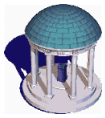


The University of North Carolina at Chapel Hill

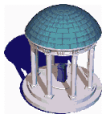
COMP 144 Programming Language Concepts

Spring 2002

Lecture 23: Object Lifetime and Garbage Collection

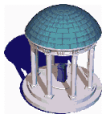
Felix Hernandez-Campos

March 18



Fundamental Concepts in OOP

- **Encapsulation**
  - Data Abstraction
  - Information hiding
  - The notion of class and object
- **Inheritance**
  - Code reusability
  - Is-a vs. has-a relationships
- **Polymorphism**
  - Dynamic method binding



Object Lifetime: Constructors

- ***Contructors*** are methods used to *initialize* the content of an object
  - They do not allocate space
- Most languages allow multiple constructors
  - They are distinguished using different names or different parameters (type and/or number)
  - Java and C++ overload the constructor name, so the appropriate methods is selected using the number and the type of the arguments
    - » `Rectangle r;`
    - » Invokes the parameterless constructor
  - Smalltalk and Eiffel support different constructor names

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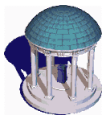
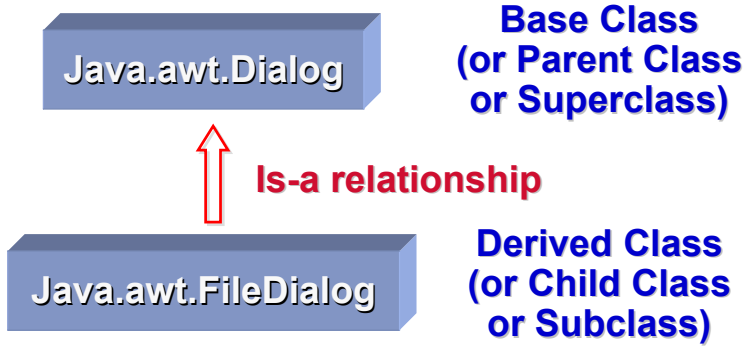


Inheritance
Notation



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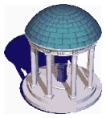
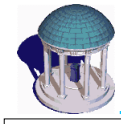


Java Example

- Dialog constructors
  - http://java.sun.com/j2se/1.4/docs/api/java/awt/Dialog.html#constructor_summary
- FileDialog contructors
  - http://java.sun.com/docs/books/jls/second_edition/html/expressions.doc.html#23302



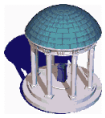
Constructors in Eiffel

```
class COMPLEX
creation
    new_cartesian, new_polar
feature {ANY}
    x, y : REAL;
    new_cartesian (x_val, y_val : REAL) is
    do
        x := x_val; y := y_val;
    end;
    new_polar (rho, theta : REAL) is
    do
        x := ro * cos (theta);
        y := ro * sin (theta)
    end;
    -- other public methods
feature {NONE}
    -- private methods
end -- class COMPLEX
...
a, b : COMPLEX;
...
!!b.new_cartesian (0, 1);
!!a.new_polar (pi/2, 1);
```

Explicit Constructor Declaration

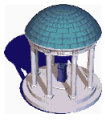
Complex Numbers Class

Constructors (!! equals *new*)



References and Values

- Some OO languages use the reference model
  - More elegant
  - Extra level of indirection on every access
  - *E.g.* Java, Simula, Smalltalk
- Other languages use the value model
  - More efficient
  - More difficult to control initialization
    - » E.g. uninitialized objects, mutual references
  - *E.g.* C++, Ada 95



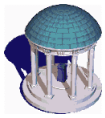
Constructors in C++

```
foo b;                  // calls foo::foo ()
...
foo b (10, 'x');        // calls foo::foo (int, char)


foo a;                  // calls foo::foo ()
bar b;                  // calls bar::bar ()
...
foo c (a);              // calls foo::foo (foo&)
foo d (b);              // calls foo::foo (bar&)

foo c = a;              // calls foo::foo (foo&)
foo d = b;              // calls foo::foo (bar&)


foo a, c, d;            // calls foo::foo () three times
bar b;                  // calls bar::bar ()
...
c = a;                  // calls foo::operator= (foo&)
d = b;                  // calls foo::operator= (bar&)
```

Initialization (*not* assignment)

Copy Constructor

`operator=`



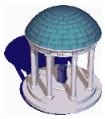
Execution Order

- How is an object of class B derived from class A initialized?
- In C++ and Java, the constructor of A is invoked before the constructor of B
  - Why?
    - » So the B constructor never sees uninitialized attributes
  - What are the arguments of the A constructor?
    - » In C++, they are explicitly defined

```
B::B (B_params) : A (A_args) { … }
```

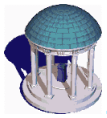
    - » Futhermore, constructors for object arguments can also be initialized

```
list_node() : prev(this), next(this),
  head_node(this), val(0) { }
```

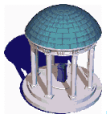
Java Example

- See Java Language Specification
  - http://java.sun.com/docs/books/jls/second_edition/html/classes.doc.html#41652
  - http://java.sun.com/docs/books/jls/second_edition/html/expressions.doc.html#23302
- Alternate constructor
- Superclass constructor
  - Unqualified superclass constructor
  - Qualified superclass constructor invocations
    - » Inner classes



Object Lifetime: Destructors

- ***Destructors*** are methods used to *finalize* the content of an object
  - They do not deallocate space
  - Language implementations that support garbage collection greatly reduce the need for destructors
    - » Most C++ compiler do not support GC

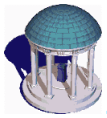


C++ Example

- In general, C++ destructors are used for manual storage reclamation

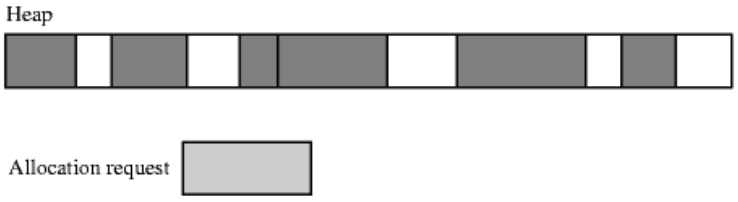
```
class name_list_node : public gp_list_node {
    char *name;             // pointer to the data in a node
public:
    name_list_node () {
        name = 0;           // empty string
    }
    name_list_node (char *n) {
        name = new char[strlen(n)];
        strcpy (name, n);   // copy argument into member
    }
    ~name_list_node () {
        if (name != 0) {
            delete name;    // reclaim space
        }
    }
};
```

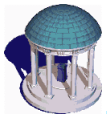
Destructor



Heap-based Allocation

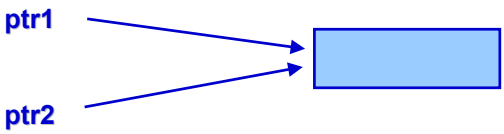
- The **heap** is a region of storage in which subblock can be allocated and deallocated
  - This not the *heap data structure*

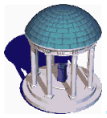




Garbage Collection

- Explicit reclamation of heap objects is problematic
  - The programmer may forget to deallocate some objects
    - » Causing *memory leaks*
    - » In the previous example, the programmer may forget to include the **`delete`** statement
  - References to deallocated objects may not be reset
    - » Creating *dangling references*





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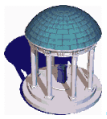
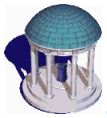


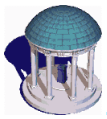
Garbage Collection

- Automatic reclamation of the head space used by object that are no longer useful
  - Developed for functional languages
    - » It is essential in this programming paradigm. Why?
  - Getting more and more popular in imperative languages
    - » Java, C#, Python
- It is generally slower than manual reclamation, but it eliminates a very frequent programming error
  - Language without GC usually have memory profiling tools
    - » *E.g.* http://www.mozilla.org/performance/tools.html, http://www.pds-site.com/VMGear/profiler/bigger/Objectallocationview.htm



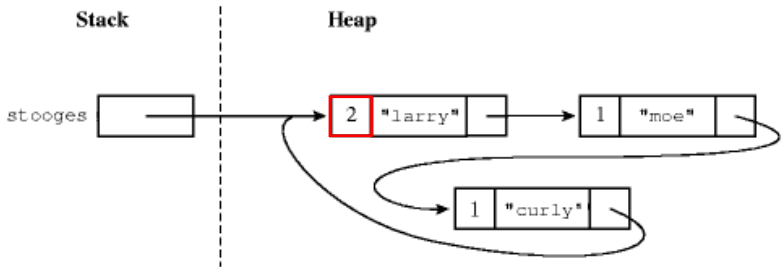
Garbage Collection Techniques

- When is an object no longer useful?
- There are several garbage collection techniques that answer this question in a different manner
  - Reference counting
  - Mark-and-sweep collection

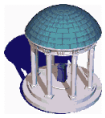


Reference Counting

- Each object has an associated reference counter

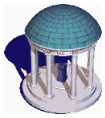


- The run-time system
  - keeps reference counters up to date, and
  - recursively deallocates objects when the counter is zero



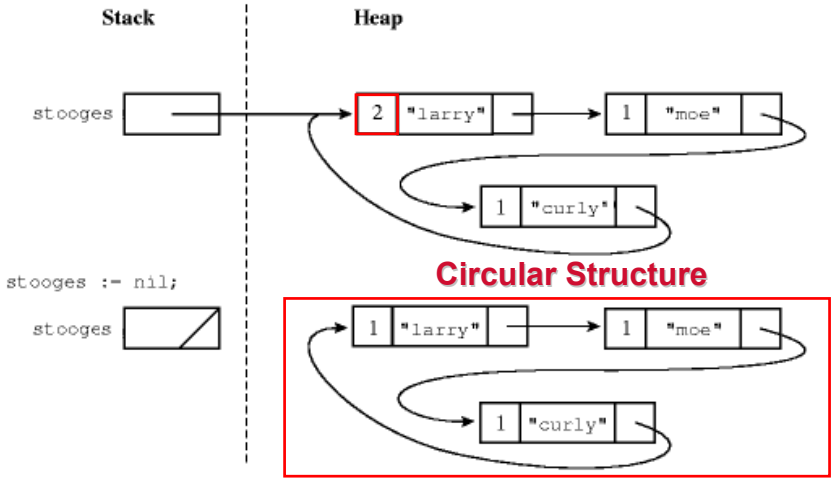
Reference Counting
Problems

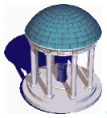
- Extra overhead of storing and updating reference counts
- Strong typing required
  - Impossible in a language like C
  - It cannot be used for variant records
- It does not work with circular data structures
  - This is a problem with this definition of *useful* object as an object with one or more references



Reference Counting
Circular Data Structures

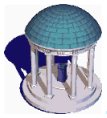
- Each object has an associated reference counter





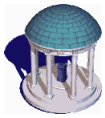
Mark-and-Sweep Collection

- A better definition of *useless* object is one that cannot be reached by following a chain of valid pointers starting from *outside* the heap
- Mark-and-Sweep GC applies this definition
- Algorithm:
  - Mark every block in the heap as useless
  - Starting with all pointers outside the heap, recursively explore all linked data structures
  - Add every block that remain marked to the *free* list
- Run whenever the free space is low



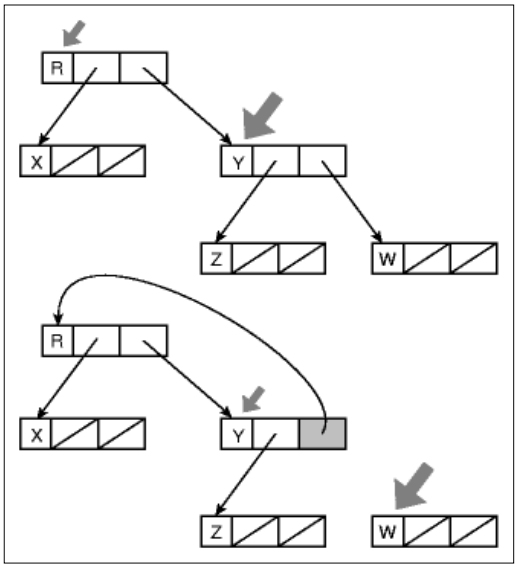
Mark-and-Sweep Collection
Problems

- Block must begin with an indication of its size
  - Type descriptor that indicate their size makes this requirement unnecessary
- A stack of depth proportional to the longest reference chain is required
  - But we are already running are out of space!
  - Pointer reversal embeds the stack in the sequence of references in the heap
    - » The GC reverses each pointer it traverses



Mark-and-Sweep Collection
Pointer Reversal

R is outside the heap



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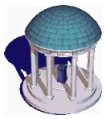

Store-and-Copy

- Use to reduce external fragmentation

- S-C divides the available space in half, and allocates everything in that half until it is full
- When that happens, copy each *useful* block to the other half, clean up the remaining block, and switch the roles of each half

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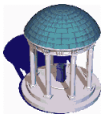

Reading Assignment

- Scott
  - Read Sect. 10.3
  - Read Sect. 7.7.2 (dangling references)
  - Read Sect. 7.7.3 (garbage collection)
  - Garbage collection in Java JDK 1.2
    - » http://developer.java.sun.com/developer/technicalArticles/ALT/RefObj/