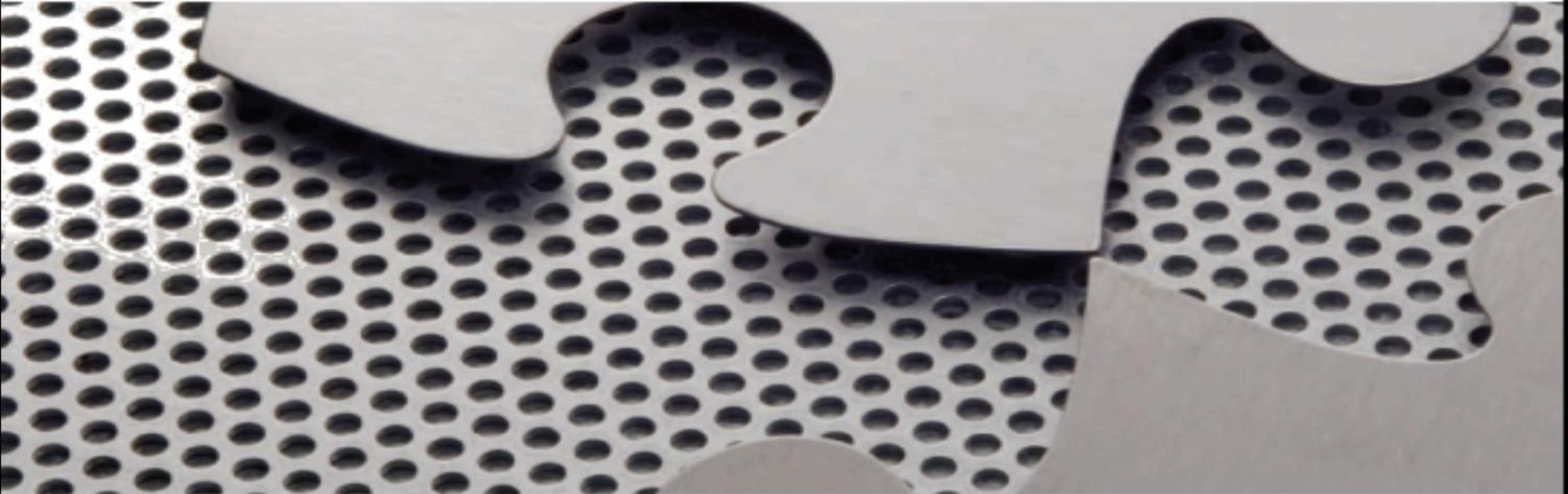
Programming Languages Third Edition



Chapter 7

Basic Semantics

Objectives

- Understand attributes, binding, and semantic functions
- Understand declarations, blocks, and scope
- Learn how to construct a symbol table
- Understand name resolution and overloading
- Understand allocation, lifetimes, and the environment

Objectives (cont'd.)

- Work with variables and constants
- Learn how to handle aliases, dangling references, and garbage
- Perform an initial static semantic analysis of TinyAda

Introduction

- Syntax: what the language constructs look like
- Semantics: what the language constructs actually do
- Specifying semantics is more difficult than specifying syntax
- Several ways to specify semantics:
  - Language reference manual
  - Defining a translator
  - Formal definition

Introduction (cont'd.)

- Language reference manual:
  - Most common way to specify semantics
  - Provides clearer and more precise reference manuals
  - Suffers from a lack of precision inherent in natural language descriptions
  - May have omissions and ambiguities

Introduction (cont'd.)

- Defining a translator:
  - Questions about a language can be answered by experimentation
  - Questions about program behavior cannot be answered in advance
  - Bugs and machine dependencies in the translator may become part of the language semantics, possibly unintentionally
  - May not be portable to all machines
  - May not be generally available

Introduction (cont'd.)

- Formal definition:
  - Formal mathematical methods: precise, but are also complex and abstract
  - Requires study to understand
  - Denotational semantics: probably the best formal method for the description of the translation and execution of programs
    - Describes semantics using a series of functions
- This course will use a hybrid of informal description with the simplified functions used in denotational descriptions

Attributes, Binding, and Semantic Functions

- **Names** (or **identifiers**): a fundamental abstraction mechanism used to denote language entities or constructs
- Fundamental step in describing semantics is to describe naming conventions for identifiers
- Most languages also include concepts of location and value
  - **Value**: any storable quantities
  - **Location**: place where value can be stored; usually a relative location

Attributes, Binding, and Semantic Functions (cont'd.)

- **Attributes**: properties that determine the meaning of the name to which they are associated
- Example in C: `const int n = 5;`
  - Attributes for variables and constants include data type and value
- Example in C:

```
double f(int n){
...
}
```

  - Attributes include "function," number, names and data type of parameters, return value data type, body of code to be executed

Attributes, Binding, and Semantic Functions (cont'd.)

- Assignment statements associate attributes to names
- Example: `x = 2;`
  - Associates attribute "value 2" to variable x
- Example in C++:

```
int* y;
y = new int;
```

  - Allocates memory (associates location to y)
  - Associates value

Attributes, Binding, and Semantic Functions (cont'd.)

- **Binding**: process of associating an attribute with a name
- **Binding time**: the time when an attribute is computed and bound to a name
- Two categories of binding:
  - **Static binding**: occurs prior to execution
  - **Dynamic binding**: occurs during execution
- Static attribute: an attribute that is bound statically
- Dynamic attribute: an attribute that is bound dynamically

Attributes, Binding, and Semantic Functions (cont'd.)

- Languages differ substantially in which attributes are bound statically or dynamically
  - Functional languages tend to have more dynamic binding than imperative languages
- Static attributes can be bound during translation, during linking, or during loading of the program
- Dynamic attributes can be bound at different times during execution, such as entry or exit from a procedure or from the program

Attributes, Binding, and Semantic Functions (cont'd.)

- Some attributes are bound prior to translation time
  - Predefined identifiers: specified by the language definition
  - Values true/false bound to data type Boolean
  - `maxint` specified by language definition and implementation
- All binding times except execution time are static binding

Attributes, Binding, and Semantic Functions (cont'd.)

- A translator creates a data structure to maintain bindings
  - Can be thought of as a function that expresses the binding of attributes to names
- **Symbol table**: a function from names to attributes

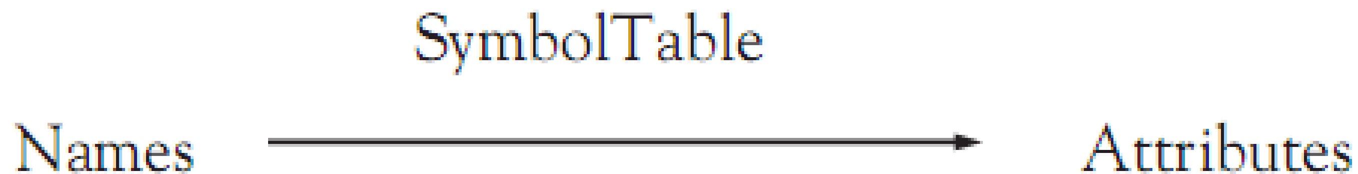


Figure 7.1 Mapping names to attributes in a symbol table

Attributes, Binding, and Semantic Functions (cont'd.)

- Parsing phase of translation includes three types of analysis:
  - Lexical analysis: determines whether a string of characters represents a token
  - Syntax analysis: determines whether a sequence of tokens represents a phrase in the context-free grammar
  - Static semantic analysis: establishes attributes of names in declarations and ensures that the use of these names conforms to their declared attributes
- During execution, attributes are also maintained

Attributes, Binding, and Semantic Functions (cont'd.)

Figure 7.2 Mapping names to locations in an environment

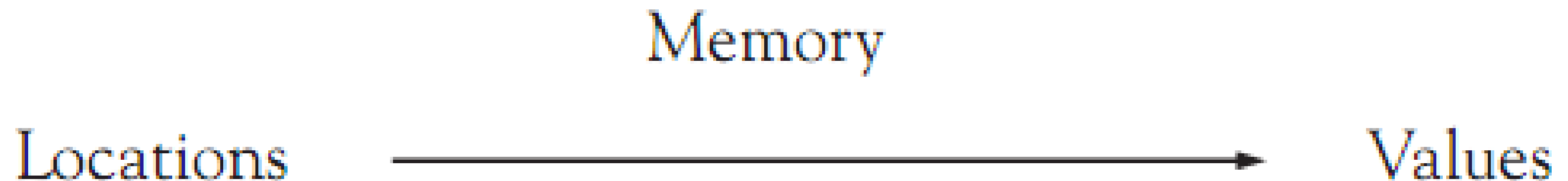


Figure 7.3 Mapping locations to values in a memory

Declarations, Blocks, and Scope

- Bindings can be **implicit** or **explicit**
- Example: `int x;`
  - Data type is bound explicitly; location of `x` is bound implicitly
- Entire declaration itself may be implicit in languages where simply using the variable name causes it to be declared
- **Definition**: in C and C++, a declaration that binds all potential attributes
- **Prototype**: function declaration that specifies the data type but not the code to implement it

Declarations, Blocks, and Scope (cont'd.)

- **Block**: a sequence of declarations followed by a sequence of statements
- **Compound statements**: blocks in C that appear as the body of functions or anywhere an ordinary program statement could appear
- **Local declarations**: associated with a block
- **Nonlocal declarations**: associated with surrounding blocks
- Block-structured languages allow nesting of blocks and redeclaration of names within nested blocks

Declarations, Blocks, and Scope (cont'd.)

- Each declared name has a **lexical address** containing a **level number** and an **offset**
  - Level number starts at 0 and increases into each nested block
- Other sources of declarations include:
  - A `struct` definition composed of local (member) declarations
  - A class in object-oriented languages
- Declarations can be collected into packages (Ada), modules (ML, Haskell, Python), and namespaces (C++)

Declarations, Blocks, and Scope (cont'd.)

- **Scope of a binding**: region of the program over which the binding is maintained
- **Lexical scope**: in block-structured languages, scope is limited to the block in which its associated declaration appears (and other blocks contained within it)
- **Declaration before use** rule: in C, scope of a declaration extends from the point of declaration to the end of the block in which it is located

```
(1)  int x;

(2)  void p(){
(3)       char y;
(4)       ...
(5)  } /* p */

(6)  void q(){
(7)       double z;
(8)       ...
(9)  } /* q */

(10) main(){
(11)      int w[10];
(12)      ...
(13) }
```

Figure 7.4 Simple C program demonstrating scope

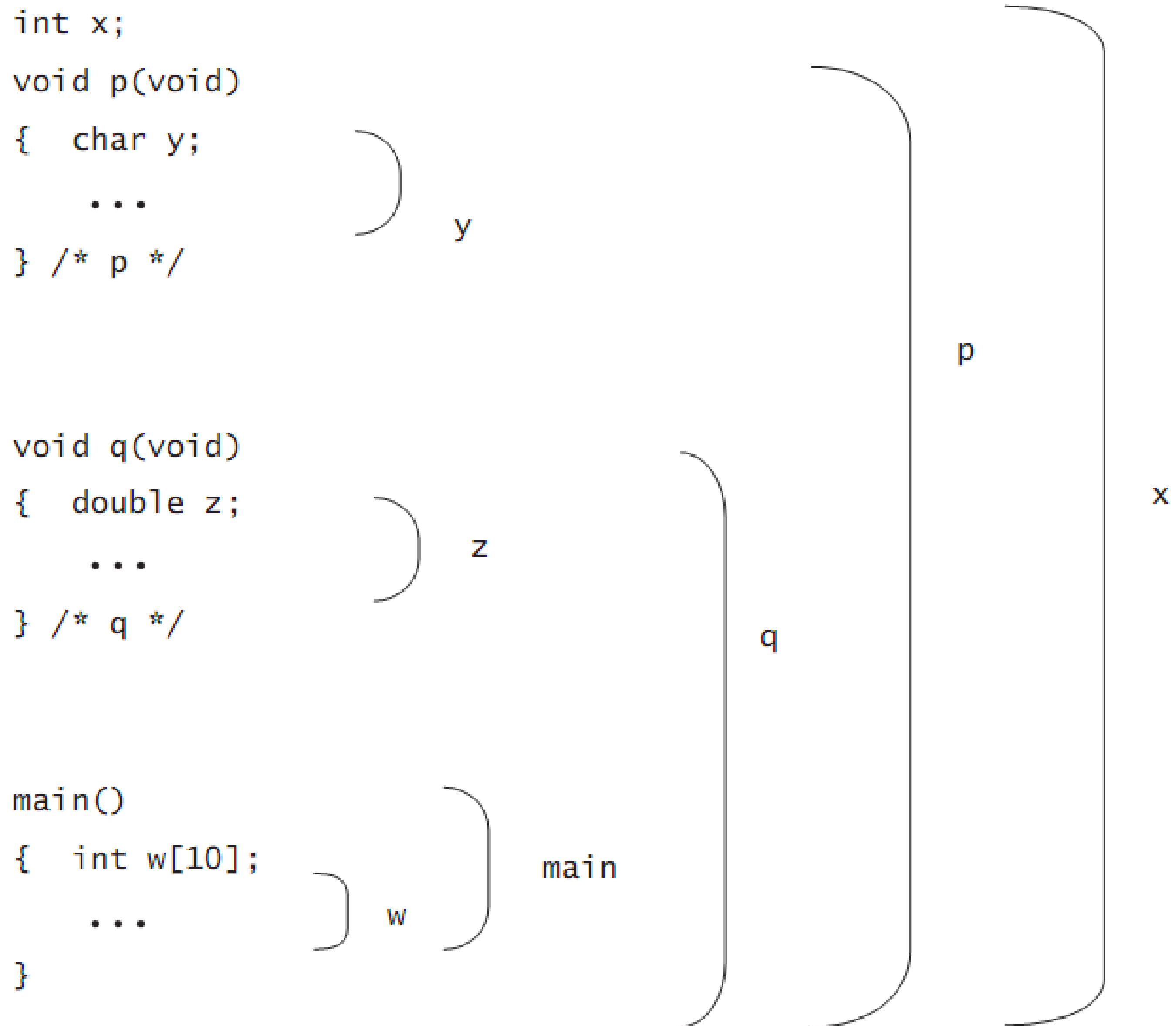


Figure 7.5 C Program from Figure 7.4 with brackets indicating scope

Declarations, Blocks, and Scope (cont'd.)

- Declarations in nested blocks take precedence over previous declarations
- A global variable is said to have a **scope hole** in a block containing a local declaration with the same name
  - Use **scope resolution operator** `::` in C++ to access the global variable
- Local declaration is said to **shadow** its global declaration
- **Visibility**: includes only regions where the bindings of a declaration apply

Declarations, Blocks, and Scope (cont'd.)

```
int x;

void p(){
char x;
  x = 'a'; // assigns to char x
  ::x = 42; // assigns to global int x
  ...
}

main(){
x = 2; // assigns to global x
  ...
}
```

Declarations, Blocks, and Scope (cont'd.)

- Scope rules need to be constructed such that recursive (self-referential) declarations are possible when they make sense
  - Example: functions must be allowed to be recursive, so function name must have scope beginning before the block of the function body

```
int factorial (int n){
    /* scope of factorial begins here */
    /* factorial can be called here */
    ...
}
```

The Symbol Table

- **Symbol table**:
  - Must support insertion, lookup, and deletion of names with associated attributes, representing bindings in declarations
- A lexically scoped, block-structured language requires a stack-like data structure to perform **scope analysis**:
  - On block entry, all declarations of that block are processed and bindings added to symbol table
  - On block exit, bindings are removed, restoring any previous bindings that may have existed

```
(1)  int x;
(2)  char y;

(3)  void p(){
(4)      double x;
(5)      ...
(6)      { int y[10];
(7)        ...
(8)      }
(9)      ...
(10) }

(11) void q(){
(12)     int y;
```

Figure 7.6 C program demonstrating symbol table structure (*continues*)

The Symbol Table (cont'd.)

(continued)

```
(13)      ...
(14) }

(15) main(){
(16)      char x;
(17)      ...
(18) }
```

Figure 7.6 C program demonstrating symbol table structure

The Symbol Table (cont'd.)

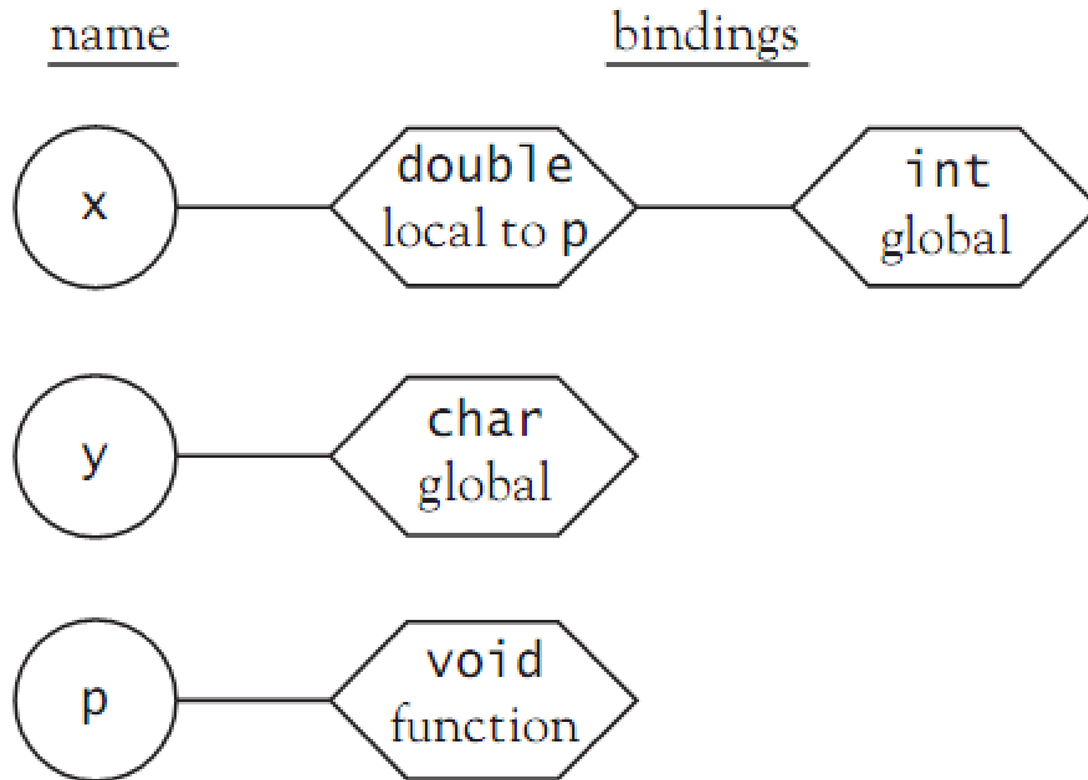


Figure 7.7 Symbol table structure at line 5 of Figure 7.6

The Symbol Table (cont'd.)

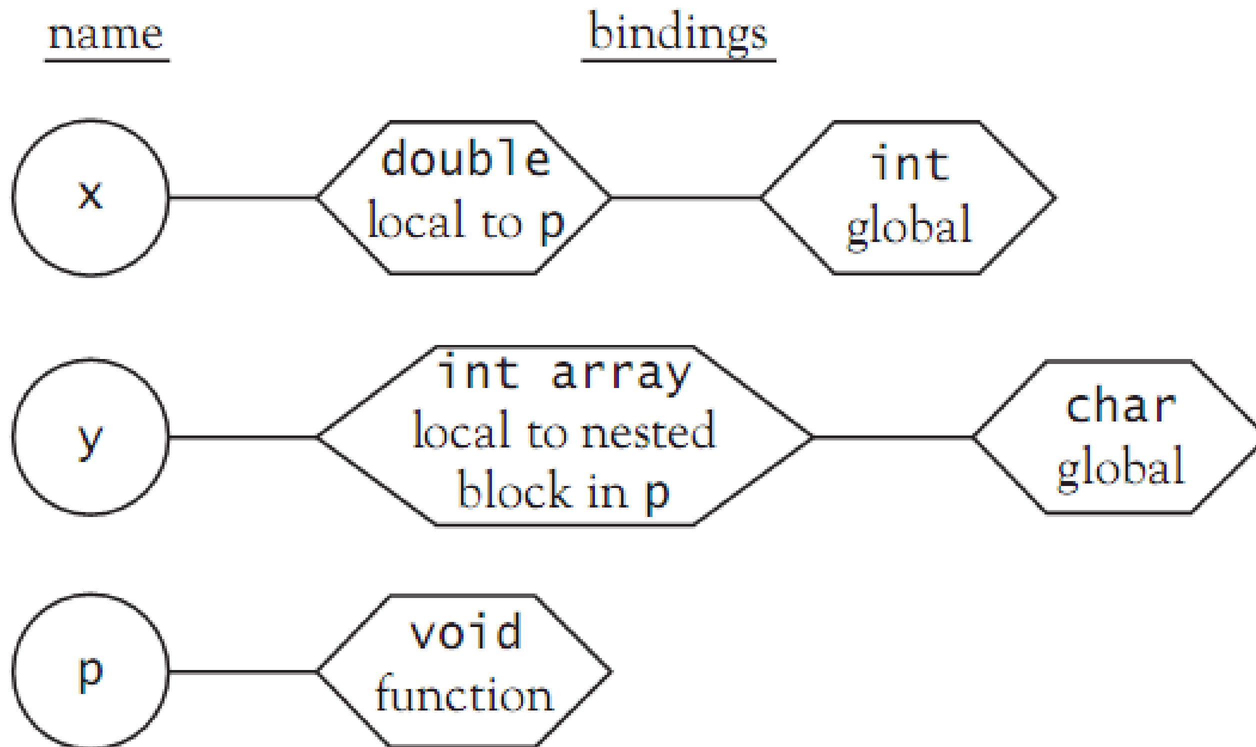


Figure 7.8 Symbol table structure at line 7 of Figure 7.6

The Symbol Table (cont'd.)

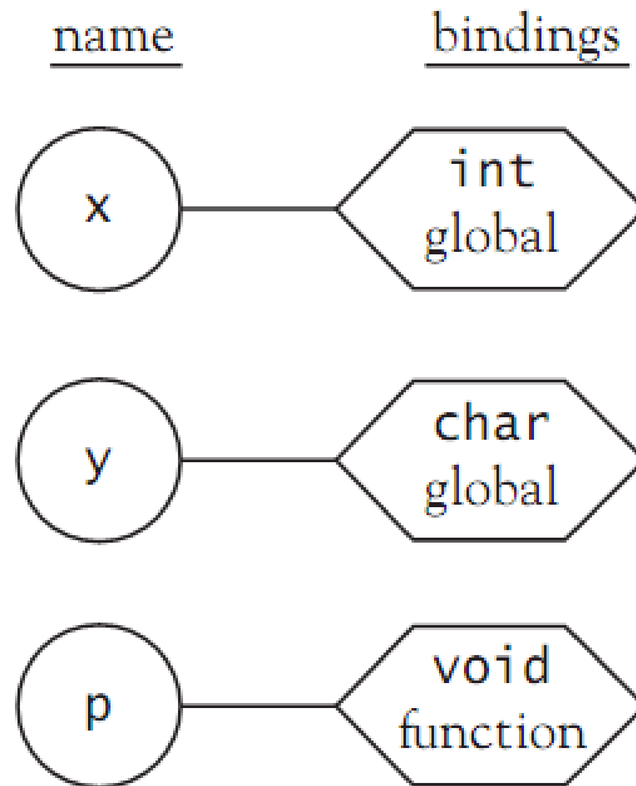


Figure 7.9 Symbol table structure at line 10 of Figure 7.6

The Symbol Table (cont'd.)

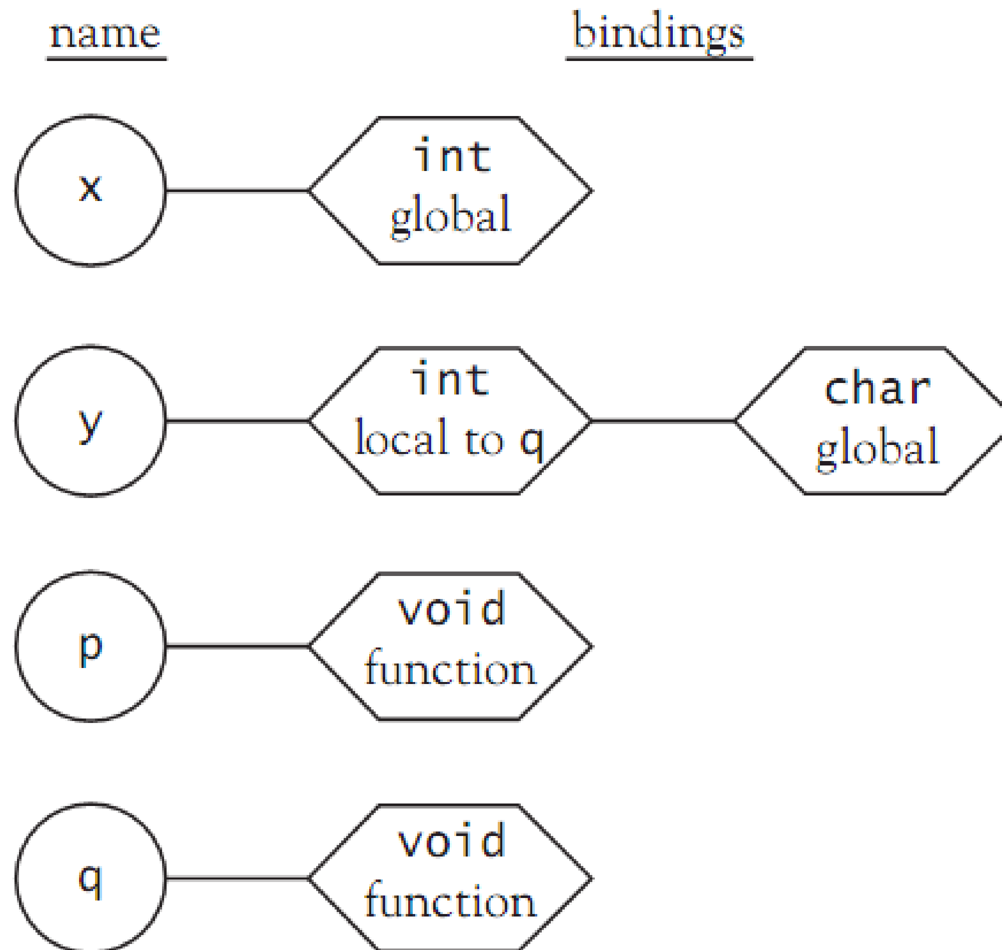


Figure 7.10 Symbol table structure at line 13 of Figure 7.6

The Symbol Table (cont'd.)

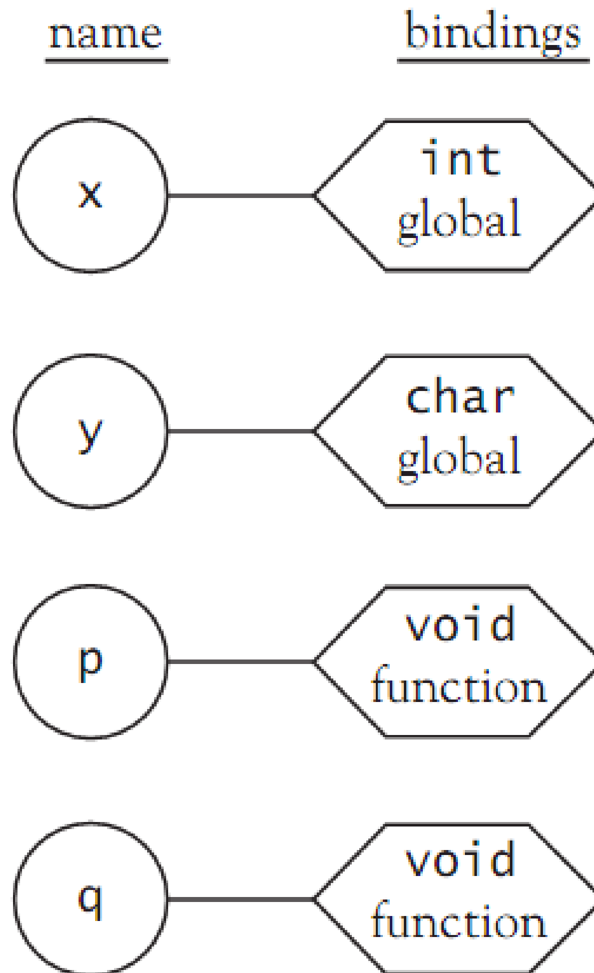


Figure 7.11 Symbol table structure at line 14 of Figure 7.6

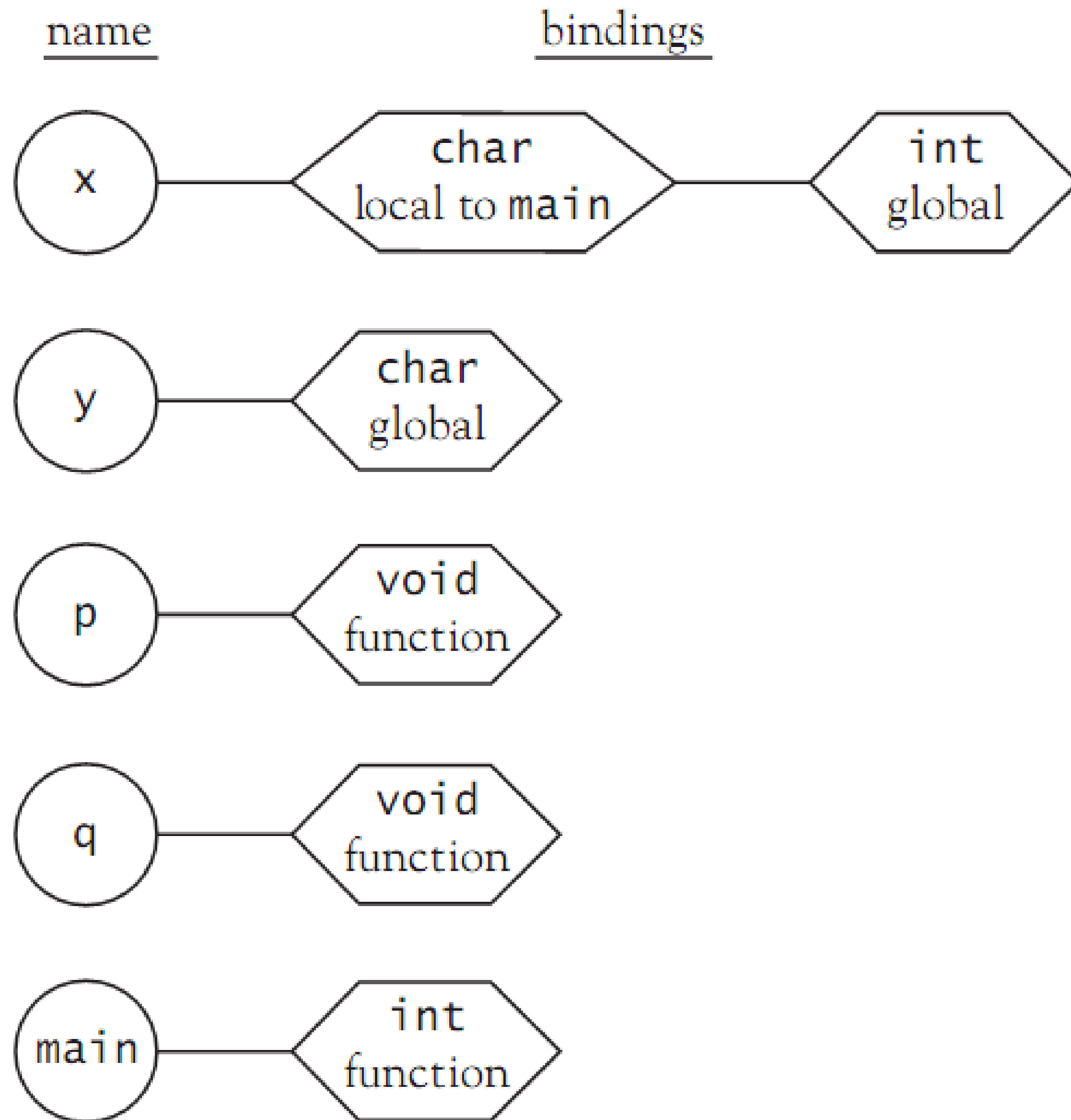


Figure 7.12 Symbol table structure at line 17 of Figure 7.6

The Symbol Table (cont'd.)

- The previous example assumes that declarations are processed statically (prior to execution)
  - This is called **static scoping** or **lexical scoping**
  - Symbol table is managed by a compiler
  - Bindings of declarations are all static
- If symbol table is managed dynamically (during execution), declarations will be processed as they are encountered along an execution path
  - This is called **dynamic scoping**

```
(1) #include <stdio.h>

(2) int x = 1;
(3) char y = 'a';
(4) void p(){
(5)     double x = 2.5;
(6)     printf("%c\n",y);
(7)     { int y[10];
(8)     }
(9) }

(10) void q(){
(11)     int y = 42;
(12)     printf("%d\n",x);
(13)     p();
(14) }

(15) main(){
(16)     char x = 'b';
(17)     q();
(18)     return 0;
(19) }
```

Figure 7.13 C program of Figure 7.6 with added code

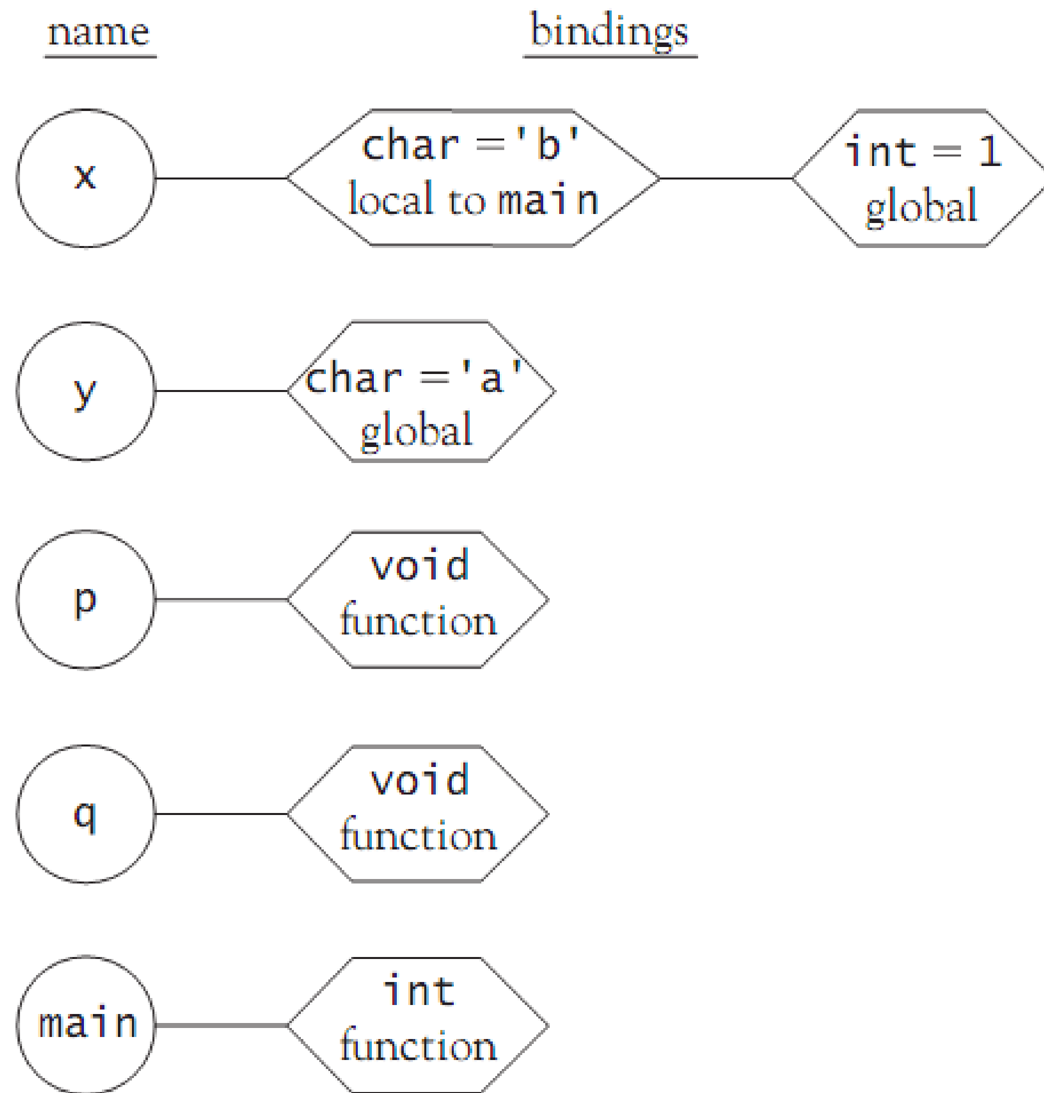


Figure 7.14 Symbol table structure at line 17 of Figure 7.13 using dynamic scope

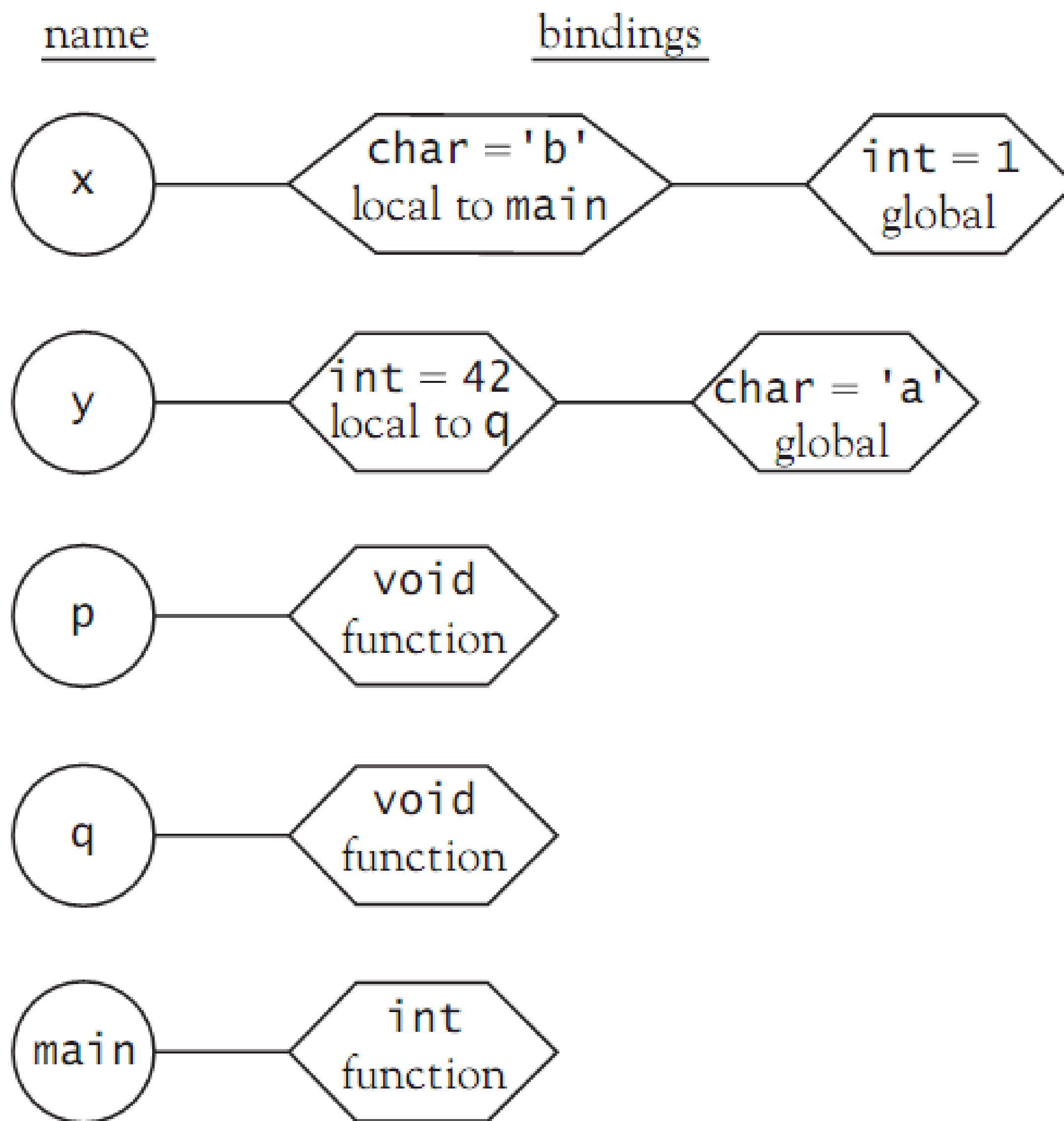


Figure 7.15 Symbol table structure at line 12 of Figure 7.13 using dynamic scope

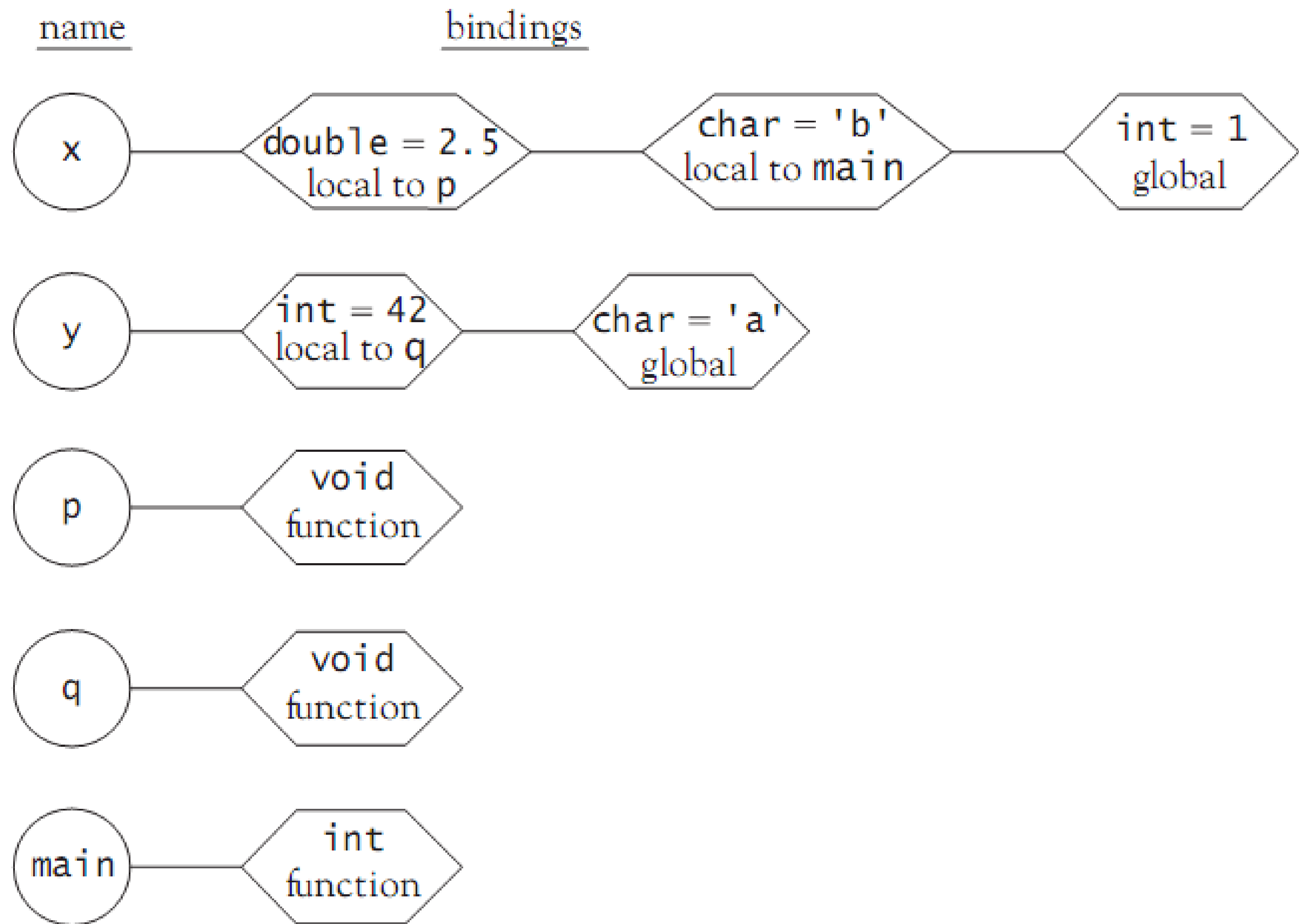


Figure 7.16 Symbol table structure at line 6 of Figure 7.13 using dynamic scope

The Symbol Table (cont'd.)

- Dynamic scoping will affect the semantics of the program and produce different output
- Output using lexical scoping:

```
1
a
```

- Output using dynamic scoping:

```
98
*
```

- Dynamic scope can be problematic, which is why few languages use it

The Symbol Table (cont'd.)

- Problems with dynamic scoping:
  - The declaration of a nonlocal name cannot be determined by simply reading the program: the program must be executed to know the execution path
  - Since nonlocal variable references cannot be predicted prior to execution, neither can their data types
- Dynamic scoping is a possible option for highly dynamic, interpreted languages when programs are not expected to be extremely large

The Symbol Table (cont'd.)

- Runtime environment is simpler with dynamic scoping in an interpreter
  - APL, Snobol, Perl, and early dialects of Lisp were dynamically scoped
  - Scheme and Common Lisp use static scoping
- There is additional complexity for symbol tables
- `struct` declaration must contain further declarations of the data fields within it
  - Those fields must be accessible using dot member notation whenever the `struct` variable is in scope

The Symbol Table (cont'd.)

- Two implications for struct variables:
  - A struct declaration actually contains a local symbol table itself as an attribute
  - This local symbol table cannot be deleted until the struct variable itself is deleted from the global symbol table of the program

```
(1)  struct{
(2)      int a;
(3)      char b;
(4)      double c;
(5)  } x = {1, 'a',2.5};

(6)  void p(){
(7)      struct{
(8)          double a;
(9)          int b;
(10)         char c;
(11)     } y = {1.2,2, 'b'};
(12)     printf("%d, %c, %g\n",x.a,x.b,x.c);
(13)     printf("%f, %d, %c\n",y.a,y.b,y.c);
(14) }

(15) main(){
(16)     p();
(17)     return 0;
(18) }
```

Figure 7.17 Code example illustrating scope of local declarations in a C `struct`

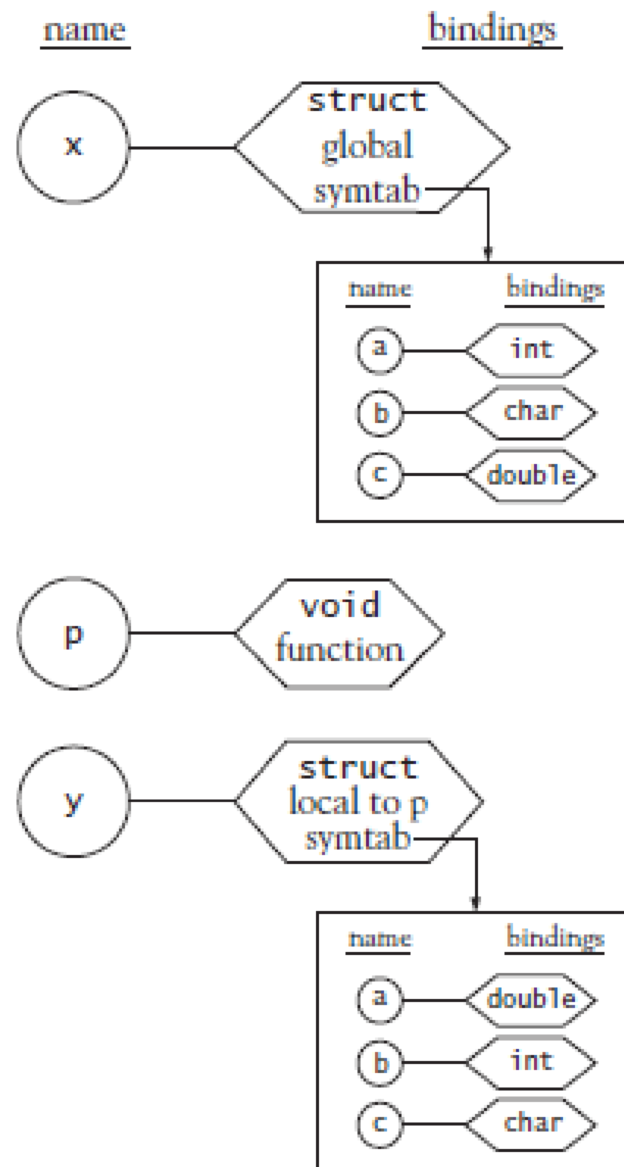


Figure 7.18 Representation of the symbol table structure at line 12 of the program of Figure 7.17, showing local `struct` symbol tables

The Symbol Table (cont'd.)

- Any scoping structure that can be referenced directly must also have its own symbol table
- Examples:
  - Named scopes in Ada
  - Classes, structs, and namespaces in C++
  - Classes and packages in Java
- Typically, there will be a table for each scope in a stack of symbol tables
  - When a reference to a name occurs, a search begins in the current table and continues to the next table if not found, and so on

```
(1)  with Text_IO; use Text_IO;
(2)  with Ada.Integer_Text_IO; use Ada.Integer_Text_IO;

(3)  procedure ex is
(4)    x: integer := 1;
(5)    y: character := 'a';

(6)    procedure p is
(7)    x: float := 2.5;
(8)    begin
(9)      put(y); new_line;
(10)   A: declare
(11)         y: array (1..10) of integer;
(12)       begin
(13)         y(1) := 2;
(14)         put(y(1)); new_line;
(15)         put(ex.y); new_line;
(16)       end A;
(17)   end p;

(18)   procedure q is
(19)     y: integer := 42;
(20)   begin
(21)     put(x); new_line;
(22)     p;
(23)   end q;

(24)    begin
(25)    declare
(26)      x: character := 'b';
(27)    begin
(28)      q;
(29)      put(ex.x); new_line;
(30)    end;
(31) end ex;
```

Figure 7.19 Ada code corresponding to Figure 7.13

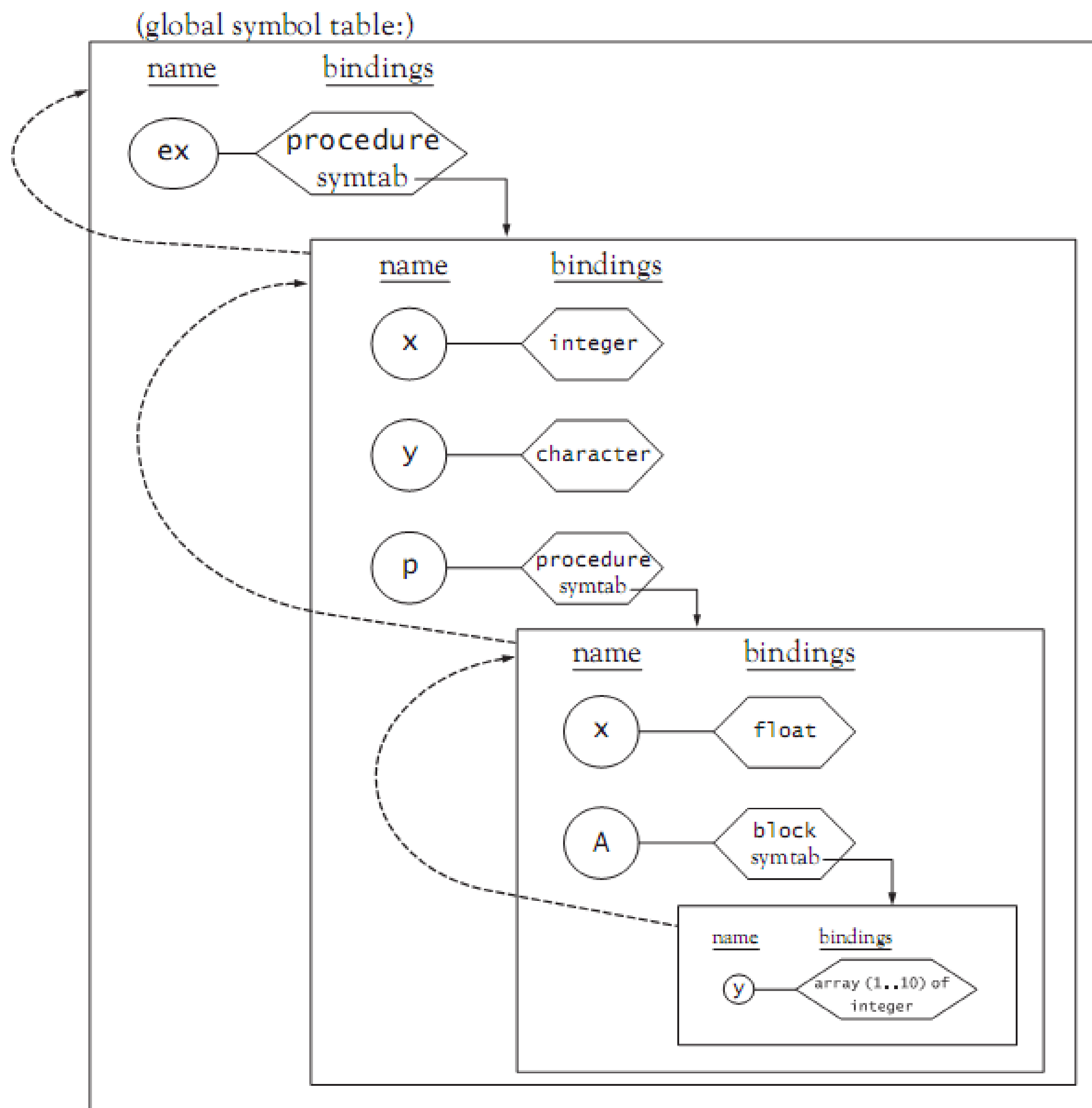


Figure 7.20 Symbol table structure at line 12 of Figure 7.19

Name Resolution and Overloading

- Addition operator + actually indicates at least two different operations: integer addition and floating-point addition
  - + operator is said to be **overloaded**
- Translator must look at the data type of each operand to determine which operation is indicated
- **Overload resolution**: process of choosing a unique function among many with the same name
  - Lookup operation of a symbol table must search on name plus number and data type of parameters

Name Resolution and Overloading (cont'd.)

```
int max(int x, int y){ // max #1
    return x > y ? x : y;
}

double max(double x, double y){ // max #2
    return x > y ? x : y;
}

int max(int x, int y, int z){ // max #3
    return x > y ? (x > z ? x : z) : (y > z ? y : z);
```

Figure 7.21 Three overloaded max functions in C++

Name Resolution and Overloading (cont'd.)

- Consider these function calls:

```
max(2,3); // calls max #1
max(2.1,3.2); // calls max #2
max(1,3,2); // calls max #3
```

- Symbol table can determine the appropriate function based on number and type of parameters
- **Calling context**: the information contained in each call
- But this **ambiguous** call depends on the language rules (if any) for converting between data types:

```
max(2.1,3); // which max?
```

Name Resolution and Overloading (cont'd.)

- Adding these definitions makes the function calls legal in C++ and Ada but is unnecessary in Java

```
double max(int x, double y){ // max #4
    return x > y ? (double) x : y;
}

double max(double x, int y){ // max #5
    return x > y ? x : (double) y;
}
```

Figure 7.22 Two more overloaded max functions in C++ (see Figure 7.21)

- Automatic conversions as they exist in C++ and Java significantly complicate overload resolution

Name Resolution and Overloading (cont'd.)

- Additional information in a calling context may be used for overload resolution:
  - Ada allows the return type and names of parameters to be used for overhead resolution
  - C++ and Java ignore the return type
- Both Ada and C++ (but not Java) allow built-in operators to be overloaded
- When overloading a built-in operator, we must accept its syntactic properties
  - Example: cannot change the associativity or precedence of the + operator

Name Resolution and Overloading (cont'd.)

- Note that there is no semantic difference between operators and functions, only syntactic difference
  - Operators are written in infix form
  - Function calls are always written in prefix form
- Names can also be overloaded
- Some languages use different symbol tables for each of the major kinds of definitions to allow the same name for a type, a function, and a variable
  - Example: Java

Name Resolution and Overloading (cont'd.)

```
class A
{  A A(A A)
   { A:
     for(;;)
     { if (A.A(A) == A) break A; }
     return A;
   }
}
```

Figure 7.26 Java class definition showing overloading of the same name for different language constructs (adapted from Arnold, Gosling, and Holmes [2000], p. 153)

Allocation, Lifetimes, and the Environment

- Environment: maintains the bindings of names to locations
  - May be constructed statically (at load time), dynamically (at execution time), or with a mixture of both
- Not all names in a program are bound to locations
  - Examples: names of constants and data types may represent purely compile-time quantities
- Declarations are also used in environment construction
  - Indicate what allocation code must be generated

Allocation, Lifetimes, and the Environment (cont'd.)

- Typically, in a block-structured language:
  - Global variables are allocated statically
  - Local variables are allocated dynamically when the block is entered
- When a block is entered, memory for variables declared in that block is allocated
- When a block is exited, this memory is deallocated

```
(1)  A: {  int x;
(2)        char y;
(3)        ...
(4)     B: {  double x;
(5)           int a;
(6)           ...
(7)        } /* end B */
(8)     C: {  char y;
(9)           int b;
(10)          ...
(11)       D: {  int x;
(12)             double y;
(13)             ...
(14)          } /* end D */
(15)          ...
(16)       } /* end C */
(17)       ...
(18)    } /* end A */
```

Figure 7.27 A C program with nested blocks to demonstrate allocation by the environment

Allocation, Lifetimes, and the Environment (cont'd.)

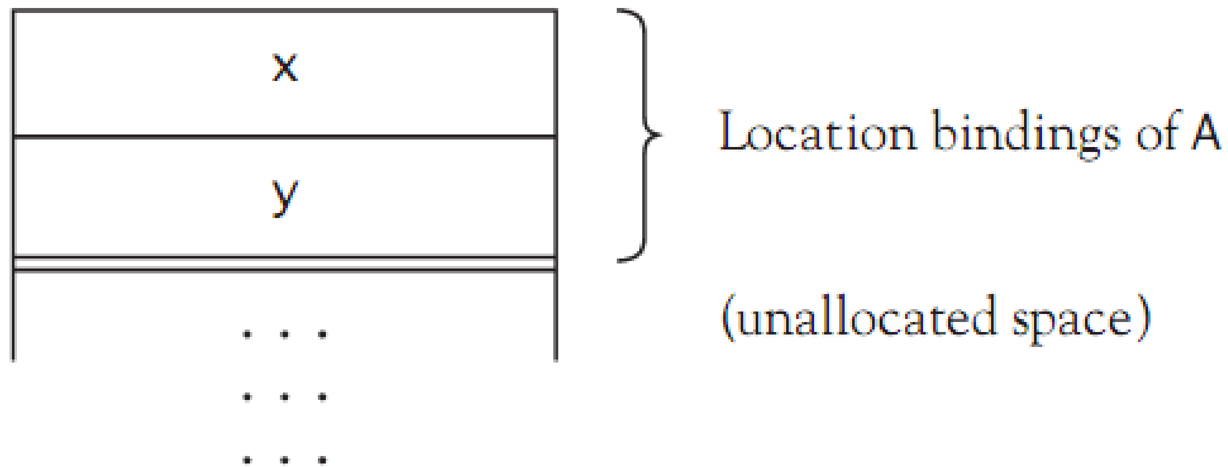


Figure 7.28 The environment at line 3 of Figure 7.27 after the entry into A

Allocation, Lifetimes, and the Environment (cont'd.)

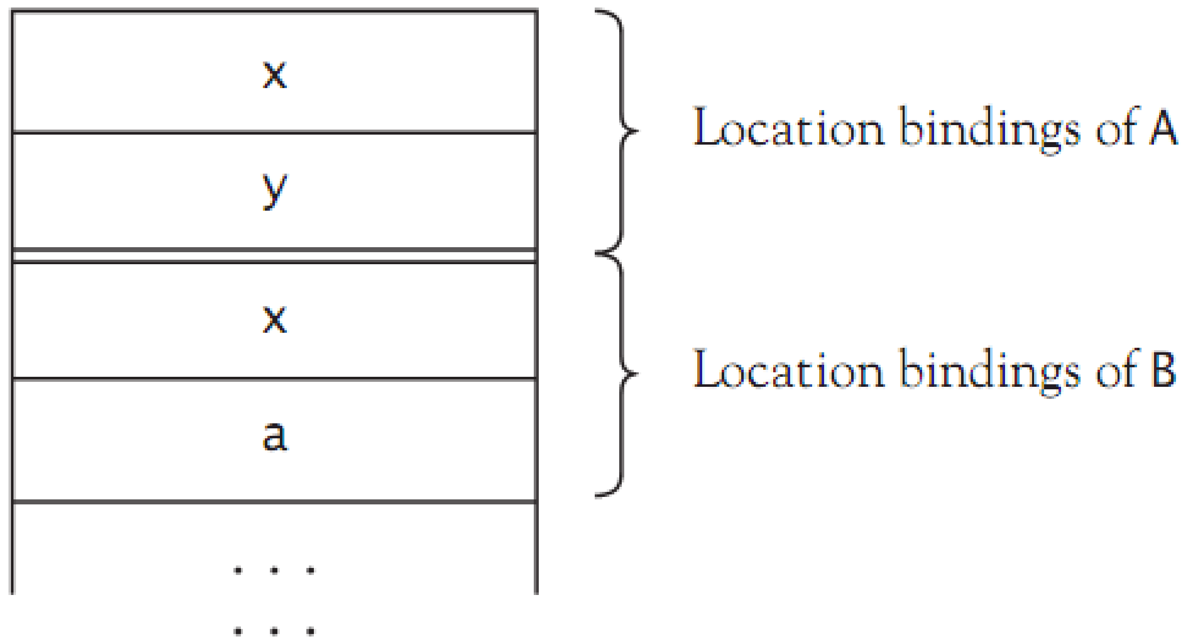


Figure 7.29 The environment at line 6 of Figure 7.27 after the entry into B

Allocation, Lifetimes, and the Environment (cont'd.)

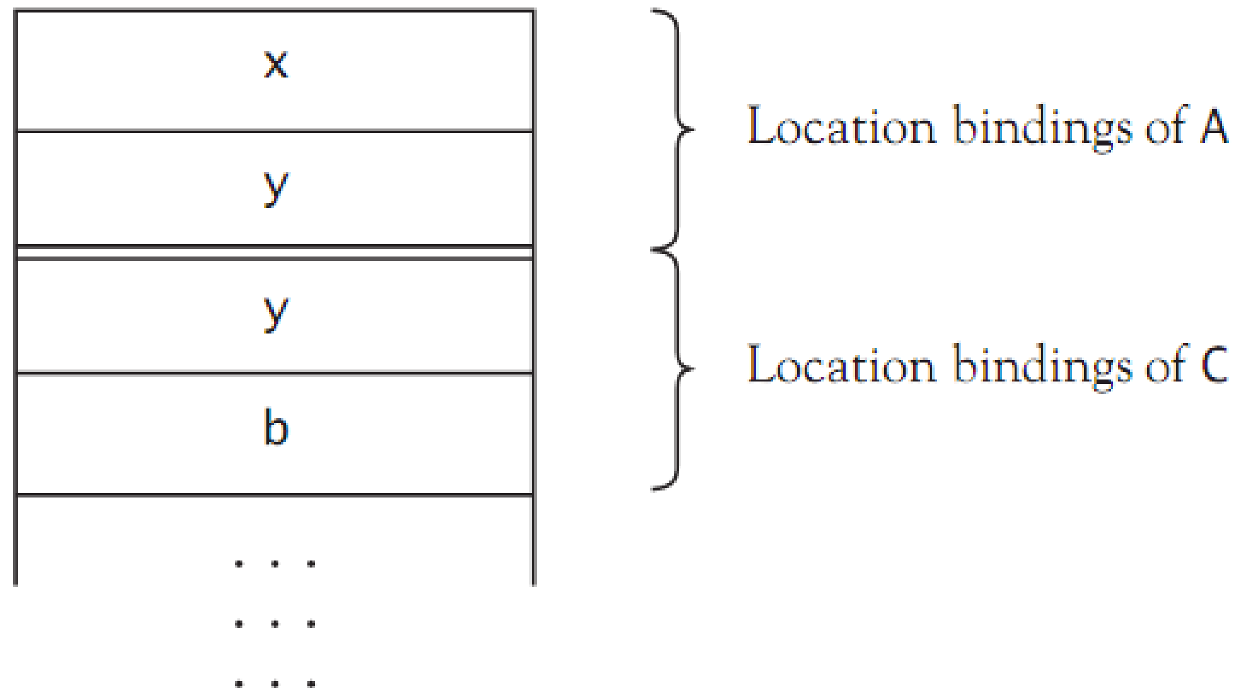


Figure 7.30 The environment at line 10 of Figure 7.27 after the entry into C

Allocation, Lifetimes, and the Environment (cont'd.)

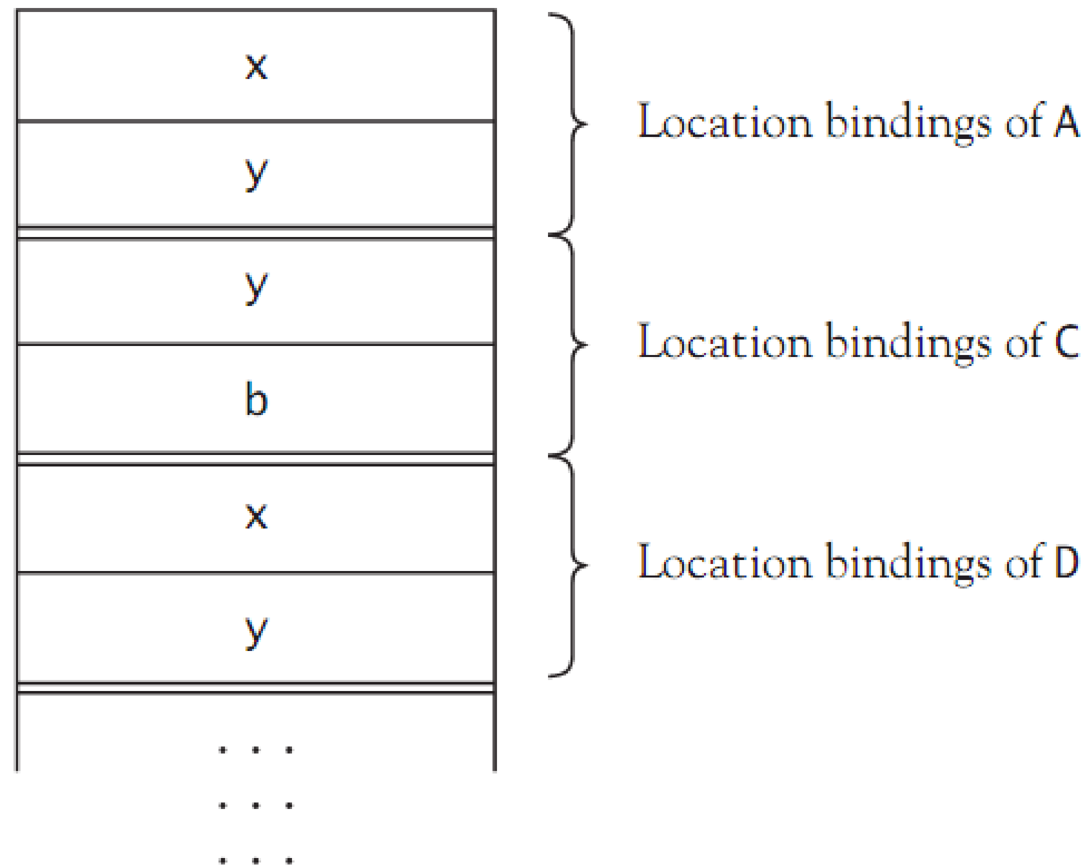


Figure 7.31 The environment at line 1 of Figure 7.27 after the entry into D

Allocation, Lifetimes, and the Environment (cont'd.)

- Memory for local variables within a function will not be allocated until the function is called
- **Activation**: a call to a function
- **Activation record**: the corresponding region of allocated memory
- In a block-structured language with lexical scope, the same name can be associated with different locations, but only one of these can be accessed at any one time
- **Lifetime** (or **extent**) of an object is the duration of its allocation in the environment

Allocation, Lifetimes, and the Environment (cont'd.)

- Lifetime of an object can extend beyond the region of a program in which it can be accessed
  - Lifetime extends through a scope hole
- **Pointer**: an object whose stored value is a reference to another object
- C allows the initialization of pointers that do not point to an allocated object:

```
int* x = NULL;
```

  - Objects must be manually allocated by use of an allocation routine
  - Variable can be dereferenced using the unary * operator

Allocation, Lifetimes, and the Environment (cont'd.)

- C++ simplifies dynamic allocation with operators `new` and `delete`:

```
int* x = new int; // C++
*x = 2;
cout << *x << endl; // output in C++
delete x;
```

  - These are used as unary operators, not functions
- **Heap**: area in memory from which locations can be allocated in response to calls to new
- **Dynamic allocation**: allocation on the heap

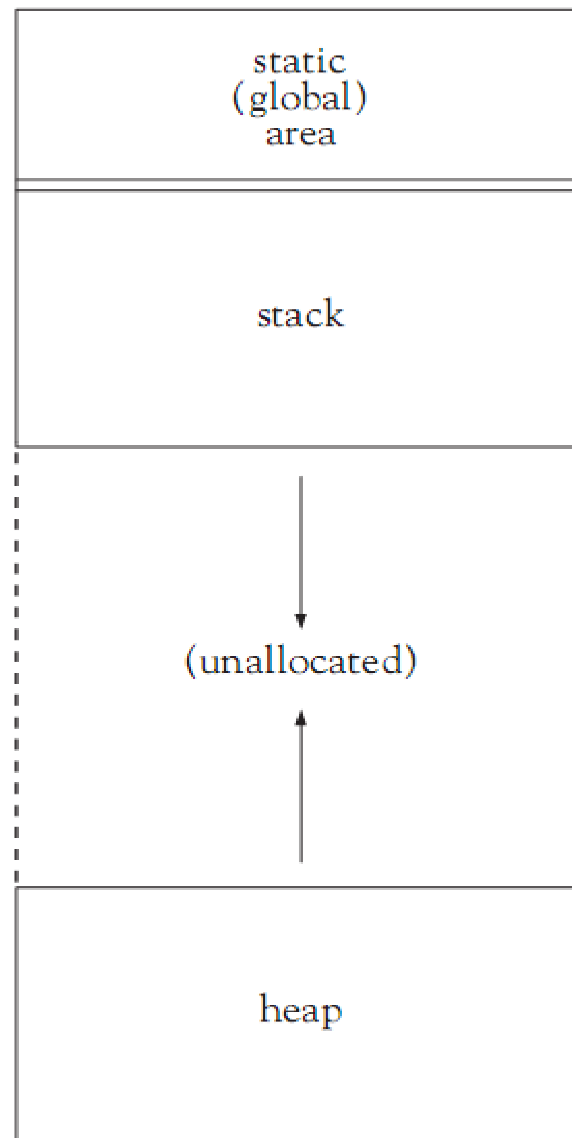


Figure 7.32 Structure of a typical environment with a stack and a heap

Allocation, Lifetimes, and the Environment (cont'd.)

- Many languages require that heap deallocation be managed automatically
- Heap allocation/deallocation and explicit pointer manipulation are inherently unsafe operations
  - Can introduce seriously faulty runtime behavior that may even compromise the operating system
- **Storage class**: the type of allocation
  - Static (for global variables)
  - Automatic (for local variables)
  - Dynamic (for heap allocation)

Variables and Constants

- Although references to variables and constants look the same in many languages, their roles and semantics are very different
- We will look at the basic semantics of both

Variables

- **Variable**: an object whose stored value can change during execution
  - Is completely specified by its attributes (name, location, value, data type, size of memory storage)
- **Box and circle diagram**: focuses on name and location

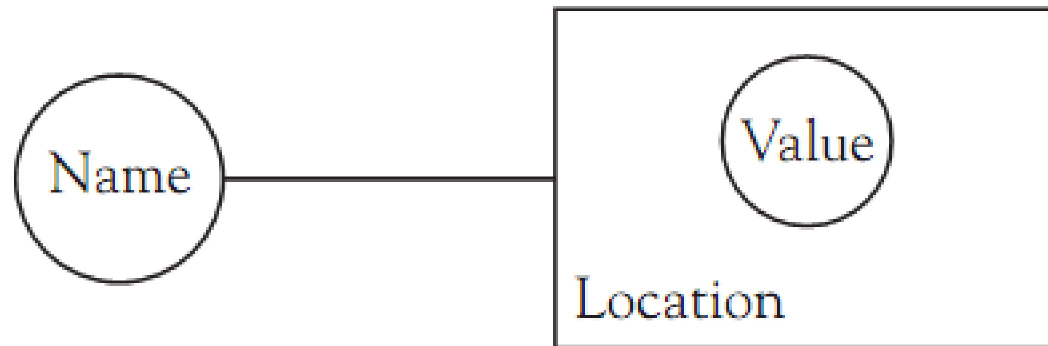


Figure 7.36 Schematic representation of a variable, its value, and its location

Variables (cont'd.)

- **Assignment** statement: principle way in which a variable changes its value
- Example: $x = e$;
  - Semantics: expression e is evaluated to a value, then copied into the location of x
- If e is a variable named y:

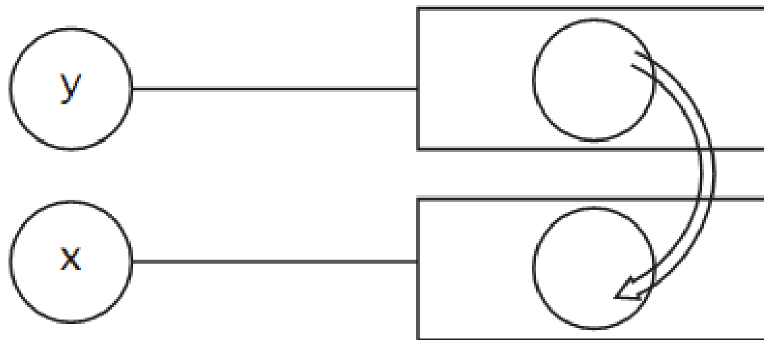


Figure 7.37 Assignment with copying of values

Variables (cont'd.)

- Variable on right side of assignment statement stands for a value (**r-value**); variable on left side stands for a location (**l-value**)
- **Address of operator** (&) in C: turns a reference into a pointer to fetch the address of a variable
- **Assignment by sharing**: the location is copied instead of the value
- **Assignment by cloning**: allocates new location, copies value, and binds to the new location
- Both are sometimes called **pointer semantics** or **reference semantics**

Variables (cont'd.)

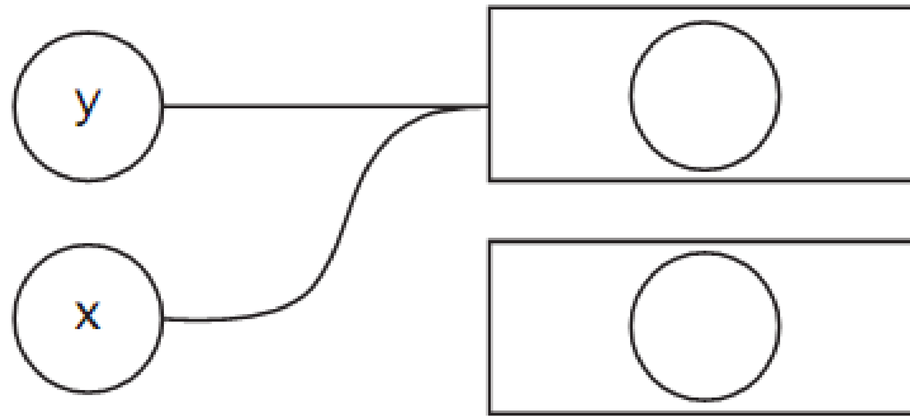


Figure 7.38 The result of assignment by sharing

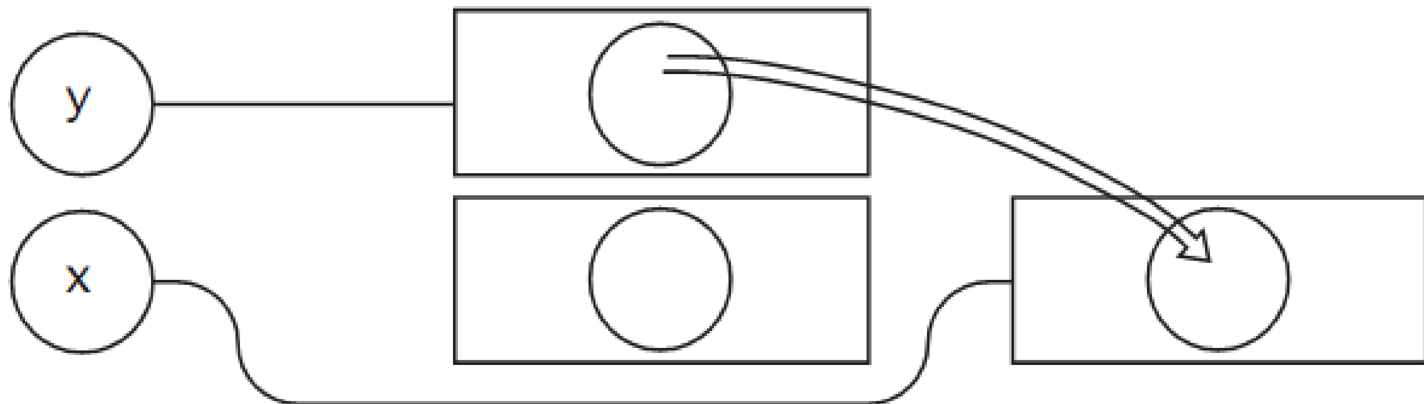


Figure 7.39 The result of assignment by cloning

Variables (cont'd.)

- **Storage semantics** or **value semantics** refer to standard assignment
- Standard implementation of assignment by sharing uses pointers and implicit dereferencing

Variables (cont'd.)

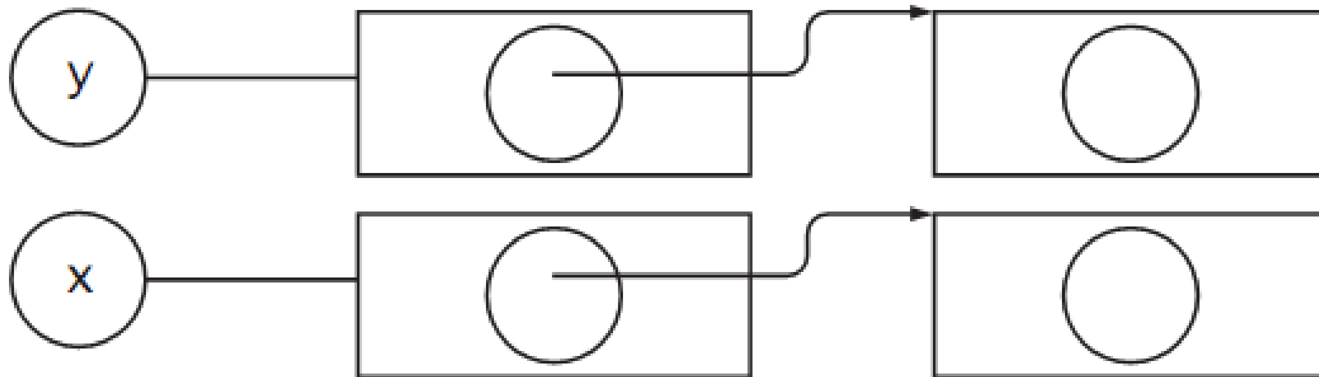


Figure 7.40 Variables as implicit references to objects

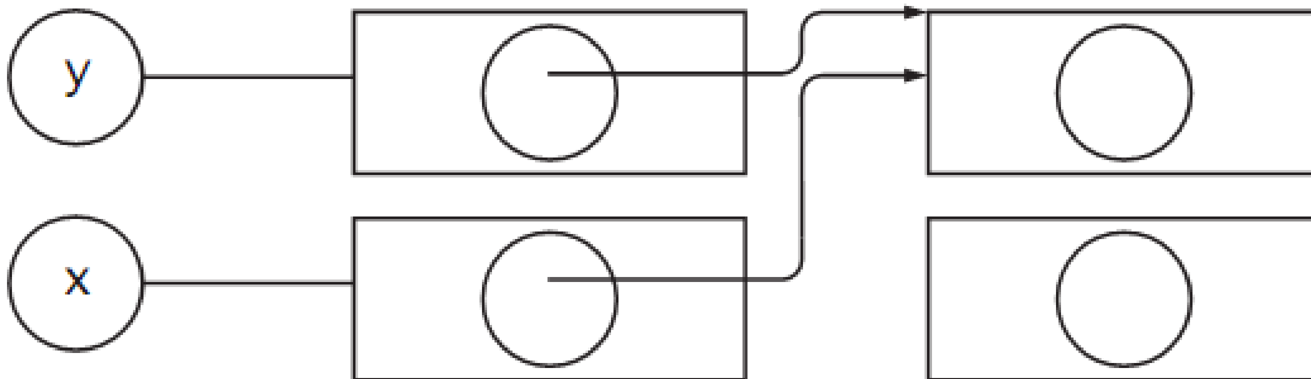


Figure 7.41 Assignment by sharing of references

Constants

- **Constant**: an entity with a fixed value for the duration of its existence in a program
  - Like a variable, but has no location attribute
  - Sometimes say that a constant has **value semantics**
- **Literal**: a representation of characters or digits
- **Compile-time constant**: its value can be computed during compilation
- **Static constant**: its value can be computed at load time

Constants (cont'd.)

- **Manifest constant**: a name for a literal
- Dynamic constant: its value must be computed during execution
- Function definitions in virtually all languages are definitions of constants whose values are functions
  - This differs from a function variable in C, which must be defined as a pointer

Constants (cont'd.)

- a and b are compile-time constants
  - a is a manifest constant
- c is a static (load-time constant)
- d is a dynamic constant

```
#include <stdio.h>
#include <time.h>

const int a = 2;
const int b = 27+2*2;
/* warning - illegal C code! */
const int c = (int) time(0);

int f( int x){
    const int d = x+1;
    return b+c;
}
...
```

Aliases, Dangling References, and Garbage

- There are several problems with naming and dynamic allocation conventions of programming languages, especially C, C++, and Ada
- As a programmer, you can learn to avoid those problematic situations
- As a language designer, you can build solutions into your language

Aliases

- **Alias**: occurs when the same object is bound to two different names at the same time
- Can occur during procedure call, through the use of pointer variables, or through assignment by sharing

```
(1) int *x, *y;
(2) x = (int *) malloc(sizeof(int));
(3) *x = 1;
(4) y = x;    /* *x and *y now aliases */
(5) *y = 2;
(6) printf("%d\n",*x);
```

Aliases (cont'd.)

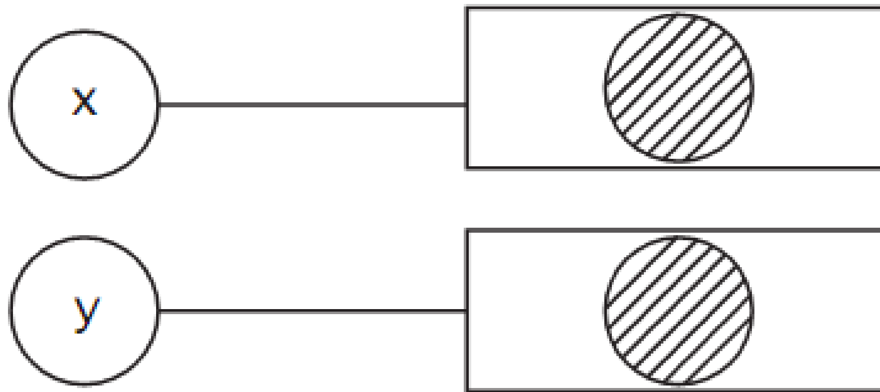


Figure 7.45 Allocation of storage for pointers x and y

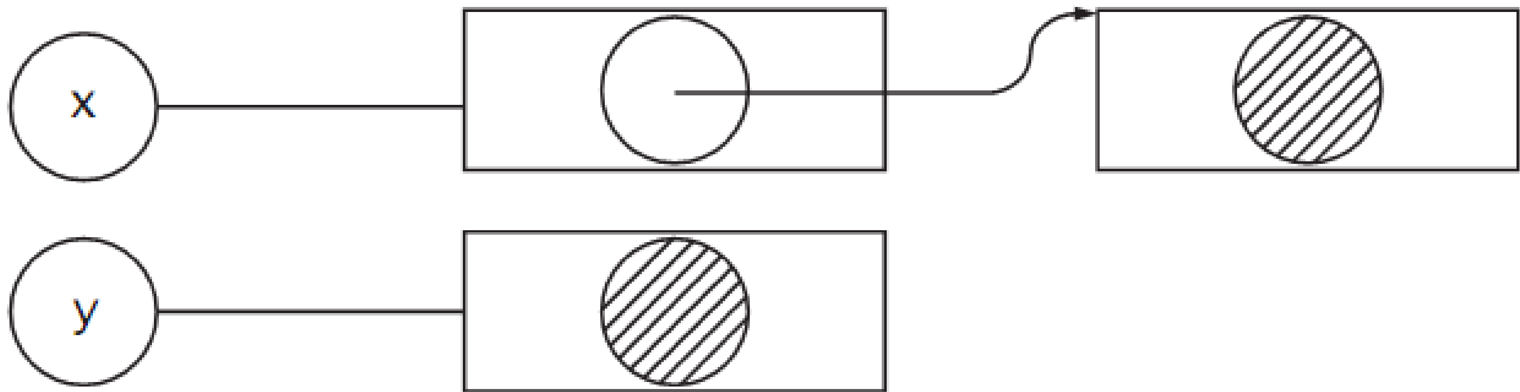


Figure 7.46 Allocation of storage for *x

Aliases (cont'd.)

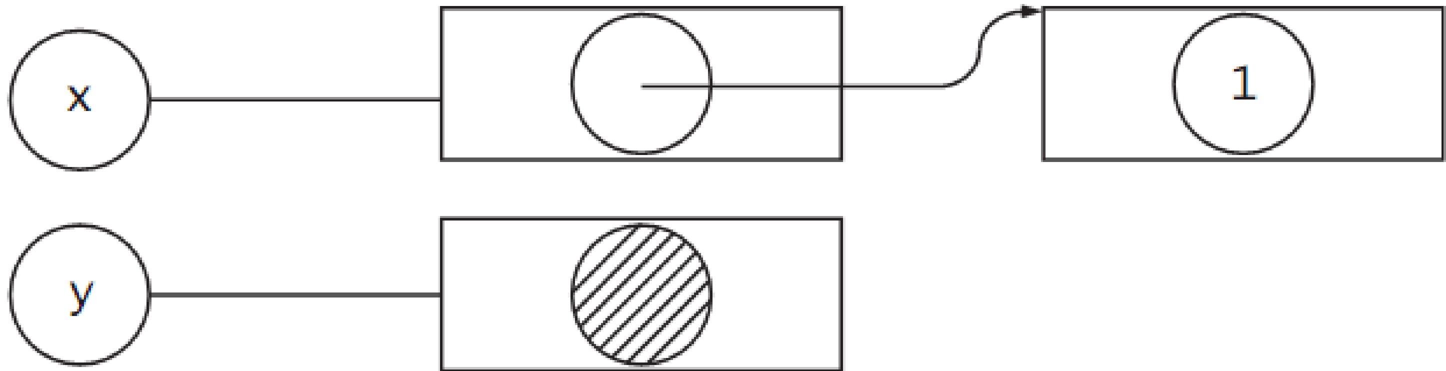


Figure 7.47 Result of *x = 1

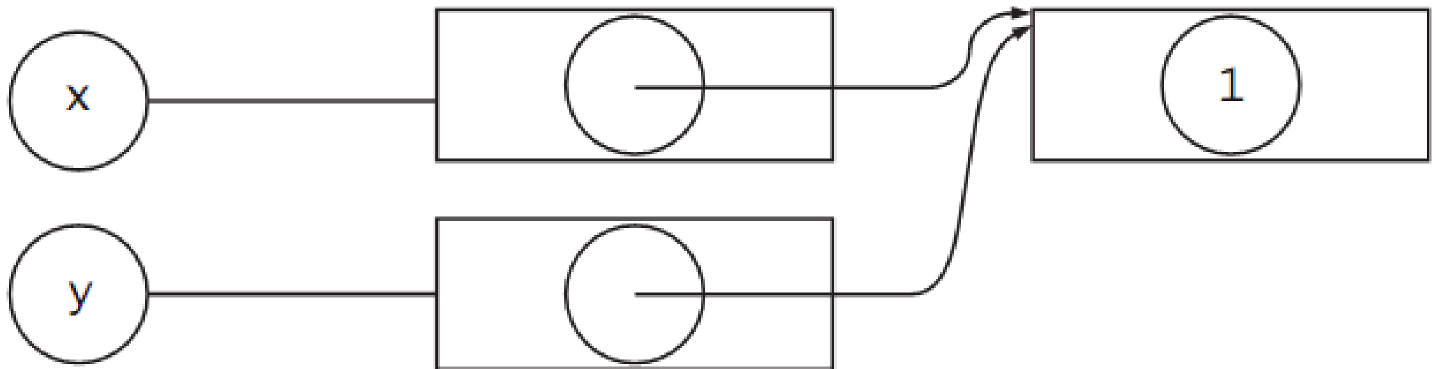


Figure 7.48 Result of y = x

Aliases (cont'd.)

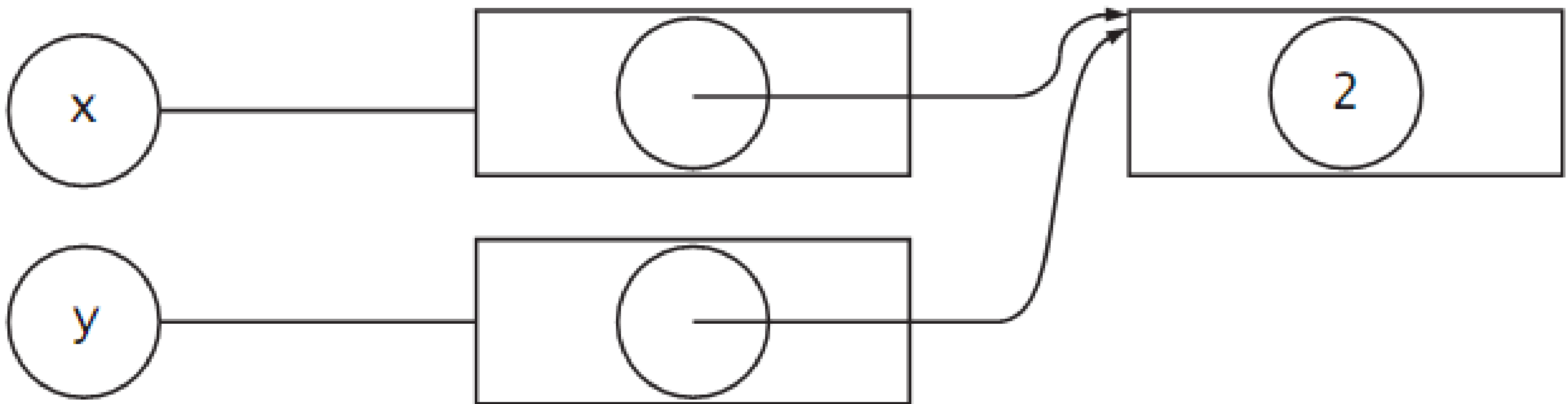


Figure 7.49 Result of *y = 2

Aliases (cont'd.)

- Aliases can potentially cause harmful side effects
- **Side effect**: any change in a variable's value that persists beyond the execution of the statement
- Not all side effects are harmful; an assignment statement is intended to cause one
- Side effects that change variables whose names do not directly appear in the statement are potentially harmful
  - Cannot be determined from the written code
- Aliasing due to pointer assignment is difficult to control

Aliases (cont'd.)

- Assignment by sharing implicitly uses pointers
- Java has a mechanism for explicitly **cloning** an object so that aliases are not created by assignment

```
(1) class ArrTest{
(2)     public static void main(String[] args){
(3)         int[] x = {1,2,3};
(4)         int[] y = x;
(5)         x[0] = 42;
(6)         System.out.println(y[0]);
(7)     }
(8) }
```

Dangling References

- **Dangling reference**: a location that has been deallocated from the environment but can still be accessed by a program
  - Occurs when a pointer points to a deallocated object

```
int *x , *y;
...
x = (int *) malloc(sizeof(int));
...
*x = 2;
...
y = x; /* *y and *x now aliases */
free(x); /* *y now a dangling reference */
...
printf("%d\n",*y); /* illegal reference */
```

Dangling References (cont'd.)

- Can also result from automatic deallocation of local variables on exit from a block, with the C address of operator

```
(1) { int * x;
(2)   { int y;
(3)     y = 2;
(4)     x = &y;
(5)   }
(6)   /* *x is now a dangling reference */
(7) }
```

Dangling References (cont'd.)

- Java does not allow dangling references at all because:
  - There are no explicit pointers
  - There is no address of operator
  - There are no memory deallocation operators such as `free` or `delete`

Garbage

- **Garbage**: memory that has been allocated in the environment but is now inaccessible to the program
- Can occur in C by failing to call free before reassigning a pointer variable

```
int *x;
...
x = (int *) malloc(sizeof(int));
x = 0;
```

- A program that is internally correct but produces garbage may run out of memory

Garbage (cont'd.)

- A program with dangling references may:
  - Produce incorrect results
  - Corrupt other programs in memory
  - Cause runtime errors that are hard to locate
- For this reason, it is useful to remove the need to deallocate memory explicitly from the programmer
- **Garbage collection**: process of automatically reclaiming garbage
- Language design is a key factor in the kind of runtime environment necessary for correct execution of programs

Case Study: Initial Static Semantic Analysis of TinyAda

- Chapter 6 introduced a syntax analyzer for TinyAda
  - A simple parsing shell that pulled tokens from a scanner until a syntax error was detected
- Here, we extend the parsing shell to perform some semantic analysis
  - Focus will be on tools for scope analysis and for restricting the use of identifiers
- Must focus on two attributes of an identifier:
  - Name
  - Role it plays (constant, variable, type, or procedure)

Scope Analysis

- TinyAda is lexically scoped, with these scope rules:
  - All identifiers must be declared before use
  - At most, one declaration for a given identifier in a single block
  - A new block starts with formal parameter specifications of a procedure and extends to the reserved word end
  - Visibility of a declared identifier extends into nested blocks unless it is redeclared in that block
  - Identifiers are not case sensitive

Scope Analysis (cont'd.)

- TinyAda has five built-in (predefined) identifiers:
  - Data type names `integer`, `char`, `boolean`
  - Boolean constants `true` and `false`
- These identifiers must be visible in a top-level scope before a source program is parsed
  - Static nesting level of this scope is 0
- Scope at nesting level 1 contains the procedure's formal parameters (if any) and any identifiers introduced in the procedures basic declarations
- Names in nested procedures follow this pattern

Scope Analysis (cont'd.)

- TinyAda's parser uses a stack of symbol tables
  - When each new scope is entered, a new table is pushed onto the stack
  - When a scope is exited, the table at the top of the stack is popped off the stack
- Two classes are defined to support scope analysis:
  - `SymbolEntry`: holds information about an identifier
  - `SymbolTable`: manages the stack of scopes

Scope Analysis (cont'd.)

Table 7.1 The interface for the `SymbolTable` class

`SymbolTable` Method	What It Does
`SymbolTable(Chario c)`	Creates an empty stack of tables, with a reference to a `Chario` object for the output of error messages.
`void enterScope()`	Pushes a new table onto the stack.
`void exitScope();`	Pops a table from the stack and prints its contents.
`SymbolEntry enterSymbol(String name);`	If `name` is not already present, inserts an entry for it into the table and returns that entry; otherwise, prints an error message and returns an empty entry.
`SymbolEntry findSymbol(String name);`	If `name` is already present, returns its entry; otherwise, prints an error message and returns an empty entry.

Identifier Role Analysis

- An identifier names an entity, such as a variable, a constant, or an entire data type
  - This attribute of an identifier is called its **role**
- An identifier's role imposes certain restrictions on its use
- Examples:
  - Only a variable or parameter identifier can appear on the left side of an assignment statement
  - Only a type identifier can appear as the element type of an array

Identifier Role Analysis (cont'd.)

- Identifier acquires its role in its declaration
  - Role is saved in the symbol table for future use
- Role analysis uses the symbol table to share contextual information about identifiers among otherwise independent parsing methods