Lecture #37

Today: A little side excursion into nitty-gritty stuff: Stora
agement.

Scope and Lifetime

- *Scope* of a declaration is portion of program text to which it
  (is *visible*).
  - Need not be contiguous.
  - In Java, is static: independent of data.
- *Lifetime* or *extent* of storage is portion of program execut
  ing which it exists.
  - Always contiguous
  - Generally dynamic: depends on data
- Classes of extent:
  - *Static:* entire duration of program
  - *Local* or *automatic:* duration of call or block execution (lo
    able)
  - *Dynamic:* From time of allocation statement (**new**) to d
    tion, if any.

Explicit vs. Automatic Freeing

- Java has no explicit means to free dynamic storage.
- However, when no expression in any thread can possibly b
enced by or change an object, it might as well not exist:

```
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 o
pointed to: *garbage collection*.

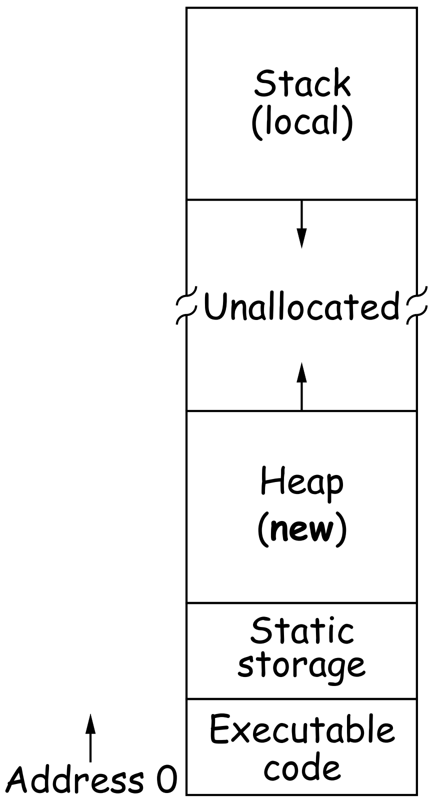
Under the Hood: Allocation

- Java pointers (references) are represented as integer addr
- Corresponds to machine's own practice.
- In Java, cannot convert integers $\leftrightarrow$ pointers,
- But crucial parts of Java runtime implemented in C, or sor machine code, where you can.
- Crude allocator in C:

```
char store[STORAGE_SIZE];  // Allocated array
size_t remainder = STORAGE_SIZE;

/** A pointer to a block of at least N bytes of storage */
void* simpleAlloc(size_t n) { // void*: pointer to anything
  if (n > remainder) ERROR();
  remainder = (remainder - n) & ~0x7;  // Make multiple of
  return (void*) (store + remainder);
}
```

Example of Storage Layout: Unix



- OS gives way to turn chunks of unallocated region into heap
- Happens automatically for stack.

Explicit Deallocating

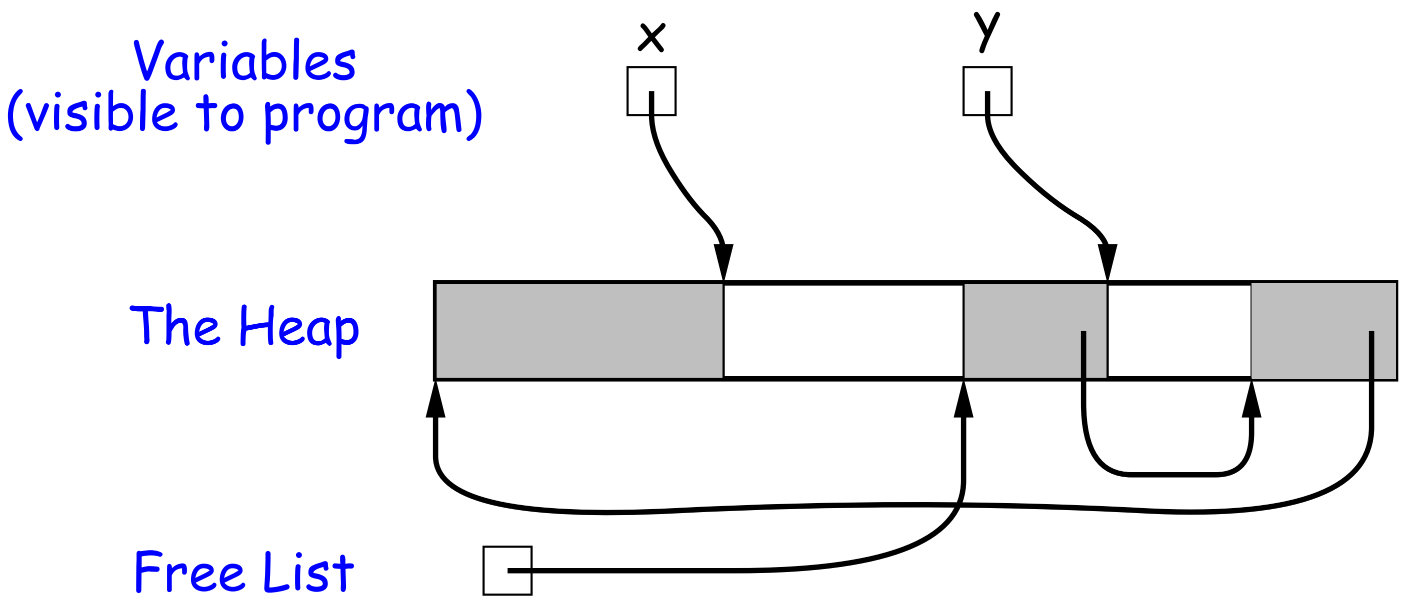
- C/C++ normally require explicit deallocation, because of
  - Lack of run-time information about what is array
  - Possibility of converting pointers to integers.
  - Lack of run-time information about *unions:*

```
union Various {
  int Int;
  char* Pntr;
  double Double;
} X;  // X is either an int, char*, or double
```

- Java avoids all three problems; automatic collection possible
- Explicit freeing can be somewhat faster, but rather error-p
  - Memory corruption
  - Memory leaks

Free Lists

- Explicit allocator grabs chunks of storage from OS and g
  applications.
- Or gives recycled storage, when available.
- When storage is freed, added to a *free list* data structur
  recycled.
- Used both for explicit freeing and some kinds of automatic g
  collection.

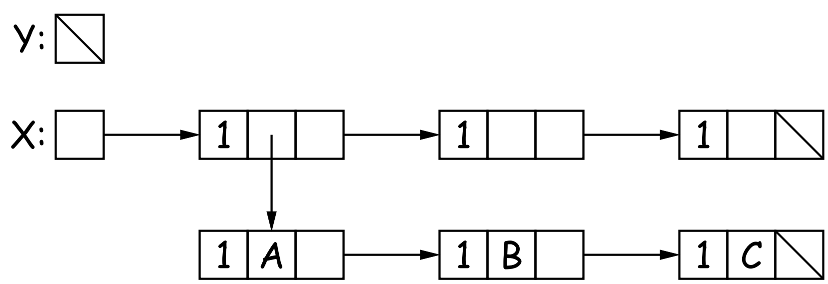


Free List Strategies

- Memory requests generally come in multiple sizes.
- Not all chunks on the free list are big enough, and one may search for a chunk and break it up if too big.
- Various strategies to find a chunk that fits have been used:
  - *Sequential fits:*
    - Link blocks in LIFO or FIFO order, or sorted by addre
    - Coalesce adjacent blocks.
    - Search for *first fit* on list, *best fit* on list, or *next fi* after last-chosen chunk.
  - *Segregated fits:* separate free lists for different chunk
  - *Buddy systems:* A kind of segregated fit where some ne jacent free blocks of one size are easily detected and co into bigger chunks.
- Coalescing blocks reduces *fragmentation* of memory into lot tle scattered chunks.

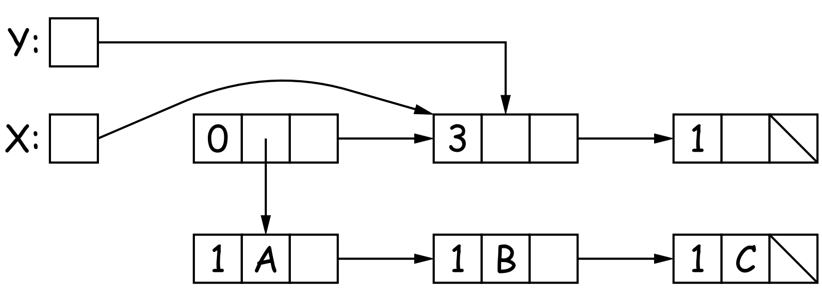
Garbage Collection: Reference Counting

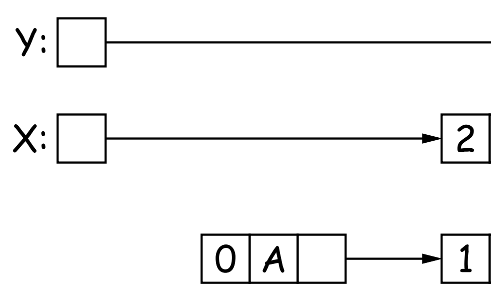
- Idea: Keep count of number of pointers to each object.



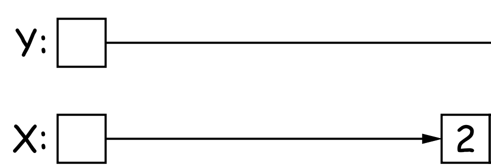
when count goes to 0.

`X = Y;`



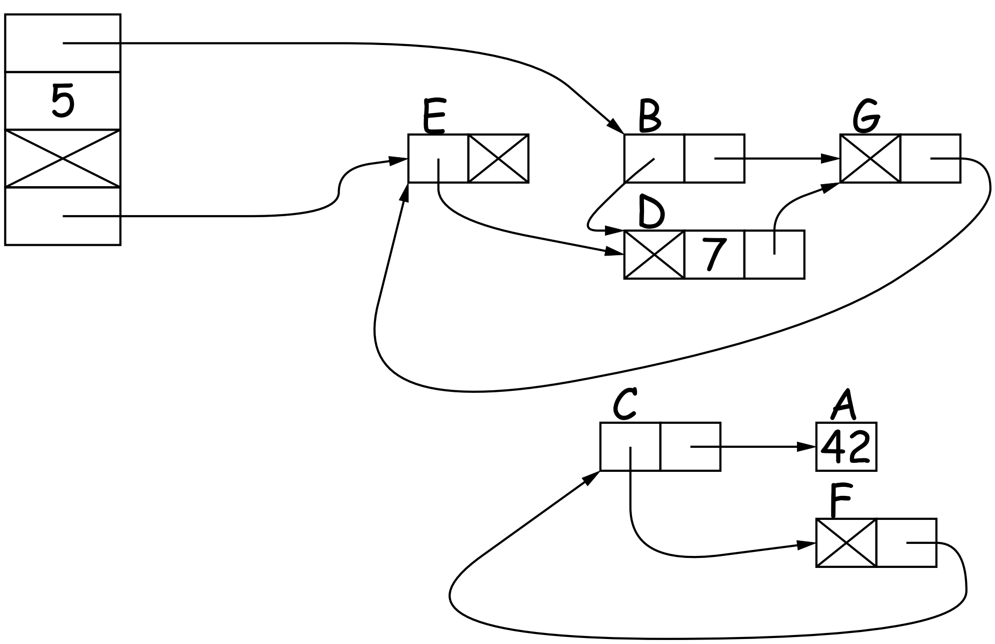


. . . etc., until:



Garbage Collection: Mark and Sweep

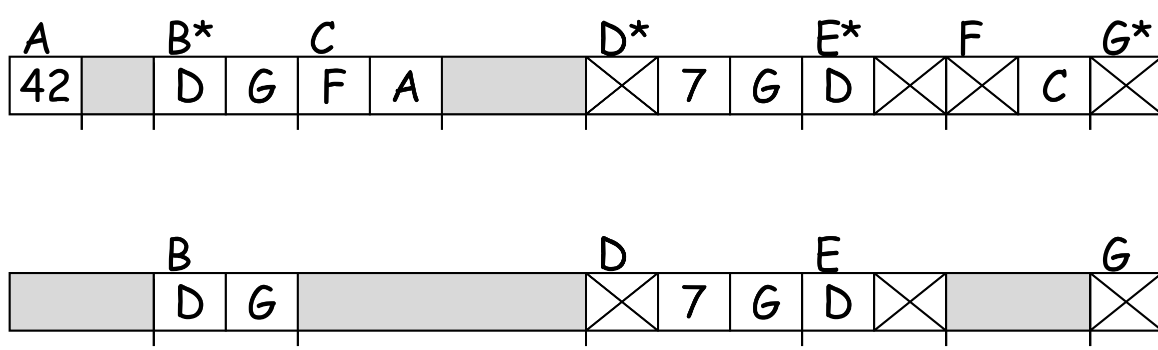
Roots (locals + statics)



1. Traverse a
   graph of o
2. Sweep thr
   memory, f
   unmarked

Before sweep:

After sweep:



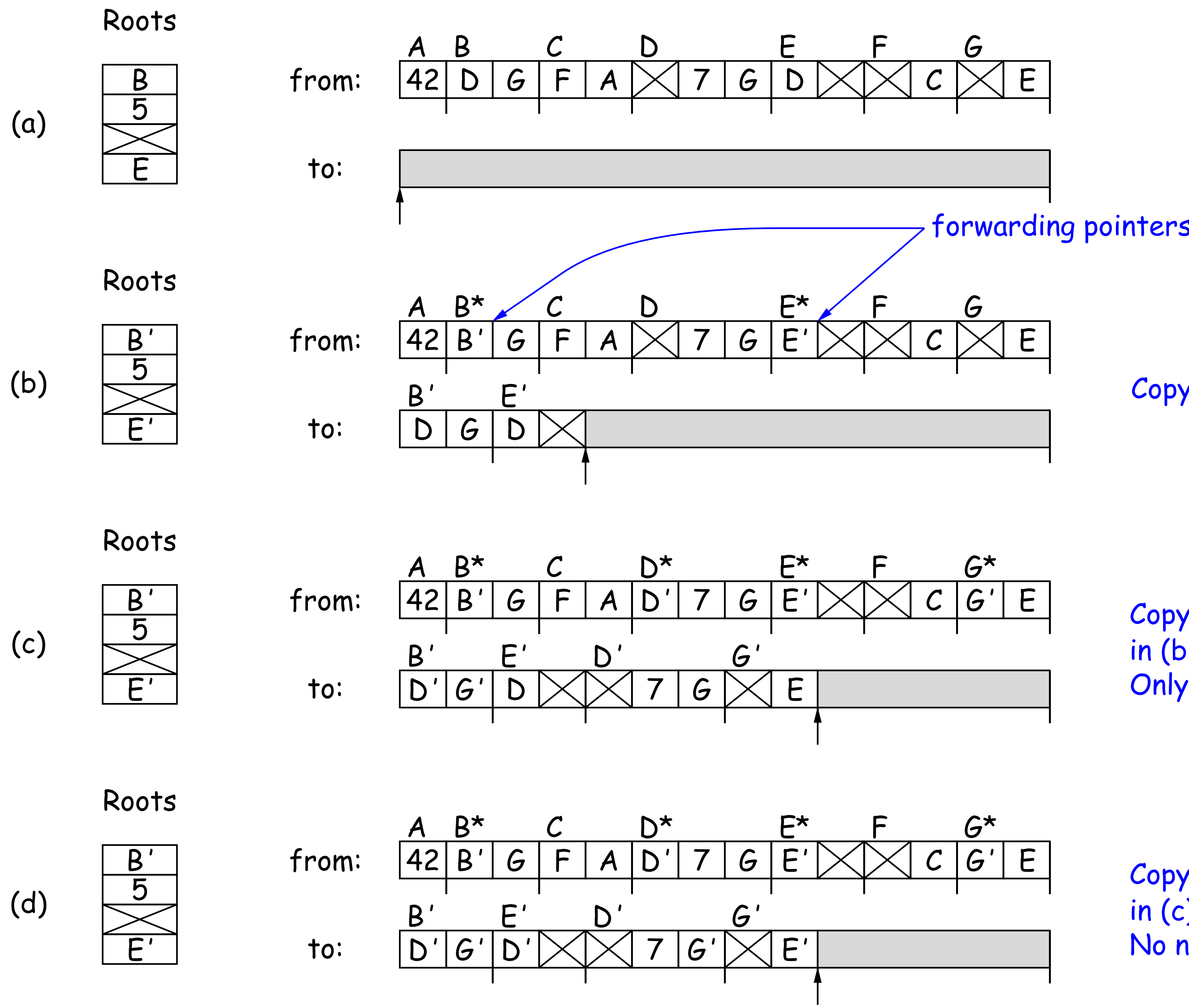
Cost of Mark-and-Sweep

- Mark-and-sweep algorithms don't move any exisiting objects-
stay the same.
- The total amount of work depends on the amount of memory
i.e., the total amount of active (non-garbage) storage + am
garbage. Not necessarily a big hit: the garbage had to be a
one time, and hence there was always some "good" processin
past for each byte of garbage scanned.

Copying Garbage Collection

- Another approach: *copying garbage collection* takes time
  tional to amount of active storage:
  - Traverse the graph of active objects breadth first, *copyi*
    into a large contiguous area (called "to-space").
  - As you copy each object, mark it and put a *forwarding*
    into it that points to where you copied it.
  - The next time you have to copy an already marked obje
    use its forwarding pointer instead.
  - When done, the space you copied from ("from-space") b
    the next to-space; in effect, all its objects are freed in c
    time.

Copying Garbage Collection Illustrated



Most Objects Die Young: Generational Collecti

- Most older objects stay active, and need not be collected.
- Would be nice to avoid copying them over and over.
- *Generational garbage collection* schemes have two (or mor spaces: one for newly created objects (*new space*) and "tenured" objects that have survived garbage collection (*olc*
- A typical garbage collection collects only in new space, ignore ers from new to old space, and moves objects to old space.
- As roots, uses usual roots plus pointers in old space that have (so that they might be pointing to new space).
- When old space full, collect all spaces.
- This approach leads to much smaller *pause times* in interact tems.

There's Much More

- These are just highlights.
- Lots of work on how to implement these ideas efficiently.
- *Distributed garbage collection:* What if objects scattered ov machines?
- *Real-time collection:* where predictable pause times are imp leads to *incremental* collection, doing a little at a time.