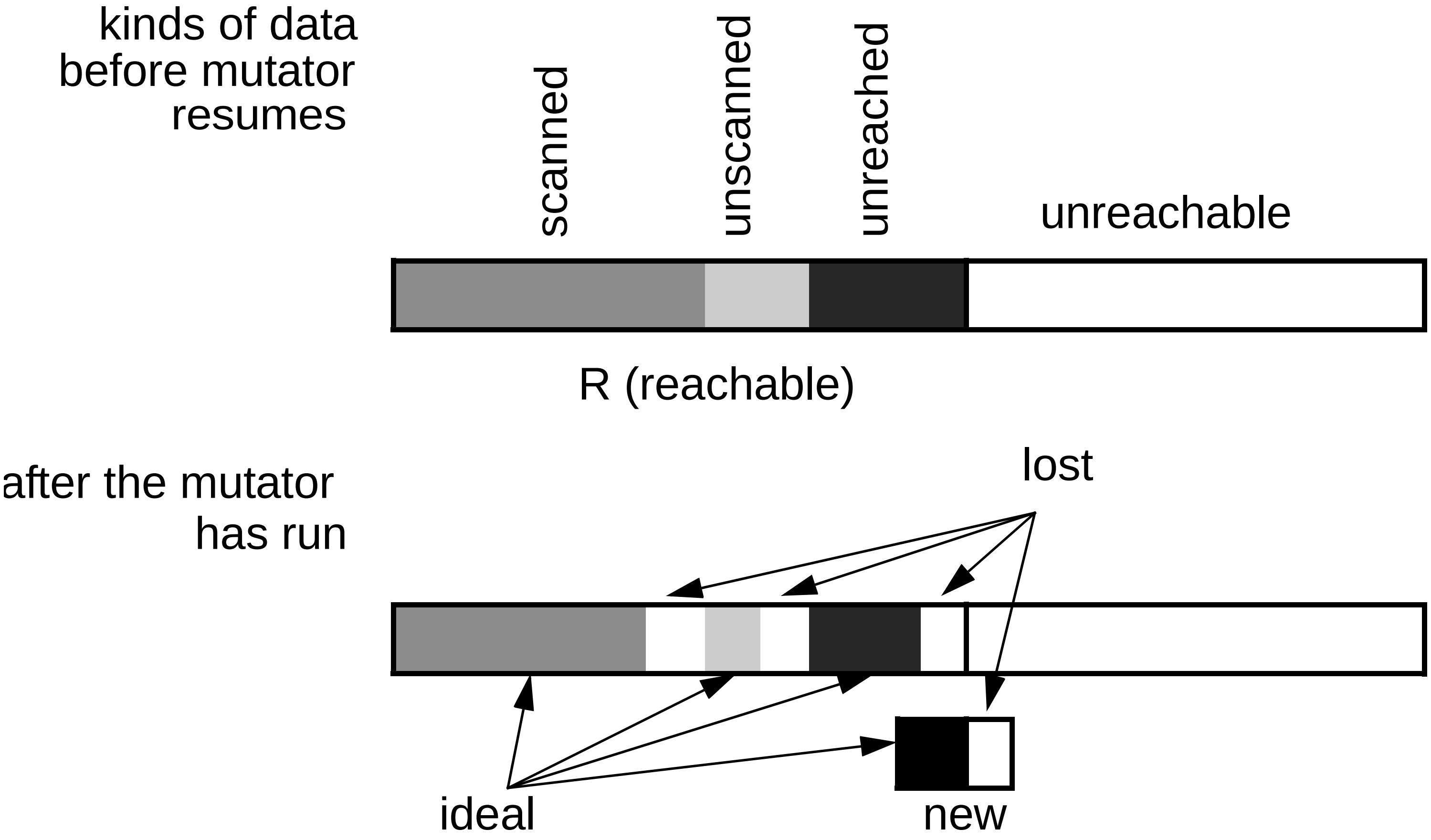
**GC**
**Done tracing**

free ← unreached

unreached ← scanned

# I. Incremental GC

- **Interleaves GC with mutator action to reduce pause time**



$$\text{Ideal} = (R \cup \text{New}) - \text{Lost}$$

$$(R \cup \text{New}) - \text{Lost} \subseteq \text{Answer} \subseteq (R \cup \text{New})$$

# Effects of Mutation

- **Reachable set changes as mutator runs**
  - R: set of reachable objects before the mutator runs
  - Ideal: set of reachable objects at the end of the GC cycle
  - New: set of newly created objects
  - Lost: set of objects that become unreachable in the interim
  - Ideal = $(R \cup \text{New}) - \text{Lost}$
- **Ideal: Very expensive**
- **Conservative Incremental GC:**
  **May misclassify some unreachable as reachable**
  - should not include objects unreachable before GC starts
  - guarantees that garbage will be eliminated in the next round

$$\text{Ideal} = (R \cup \text{New}) - \text{Lost} \subseteq \text{Answer} \subseteq (R \cup \text{New})$$

# Algorithm Proposal 1

- **Initial condition**
    - Scanned, Unscanned lists from before
- **To resume GC**
    - Find root sets
    - Place newly reached objects in “unscanned list”
    - Continue to trace reachability without redoing “scanned” objects
- **Did we find all reachable objects?**

# Missed Reachable Objects

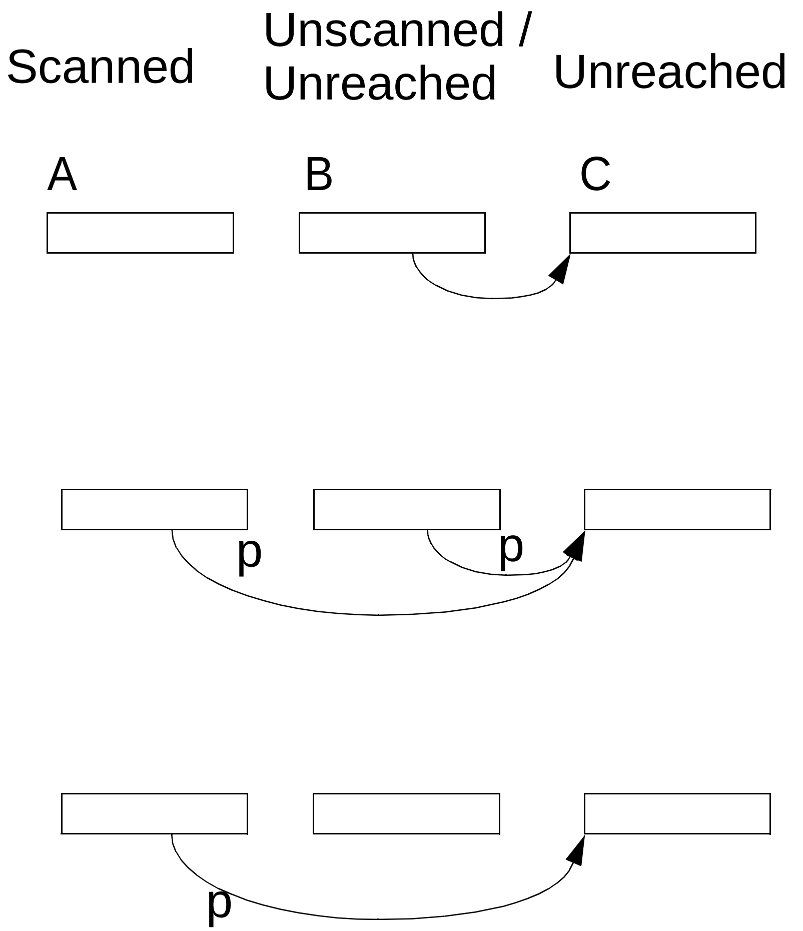
- **All reaching pointers are found in “scanned objects”**
- **Requires the occurrence of a 3-step sequence in the mutator:**

0. after a stage of GC

1. Load p = ptr from B to C

2. Store p in A

3. Store new pointer in B,
   overwriting value p



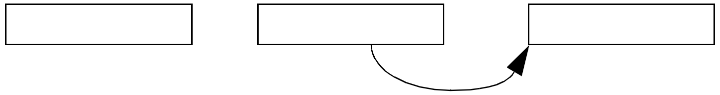
# Solution

- **Intercept p in any of the three-step sequence**
- **Treat pointee of p as “unscanned”**

A B C

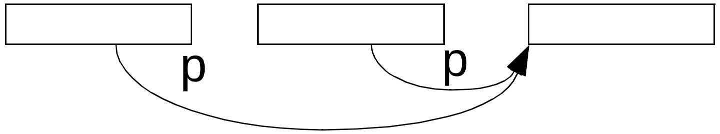
Scanned | Unscanned / Unreached | Unreached

0. after a stage of GC



1. Load p = ptr from B to C

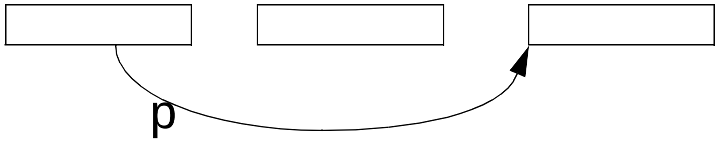
Read barrier: remember all loads of pointers from B → C



2. Store p in A

Write barrier: remember all stores of pointers A → C

3. Store new pointer in B, overwriting value p



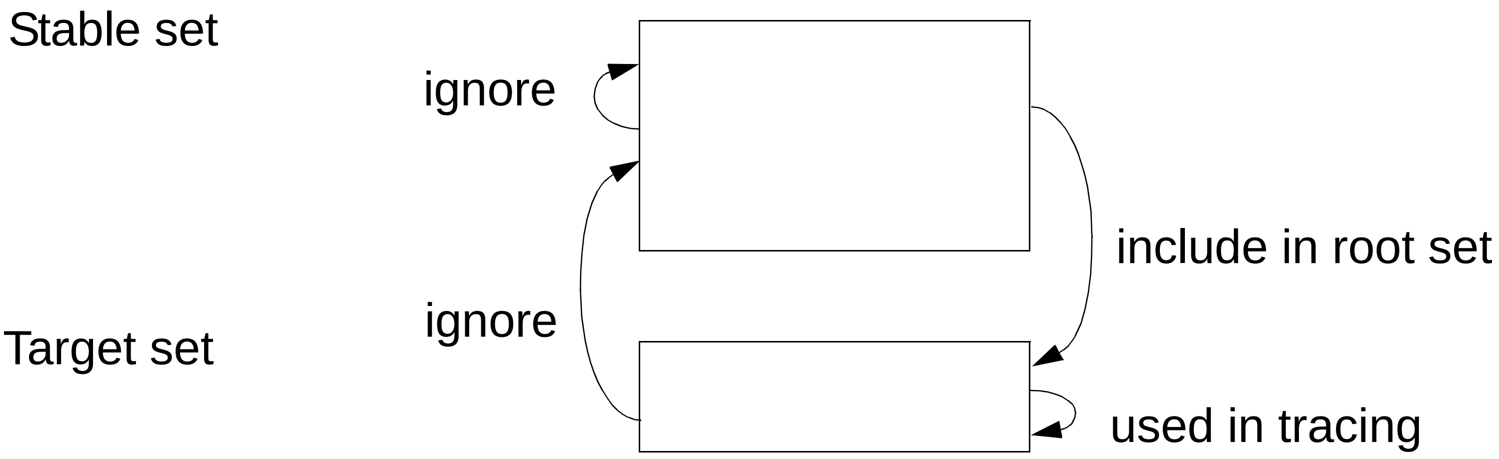
Overwrite barrier: remember all overwrites of pointer B → C

# Efficiency of Different Barriers

- **Most efficient: Write barrier**
  - less instances than read barrier
  - includes less unreachable objects than over-write barriers

# II. Partial GC

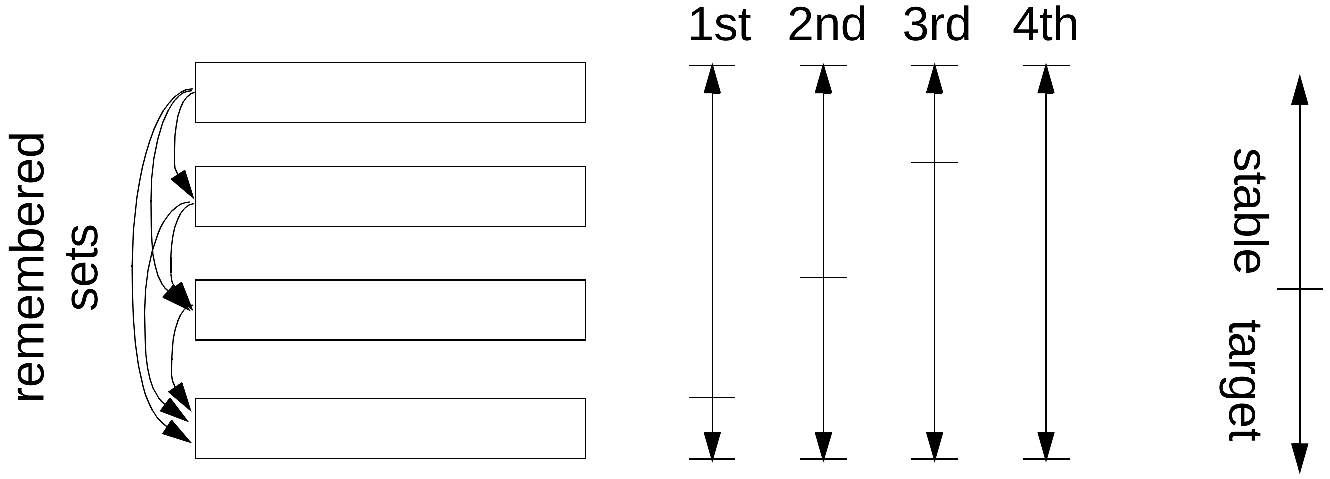
- **Reduces pause time by collecting only objects in the target area:**



- **Algorithm**
  - New “root set”
    = original root set + pointers from Stable to Target set
  - Change program to intercept all writes to Stable set
- **Never misclassify reachable as unreachable**
- **May misclassify unreachable as reachable**

# Generational GC

- **Observation: objects die young**
  - 80-98% die within a few million instructions
    or before 1 MB has been allocated
- **Generational GC: collect newly allocated objects more often**



- ith generation
  - new root set
    = original root set + all pointers from generations j to i (j > i)
- When 1st generation fills up,
  GC copies reachable objects into 2nd generation,
  and so on.

# Properties

- **Never misclassify reachable as unreachable**
- **Misclassify unreachable as reachable**
  - when pointers in earlier generations are overwritten
  - eventually collect all garbage as generations get larger
- **Effective: time spent on objects that are mostly garbage**
- **GC of mature objects takes longer**
  - Size of target set increases
  - Eventually a full GC is performed

# Conclusions

- **Trace-based GC:**
  **find all reachable objects, complement to get unreachable**
    - 4 states: free, unreached, unscanned, scanned
    - break up reachability analysis
        - in time (incremental)
        - in space (partial: generational)