"A C program is like a fast dance on a newly waxed dance floor by people carrying razors."

- W. Ravens

CSE341
Programming Languages

Lecture 4 – October 2019

Variables

Largely adapted from V. Shmatikov, J. Mitchell and R.W. Sebesta

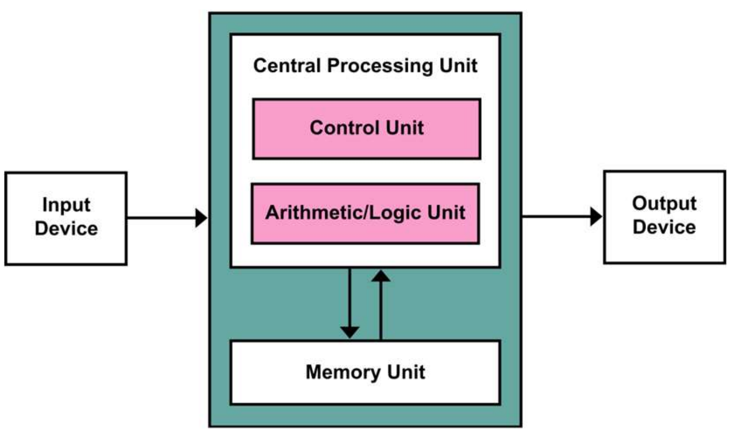
Variables, Bindings and Scopes

- Variables
- Initialization
- Constants
- Binding
- Type Checking
- Scope

Variables

- Imperative languages are abstractions of von Neumann architecture
  - Memory / Storage
  - Processor / CPU
- Variable: an abstraction of a computer memory cell or collection of cells
- Variables are characterized by attributes
- Their design must consider
  - Location
  - Referencing
  - Scope
  - Lifetime
  - Type checking
  - Initialization
  - Type compatibility

Von Neumann Architecture



Turing Machine

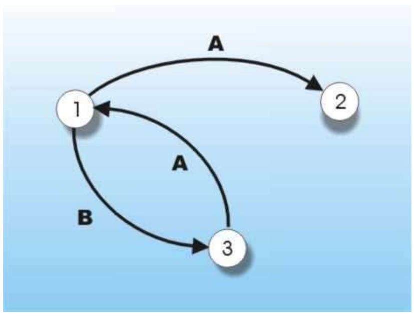
- Von Neumann computer implements a universal Turing machine
- It specifies sequential architectures…

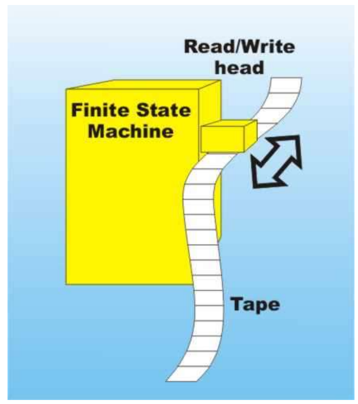
Turing Machine

- A mathematical tool equivalent to a digital computer
- Suggested by Turing in 1936
- The most widely used model of computation in computability and complexity theory
- Although simple, the machine can simulate any computer algorithm, no matter how complicated it is

Turing Machine

Actions:
- Print something on the tape
- Move the tape right or left by one cell
- Change to a new state





Variables

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  – Initialization
  – Type compatibility

Variable Attributes

- Variable is an abstraction of memory cell(s)
- Characterized by six attributes:
  - Name (usually)
  - Address (in memory)
  - Value (if initialized)
  - Type (range of values, interpretation, operations)
  - Lifetime
  - Scope
- Name - not all variables have them!

Characters

- Character Sets
  - 40 character BCD
  - 48 Fortran II
  - 128 ASCII characters
  - Unicode
  - Some Character Categories
    - <digit> -> 0|1|2|3|4|5|6|7|8|9
    - <lcletter> -> a|b|c|d|e|f|g|h|i|j|k|l|m|n|o|p|q|r|s|t|u|v|w|x|y|z
    - <ucletter> -> A|B|C|D|E|F|G|H|I|J|K|L|M|N|O|P|Q|R|S|T|U|V|W|X|Y|Z
    - <underscore> -> _

American Standard Code for Information Interchange

Names

- Set of characters
- Names, or identifiers, are used for variables, subprograms (or methods), types, classes, etc.
- Not names
  - Comments, line boundaries, white spaces
- Tokens
  - Punctuations, operators, numbers and other literals
  - Names (identifiers)
  - Keywords, reserved words

Variable Names

- User-defined names
- Design issues for names:
  - Maximum length?
  - Are connector characters allowed?
  - Are names case sensitive?
  - Are some words reserved words or keywords?
  - ONLY UPPERCASE LETTERS ALLOWED?

Name Length

- If too short, they can’t explain the meaning
  - Readability, writability
- If too long
  - ?
- Language examples:
  - FORTRAN I: maximum 6
  - COBOL: maximum 30
  - FORTRAN 90 and ANSI C: maximum 31
  - Ada and Java: no limit, all are significant
  - C++: no limit, but implementers often impose one
- What is a good maximum length?

Connectors / Non-Letter Characters

- Pascal _
  - underscore only
- Modula-2, and FORTRAN 77
  - none allowed
- Java
  - $,_ (but $ is by the system used for inner classes)
- Common Lisp
  - many, including *,+,-,_, …
- Advantages of having connectors?
- Disadvantages of having connectors?

Case Sensitivity in Variable Names

- Many languages **are not** case sensitive
- C, C++, and Java names are case sensitive
- Common Lisp: case sensitive (default)
- Prolog: case of first character determines whether it's constant or variable!
- Disadvantage: readability
  - names that look alike are different
- C++ and Java: predefined names are mixed case
  - e.g. IndexOutOfBoundsException)
- Effects on writability?

Named Constants

- **Named constant**
  - variable bound to a value only when it is bound to storage
- Advantages:
  - readability and modifiability
- Used to parameterize programs
- The binding of values to constants can be either static (called **manifest constants**) or dynamic
  - Pascal: literals only
  - FORTRAN 90: constant-valued expressions
  - Ada, C++, and Java: expressions of any kind

Variable Addresses

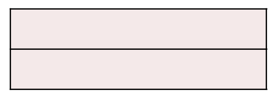
- **Memory address** associated with variable
  - also called l-value
- Location may change during execution
  - i.e. may have different addresses at different times
- **Aliases**
  - variable names that refer to the same memory location
- Aliases often reduce readability
  - program readers must remember that changing value of one variable means a change of all others

Variable Aliases

- Created by
  - pointers
  - reference variables
  - C and C++ unions
  - Pascal **variant-records**
  - and by parameters!
- Original reasons for aliases are no longer valid
  - memory limits forced re-use of space in FORTRAN
- Instead, use **dynamic allocation**

Variable Types and Values

- **Type** - determines the
  - range of values
  - set of operations that are defined for the variable
  - interpretation of bit patterns
  - for floating point, determines the precision
- **Value** - contents of the memory location associated with the variable
  - r–value (when appearing on right side of assignment)
- **Abstract memory cell** – (graphical) representation of collection of cells associated with a variable



The Concept of Binding

- The **l-value** = address
- The **r-value** = value

- **Binding** = association
  - for a variable, the association of l-value to r-value
- **Binding time**
  - time (during execution) when l-value is associated with r-value

Variable Initialization

- **Initialization**
  - the initial binding of a variable to a value

- Often done with the **declaration statement**
  - e.g., in Java
    - int sum = 0;
  - e.g., in Lisp
    - (defvar sum 0)
  - e.g., in Clojure
    - ?

Possible Binding Times

- Language design time
  - e.g., bind operator symbols to operations
- Language implementation time
  - e.g., bind floating point type to a representation
- Compile time
  - e.g., bind a variable to a type in C or Java
- Load time
  - e.g., bind a FORTRAN 77 variable to a memory cell, or
  - bind static variable in C or Java
- Runtime
  - e.g., bind a non-static local variable to a memory cell

Static vs. Dynamic Binding

- Static
  - first occurs before run time and
  - remains unchanged throughout program execution
- Dynamic
  - first occurs during execution, or
  - can change during execution of the program.

Type Bindings

- How is a variable's type specified?
- When does the binding take place?
- If static, type specified by either
  - explicit declaration or
  - implicitly

Implicit vs. Explicit Declaration

- Explicit type declaration
  - as program statement
- Implicit type declaration
  - default mechanism - at the first appearance in the program
  - e.g., in FORTRAN, BASIC, and Perl
- Type Inferencing (ML, Miranda, and Haskell)
  - Type is determined from the context of the reference
- Unification (Prolog)
  - Variables are unified with other variables or constants during the resolution process
- Advantage of implicit declaration: writability
- Disadvantage: reliability

Dynamic Binding

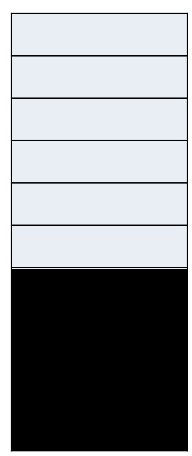
- JavaScript, PHP, Common Lisp
- Specified through an assignment statement e.g., JavaScript
  - list = [2, 4.33, 6, 8];
  - list = 17.3;
- Advantage: flexibility (generic program units)
- Disadvantages:
  - Speed penalty for type checking and interpretation
  - Type error detection by the compiler is more difficult

Variable Lifetime

- Lifetime
  - the time during which it is bound to a particular memory cell
- Allocation
  - getting a cell from a pool of available cells
- De-allocation
  - returning a cell back into the pool

Static Variables

- Static variables
  - bound to memory cells before program execution begins
  - remain bound to same memory cells until program execution terminates
- Example
  - all FORTRAN 77 variables
  - C static variables
- Advantages:
  - efficiency (direct addressing)
  - history-sensitive subprogram support
- Disadvantage:
  - less flexible (no recursion)



Stack Dynamic Variables

- Storage bindings are created for variables when their declaration statements are elaborated (storage allocation and binding)
  - Allocated from the run-time stack
  - De-allocate after execution (garbage collection)
  - Can happen at the beginning of block or anywhere
- Advantage:
  - allows recursion
  - conserves storage – allocate when and where needed
- Disadvantages (compared to static vars):
  - Overhead of allocation and de-allocation
  - Subprograms cannot be history sensitive
  - Indirect addressing (longer time)

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Runtime Stack (Dynamic)

- Stack-dynamic
  - allocation during execution at declaration elaboration time

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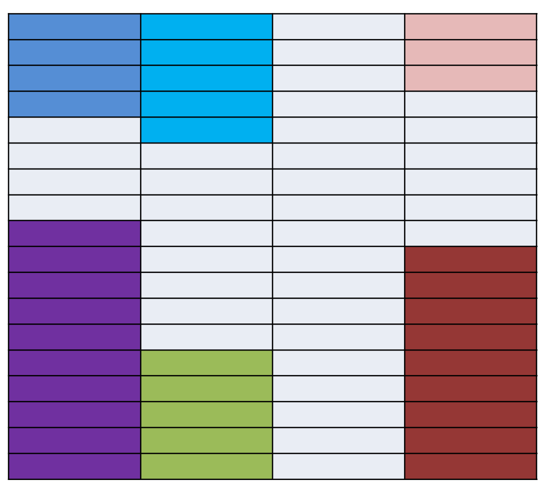
Stack Dynamic Variables

- If scalar, all attributes except address are statically bound
  - e.g. local variables in C subprograms and Java methods
- Examples
  - Variables defined in methods in Java, C, C#

Heap Variables (Dynamic)

- Implicit
  - Automatic
- Explicit
  - programmer's instruction



The heap is a collection of highly disorganized storage cells for unpredictable use…

Explicit Heap-Dynamic Variables

- Nameless abstract memory cells (heap)
  - Allocated and de-allocated by explicit directives
  - Specified by the programmer
  - Takes effect during execution
  - Referenced only through pointers or references
    - e.g. dynamic objects in C++ (via new and delete)
      ```
      int  * i;
      i = new int;
      …
      delete i;
      ```
    - all objects in Java
- Advantage:
  - provides for dynamic storage management (flexibility)
- Disadvantage:
  - inefficient by comparison (cost of reference)
  - reliability must be shown

Implicit Heap-Dynamic Variables

- Bound to heap storage automatically
  - Only when they are assigned values
  - All attributes are bound every time they are assigned
- Allocation and de-allocation caused by assignments
  - e.g. all variables in APL
  - all strings and arrays in Perl an JavaScript
- Example: Java statement “highs = [74, 84, 490, 44, 45];”
  - “highs” is now an array …
- Advantage:
  - Flexibility
  - Writability
- Disadvantages:
  - Inefficient, because all attributes are dynamic
  - More work to do error detection

Variable Bindings

- Static
  - E.g., C static variables
- Stack dynamic
  - E.g., C method variables
- Heap dynamic variables
  - Explicit Heap-Dynamic Variables
    - E.g., dynamic objects in C++ (new and delete)
  - Implicit Heap-Dynamic Variables
    - E.g., arrays in JavaScript

Variables

- Six attributes
  - Name (usually)
  - Address (in memory)
  - Value (if initialized)
  - Type (range of values, interpretation, operations)
  - Lifetime
  - Scope

Type Checking

- Type checking ensures that the operands and the operator are of compatible types
- Generalized to include subprograms and assignments

- Compatible type is either
  - legal for the operator, or
  - language rules allow it to be converted to a legal type
- Coercion
  - Automatic (implicit) conversion
- Type error
  - Application of an operator to an operand of incorrect type

- Nearly all type checking can be static for static type bindings
- Type checking must be dynamic for dynamic type bindings

Strong Typing

- Strongly typed programming language
  - PL where type errors are always detected
- Advantages:
  - Reliability
  - Detection of the misuses of variables that result in type errors
- Disadvantages:
  - Increased size of code
  - Slower development - declarations
  - Reduced writability
  - Exception handling may be more complicated

Strong Typing in PLs

- Examples:
  - FORTRAN 77 is not: parameters, EQUIVALENCE
  - Pascal is not: variant records
  - C and C++ are not: parameter type checking can be avoided; unions are not type checked
  - Ada is, almost (UNCHECKED CONVERSION is loophole)
  - Java is similar to Ada
- Coercion rules affect strong typing
  - can weaken it considerably (C++ versus Ada)
  - C++ is less reliable than Ada (less coercion)
- Java has just half the assignment coercions of C++
- Java's strong typing is still less effective than in Ada

Coercion in Java

```
short x = 2;
x += 2.2;
```

```
short x = 3;
x = (short)(x + 4.6);
```

```
void mymethod() {
   int a, b, c;
   float d;
   …
   a = b * d;
      …
}
```

Type Compatibility

- The result of two variables being of compatible types is that either one can have its value assigned to the other
- Two different type compatibility methods:
  - Name compatibility
  - Structure type compatibility
- Most languages use combinations of the different techniques
- There are some variations of these two methods

Name Type Compatibility

- Variables have compatible types if they are either
  - in the same declaration
  - or in declarations that use the same type name
- Easy to implement but highly restrictive
  - Sub-ranges of integer are not compatible with integer (as in Pascal)
  - Formal parameters must be the same type as their corresponding actual parameters (Pascal)

Structure Type Compatibility

- Variables have compatible types if their types have identical structures
  - More flexible
  - But harder to implement
    - Because of structured types (comparison of whole structures instead of names)
    - Others are much simpler
- Questions:
  - Structurally the same record types with different field names?
  - Array types with the same base type but different subscripts? E.g. [1..10] vs. [0..9]
  - Enumeration types whose components are spelled differently?
- With structural type compatibility, you can not differentiate between types of the same structure
  - E.g. different units of speed, when both are floating point

Type Compatibility Examples

- Pascal: usually structure, but in some cases name is used (formal parameters)
- C: structure, except for records
- Ada: restricted form of name
  - Derived types allow types with the same structure to be different
  - Anonymous types are all unique, even in:

    A, B : array (1..10) of INTEGER

C# and Implicit Typed Local Variables

Local variables can be given an inferred "type“ of **var** instead of an explicit type. The **var** keyword instructs the compiler to infer the type of the variable from the expression on the right side of the initialization statement.

```
// i is compiled as an int
var i = 5;
// s is compiled as a string
var s = "Hello";
// a is compiled as int[]
var a = new[] { 0, 1, 2 };
// expr is compiled as IEnumerable<Customer>
// or perhaps IQueryable<Customer>
var expr =
  from c in customers
  where c.City == "London“
  select c;
// anon is compiled as an anonymous type
var anon = new { Name = "Terry", Age = 34 };
// list is compiled as List<int>
var list = new List<int>();
```


Any Advantage

There's no problem with declaring types for locals, but the compiler can work it out, so it's redundant information to add types…

Using var does not change the meaning of a program, only its textual representation….

```
public static IMyType GetGateWayManager() {
  var container = GetContainer();
  var gateWayManager = container.Resolve<IMyType>();
  return gateWayManager;
}
```

Choice

Summing up, my advice is:

- Use var when you have to; when you are using anonymous types.
- Use var when the type of the declaration is obvious from the initializer, especially if it is an object creation. This eliminates redundancy.
- Consider using var if the code emphasizes the semantic "business purpose" of the variable and downplays the "mechanical" details of its storage.
- Use explicit types if doing so is *necessary* for the code to be correctly understood and maintained.
- Use descriptive variable names regardless of whether you use "var". Variable names should represent the semantics of the variable, not details of its storage; "decimalRate" is bad; "interestRate" is good.

http://blogs.msdn.com/b/ericlippert/archive/2011/04/20/uses-and-misuses-of-implicit-typing.aspx