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CS 106B

Handout #44
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Expression Trees

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Outline for Today

1. Review the structure of expressions
2. Review the idea of inheritance in general
3. Discuss how inheritance is represented in C++
4. Design the expression hierarchy
5. Implement `eval` for each of the subclasses
6. Explore the relationship between parsing and grammars
7. Look at the final version of `parser.cpp`
8. Play with the BASIC interpreter

Recursive Structure of Expressions

- An arithmetic expression in a programming language is a recursive structure that can be thought of as a tree.
- In the simple model I use in Chapter 14, every expression falls into one of the following forms:
  - An integer constant
  - A variable name that holds an integer value
  - Two expressions joined by an operator
  - An expression enclosed in parentheses
- This structure can be represented in the form of a ***grammar***.

E → *constant*
E → *identifier*
E → E *op* E
E → (E)

Expression Trees

- When the C++ compiler looks at an expression, it needs to understand what the expression means by translating it into an internal form. This process generally consists of two steps:
  - ***Lexical analysis***, in which the line is broken up into units
  - ***Parsing***, in which the tokens are assembled into a tree that embodies the expression structure

```
y = 3 * ( x + 1 )
```

Classes Hierarchies

- In any object-oriented language, classes serve as templates for individual objects. Each object is an ***instance*** of a particular class, which can serve as a pattern for many different objects.
- One of the defining characteristics of the object-oriented paradigm is that classes form ***hierarchies***. Any class can be designated as a ***subclass*** of some other class, which is called its ***superclass***. As noted on this week's section handout, most class hierarchies are tree-structured even though C++ permits more complicated structures.
- A class represents a specialization of its superclass. If you create an object that is an instance of a class, that object is also an instance of all other classes in the hierarchy above it in the superclass chain.
- When you define a new class in C++, that class automatically **inherits** the behavior of its superclass.

Biological Class Hierarchy

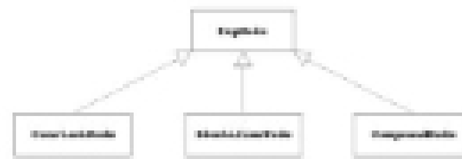
Living Things
Kingdom: Plants, Animals, Fungi

Classification of the red ant *Iridomyrmex purpureus*

Note that there can be many individual red ants, each of which is an **instance** of the same basic class.

Inheritance Hierarchies

- Because expressions have more than one form, a C++ class that represents expressions can be represented most easily by a class hierarchy in which each of the expression types is a separate subclass, as shown in the following diagram:



- Even though the class hierarchy is organized in terms of the different types of nodes, clients of the expression package will almost always work with pointers to nodes instead. As I did last time, I will therefore give the pointer type the name `expressionT`.

Representing Inheritance in C++

- The first step in creating a C++ subclass is to indicate the superclass on the header line, using the following syntax:

```
class subclass : public superclass {
    body of class definition
}
```

- In contrast to Java, a subclass cannot automatically override the definition of a method in its superclass. To permit such overriding, both classes must mark the prototype for that method with the keyword `virtual`.
- An ***abstract class*** is a class that doesn't actually represent any objects but instead serves only as a common superclass for ***concrete classes*** that do generate objects. In C++, methods for an abstract class that are always implemented by the concrete subclasses are indicated by including `= 0` before the semicolon on the prototype line.

The `exp.h` Interface

```
/*
 * File: exp.h
 * -----------
 * This interface defines a class hierarchy for expressions,
 * which allows the client to represent and manipulate simple
 * binary expression trees.
 */

#ifndef _exp_h
#define _exp_h

#include "genlib.h"
#include "map.h"

/*
 * Type: expressionT
 * -----------------
 * For clients, the most important type exported by this interface
 * is the expressionT type, which is defined as a pointer to an
 * expNode object.  This is the type used by all other functions
 * and methods in the expression package.
 */

class expNode;
typedef expNode *expressionT;
```

The `exp.h` Interface

```
/*
 * Class: evalState
 * ----------------
 * This class is passed by reference through the recursive levels
 * of the evaluator and contains information from the evaluation
 * environment that the evaluator may need to know.  The only
 * such information implemented here is a symbol table that maps
 * variable names into their values.
 */

class evalState {

public:
    evalState();
    ~evalState();
    void setValue(string var, int value);
    int getValue(string var);
    bool isDefined(string var);

private:
    Map<int> symbolTable;

};
```

The `exp.h` Interface

```
/*
 * Class: expNode
 * --------------
 * This class is used to represent a node in an expression tree.
 * expNode is an example of an abstract class, which defines the
 * structure and behavior of a set of classes but has no objects
 * of its own.  Any object must be one of the three concrete
 * subclasses of expNode:
 *
 *  1. ConstantNode   -- an integer constant
 *  2. IdentifierNode -- a string representing an identifier
 *  3. CompoundNode   -- two expressions combined by an operator
 *
 * The expNode class defines the interface common to all expNode
 * objects; each subclass provides its own specific implementation
 * of the common interface.
 *
 * Note on syntax: Each of the virtual methods in the expNode class
 * is marked with the designation = 0 on the prototype line.  This
 * notation is used in C++ to indicate that this method is purely
 * virtual and will always be supplied by the subclass.
 */
```

The `exp.h` Interface

```
/* Enumeration type for the three expression types */

enum expTypeT { ConstantType, IdentifierType, CompoundType };

/* [illegible] for expNode class */

class expNode {

public:
    expNode();
    virtual ~expNode();
    virtual expTypeT type() = 0;
    virtual int eval(evalState & state) = 0;
    virtual string toString() = 0;

};
```

The `exp.h` Interface

```
[illegible]
```

The `exp.h` Interface

```
[illegible]
```

The `exp.h` Interface

```
[illegible]
```

Code for the `eval` Method

```
[illegible]
```

A Two-Level Grammar

- The problem of parsing an expression can be simplified by changing the grammar to one that has two levels:
  - An ***expression*** is either a ***term*** or two expressions joined by an operator.
  - A ***term*** is either a constant, an identifier, or an expression enclosed in parentheses.
- This design is reflected in the following revised grammar.

$$E \rightarrow T$$
$$E \rightarrow E \ \textit{op} \ E$$
$$T \rightarrow \textit{constant}$$
$$T \rightarrow \textit{identifier}$$
$$T \rightarrow (\ E\ )$$

The `parser.cpp` Implementation

```
[illegible]
```