# CSc 520

# Principles of Programming Languages

## *6 : Memory Management — Heap Allocation*

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# Dynamic Memory Management

- The run-time system linked in with the generated code should contain routines for allocation/deallocation of dynamic memory.

**Pascal, C, C++, Modula-2** Explicit deallocation of dynamic memory only. I.e. the programmer is required to keep track of all allocated memory and when it's safe to free it.

**Eiffel** Implicit deallocation only. Dynamic memory which is no longer used is recycled by the garbage collector.

**Ada** Implicit or explicit deallocation (implementation defined).

**Modula-3** Implicit and explicit deallocation (programmer's choice).



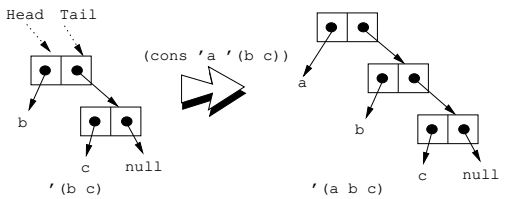
# Interface to Dynamic allocation

**C, C++:** `char* malloc(size)` and `free(char*)` are standard library routines.

**Pascal:** `new(`*`pointer var`*`)` and `dispose(`*`pointer var`*`)` are builtin standard procedures.

**Java:** `new(`*`class name`*`)` is a standard function.

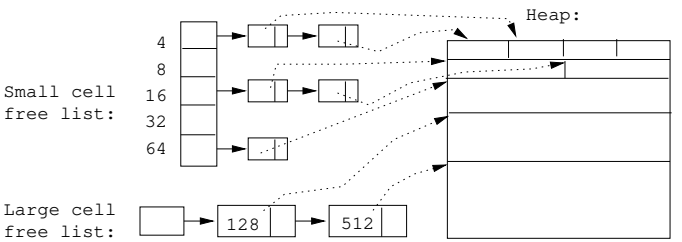
**LISP:** `cons` creates new cells:






# Explicit Deallocation

- Pascal's `new/dispose`, Modula-2's `ALLOCATE/DEALLOCATE`, C's `malloc/free`, C++'s `new/delete`, Ada's `new/unchecked_deallocation` (some implementations).
- Problem 1: Dangling references: `p=malloc(); q=p; free(p);`.
- Problem 2: Memory leaks, Heap fragmentation.



# Memory Leaks

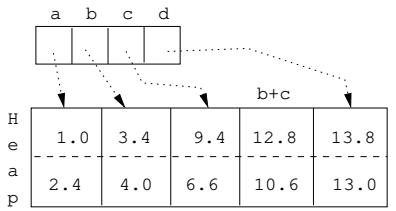
```
DEFINITION MODULE Complex;
  TYPE T;
  PROCEDURE Create (Re, Im :  REAL) : T;
  PROCEDURE Add (A, B : T) : T;
END Complex.

IMPLEMENTATION MODULE Complex;
  TYPE T = POINTER TO RECORD
             Re, Im :  REAL; END;
  PROCEDURE Create (Re, Im :  REAL) : T;
  BEGIN
    NEW(x); x↑.Re := Re; x↑.Im := Im;
    RETURN x; END Create;
  PROCEDURE Add (A, B : T) : T;
  BEGIN
    NEW(x); x↑.Re := ···; x↑.Im := ···;
    RETURN x; END Add;
END Complex;
```



# Memory Leaks...

```
MODULE Use;
   IMPORT Complex;
   VAR a,b,c,d :  Complex.T;
BEGIN
   a := Complex.Create(1.0, 2.4);
   b := Complex.Create(3.4, 4.0);
   c := Complex.Create(9.4, 6.6);
   d := Complex.Add(a,Complex.Add(b,c));
END Use.
```

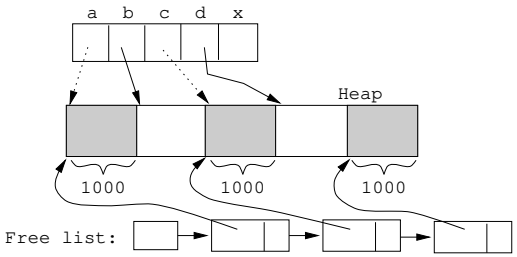
- `Complex.Add(b, c)` creates a new object which can never be reclaimed.






# Fragmentation

```
   VAR a, b, c, d :  POINTER TO
         ARRAY [1..1000] OF BYTE;
   VAR x :  POINTER TO
         ARRAY [1..2000] OF BYTE;
BEGIN
   NEW(a); NEW(b); NEW(c); NEW(d);
   DISPOSE(a); DISPOSE(c); NEW(x);
```




- Without compaction the last allocation will fail, even though enough memory is available.



# Implicit Deallocation

- LISP, Prolog – Equal-sized cells; No changes to old cells.
- Eiffel, Modula-3 – Different-sized cells; Frequent changes to old cells.
- When do we GC?

  **Stop-and-copy** Perform a GC whenever we run out of heapspace (Modula-3).

  **Real-time/Incremental** Perform a partial GC for each pointer assignment or `new` (Eiffel, Modula-3).

  **Concurrent** Run the GC in a separate process.

# Implicit Deallocation...

- Fragmentation – Compact the heap as a part of the GC, or only when the GC fails to return a large enough block.
- Algorithms: Reference counts, Mark/ssweep, Copying, Generational.



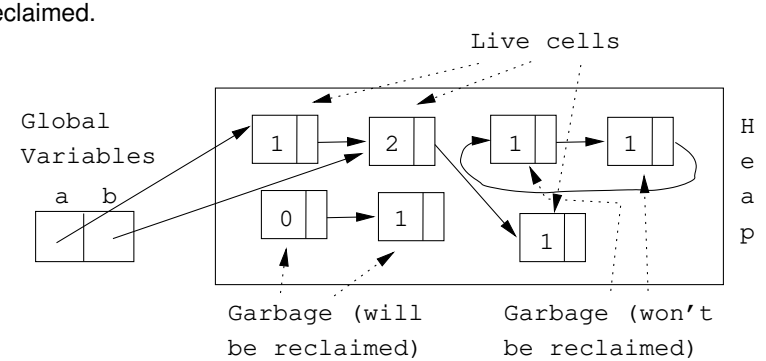
# Algorithm: Reference Counts

- An extra field is kept in each object containing a count of the number of pointers which point to the object.
- Each time a pointer is made to point to an object, that object's count has to be incremented.
- Similarly, every time a pointer no longer points to an object, that object's count has to be decremented.
- When we run out of dynamic memory we scan through the heap and put objects with a zero reference count back on the free-list.
- Maintaining the reference count is costly. Also, circular structures (circular linked lists, for example) will not be collected.



# Algorithm: Reference Counts...

- Every object records the number of pointers pointing to it.
- When a pointer changes, the corresponding object's reference count has to be updated.
- GC: reclaim objects with a zero count. Circular structures will not be reclaimed.






# Algorithm: Reference Counts...

`NEW(p)` is implemented as:

```
malloc(p); p↑.rc := 0;
```

`p↑.next:=q` is implemented as:

```
z := p↑.next;
if z ≠ nil then
   z↑.rc--; if z↑.rc = 0 then reclaim z↑ endi
endif;
p↑.next := q;
q↑.rc++;
```

- This code sequence has to be inserted by the compiler for *every* pointer assignment in the program. This is very expensive.

# Readings and References

- Read Scott, pp. 395–401.
- Apple's Tiger book, pp. 257–282
- Topics in advanced language implementation, Chapter 4, Andrew Appel, Garbage Collection. Chapter 5, David L. Detlefs, Concurrent Garbage Collection for C++. ISBN 0-262-12151-4.
- Aho, Hopcroft, Ullman. Data Structures and Algorithms, Chapter 12, Memory Management.



# Readings and References...


- Nandakumar Sankaran, A Bibliography on Garbage Collection and Related Topics, ACM SIGPLAN Notices, Volume 29, No. 9, Sep 1994.
- J. Cohen. Garbage Collection of Linked Data Structures, Computing Surveys, Vol. 13, No. 3, pp. 677–678.