Warm-up exercise

- A riddle courtesy of Dr. Chris Johnson: what will the following Java program print?
  - (and why?)

```
public class Riddle
{
  public static void main(String[] args) {
    System.out.println(getTrue() || getFalse());
  }
  public static boolean getTrue() {
    System.out.print("true ");
    return true;
  }
  public static boolean getFalse() {
    System.out.print("false ");
    return false;
  }
}
```

Warm-up exercise

- A riddle courtesy of @cpuGoogle: what will the following C++ program return?
  - (assume “=” is evaluated R-to-L and returns lvalue)

```
int main() {
  int i = 0;
  (i = 12) = i++;
  return i;
}
```

https://twitter.com/cpugoogle/status/1498155508238204930

CS 430
Spring 2022

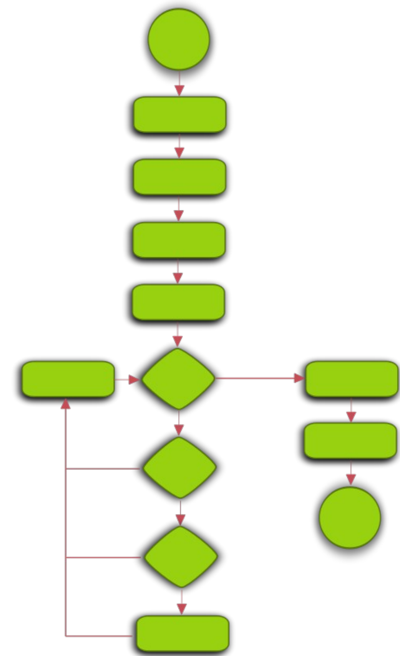
Mike Lam, Professor

$$x = a + b + c$$

$$y = \sin(x)$$

$$E = mc^2$$

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



Expressions and Control Structures

Motivation

- Most programs produce and consume information
  - Code that produces information is called an expression
  - Evaluating an expression produces a value
- Most programs require decision-making and repetition
  - Dynamic control flow enabled by conditional jumps at the machine level (remember CS 261?)
  - In high-level languages, control flow is prescribed by 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
  - Number of operands: unary vs. binary vs. ternary
    - Unary examples: `!x` `x++`
    - Binary examples: `x+y` `x=y` `x+=y`
    - Ternary example: `x?y:z`
  - Code location relative to operands: infix vs. prefix vs. postfix
    - Infix examples: `x*y` ``x `mod` y``
    - Prefix examples: `~x` `*x` `++x`
    - Postfix examples: `x?` `x++`
  - Precedence (higher or lower)
  - Associativity (left or right)

Expressions

- Overloaded operators: similar operators on different data types
  - Most languages provide overloaded operators for built-in types
    - E.g., '/' is used for both integer and floating-point division
  - Some languages allow overloaded operators for user-defined types
    - Type parity: user-defined types are indistinguishable from built-in types

```
class Vector2D {
    public:
        double x, y;

        Vector2D(double x, double y) {
            this->x = x;
            this->y = y;
        }

        Vector2D operator+(const Vector2D& v) {
            return Vector2D(this->x + v.x,
                            this->y + v.y);
        }

        Vector2D operator*(int scale) {
            return Vector2D(this->x * scale,
                            this->y * scale);
        }
};
```

```
#include <iostream>
using namespace std;

ostream& operator<<(ostream& os, const Vector2D& v) {
    os << "(" << v.x << "," << v.y << ")";
    return os;
}

int main() {
    Vector2D v1(1.0, 2.0), v2(2.8, 3.5);
    Vector2D v3 = v1 + v2;
    Vector2D v4 = v1 * 3;
    cout << v3 << endl << v4 << endl;
    return 0;
}
```

Output:

```
(3.8,5.5)
(3,6)
```

Expressions

- Short-circuited operators (e.g., `&&`, `||`, `?:`)
  - At least one operand is not evaluated if not needed
  - Optional chaining operators (not covered in CPL) guard access to potentially-null pointers/references
  - Null coalescing operators (also not in CPL) allow for default values
  - We’ll see another (more functional) take on this later

```
if (pet !== null) {
  console.log(pet.name);      // what if “pet” is null?
}

// optional chaining operator ‘?’
console.log(pet?.name);

// null coalescing operator
console.log(pet?.name ?? 'NPE: no pet exception');
```

Expressions

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

Type Compatibility

- Type conversions
  - If variables of a particular type can be converted to a different type, those types are compatible
  - Widening vs. narrowing
    - Latter may cause information loss
    - (in CPL definition, former may cause *precision* loss but not *accuracy* loss; e.g., `int` to `float`)
  - Implicit vs. explicit
    - Implicit: coercion, e.g., `float x = 5;`
    - Explicit: casting, e.g., `int x = (int)3.14;`

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 (i.e., no side effects)

```
(2 + 2)          (2 * 2)
```

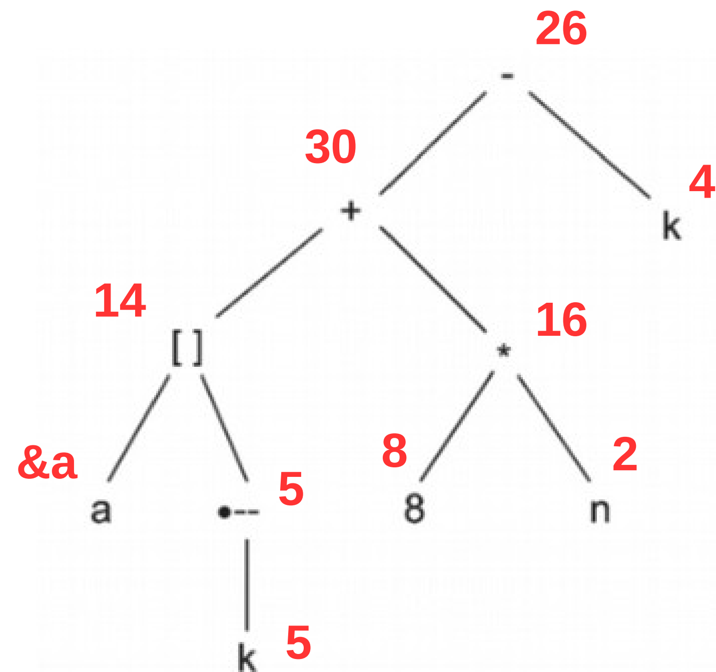
```
def foo
  $n += 1
  return 4
```

Assignment Statements

- Symbol and ambiguity with equality operator
  - "=" vs. ":=" vs. "==" vs. "←"
  - Assignments as expressions; returns lvalue or rvalue?
- Conditional targets (ternary LHS)
  - `(n > 5 ? a : b) = n*2`
- Compound assignments
  - Shortened forms of an assignment: "+=" and "++"
  - Example of syntactic sugar (unnecessary but helpful)
- 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 = ~~5~~ 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 or conditional branches from CS 261!
      - Could be a backwards jump for iteration
  - Facilitates automated translation of block-structured code
    - Conversion to linear code (e.g., machine 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
```