CSc 520

Principles of Programming Languages

38: Garbage Collection — Introduction

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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).

Memory Management

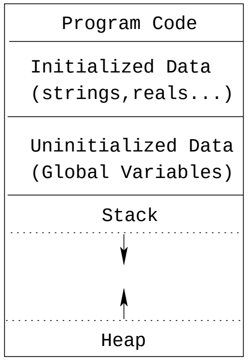
- In a language such as C or Pascal, there are three ways to allocate memory:
  1. Static allocation. Global variables are allocated at compile time, by reserving
  2. Stack allocation. The stack is used to store activation records, which holds procedure call chains and local variables.
  3. Dynamic allocation. The user can create new memory at will, by calling a new or (in unix) malloc procedure.
- The compiler and run-time system divide the available address space (memory) into three sections, one for each type of allocation:

Memory Management. . .

- 1. The static section is generated by the compiler and cannot be extended at run-time. Called the `uninitialized data section` in unix's `a.out`.
  2. The stack. The stack grows and shrinks during execution, according to the depth of the call chain. Infinite recursion often leads to stack overflow. Large parameters can also result in the program running out of stack space.
  3. The heap. When the program makes a request for more dynamic memory (by calling malloc, for example), a suitable chunk of memory is allocated on the heap.

Memory Management. . .

- Static allocation – Global variables
- Stack allocation – Procedure call chains, Local variables.
- Dynamic allocation – NEW, `malloc`, On the heap.



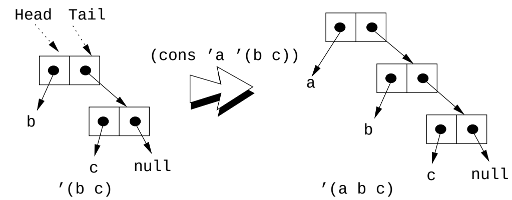
Interface to Dynamic allocation

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

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

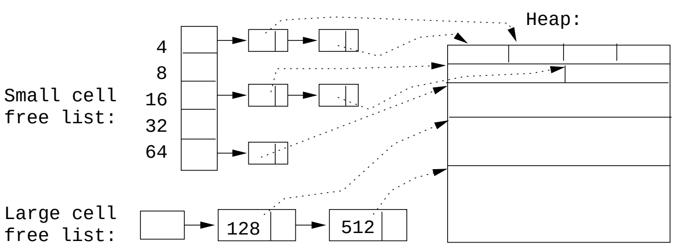
Java: `new(`*`class name`*`)` is a standard function.

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

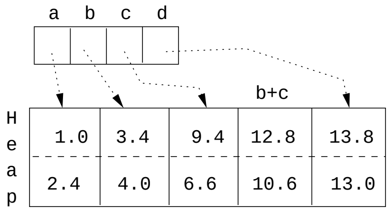
```
DEFINITION MODULE Complex;
  TYPE T;
  PROCEDURE Create (Re, Im :  REAL) : T;
  PROCEDURE Add (A, B : T) : T;
END Complex.

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…

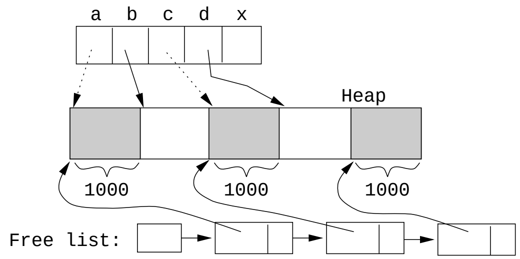
```
MODULE Use;
   IMPORT Complex;
   VAR a,b,c,d :  Complex.T;
BEGIN
   a := Complex.Create(1.0, 2.4);
   b := Complex.Create(3.4, 4.0);
   c := Complex.Create(9.4, 6.6);
   d := Complex.Add(a,Complex.Add(b,c));
END Use.
```

- `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…

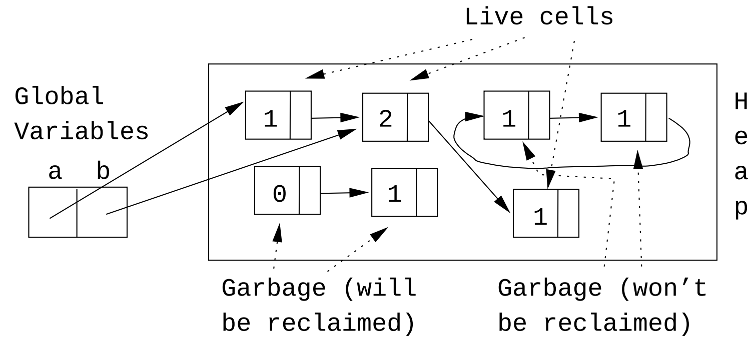
- Fragmentation – Compact the heap as a part of the GC, or only when the GC fails to return a large enough block.
- Algorithms: Reference counts, Mark/ssweep, Copying, Generational.

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↑ endif
endif;
p↑.next := q;
q↑.rc++;
```

his code sequence has to be inserted by the compiler
r *every* pointer assignment in the program. This is
ery 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.