**Administrivia**

- HW #5 online. Hand in with Subversion.
- Project #4 description online; files follow Real Soon.

**Storage Management**

- Java has no means to free dynamic storage.
- However, when no expression in any thread can possibly be influenced by or change an object, it might as well not exist:
  ```java
  IntList wasteful ()
  {
      IntList c = new IntList (3, new IntList (4, null));
      return c.tail;
      // variable c now deallocated, so no way
      // to get to first cell of list
  }
  ```
- At this point, Java runtime, like Scheme's, recycles the object `c` pointed to: *garbage collection.*

**Garbage Collection: Reference Counting**

- Idea: Keep count of number of pointers to each object.

```
X = Y;
X = Y.tail;
Y = X.tail;
X = Y;
```

**Garbage Collection: Mark and Sweep**

- Start at roots (named variables, static and on stack)
- Perform graph traversal to find and mark all reachable storage.
- **Sweep** over memory, adding all unmarked storage to free list.
Copying Garbage Collection

- Copy (and move) only reachable (useful) storage from 'from' space to 'to' space.
- The 'from' and 'to' areas are called semispaces. Need twice the virtual memory you actually use.
- As you copy, mark 'from' storage as moved, and leave behind a forwarding pointer that tells how to translate other references to the old storage.
- At end of algorithm, 'from' and 'to' swap roles, and the old 'from' area is freed en masse.
- Copied storage is compacted (gaps squeezed out) with possible advantages for memory access.

Copying Garbage Collection, Illustrated

Roots

From:

| B | 42 | G | F | A | 7 | G | E | C | B |

To:

| D | G | 7 | G | 7 | B |

Roots

| B | E | D | G |

Conservative Garbage Collection

- With C, you have none of the needed information.
- But easy to know the addresses of allocated storage, and sizes of allocated objects (allocator keeps them around).
- So, guess that any word that looks like an address of allocated storage is a valid address.
- Do mark-and-sweep on this assumption (look at whole stack and static storage for roots).
- Marks some garbage, but can be surprisingly effective.

Roots and Other Pointers

- Above methods require that we know locations of roots and of pointer fields in objects.
- Positions of some roots change during execution.
- Compiler keeps tables mapping PC to where roots are.
- Runtime type information (virtual tables) keep information of where pointer fields are.
- Implementation must guarantee that fields are initialized.
Generational Garbage Collection

- Heap storage tends to "die young."
- So divide memory into young and old storage, and do copying only on young storage.
- Must add old storage that points to young storage to roots.
- When young storage survives a GC (or two), move it to old storage.
- Every now and then, stop the world and do a full garbage collection.
- This technique significantly speeds up GC.

Region-Based Allocation

- Garbage collection (all forms) does incur overheads, which can be unpredictable.
- While manual freeing is prone to error and inconvenient.
- One compromise is region-based allocation.
- Idea:
  - Create a data structure known as a region (or zone, or arena, or various other names).
  - Provides two operations: allocate object, and free all objects.
- Thus, to perform calculation that creates lots of temporary heap objects,
  - Create region (a local variable).
  - Allocate all the temporary storage in this region.
  - Delete whole region at end.

Region Implementation

- Simple implementation: allocate storage in big blocks, and allocate objects sequentially in the blocks.
- Freeing all blocks frees all the objects quickly.

```cpp
x = aRegion.alloc (40);
y = aRegion.alloc (100);
z = aRegion.alloc (120);
v = aRegion.alloc (100);
```