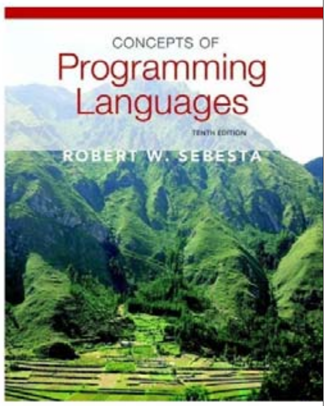
Chapter 5

Names, Bindings, and Scopes



Chapter 5 Topics

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

5.1 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

5.2 Names

- Design issues for names:
  - Are names case sensitive?
  - Are special words reserved words or keywords?

Sum   sum   are two diff. variables if have case sensitivity

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   & _ + ! etc..
  - 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`)

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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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5.3 Variables / identifiers

- A **variable** is an abstraction of a memory cell
- Variables can be characterized as a sextuple of attributes:
  - Name
  - Address memory location
  - Value
  - Type int, float, etc...
  - Lifetime
  - Scope

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Sum = 5 + count

Variables Attributes

- Name - not all variables have them identifier
- 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)

l-value = address of variable

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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

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5.4 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.

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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

EX:

```
⋮
integer :: count
⋮
count = count + 5
⋮
```

possible data types for "count" are bound at language design time

actual data type for count is bound at compile time

set of possible values for count – bound at compiler design time

actual value for count is bound at run time

set of possible meanings for + – bound at language design time

actual meaning of + in this program is bound at compile time

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? int vs. integer
- When does the binding take place?
- If static, the type may be specified by either an explicit or an implicit declaration

integer :: count

count → real
icount → int

(rule) i-n → integer
all others → real

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

EX: type error detection problem

i, x are integer variables
y is floating-pt. array

Want to type i := x

but mistype i := y
the compiler does not catch as an error, it simply changes i to a floating-pt array

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

begins w/ allocation and ends w/ deallocation

Categories of Variables by Lifetimes

1. - 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

2. - 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

(3)

- *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

new ...
:
delete

Categories of Variables by Lifetimes

(4)

- *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

5.5 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

A variable is "visible" in a statement if it can be referenced or used in that statement

Static Scope

method of binding names to nonlocal variables

- 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++;
    ...
  }
  ...
}
```

scope

scope

this count is hidden from the rest of subprogram

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

Example

```
procedure big;
   var x : integer;
   procedure sub1;
      begin {sub1}
      ... x ...
      end; {sub1}
   procedure sub2;
      var x : integer;
      begin {sub2}
      ...
      end; {sub2}
```

← x declared once (in big)

← x referenced

← x declared twice (in sub2)

```
begin {big}
...
end; {big}
```

when x is referenced in sub1, which declaration is found & used?

we search in sub1 and find no declaration for x

so we go next to big (since sub1 is inside big but not inside sub2) and we find the declaration to use

big is the static parent of sub1

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

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

```
for (int n=0; n<=5; n++)
   :
```


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

```
procedure main
   var x: integer;
   begin {main}
     .
     .
     .
   end {main}
```

← this declaration occurs outside function definitions

so it will have global scope

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

Static scoping based on layout

if we want B to call C

or D to call E

then we need dynamic scoping

(b/c not based on layout but on calling sequence)

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   x=3
- Dynamic scoping
  - Reference to x in sub2 is to sub1's x   x=7

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

5.6 Scope and Lifetime

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

scope is only the unit/function it is declared in

lifetime is the entire execution of the whole program

Scope cannot be larger than its lifetime

5.7 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

Example Indicate the referencing environment at the 4 marked points in the following program. (static scoped language)

```
program example;
  var a,b: integer;
  ...
  procedure sub1;
    var x,y: integer;
    begin {sub1}
      ...            <- 1
    end; {sub1}
  procedure sub2;
```

```
        var x: integer;
        ...
        procedure sub3;
            var x : integer;
            begin {sub3}
            ...            ← 2
            end; {sub3
        begin {sub2}
        ...                ← 3
        end; {sub2}
    begin {example}
    ...                    ← 4
    end. {example}
```

point	referencing environment (static)
1	x,y of sub1; a,b of example
2	x of sub3; (x of sub2 is hidden) a,b of example
3	x of sub2; a,b of example
4	a,b of example

Example: Indicate the referencing environments at the 3 marked locations. Assume main calls sub2 which calls sub1 and dynamic scoping.

```
void sub1() {
  int a,b;
  ...              ← 1
} /* end of sub1 */
void sub2() {
  int b,c;
  ...              ← 2
  sub1;
} /* end of sub2 */
void main() {
  int c,d;
  ...              ← 3
  sub2;
} /* end of main */
```

point	referencing environment (dynamic)
1	a,b of sub1; c of sub2, (b of sub2 is hidden); d of main (c of main is hidden)
2	b,c of sub2; d of main (c of main is hidden)
3	c,d of main

5.8 Named Constants

const PI = 3.14159;
tells compiler do not allow this value to be changed

- 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

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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

Chapter 5 Homework

- Review Questions
  - p.235 2, 3, 4, 6, 7, 8, 9, 12, 16, 23
- Problem Set
  - p.236 1, 2, 4, 5, 8, 9, 10, 12acf
- Programming Exercises
  - p.241 5 using C++ only

turn in { program, run, explanation

```
:
x=21;
int x;
x=42;
:
```