Chapter 5

Names, Bindings, and Scopes
Chapter 5 Topics

- Introduction
- Names
- Variables
- The Concept of Binding
- Scope
- Scope and Lifetime
- Referencing Environments
- Named Constants
Introduction

• Imperative languages are abstractions of von Neumann architecture
  – Memory
  – Processor

• Variables are characterized by attributes
  – To design a type, must consider scope, lifetime, type checking, initialization, and type compatibility
Names

• **Design issues for names:**
  - Are names case sensitive?
  - Are special words reserved words or keywords?
Names (continued)

• Length
  – If too short, they cannot be connotative
  – Language examples:
    • C99: no limit but only the first 63 are significant; also, external names are limited to a maximum of 31
    • C# and Java: no limit, and all are significant
    • C++: no limit, but implementers often impose one
Names (continued)

- Special characters
  - PHP: all variable names must begin with dollar signs
  - Perl: all variable names begin with special characters, which specify the variable’s type
  - Ruby: variable names that begin with @ are instance variables; those that begin with @@ are class variables
Names (continued)

- Case sensitivity
  - Disadvantage: readability (names that look alike are different)
    - Names in the C–based languages are case sensitive
    - Names in others are not
    - Worse in C++, Java, and C# because predefined names are mixed case (e.g. `IndexOutOfBoundsException`)
Names (continued)

- Special words
  - An aid to readability; used to delimit or separate statement clauses
  - A *keyword* is a word that is special only in certain contexts
  - A *reserved word* is a special word that cannot be used as a user-defined name
  - Potential problem with reserved words: If there are too many, many collisions occur (e.g., COBOL has 300 reserved words!)
Variables

• **A variable is an abstraction of a memory cell**

• Variables can be characterized as a sextuple of attributes:
  - Name
  - Address
  - Value
  - Type
  - Lifetime
  - Scope
Variables Attributes

- **Name** – not all variables have them
- **Address** – the memory address with which it is associated
  - A variable may have different addresses at different times during execution
  - A variable may have different addresses at different places in a program
  - If two variable names can be used to access the same memory location, they are called aliases
  - Aliases are created via pointers, reference variables, C and C++ unions
  - Aliases are harmful to readability (program readers must remember all of them)
Variables Attributes (continued)

- **Type** – determines the range of values of variables and the set of operations that are defined for values of that type; in the case of floating point, type also determines the precision
- **Value** – the contents of the location with which the variable is associated
  - The l–value of a variable is its address
  - The r–value of a variable is its value
- **Abstract memory cell** – the physical cell or collection of cells associated with a variable
The Concept of Binding

A binding is an association between an entity and an attribute, such as between a variable and its type or value, or between an operation and a symbol.

- **Binding time** is the time at which a binding takes place.
Possible Binding Times

- Language design time -- bind operator symbols to operations
- Language implementation time -- bind floating point type to a representation
- Compile time -- bind a variable to a type in C or Java
- Load time -- bind a C or C++ static variable to a memory cell
- Runtime -- bind a nonstatic local variable to a memory cell
Static and Dynamic Binding

- A binding is *static* if it first occurs before run time and remains unchanged throughout program execution.
- A binding is *dynamic* if it first occurs during execution or can change during execution of the program.
Type Binding

- How is a type specified?
- When does the binding take place?
- If static, the type may be specified by either an explicit or an implicit declaration
Explicit/Implicit Declaration

- An *explicit declaration* is a program statement used for declaring the types of variables.

- An *implicit declaration* is a default mechanism for specifying types of variables through default conventions, rather than declaration statements.

- Basic, Perl, Ruby, JavaScript, and PHP provide implicit declarations.
  - Advantage: writability (a minor convenience)
  - Disadvantage: reliability (less trouble with Perl)
Explicit/Implicit Declaration (continued)

- Some languages use type inferencing to determine types of variables (context)
  - C# – a variable can be declared with `var` and an initial value. The initial value sets the type
  - Visual Basic 9.0+, ML, Haskell, and F# use type inferencing. The context of the appearance of a variable determines its type
Dynamic Type Binding

- Dynamic Type Binding (JavaScript, Python, Ruby, PHP, and C# (limited))
- Specified through an assignment statement e.g., JavaScript
  - `list = [2, 4.33, 6, 8];
  - `list = 17.3;`
- Advantage: flexibility (generic program units)
- Disadvantages:
  - High cost (dynamic type checking and interpretation)
  - Type error detection by the compiler is difficult
Variable Attributes (continued)

• **Storage Bindings & Lifetime**
  - **Allocation** – getting a cell from some pool of available cells
  - **Deallocation** – putting a cell back into the pool

• **The lifetime of a variable is the time during which it is bound to a particular memory cell**
Categories of Variables by Lifetimes

- **Static**—bound to memory cells before execution begins and remains bound to the same memory cell throughout execution, e.g., C and C++ `static` variables in functions
  - **Advantages**: efficiency (direct addressing), history-sensitive subprogram support
  - **Disadvantage**: lack of flexibility (no recursion)
Categories of Variables by Lifetimes

• Stack–dynamic--Storage bindings are created for variables when their declaration statements are elaborated.

(A declaration is elaborated when the executable code associated with it is executed)

• If scalar, all attributes except address are statically bound
  – local variables in C subprograms (not declared static) and Java methods

• Advantage: allows recursion; conserves storage

• Disadvantages:
  – Overhead of allocation and deallocation
  – Subprograms cannot be history sensitive
  – Inefficient references (indirect addressing)
Categories of Variables by Lifetimes

• *Explicit heap–dynamic* — Allocated and deallocated by explicit directives, specified by the programmer, which take effect during execution
  
  • Referenced only through pointers or references, e.g. dynamic objects in C++ (via `new` and `delete`), all objects in Java
  
  • **Advantage:** provides for dynamic storage management
  
  • **Disadvantage:** inefficient and unreliable
Categories of Variables by Lifetimes

- *Implicit heap–dynamic*—Allocation and deallocation caused by assignment statements
  - all variables in APL; all strings and arrays in Perl, JavaScript, and PHP
- **Advantage**: flexibility (generic code)
- **Disadvantages**:
  - Inefficient, because all attributes are dynamic
  - Loss of error detection
Variable Attributes: Scope

- The *scope* of a variable is the range of statements over which it is visible.
- The *local variables* of a program unit are those that are declared in that unit.
- The *nonlocal variables* of a program unit are those that are visible in the unit but not declared there.
- *Global variables* are a special category of nonlocal variables.
- The scope rules of a language determine how references to names are associated with variables.
Static Scope

- Based on program text
- To connect a name reference to a variable, you (or the compiler) must find the declaration
- **Search process**: search declarations, first locally, then in increasingly larger enclosing scopes, until one is found for the given name
- Enclosing static scopes (to a specific scope) are called its *static ancestors*; the nearest static ancestor is called a *static parent*
- Some languages allow nested subprogram definitions, which create nested static scopes (e.g., Ada, JavaScript, Common Lisp, Scheme, Fortran 2003+, F#, and Python)
Scope (continued)

- Variables can be hidden from a unit by having a "closer" variable with the same name
Blocks

- A method of creating static scopes inside program units—from ALGOL 60
- Example in C:

```c
void sub() {
    int count;
    while (...) {
        int count;
        count++;
        ...
    }
    ...
}
```

- Note: legal in C and C++, but not in Java and C#—too error-prone
The \texttt{let} Construct

- Most functional languages include some form of \texttt{let} construct
- A \texttt{let} construct has two parts
  - The first part binds names to values
  - The second part uses the names defined in the first part
- \textbf{In Scheme:}

\begin{verbatim}
(LET ( 
    (name$_1$ expression$_1$) 
    ...
    (name$_n$ expression$_n$) 
)
\end{verbatim}
The **LET** Construct (continued)

- **In ML:**
  ```ml
  let
      val name₁ = expression₁
  ...
      val nameₙ = expressionₙ
  in
      expression
  end;
  ```

- **In F#:**
  - First part: `let left_side = expression`
  - `(left_side is either a name or a tuple pattern)`
  - All that follows is the second part
C99, C++, Java, and C# allow variable declarations to appear anywhere a statement can appear

- In C99, C++, and Java, the scope of all local variables is from the declaration to the end of the block
- In C#, the scope of any variable declared in a block is the whole block, regardless of the position of the declaration in the block
  - However, a variable still must be declared before it can be used
• In C++, Java, and C#, variables can be declared in for statements
  - The scope of such variables is restricted to the for construct
Global Scope

- C, C++, PHP, and Python support a program structure that consists of a sequence of function definitions in a file
  - These languages allow variable declarations to appear outside function definitions

- C and C++ have both declarations (just attributes) and definitions (attributes and storage)
  - A declaration outside a function definition specifies that it is defined in another file
Global Scope (continued)

- **PHP**
  - Programs are embedded in HTML markup documents, in any number of fragments, some statements and some function definitions
  - The scope of a variable (implicitly) declared in a function is local to the function
  - The scope of a variable implicitly declared outside functions is from the declaration to the end of the program, but skips over any intervening functions
    - Global variables can be accessed in a function through the `$GLOBALS` array or by declaring it `global`
Global Scope (continued)

• Python
  - A global variable can be referenced in functions, but can be assigned in a function only if it has been declared to be *global* in the function.
Evaluation of Static Scoping

• **Works well in many situations**

• **Problems:**
  
  – In most cases, too much access is possible
  
  – As a program evolves, the initial structure is destroyed and local variables often become global; subprograms also gravitate toward become global, rather than nested
Dynamic Scope

- Based on calling sequences of program units, not their textual layout (temporal versus spatial)
- References to variables are connected to declarations by searching back through the chain of subprogram calls that forced execution to this point
Scope Example

```javascript
function big() {
    function sub1() {
        var x = 7;
        function sub2() {
            var y = x;
        }
        var x = 3;
    }
}
```

- **Static scoping**
  - Reference to `x` in `sub2` is to `big's x`

- **Dynamic scoping**
  - Reference to `x` in `sub2` is to `sub1's x`
Scope Example

- **Evaluation of Dynamic Scoping:**
  - Advantage: convenience
  - **Disadvantages:**
    1. While a subprogram is executing, its variables are visible to all subprograms it calls
    2. Impossible to statically type check
    3. Poor readability – it is not possible to statically determine the type of a variable
Scope and Lifetime

- Scope and lifetime are sometimes closely related, but are different concepts
- Consider a static variable in a C or C++ function
Referencing Environments

- The *referencing environment* of a statement is the collection of all names that are visible in the statement.
- In a static-scoped language, it is the local variables plus all of the visible variables in all of the enclosing scopes.
- A subprogram is **active** if its execution has begun but has not yet terminated.
- In a dynamic-scoped language, the referencing environment is the local variables plus all visible variables in all active subprograms.
Named Constants

• A named constant is a variable that is bound to a value only when it is bound to storage
• Advantages: readability and modifiability
• Used to parameterize programs
• The binding of values to named constants can be either static (called manifest constants) or dynamic
• Languages:
  – C++ and Java: expressions of any kind, dynamically bound
  – C# has two kinds, readonly and const
    – the values of const named constants are bound at compile time
    – The values of readonly named constants are dynamically bound
Summary

• Case sensitivity and the relationship of names to special words represent design issues of names
• Variables are characterized by the sextuples: name, address, value, type, lifetime, scope
• Binding is the association of attributes with program entities
• Scalar variables are categorized as: static, stack dynamic, explicit heap dynamic, implicit heap dynamic
• Strong typing means detecting all type errors