

CONCEPTS OF Programming Languages



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COLLEGE OF ENGINEERING

Chapter 5

Names, Binding, and Scope

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:
 - FORTRAN 95: maximum of 31
 - C99: no limit but only the first 63 are significant; also, external names are limited to a maximum of 31
 - C#, Ada, 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, e.g., in Fortran
 - `Real VarName` (*Real is a data type followed with a name, therefore Real is a keyword*)
 - `Real = 3.4` (*Real is a variable*)
- 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!)



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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
- Fortran, BASIC, Perl, Ruby, JavaScript, and PHP provide implicit declarations (Fortran has both explicit and implicit)
 - 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, F#, and Go 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 references¹⁻²¹ (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
- Ada allows access to these "hidden" variables
 - E.g., `unit.name`

Blocks

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

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

- Note: legal in C and C++, but not in Java and C# - too error-prone

Declaration Order

- 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

The `LET` Construct

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

```
(LET (
  (name1 expression1)
  ...
  (namen expressionn)
)
```

The `LET` Construct (continued)

- In 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



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Declaration Order (continued)

- 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

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

big **calls** sub1
sub1 **calls** sub2
sub2 **uses** x

- 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:
 - Ada, 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