

Organization of Programming Languages

CS320/520N

Lecture 07

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Control Flow

- **Control flow** = the flow of control, or execution sequence, in a program.
- Levels of control flow:
 1. Within **expressions**.
 2. Among **program statements**.
 3. Among **program units**.

Expressions

- Expressions are the fundamental means of specifying computations in a programming language:
 1. **Arithmetic** expressions.
 2. **Relational** expressions.
 3. **Boolean** expressions.
- The control flow in expression evaluation is determined by:
 1. The order of operator evaluation:
 - **Associativity**;
 - **Precedence**.
 2. The order of operand evaluation.

Arithmetic Expressions

- Arithmetic evaluation was one of the motivations for the development of the first programming languages.
- Arithmetic expressions consist of:
 - operators;
 - unary, binary, ternary.
 - operands;
 - parentheses;
 - function calls;

Arithmetic Expressions: Design Issues

- Operator precedence rules?
- Operator associativity rules?
- Operator overloading?

- Order of operand evaluation?
- Operand evaluation side effects?

- Type mixing in expressions?

Operator Precedence Rules

- The **operator precedence rules** for expression evaluation define the order in which “adjacent” operators of different precedence levels are evaluated.
- Typical precedence levels:
 - parentheses;
 - unary operators;
 - ** (where supported by the language);
 - *, /
 - +, -

Operator Associativity Rules

- The **operator associativity rules** for expression evaluation define the order in which adjacent operators with the same precedence level are evaluated.
- Typical associativity rules:
 - Left to right, except **, which is right to left.
 - Sometimes unary operators associate right to left (e.g., FORTRAN).
- Precedence and associativity rules can be overridden with parentheses.

Operator Overloading

- **Operator overloading** = the use of an operator for more than one purpose.
- Some are common (e.g., `+` for `int` and `float`).
- Some are potential trouble (e.g., `*`, `&` in C and C++):
 - Loss of readability.
 - Loss of compiler error detection:
 - omission of an operand should be a detectable error
 - Can be avoided by introduction of new symbols:
 - e.g., Pascal's **`div`** for integer division.

Operator Overloading

- C++, Ada, Fortran 95, and C# allow user-defined overloaded operators.
 - Problem: users can define nonsense operations.
- In Ruby, all arithmetic, relational, and assignment operators, as well as array indexing, shifts, and bit-wise logic operators, are implemented as methods:
 - These operators can all be overridden by application programs.

Operands Evaluation & Evaluation Order

1. Variables:
 - fetch the value from memory.
2. Constants:
 - sometimes a fetch from memory;
 - sometimes the constant is in the machine language instruction.
3. Parenthesized expressions:
 - evaluate all operands and operators first.
4. Function calls:
 - potential for *side effects* \Rightarrow **operand evaluation order** is relevant.

Functional Side Effects

- **Functional side effects:** when a function changes a two-way parameter or a non-local variable.
- Problem with functional side effects:
 - When a function referenced in an expression alters another operand of the expression:

```
a = 10;
```

```
/* assume that fun changes its parameter */
```

```
b = a + fun(a);
```

Functional Side Effects: Possible Solutions

1. Write the language definition to disallow functional side effects:
 - No two-way parameters in functions
 - No non-local references in functions
 - **Advantage:** it works!
 - **Disadvantage:** inflexibility of one-way parameters and lack of non-local references
2. Write the language definition to demand that operand evaluation order be fixed
 - **Disadvantage:** limits some compiler optimizations
 - Java requires that operands appear to be evaluated in left-to-right order

Referential Transparency

- **Referential Transparency:** an expression can be substituted with its value, without changing the effects of the program.
 - Functional side effects violate referential transparency.
- Advantages of referential transparency:
 - Program semantics is much easier to understand.
- Programs written in functional programming languages are referential transparent:
 - no variables \Rightarrow functions cannot have state.
 - value of function depends only on its parameters and global constants.

Type Conversions

- A **narrowing conversion** is one that converts an object to a type that cannot include all of the values of the original type e.g., `float` to `int`.
- A **widening conversion** is one in which an object is converted to a type that can include at least approximations to all of the values of the original type e.g., `int` to `float`.
- Implicit type conversions i.e. **coercions**.
- Explicit type conversions i.e. **casts** in C/C++/Java:
 - C: `(int)angle`
 - Ada: `Float (Sum)`

Mixed-Mode Expressions

- A **mixed-mode expression** is one that has operators with operands of different types.
 - Type coercions are used in mixed-mode expressions to convert all operands to the same type.
- Disadvantage of coercions:
 - They decrease the type error detection ability of the compiler.
- Scenarios:
 - All numeric types are coerced in expressions, using widening conversions (most languages).
 - In Ada, there are virtually no coercions in expressions.

Relational Expressions

- Relational Expressions
 - Use relational operators and operands of various types.
 - Evaluate to some Boolean representation.
 - Always lower precedence than the arithmetic operators.
 - Operator symbols used vary somewhat among languages (`!=` , `/=` , `.NE.` , `<>` , `#`).
- JavaScript and PHP have two additional relational operator, `===` and `!==` :
 - Similar to their cousins, `==` and `!=`, except that they do not coerce their operands.
 - Ex: `"7" == 7` vs. `"7" === 7`.

Boolean Expressions

- Boolean Expressions
 - Operands are Boolean and the result is Boolean.
 - Example operators:

FORTRAN 77	FORTRAN 90	C	Ada
<code>.AND.</code>	<code>and</code>	<code>&&</code>	<code>and</code>
<code>.OR.</code>	<code>or</code>	<code> </code>	<code>or</code>
<code>.NOT.</code>	<code>not</code>	<code>!</code>	<code>not</code>
			<code>xor</code>

Boolean Expressions in C/C++

- C versions prior to C99 have no Boolean type:
 - use `int` type with 0 for false and nonzero for true.
- Odd characteristic of C/C++ boolean expressions:
 - arithmetic expressions can be used for Boolean expressions.
 - `a < b < c` is a legal expression, but the result is not what you might expect:
 - Left operator is evaluated, producing 0 or 1.
 - The evaluation result is then compared with the third operand.
- Disadvantages:
 - loss in readability.
 - loss in type error detection.

Short-Circuit Evaluation

- The result of an expressions is determined without evaluating all of the operands and/or operators:
 - Example: $(13 * a) * (b / 13 - 1)$
 - if a is zero, there is no need to evaluate $(b / 13 - 1)$.
- Problem with non-short-circuit evaluation:

```
index = 1;
while (index <= length) && (LIST[index] !=
    value)
    index++;
```

 - When $index=length$, `LIST [index]` will cause an indexing problem (assuming `LIST` has $length - 1$ elements).

Short-Circuit Evaluation

- C, C++, and Java:
 - use short-circuit evaluation for the usual Boolean op. (`&&`, `||`).
 - provide bitwise Boolean operators that are not short circuit (`&`, `|`).
- Ada:
 - programmer can specify either:
 - short-circuit is specified with `and then` and `or else`.
- Short-circuit evaluation + side effects \Rightarrow subtle errors:
 - Example: `(a > b) || (b++ / 3)`

Simple Assignment Statements

- The general syntax:
`<target_var> <assign_operator> <expression>`
- The assignment operator:
 - = FORTRAN, BASIC, the C-based languages
 - := ALGOLs, Pascal, Ada
- Operator sign '=' can be bad when it is overloaded for the relational operator for equality (that's why the C-based languages use == as the relational operator)

Assignments with Conditional Targets

- Conditional targets (C++, Perl):

```
flag ? total : subtotal = 0;
```

Equivalent to:

```
if (flag)
    total = 0;
else
    subtotal = 0;
```

Compound Assignment Operators

- A shorthand method of specifying a commonly needed form of assignment:
$$a = a \text{ <op> } b$$
- Introduced in ALGOL 68, adopted by C based languages.
- Example:

$a = a + b$

is written as

$a += b$

Unary Assignment Operators

- Unary assignment operators combine increment and decrement operations with assignment.
- Perl, JavaScript, in C-based languages.
- Examples:
 - sum = ++count (count incremented, count assigned to sum).
 - sum = count++ (count assigned to sum, count incremented).
 - count++ (count incremented)
- When two unary operators, association is from right to left:
 - count++ (count incremented then negated)

Assignments as Expressions

- Perl, JavaScript, and C-based: the assignment statement produces a result that can be used as an expression.
- Examples:
 - `while ((ch = getchar()) != EOF) {...}`
 - `ch = getchar()` is carried out; the result (assigned to `ch`) is used as a conditional value for the `while` statement.
 - `a = b = 0`
- Problems:
 - loss of error detection: `if (x=y)` instead of `if (x == y)`

List Assignments

- List assignment: multiple source, multiple target.
- Perl, Python, Ruby support list assignments:

```
($first, $second, $third) = (20, 30, 40);
```

```
($first, $second) = ($second, $first);
```

Mixed-Mode Assignments

- Assignment statements can also be mixed-mode, for example:

```
int a, b;
```

```
float c;
```

```
c = a / b;
```

- In Fortran, C, and C++, any numeric type value can be assigned to any numeric type variable.
- In Java, only widening assignment coercions are allowed.
- In Ada, there is no assignment coercion.

Reading Assignment

Chapter 7