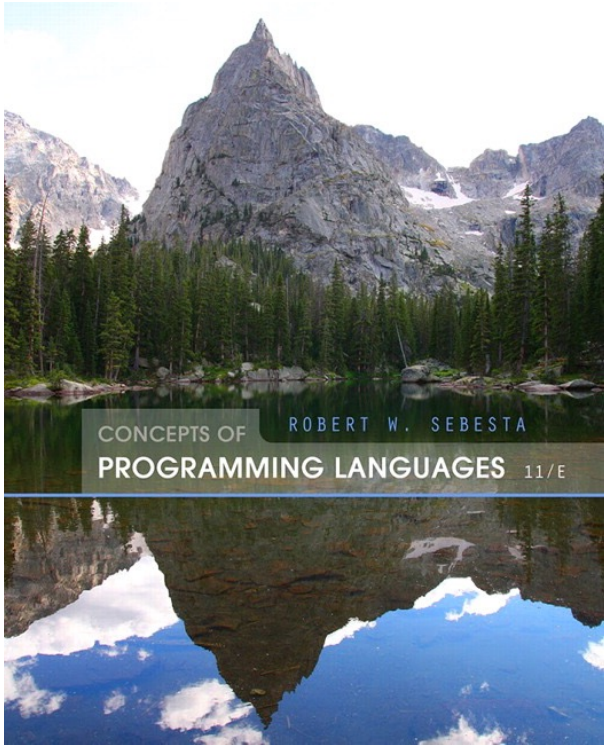
Chapter 5

Names, Bindings, and Scopes



ISBN 0-321-49362-1

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 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
  - Language examples:
    - Earliest languages used single character! (math influence)
    - FORTRAN I: maximum 6
    - COBOL: maximum 30
    - FORTRAN 90 and C89: maximum 31
    - C99: maximum 63
    - C#, Ada, and Java: no limit, and all are significant
    - C++: no limit, but implementers often impose one

Names (continued)

- 1970s and 80s: underscore
  example: my_stack
- Camel form in C-based languages
  example: myStack

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!)

Variables

- A variable is an abstraction of a memory cell
- Variables can be characterized as a sextuple of attributes:
  - Name
  - Address
  - Type
  - Value
  - Lifetime
  - Scope

Variables Attributes

- Name - not all variables have them (later)
- 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, such as between an attribute and an entity, 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 non-static 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

1. How is a type specified?
2. 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 (the first appearance of the variable in the program)
- FORTRAN, PL/I, BASIC, and Perl provide implicit declarations
  - Advantage: writability
  - Disadvantage: reliability (less trouble with Perl)

Dynamic Type Binding

- Dynamic Type Binding (JavaScript and PHP)
- Specified through an assignment statement e.g., JavaScript

```
list = [2, 4.33, 6, 8];
list = 17.3;
```

  - Advantage: flexibility (generic program units)
  - Disadvantages:
    - Type error detection by the compiler is difficult
    - High cost (dynamic type checking and interpretation)

Variable Attributes (continued)

- Type Inferencing (ML, Miranda, and Haskell)
  - Rather than by assignment statement, types are determined (by the compiler) from the context of the reference
- 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
  - 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 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, often used for lists and trees
- 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

Type Checking

- Generalize the concept of operands and operators to include subprograms and assignments
- Type checking is the activity of ensuring that the operands of an operator are of compatible types
- A compatible type is one that is either legal for the operator, or is allowed under language rules to be implicitly converted, by compiler- generated code, to a legal type
  - This automatic conversion is called a coercion.
- A type error is the application of an operator to an operand of an inappropriate type

Type Checking (continued)

- If all type bindings are static, nearly all type checking can be static
- If type bindings are dynamic, type checking must be dynamic
- A programming language is strongly typed if type errors are always detected
- Advantage of strong typing: allows the detection of the misuses of variables that result in type errors

Strong Typing

Language examples:

- FORTRAN 95 is not: parameters, `EQUIVALENCE`
- C and C++ are not: parameter type checking can be avoided; unions are not type checked
- Ada is, almost (`UNCHECKED CONVERSION` is loophole), e.g. user-defined storage allocation, addresses are Integers, but must be used as pointers

  (Java and C# are similar to Ada)

- ML is strongly typed

Strong Typing (continued)

- Coercion rules strongly affect strong typing--they can weaken it considerably (C++ versus Ada)
- Although Java has just half the assignment coercions of C++, its strong typing is still far less effective than that of Ada

Name Type Equivalence

- Name type equivalence means the two variables have equivalent types if they are in either the same declaration or in declarations that use the same type name
- Easy to implement but highly restrictive:
  - Subranges of integer types are not equivalent with integer types
  - Formal parameters must be the same type as their corresponding actual parameters

Structure Type Equivalence

- Structure type equivalence means that two variables have equivalent types if their types have identical structures
- More flexible, but harder to implement

Type Equivalence (continued)

- Consider the problem of two structured types:
  - Are two record types equivalent if they are structurally the same but use different field names?
  - Are two array types equivalent if they are the same except that the subscripts are different?

    (e.g. [1..10] and [0..9])
  - Are two enumeration types equivalent if their components are spelled differently?
  - With structural type equivalence, you cannot differentiate between types of the same structure (e.g. different units of speed, both float)

Variable Attributes: Scope

- The scope of a variable is the range of statements over which it is visible
- The nonlocal variables of a program unit are those that are visible but not declared there
- 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, and PHP)

Scope (continued)

- Variables can be hidden from a unit by having a "closer" variable with the same name
- C++ and Ada allow access to these "hidden" variables
  - In Ada: `unit.name`
  - In C++: `class_name::name`

Blocks

- A method of creating static scopes inside program units--from ALGOL 60
- Examples:

C-based languages:

```
while (...) {
        int index;
   ...
  }
```

Ada:

```
declare Temp : Float;
 begin
     ...
 end
```

Evaluation of Static Scoping

- Assume MAIN calls A and B

  A calls C and D

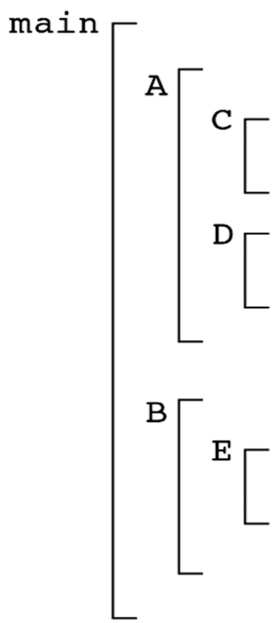
  B calls A and E

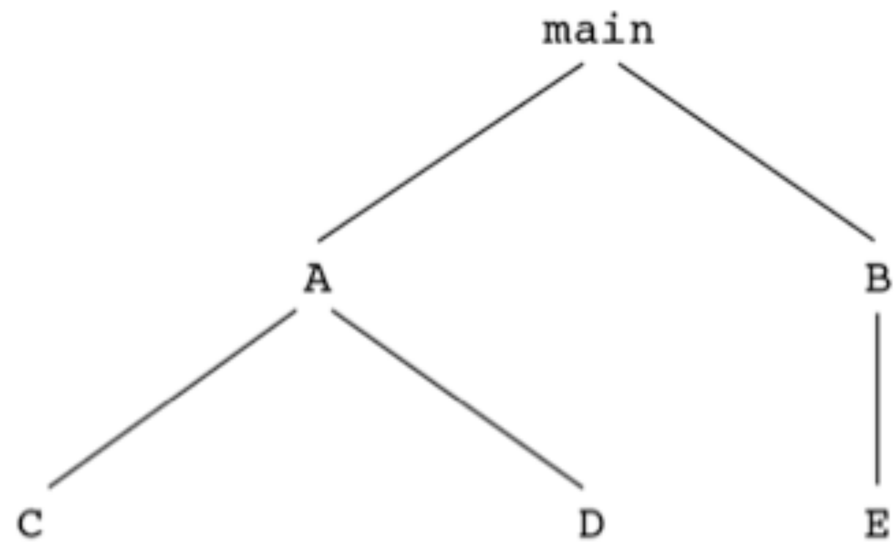
Figure 5.2

The tree structure of the program in Figure 5.1

Figure 5.1

The structure of a program

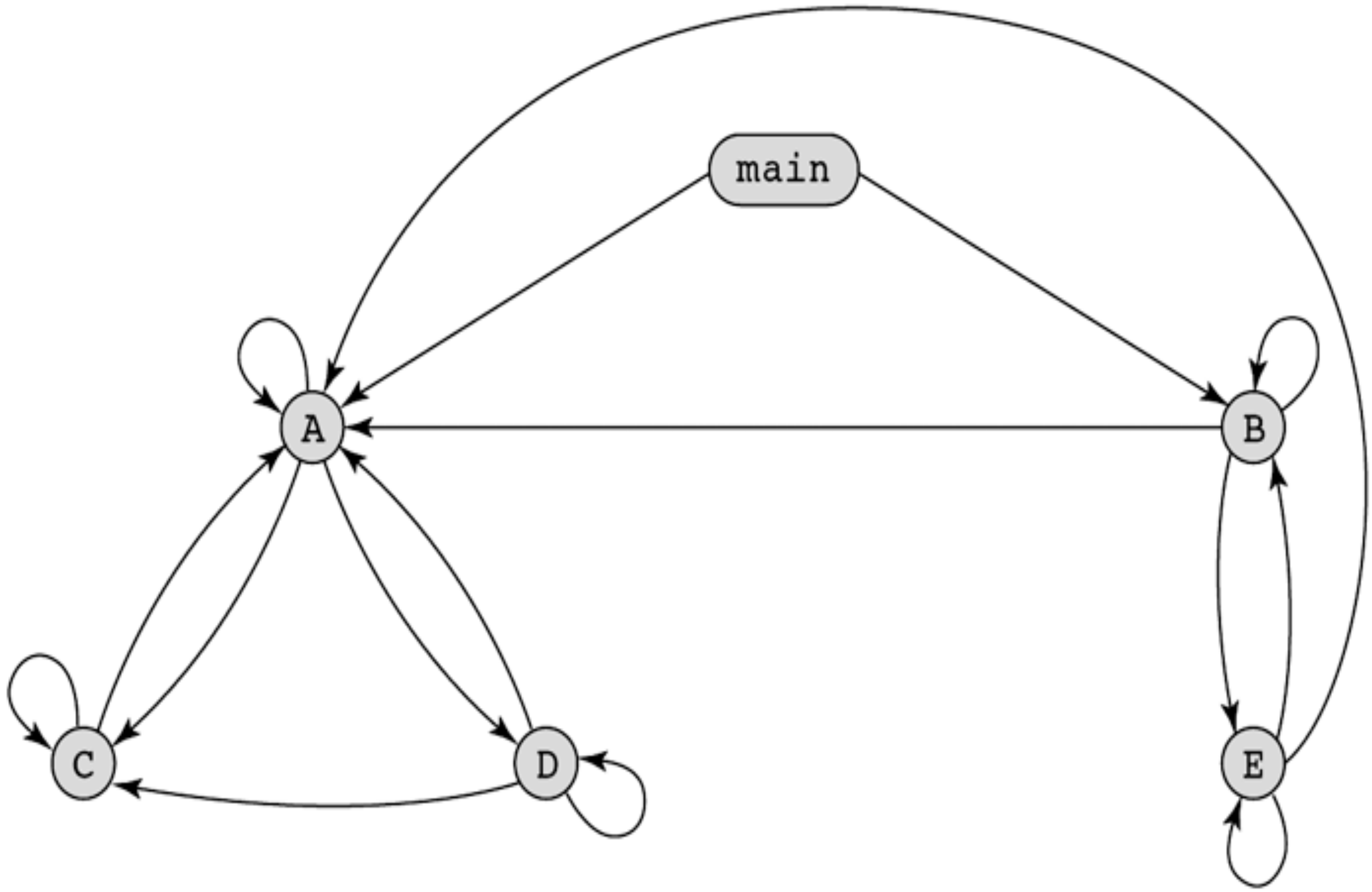




Static Scope Example

Figure 5.3

The potential call graph of the program in Figure 5.1

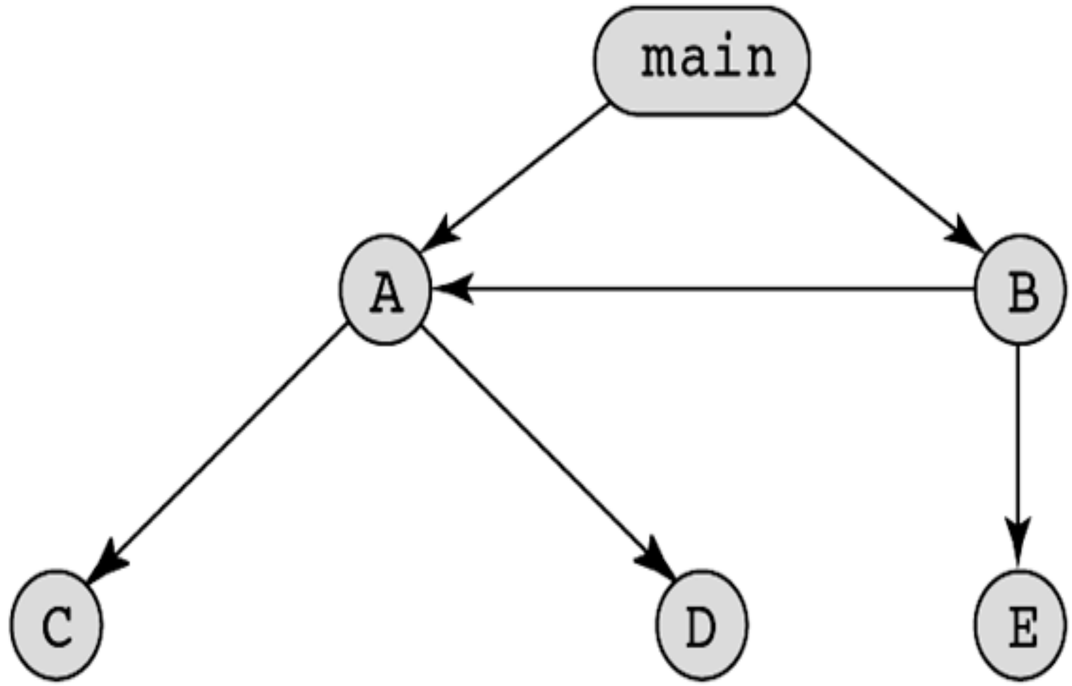


A lot of calling opportunities!

Static Scope Example

Figure 5.4

The graph of the desirable calls in the program in Figure 5.1

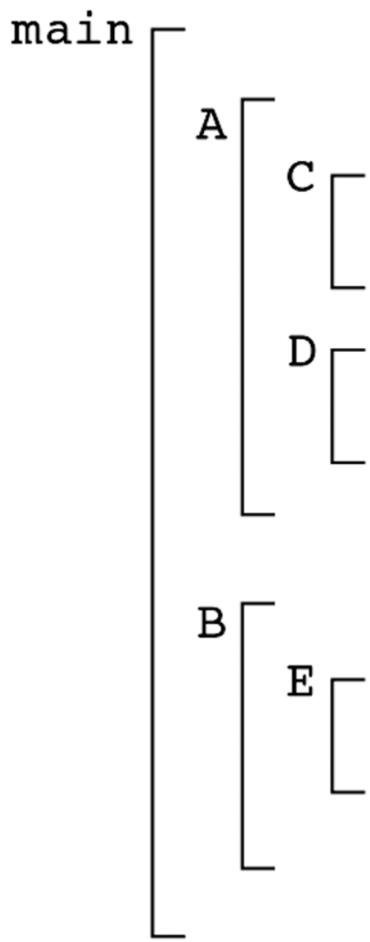


Desired calling opportunities

Static Scope (continued)

Figure 5.1

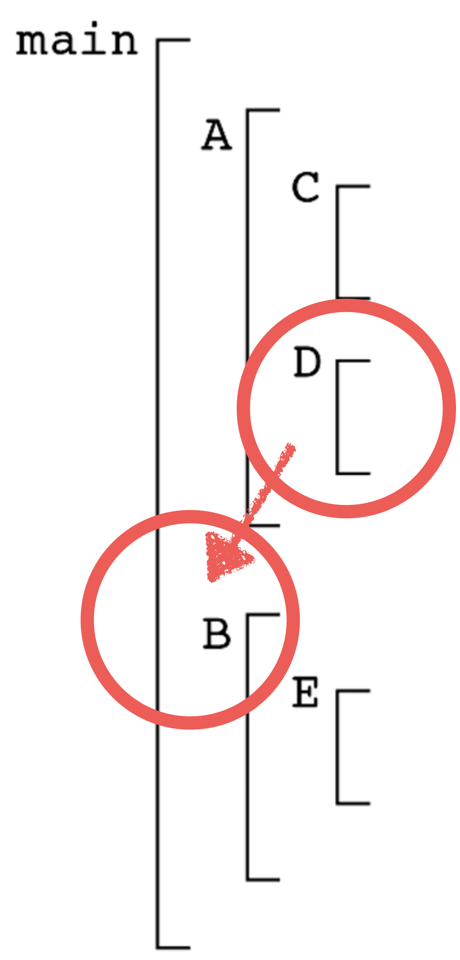
The structure of a program



Static Scope (continued)

Figure 5.1

The structure of a program

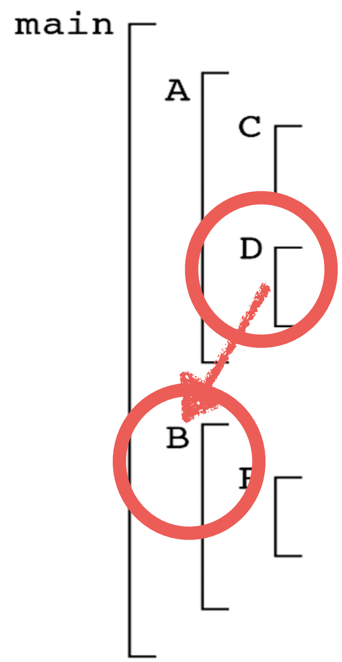


Suppose the spec is changed so that D must now access some data in B

Static Scope (continued)

Figure 5.1

The structure of a program



- Solutions:
  - Put D in B (but then D cannot access A's variables)
  - Move the data from B that D needs to MAIN (but then all procedures can access them)
- Overall: static scoping often encourages many globals

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

Big
- declaration of X
  Sub1
  - declaration of X -
  ...
  call Sub2
  ...

  Sub2
  ...
  - reference to X -
  ...

...
call Sub1
...

Big calls Sub1
Sub1 calls Sub2
Sub2 uses X

Scope Example

- Static scoping
  - Reference to X is to Big's X
- Dynamic scoping
  - Reference to X is to Sub1's X
- Evaluation of Dynamic Scoping:
  - Advantage: convenience (called subprogram is executed in the context of the caller)
  - Disadvantage: poor readability

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
- Examples on board…

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:
  - FORTRAN 95: constant-valued expressions
  - Ada, C++, and Java: expressions of any kind
  - 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

Example Named Constants

```
void example() {
  int[] intList = new int[100];
  String[] strList = new String[100];
  ...
  for (index=0; index<100; index++) {
    ...
  }
  for (index=0; index<100; index++) {
    ...
  }
  ...
  average = sum / 100;
  ...
}
```

Example Named Constants

```
void example() {
  final int len = 100;
  int[] intList = new int[len];
  String[] strList = new String[len];
  ...
  for (index=0; index<len; index++) {
    ...
  }
  for (index=0; index<len; index++) {
    ...
  }
  ...
  average = sum / len;
  ...
}
```

Variable Initialization

- The binding of a variable to a value at the time it is bound to storage is called initialization
- Initialization is often done on the declaration statement, e.g., in Java

```
int sum = 0;
```

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 (can be static or dynamic scope)
- Variables are categorized considering lifetime as: static, stack dynamic, explicit heap dynamic, implicit heap dynamic
- Referencing environment is collection of all variables visible to that statement
- named constants are variables bound to values only once