Lecture #37

Friday: HKN surveys. Extra points awarded to those who participate!

Today: A little side excursion into nitty-gritty stuff: Storage management.

Scope and Lifetime

- *Scope* of a declaration is portion of program text to which it applies (is *visible*).
  - Need not be contiguous.
  - In Java, is static: independent of data.
- *Lifetime* or *extent* of storage is portion of program execution during 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 (local variable)
  - *Dynamic:* From time of allocation statement (**new**) to deallocation, if any.

Explicit vs. Automatic Freeing

- 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:

```
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*.

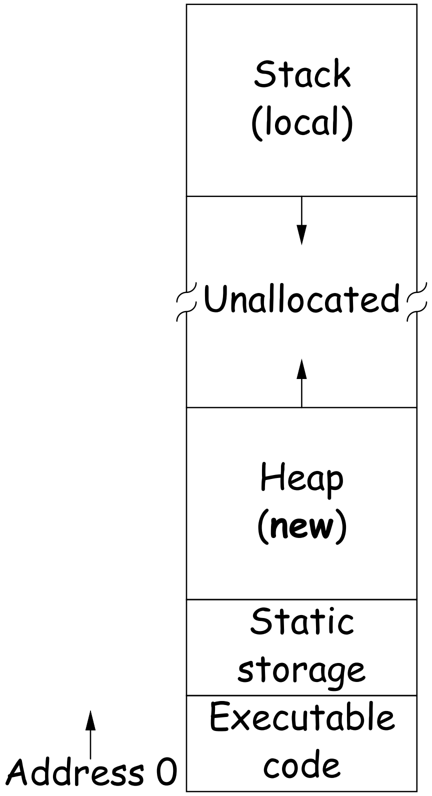
Under the Hood: Allocation

- Java pointers (references) are represented as integer addresses.
- Corresponds to machine's own practice.
- In Java, cannot convert integers ↔ pointers,
- But crucial parts of Java runtime implemented in C, or sometimes 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 8
  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:*

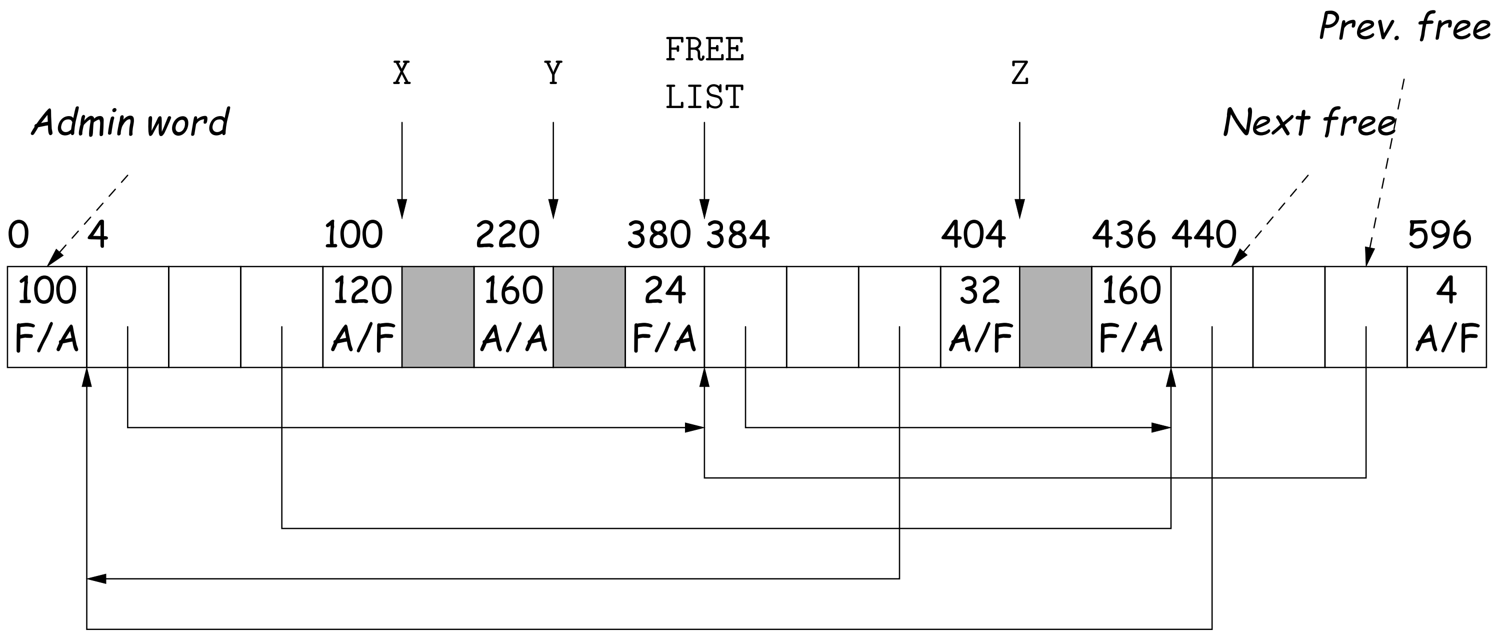
```
union Various {
  int Int;
  char* Pntr;
  double Double;
} X;  // X is either an int, char*, or double
```

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

Free Lists

- Explicit allocator grabs chunks of storage from OS and gives to applications.
- Or gives recycled storage, when available.
- When storage is freed, added to *free list* data structure to be recycled.
- Used both for explicit freeing and some kinds of automatic garbage collection.
- Problem: free memory *fragments.*

Boundary Tag Methods



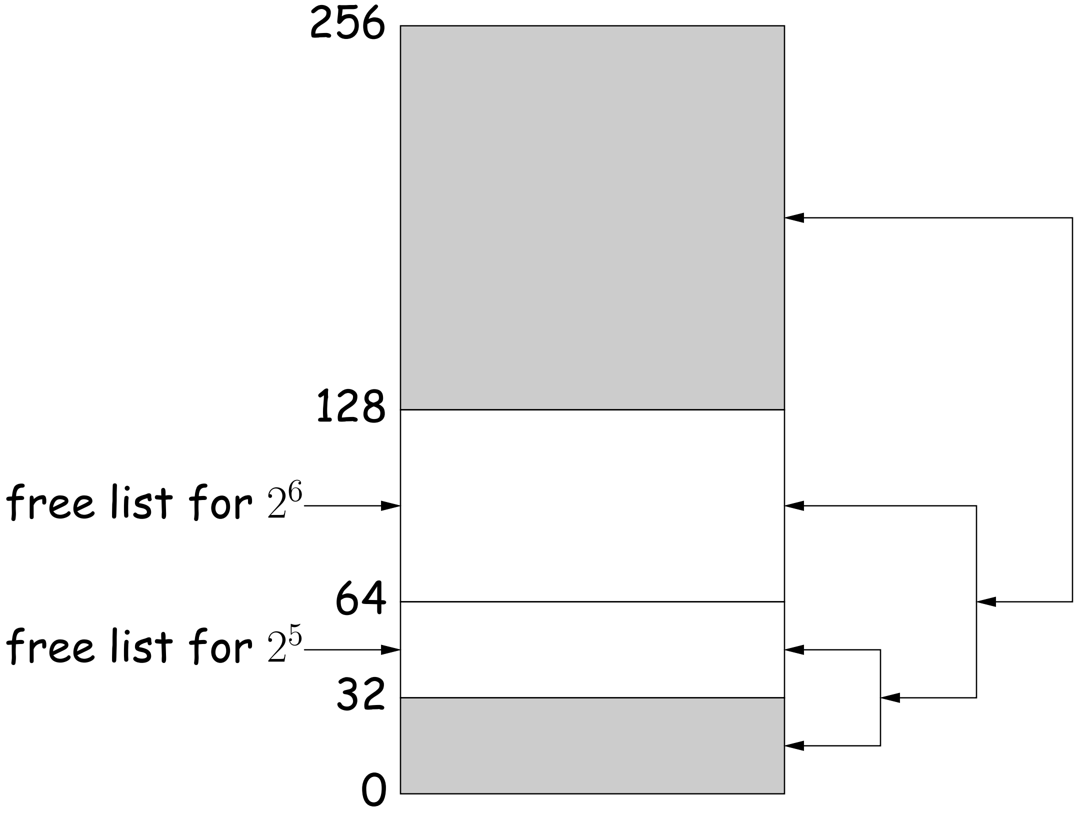
```
G1 = malloc(96);
X = malloc(115);
Y = malloc(156);
G2 = malloc(19);
Z = malloc(26);
G3 = malloc(155);
free(G1); free(G3); free(G2);
```

Admin word

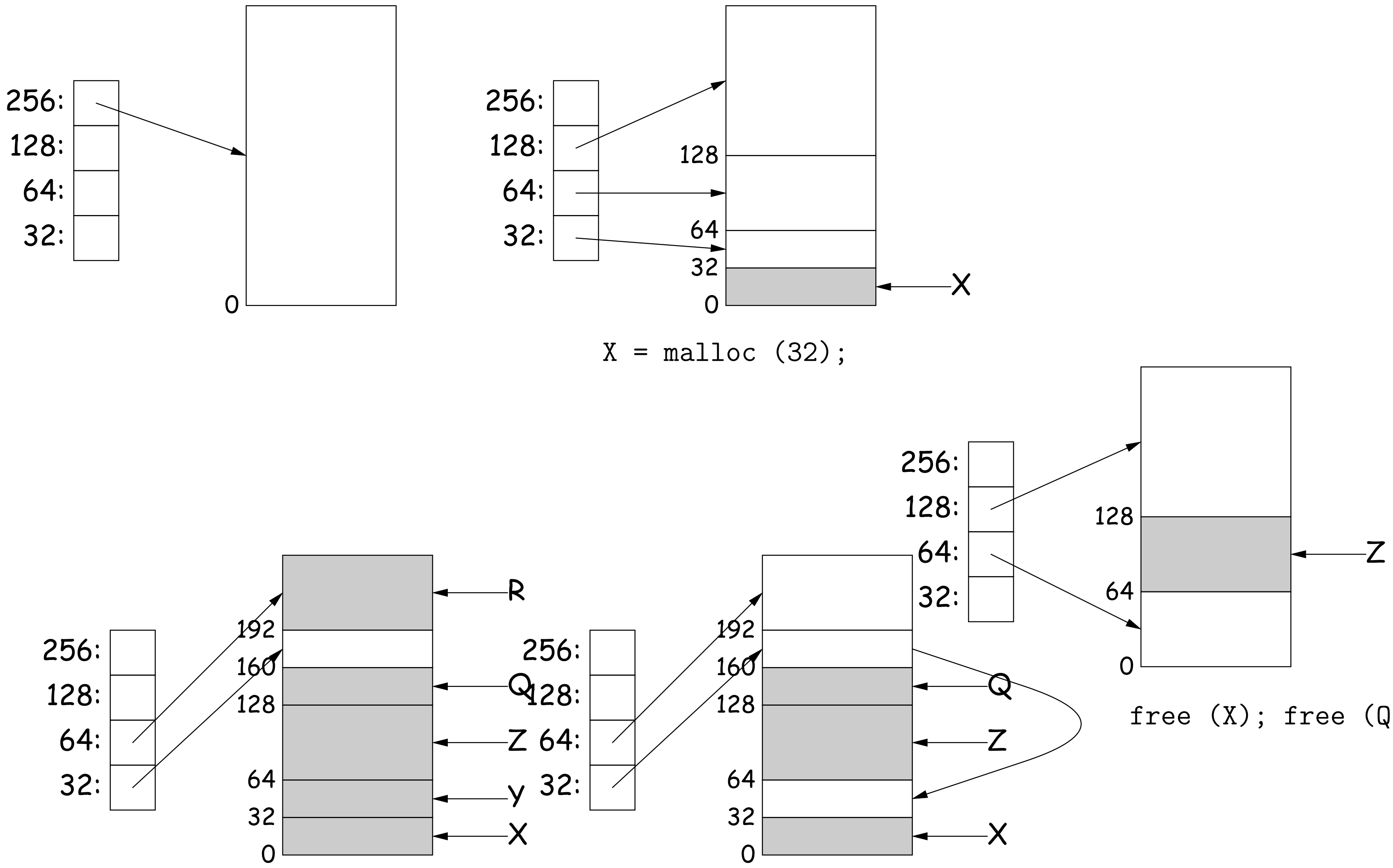
Size
Free?/Prev Free?

Simplifying Coalescence: The Buddy System

- Allocate in powers of 2.
- Coalesce only with your buddy:
  - For object of size 2^n at byte #M, buddy at byte #`(M ^ (1<<n)`.
  - Just need a bit to indicate if it is allocated, plus list of free blocks for each n.



Buddy System at Work



X = malloc (32);

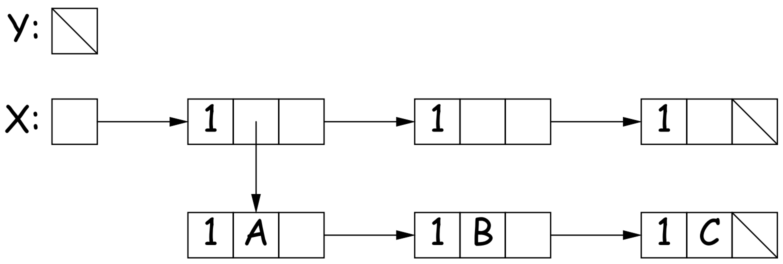
free (X); free (Q);

free (Y); free (R);

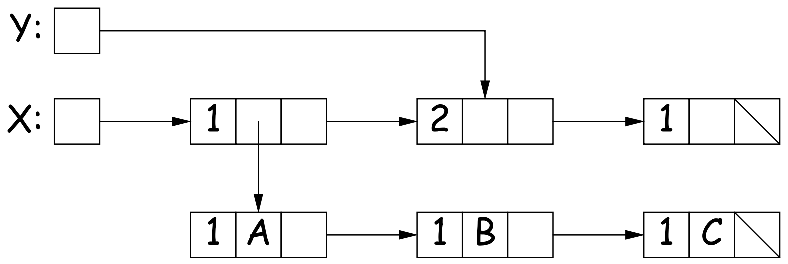
```
Y = malloc (32); Z = malloc (64);
Q = malloc (32); R = malloc (64)
```

Garbage Collection: Reference Counting

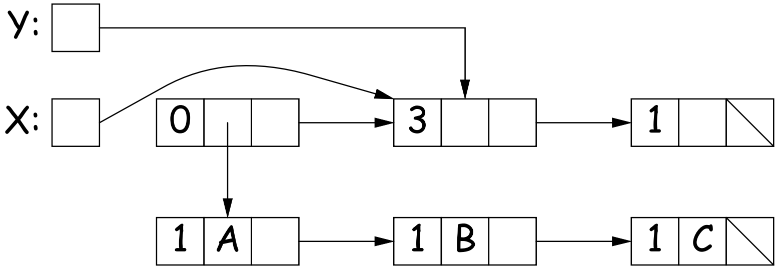
- Idea: Keep count of number of pointers to each object. Release when count goes to 0.

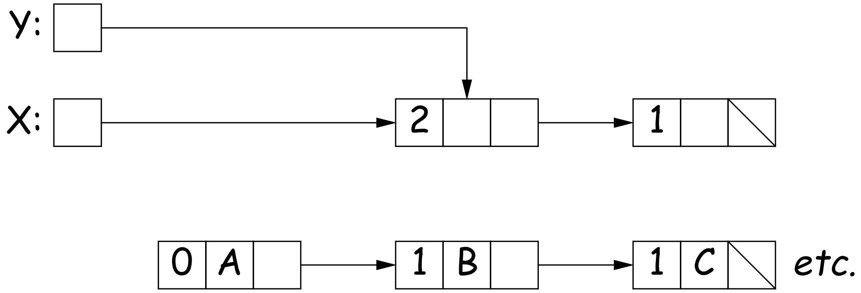


```
Y = X.tail;
```



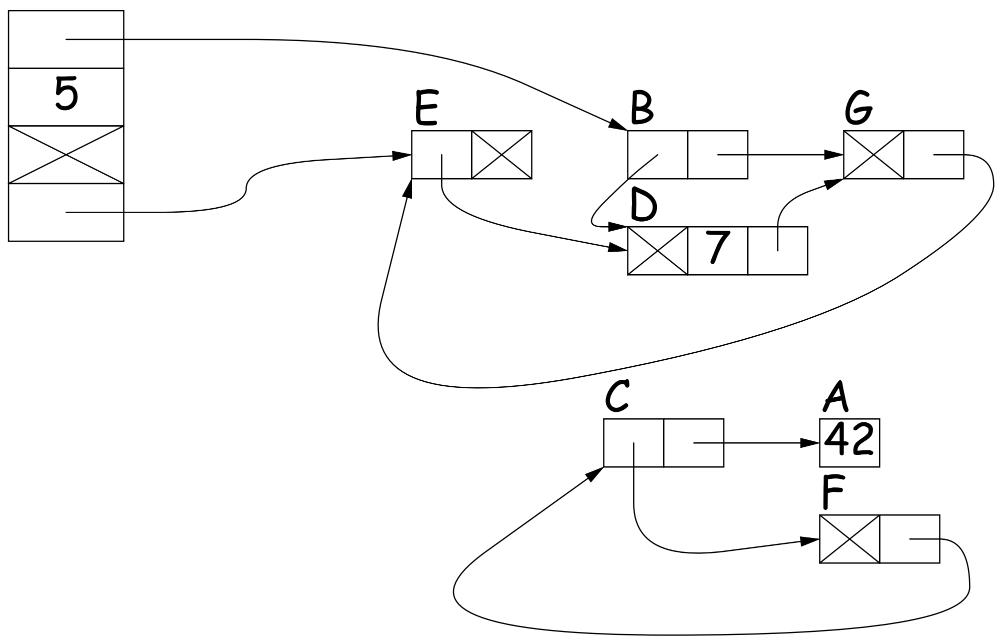
```
X = Y;
```



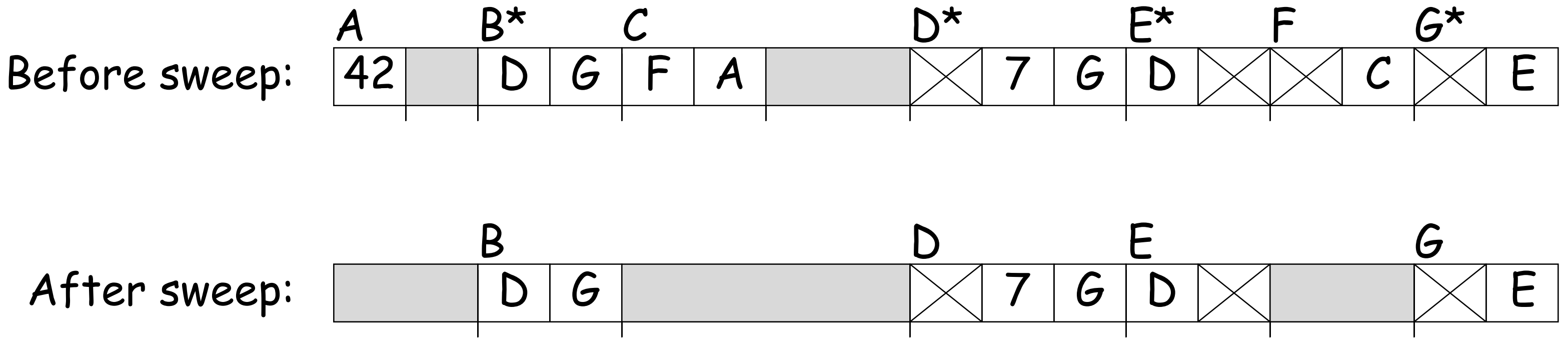


Garbage Collection: Mark and Sweep

Roots (locals + statics)



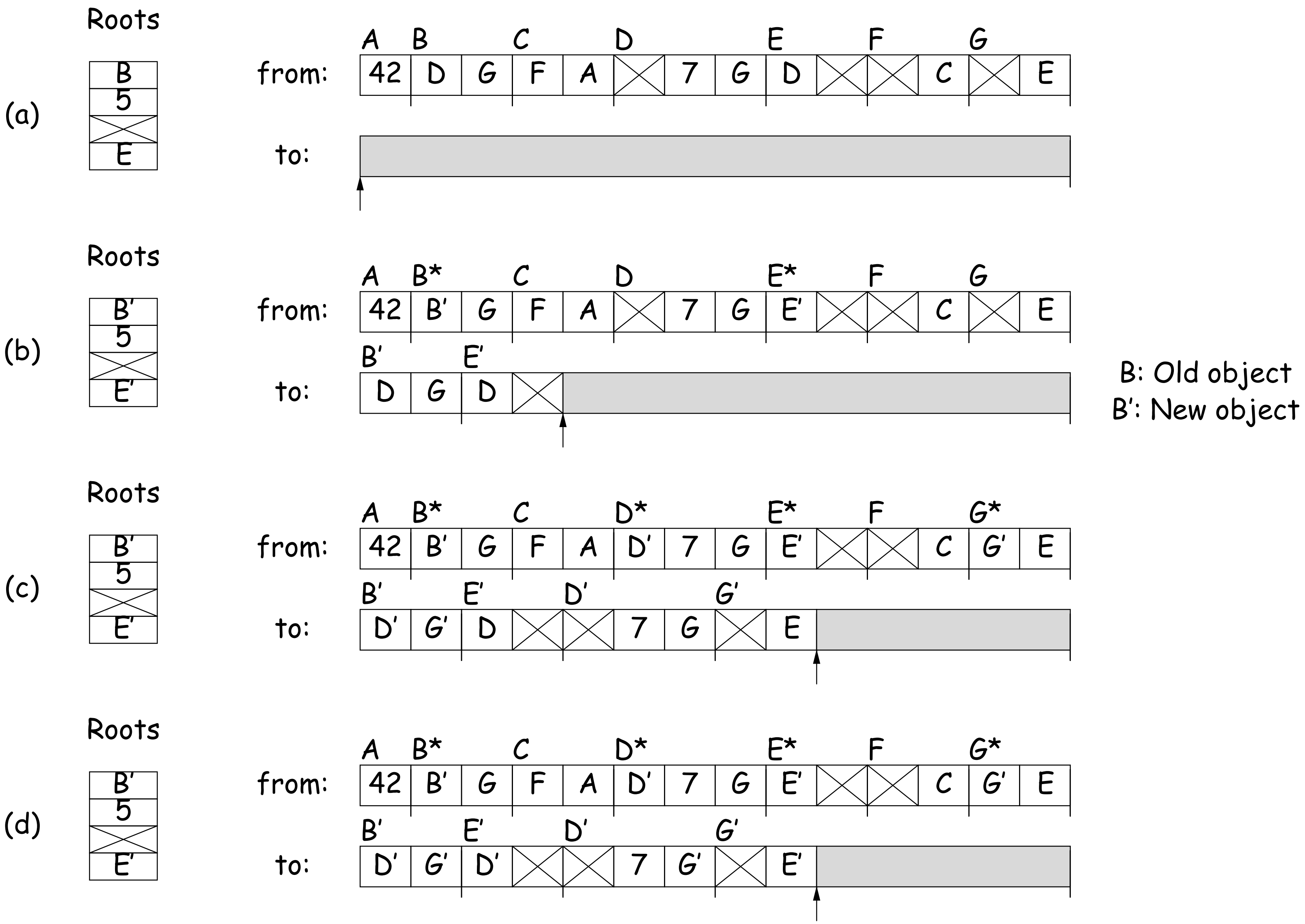
1. Traverse and mark graph of objects.
2. Sweep through memory, freeing unmarked objects.



Copying Garbage Collection

- Mark-and-sweep algorithms don't move any exisiting objects—pointers stay the same.
- The total amount of work depends on the amount of memory swept—i.e., the total amount of active (non-garbage) storage + amount of garbage. Not necessarily a big hit: the garbage had to be active at one time, and hence there was always some "good" processing in the past for each byte of garbage scanned.
- Another approach: *copying garbage collection* takes time proportional to amount of active storage:
  - Traverse the graph of active objects breadth first, *copying* them into a large contiguous area (called "to-space").
  - As you copy each object, mark it and put a *forwarding pointer* into it that points to where you copied it.
  - The next time you have to copy a marked object, just use its forwarding pointer instead.
  - When done, the space you copied from ("from-space") becomes the next to-space; in effect, all its objects are freed in constant time.

Copying Garbage Collection Illustrated



(a)

Roots: B, 5, ☒, E

	A	B		C		D			E		F		G	
from:	42	D	G	F	A	☒	7	G	D	☒	☒	C	☒	E

to:

(b)

Roots: B′, 5, ☒, E′

	A	B*		C		D			E*		F		G	
from:	42	B′	G	F	A	☒	7	G	E′	☒	☒	C	☒	E

	B′		E′	
to:	D	G	D	☒

B: Old object
B′: New object

(c)

Roots: B′, 5, ☒, E′

	A	B*		C		D*			E*		F		G*	
from:	42	B′	G	F	A	D′	7	G	E′	☒	☒	C	G′	E

	B′		E′		D′			G′	
to:	D′	G′	D	☒	☒	7	G	☒	E

(d)

Roots: B′, 5, ☒, E′

	A	B*		C		D*			E*		F		G*	
from:	42	B′	G	F	A	D′	7	G	E′	☒	☒	C	G′	E

	B′		E′		D′			G′	
to:	D′	G′	D′	☒	☒	7	G′	☒	E′