CS 430 Spring 2020

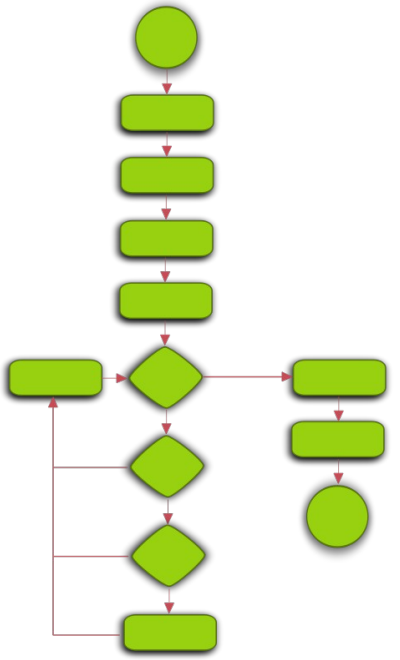
Mike Lam, Professor

$$x = a + b + c$$

$$y = \sin(x)$$

$$E = m c^2$$

$$e^{ix} = \cos x + i \sin x$$



Expressions and Control Structures

Expressions

- Expression: specification of computation
  - Fundamental to high-level languages
  - Form/syntax expressed using BNF grammars
  - Four main components:
    1) Operations
    2) Operands
    3) Parentheses
    4) Function calls

Expressions

- Operators: symbols representing computation
  - Unary vs. binary vs. ternary
  - Infix vs. prefix vs. postfix
  - Precedence
  - Associativity (left or right)
  - Overloading
  - Short-circuit boolean operators

Expressions

- Operands: input data for computation
  - Evaluation order (left-to-right or right-to-left)
  - Type conversions
    - Implicit vs. explicit
    - Narrowing vs. widening
  - Errors
    - Overflow and underflow
    - Division by zero
    - Floating-point issues (e.g., NaN, subnormal)

Expressions

- Parentheses
  - Explicit precedence and associativity
  - Tuple creation
  - Function invocation (in some languages)
- Function calls
  - Side effects: a function changes a parameter or a non-local variable
  - Referential transparency: expressions with the same value can be substituted for each other

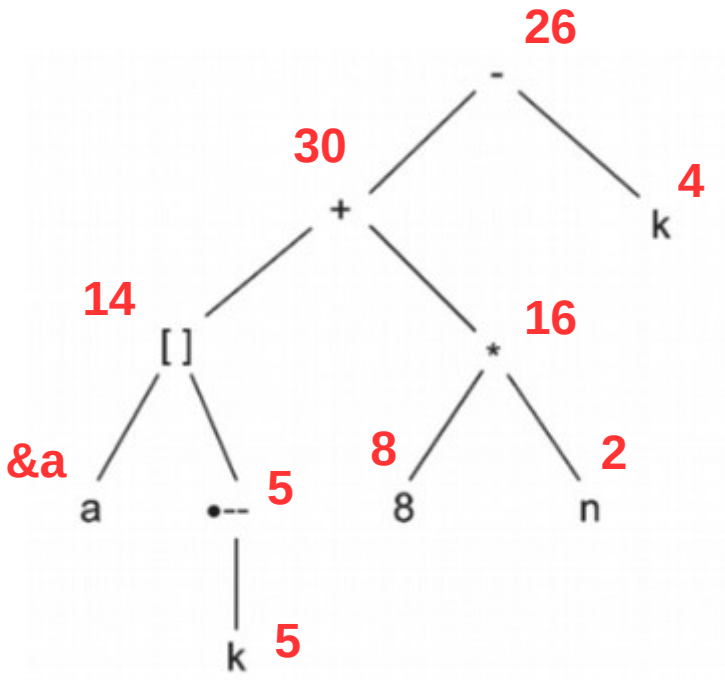
Assignment Statements

- Symbol and ambiguity with equality operator
  - "=" vs. ":=" vs. "==" vs. "←"
  - Assignments as expressions; good idea?
- Conditional targets (ternary LHS)
  - `(n > 5 ? a : b) = n*2`
- Compound assignments
  - Shortened forms of an assignment: "+=" and "++"
- Multiple assignments
  - `a,b = c/2,c%2` `a,b = b,a`

Evaluating Expressions

- Construct expression tree (e.g., *parse* the expression)
  - Build tree from root (“which operation is done last?”)
  - Use precedence and associativity to guide you
- Evaluate using a post-order traversal
  - Use evaluation order to guide you
  - Track side effects as you go
- Example:
  - Use standard prec., assoc. and eval order
  - Suppose k=5, n=2
  - Suppose a={1,3,6,8,11,14,16}
  - Evaluate a[k--]+8*n-k

k = 4



Method originally described by Dr. Christopher Fox

Control Structures

- Control flow path: sequence order of executed instructions
- Control structure: control statement and its associated flow path
- Selection statements (e.g., `if/then/else`, `switch/case`)
  - Choose between alternative control flow paths
- Iteration statements (e.g., `do`, `while`, `for`, `until`)
  - Repeatedly execute a control flow path
- How many kinds of control statements?
  - Many: higher expressivity
  - Few: higher readability, learnability, and orthogonality

Selection Structures

- Two-way selection (`if/then`)
  - Inclusion of "else" clause
  - Blocks often delimited by braces, keywords (e.g., "begin", "end") or indentation
  - Nesting issues
- Multiple selection (`switch/case`)
  - Form ("`if/elseif/else`" vs. "`switch/case`")
  - Case value types
  - Multiple execution
  - Fallthrough
  - Default cases
  - Efficient implementation using jump tables

Iteration Structures

- Control form: logic vs. counter vs. user-controlled vs. iterator-based
  - Counter loop parameters: loop variables, initial/terminal values, step sizes
  - Counter variable in scope outside loop? (no, starting with Ada)
- Control location: pre-test vs. post-test vs. user-defined
- Examples:
  - While loop: **logic pre-test**
  - Do-while loop: **logic post-test**
  - For loop: **counter pre-test**
  - For-each “enhanced for” loop: **iterator-based pre-test**
- Functional languages: recursion instead of iteration

Language Design

- Can iteration structures have multiple entries?
  - General answer: no!
  - Increase in flexibility/expressiveness is small relative to decrease in readability
- Can iteration structures have multiple exits?
  - For most procedural languages: yes
  - Same as "should `goto` or `break` be included?"

Minimally-Sufficiency Constructs

- Böhm and Jacopini (1966)
  - “Structured program theorem”
  - Strictly necessary: 1) sequencing, 2) two-way logical selection, and 3) logical iteration
    - Can implement ALL flowchart-representable programs
    - Alternatively: a selectable `goto` statement
      - E.g., “if (E) goto L1” goto code from CS 261!
  - Facilitates automated translation of block-structured code
    - Use “templates” to guide translation

Minimally-Sufficient Constructs

if statement: if (E) B1

```
        << E code >>
        if E goto l1
        goto l2
    l1:
        << B1 code >>
    l2:
```

Minimally-Sufficient Constructs

if statement: if (E) B1 else B2

```
        << E code >>
        if E goto l1
        goto l2
    l1:
        << B1 code >>
        goto l3
    l2:
        << B2 code >>
    l3:
```

Minimally-Sufficient Constructs

while loop: while (E) B

```
    l1:                                 ; CONTINUE target
        << E code >>
        if E goto l2
        goto l3
    l2:
        << B code >>
        goto l1
    l3:                                 ; BREAK target
```

Minimally-Sufficient Constructs

for loop: for V in E1, E2 B

```
        << E1 code >>
        << E2 code >>
        V = E1
    l1:
        if (V >= E2) goto l2
        << B code >>
        V = V + 1                   ; CONTINUE target
        goto l1
    l2:                             ; BREAK target
```

Minimally-Sufficient Constructs

- Use only the following constructs:
  - S → S; S
  - S → **if** (E) { S } **else** { S }
  - S → **while** (E) { S }
  - S → *<assignment statement>*
  - E → *<boolean expression>*

```
case (n % 3)
when 0
  d = 1
when 1
  d = 2
when 2
  d = 3
end
```

- Rewrite the following Ruby code:

```
until a >= b
  a += 5
end
```

```
3.times do
  x = x * 2
end
```

```
1.upto(10) do |i|
  y = y + i
end
```

```
if x > 90 then
  g = 'A'
elsif x > 80 then
  g = 'B'
elsif x > 70 then
  g = 'C'
else
  g = 'D'
end
```

Greatest Argument in PL History

- "Should languages provide a `goto` statement?"
  - Pro: extremely powerful construct – high expressiveness and writability
  - Against: without restrictions, can make programs very difficult to understand – low readability and maintainability
- Classic 1968 CACM letter by Edsger Dijkstra: "*Go To Statement Considered Harmful*"
  - Widely misunderstood
  - Original title: "A Case Against the Goto Statement"
  - Criticized **excessive** use of `goto`
  - Consensus: structured control flow is safer
    - Use control structures, exceptions, or tail recursion instead
    - Only C descendants tend to have `goto` statements these days

Guarded Commands

- Dijkstra (1975): guarded selection and iteration statements: `if/fi` and `do/od`
  - More than one boolean condition may be true
  - Control flow path is chosen **non-deterministically** out of the available true conditions
  - Pro: sometimes more elegant and easily proven correct
  - Con: greatly-increased complexity and lowered readability

Guarded Commands

- Maximum of (x,y):
  - `if  x >= y  →  max := x`
  - `[]  y >= x  →  max := y`
  - `fi`

- Sorting four integers (q1, q2, q3, q4):
  - `do  q1 > q2  →  temp := q1; q1 = q2; q2 := temp;`
  - `[]  q2 > q3  →  temp := q2; q2 = q3; q3 := temp;`
  - `[]  q3 > q4  →  temp := q3; q3 = q4; q4 := temp;`
  - `od`