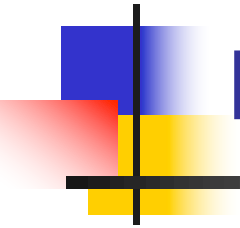


Binding and Scoping

Read: Scott, Chapter 3.1, 3.2 and 3.3.1, 3.3.2 and 3.3.6

Lecture Outline

- Notion of binding time
- Object lifetime and storage management

- An aside: Stack Smashing 101

- Scoping
  - Static scoping
  - Dynamic scoping

Notion of Binding Time

- Binding time (Scott): the time an answer becomes associated to an open question

Notion of Binding Time

- Static
  - Before program execution
- Dynamic
  - During program executes

Examples of Binding Time Decisions

- Binding time (Scott): the time an answer becomes associated to an open question

- Binding a variable name to a memory location
  - Static or dynamic
  - Determined by scoping rules
- Binding a variable/expression to a type
  - Static or dynamic
- Binding a call to a target subroutine
  - Static (as it is in C, mostly) or dynamic (virtual calls in Java, C++)

Example: Binding Variables to Locations

- Map a variable to a location
  - Map variable at use to a location
  - Map subroutine at use to target subroutine
- Determined by scoping rules
  - Static scoping
    - Binding before execution
  - Dynamic scoping
    - Binding during execution
- More on scoping later…

```
int x,y;
void foo(int x)
{
    y = x;
    int y = 0;
    if (y) {
      int y;
      y = 1;

    }
}
```

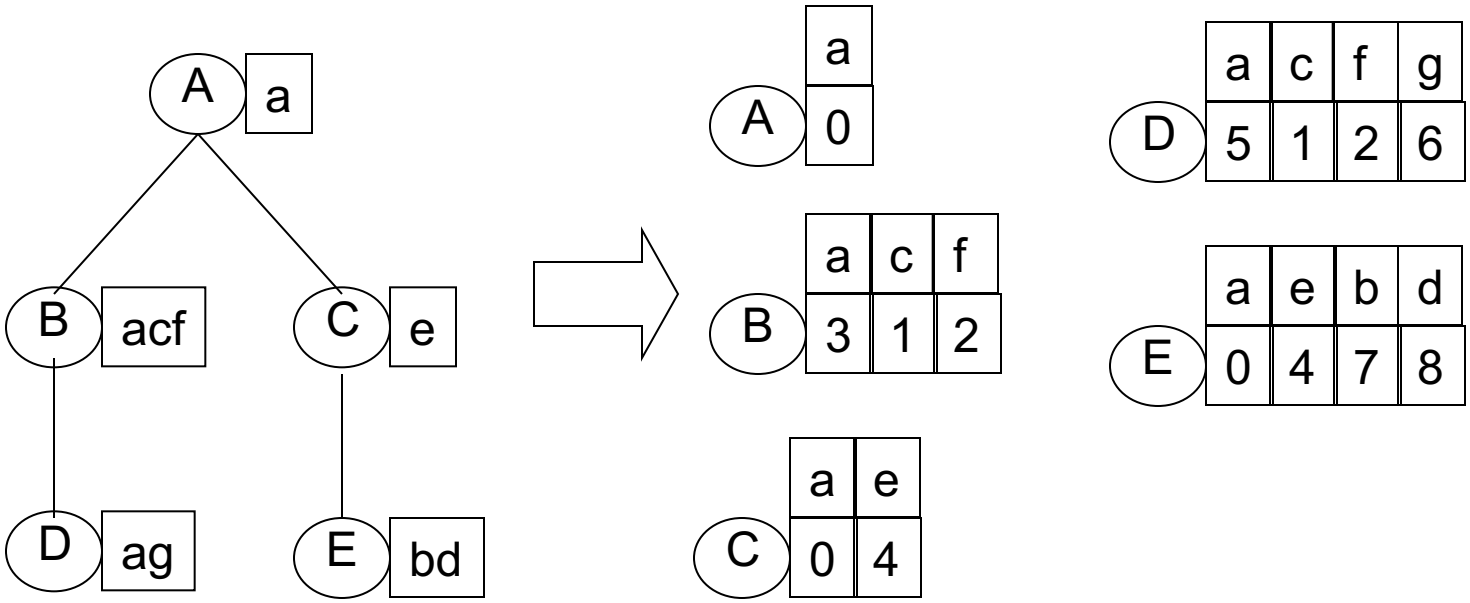
General View of Dynamic Binding

- Dynamic binding
  - What are the advantages of dynamic binding?
  - Disadvantages?

- An example: Cost of dynamic binding of call to target method in OO languages

Example: Cost of Dynamic Dispatch in C++

- Source: Driesen and Hölzle, OOPSLA'96



Virtual function tables (VFTs)
Capital characters denote classes,
lowercase characters message selectors,
and numbers method addresses

```
load [object_reg+#VFTOffset],table_reg
load [table_reg+#selectorOffset],method_reg
call method_reg
```

Extra instructions: cost extra

Other Choices Related to Binding Time

- Pointers: introduce "heap variables"
  - Good for flexibility – allows dynamic structures
  - Bad for efficiency – direct cost: accessed indirectly; indirect cost: compiler unable to perform optimizations
- Most PLs support pointers
  - Issues of management of heap memory
    - Explicit allocation and deallocation
    - Implicit deallocation (garbage collection)
- PL design choices – many subtle variations
  - No pointers (FORTRAN 77)
  - Explicit pointers (C++ and C)
  - Implicit pointers (Java)

Lecture Outline

- Notion of binding time
- Object lifetime and storage management

- An aside: Stack Smashing 101

- Scoping
  - Static scoping
  - Dynamic scoping

Storage Allocation Mechanisms

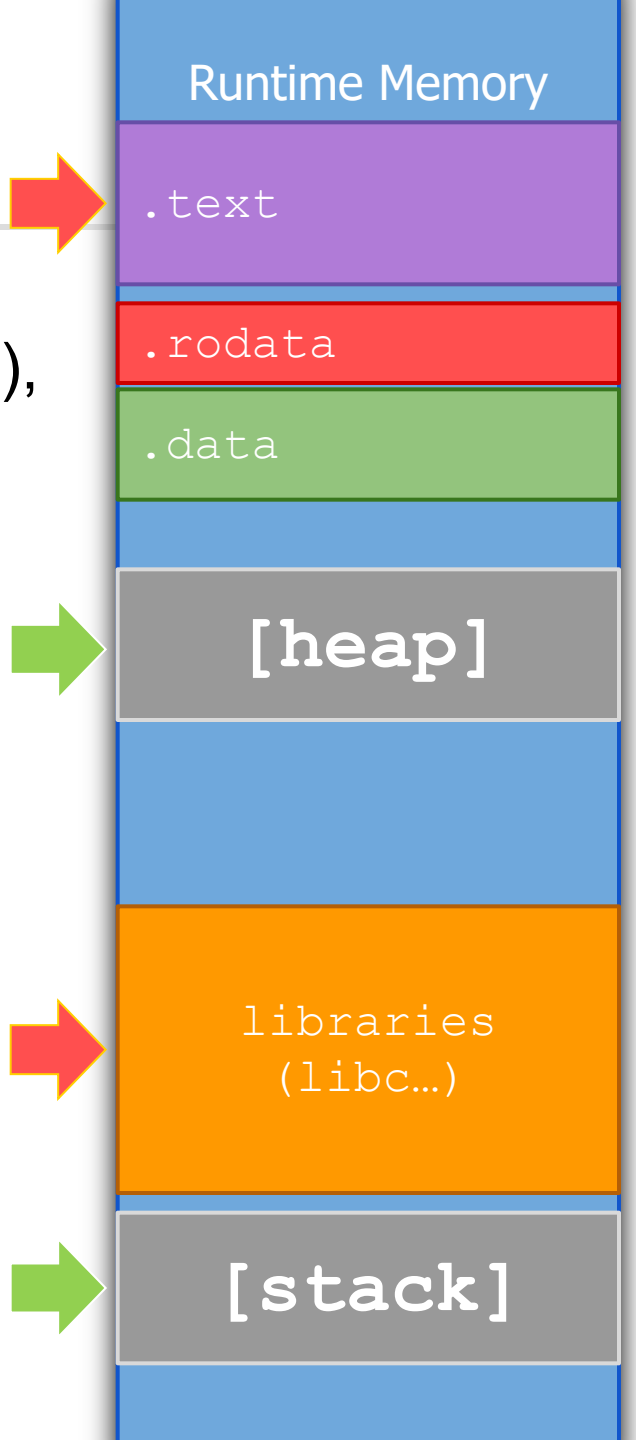
- Static storage – an object is given absolute address, which is the same throughout execution
  - What is an example of static data?
- Stack storage – stack objects are allocated on a run-time stack at subroutine call and deallocated at return
  - Needs a stack management algorithm
  - What is an example of stack data?
- Heap storage - long-lived objects are allocated and deallocated at arbitrary times during execution
  - Needs the most complex storage management algorithm

Combined View

- Static storage: .text (program code), .rodata, .data, etc.

- Stack contains one stack frame per executing subroutine
- Stack grows from higher towards lower memory addresses

- Heap contains objects allocated and not yet de-allocated
- Heap grows from lower towards higher memory addresses



Memory graph courtesy of RPISEC/MBE class.

Examples of Static Data

- Program code
- Global variables
- Tables of type data (e.g., inheritance structure)
- Dispatch tables (VFTs) and other tables
- Other

Examples of Stack Data

- What data is stored on the stack?
- Local variables, including parameters
- Compiler-generated temporaries (i.e., for expression evaluation)
- Bookkeeping (stack management) information
- Return address

Run-time Stack

- Stack contains frames of all subroutines that have been entered and not yet exited from
- Frame contains all information necessary to update stack when subroutine is exited
- Stack management uses two pointers: fp (**f**rame **p**ointer) and sp (**s**tack **p**ointer)
  - fp points to a location at the start of current frame
    - In higher memory (but lower on picture)
  - sp points to the next available location on stack (or the last used location on some machines)
    - In lower memory (but higher up on picture)
  - fp and sp define the beginning and the end of the frame

Run-time Stack

Run-time Stack Management

- Addresses for local variables are encoded as sp + offset
  - But may also have fp - offset

- Idea:
  - When subroutine is entered, its frame is placed on the stack. sp and fp are updated accordingly
  - All local variable accesses refer to this frame
  - When subroutine is exited, its frame is removed from the stack and sp and fp are updated accordingly

Frame Details

- Arguments to called routines
- Local variables, including parameters
- Temporaries
- Miscellaneous bookkeeping information
  - Saved address of start of caller's frame (old fp)
  - Saved state (register values of caller), other
- Return address

Frame Example

```
void foo(double rate, double initial) {
  double position; …
  position = initial + rate*60.0; …
  return;
}
```

Assume **bar** calls **foo**.

Frame for **foo**: