Compiler Construction
Lent Term 2014
Lecture 8 (of 16)

Read related chapter of Appel

- **The heap and garbage collection**
  - **Reference counting**
  - **Mark and sweep**
  - **Copy collection**
  - **Generational collection**

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Memory Management

- Modern programming languages allow programmers to allocate new storage dynamically
  - New records, arrays, tuples, objects, closures, etc.
- Memory could easily be exhausted without some method of reclaiming and recycling the storage that will no longer be used.
  - Let programmer worry about it (use **malloc** and **free** in C…)
  - Automatic “garbage collection”

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Solutions

- Let programmer worry about it (use **malloc** and **free** in C…)
- Automatic "garbage collection"
  - Reference Counting
  - Mark and Sweep
  - Copy Collection
  - Generational Collection
  - … there are other GC techniques…

In general, we must approximate since determining exactly what objects will never be used again is **not decidable.**

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Explicit Memory Management

- User library manages memory; programmer decides when and where to allocate and de-allocate
  - void* malloc(long n)
  - void free(void *addr)
  - Library calls OS for more pages when necessary
  - Advantage: Gives programmer a lot of control.
  - Disadvantage: people too clever and make mistakes. Getting it right can be costly. And don't we want to automate-away tedium?
  - Advantage: With these procedures we can implement garbage collection for "higher level" languages ;-)

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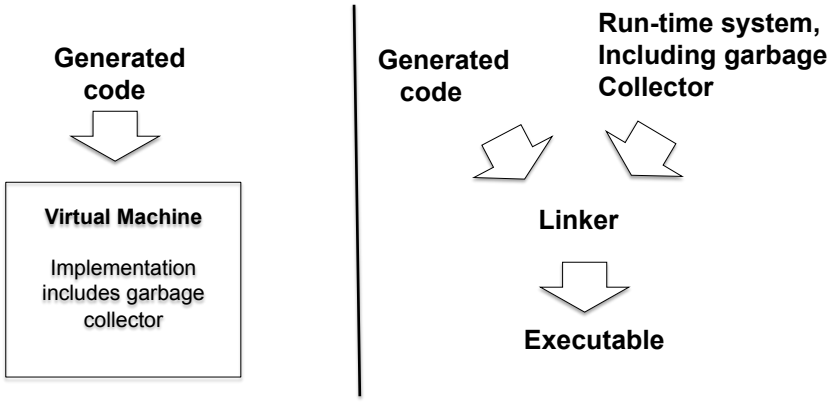
Automatic Memory Management



- When to invoke collection?
  - When out of memory?
  - When allocating new space?
  - …

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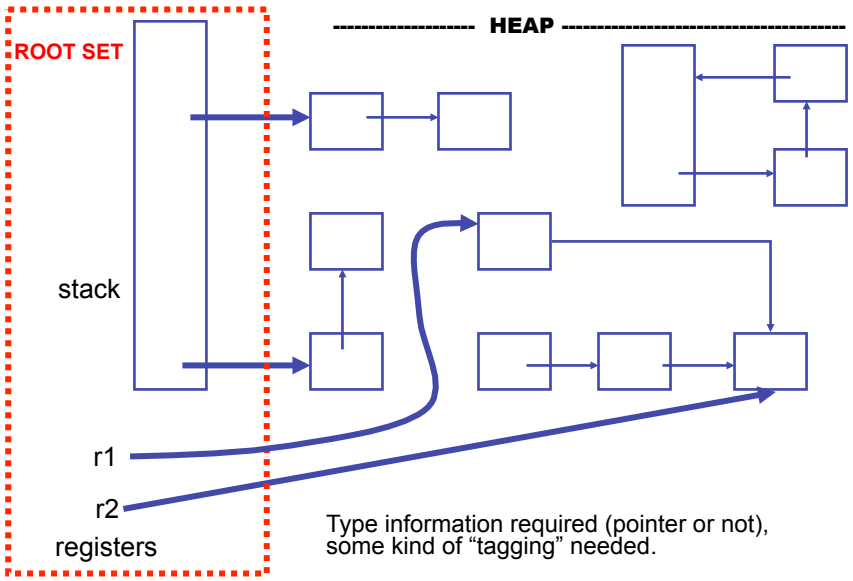
Automation is based on an approximation : if data can be reached from a root set, then it is not "garbage"



Type information required (pointer or not), some kind of "tagging" needed.

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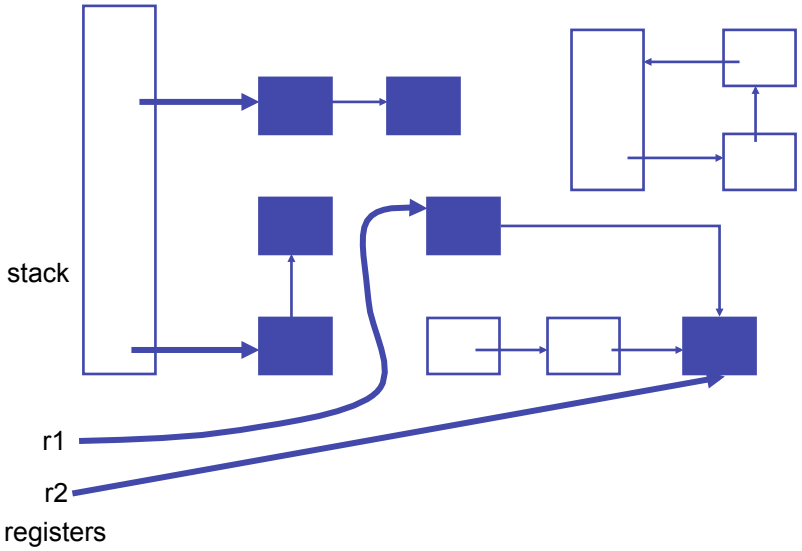
... Identify Cells Reachable From Root Set...



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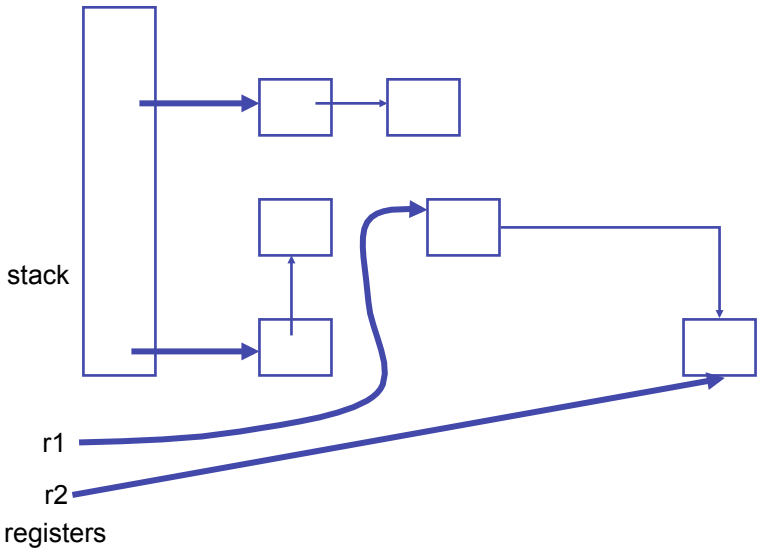
... reclaim unreachable cells



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But How? Two basic techniques, and many variations

- **Reference counting** : Keep a reference count with each object that represents the number of pointers to it. Is garbage when count is 0.
- **Tracing** : find all objects reachable from root set. Basically transitive close of pointer graph.

For a very interesting (non-examinable) treatment of this subject see

A Unified Theory of Garbage Collection.
David F. Bacon, Perry Cheng, V.T. Rajan.
OOPSLA 2004.

In that paper reference counting and tracing are presented as "dual" approaches, and other techniques are hybrids of the two.

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Reference Counting, basic idea:

- Keep track of the number of pointers to each object (the reference count).
- When Object is created, set count to 1.
- Every time a new pointer to the object is created, increment the count.
- Every time an existing pointer to an object is destroyed, decrement the count
- When the reference count goes to 0, the object is unreachable garbage

Clearly --- this can be VERY costly....

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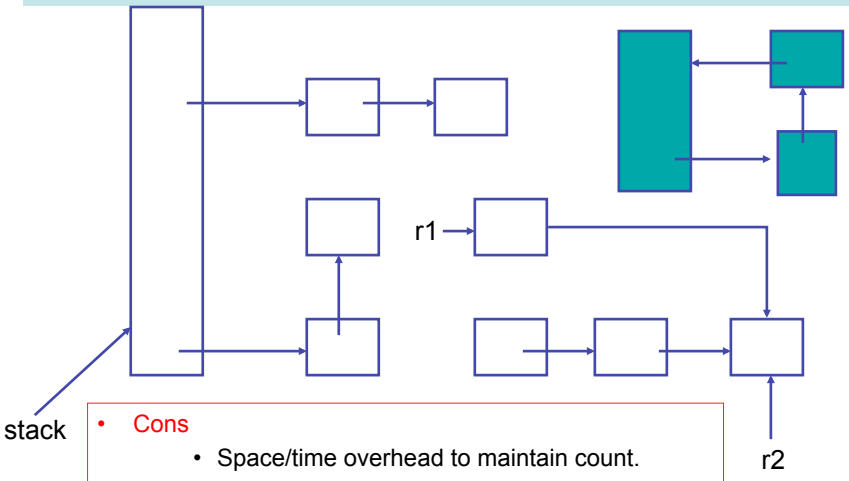
Reference counting can't detect cycles!



- Cons
  - Space/time overhead to maintain count.
  - Memory leakage when cycles in data.
- Pros
  - Incremental (no long pauses to collect…)

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Mark and Sweep

- A two-phase algorithm
  - Mark phase: Depth first traversal of object graph from the roots to mark live data
  - Sweep phase: iterate over entire heap, adding the unmarked data back onto the free list

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Cost of Mark Sweep (somewhat crude)

- Cost of mark phase:
  - O(R) where R is the # of reachable words
  - Assume cost is c1 * R (c1 may be 10 instr's)
- Cost of sweep phase:
  - O(H) where H is the # of words in entire heap
  - Assume cost is c2 * H (c2 may be 3 instr's)
- Analysis
  - The "good" = each collection returns H - R words reclaimed
  - Amortized cost = time-collecting/amount-reclaimed
    - ((c1 * R) + (c2 * H)) / (H - R)
    - If R is close to H, then each collection reclaims little space..
  - R / H must be sufficiently small or GC cost is high.
    Could dynamically adjust. Say, if R / H is larger than .5, increase heap size

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Other Problems

- Depth-first search is usually implemented as a recursive algorithm
  - Uses stack space proportional to the longest path in the graph of reachable objects
    - one activation record/node in the path
    - activation records are big
  - If the heap is one long linked list, the stack space used in the algorithm will be greater than the heap size!!
  - What do we do? Pointer reversal [See Appel]
- Fragmentation

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Copying Collection

- Basic idea: use 2 heaps
  - One used by program
  - The other unused until GC time
- GC:
  - Start at the roots & traverse the reachable data
  - Copy reachable data from the active heap (from-space) to the other heap (to-space)
  - Dead objects are left behind in from space
  - Heaps switch roles

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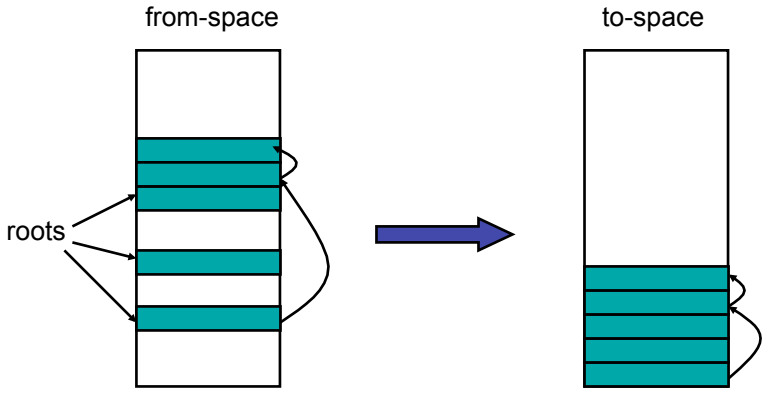
Copying Collection



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Copying GC

- Pros
  - Simple & collects cycles
  - Run-time proportional to # live objects
  - Automatic compaction eliminates fragmentation
- Cons
  - Twice as much memory used as program requires
    - Usually, we anticipate live data will only be a small fragment of store
    - Allocate until 70% full
    - From-space = 70% heap; to-space = 30%
  - Long GC pauses = bad for interactive, real-time apps

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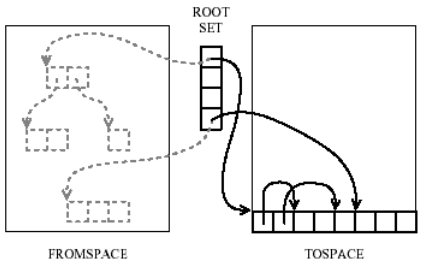
OBSERVATION: for a copying garbage collector



- 80% to 98% new objects die very quickly.
- An object that has survived several collections has a bigger chance to become a long-lived one.
- It's a inefficient that long-lived objects be copied over and over.

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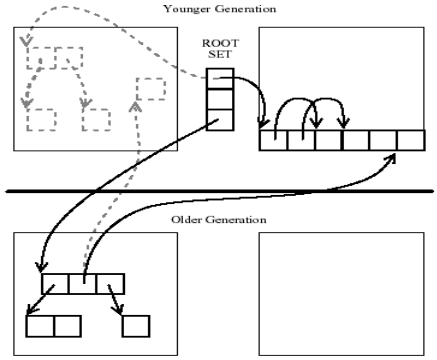
IDEA: Generational garbage collection



Segregate objects into multiple areas by age, and collect areas containing older objects less often than the younger ones.

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Other issues…

- When do we promote objects from young generation to old generation
  - Usually after an object survives a collection, it will be promoted
- Need to keep track of older objects pointing to newer ones!
- How big should the generations be?
  - Appel says each should be exponentially larger than the last
- When do we collect the old generation?
  - After several minor collections, we do a major collection
- Sometimes different GC algorithms are used for the new and older generations.
  - Why? Because the have different characteristics
  - Copying collection for the new
    - Less than 10% of the new data is usually live
    - Copying collection cost is proportional to the live data
  - Mark-sweep for the old

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