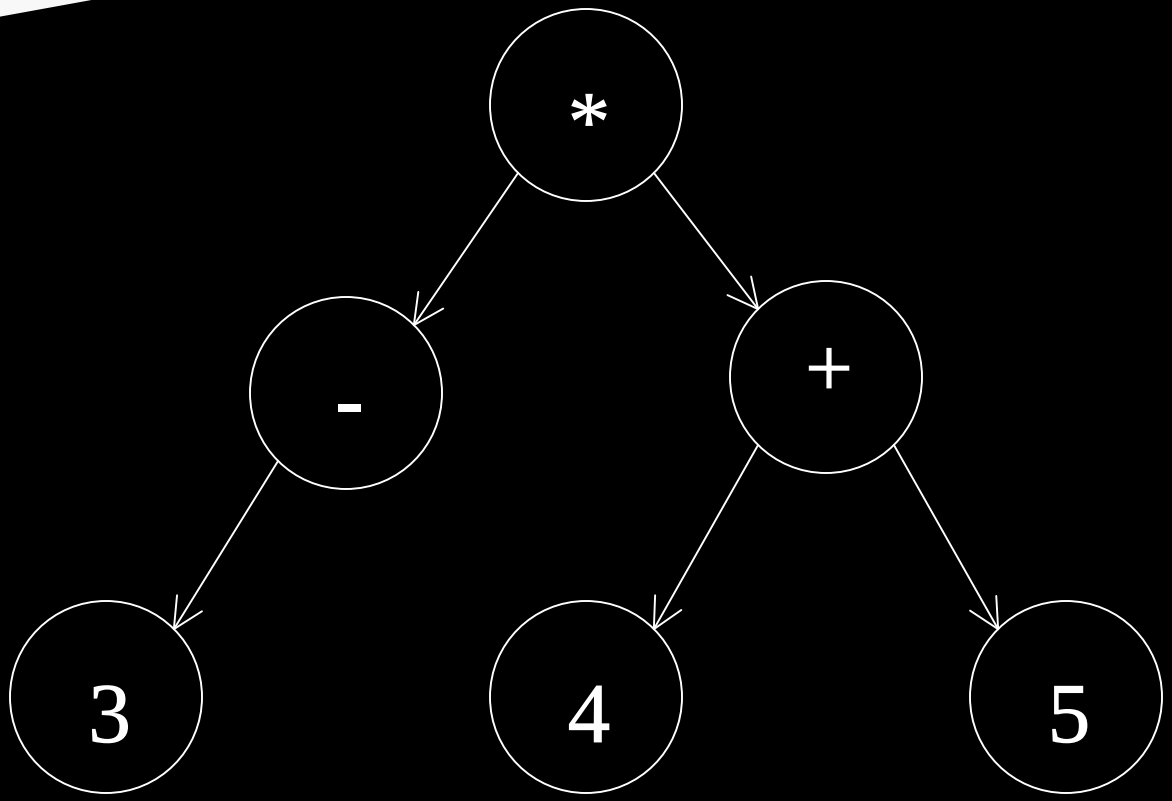
An object-oriented example

Expression trees as objects

The problem

- Find a useful way to represent expression trees
- Do something interesting with them
- Consolidate what we've learned so far
  - data abstraction
  - inheritance
  - dynamic binding

Example of an expression tree



Representation of `(-3)*(4+5)`

Why are trees useful?

- A tree represents the result of parsing an expression
  - Error checking has already been done
  - Recomputation not necessary
- Working with trees is easier
  - We get the notion of "subexpression" for free
  - Common operations are easy

Properties of trees

- Each tree represents an expression (or subexpression)
- Each node represents a token
- Parentheses are represented implicitly in the tree structure
- We will often equate a tree with a pointer to the root of the tree

Kinds of trees

- Integer nodes
- Operator nodes
  - unary
  - binary
- This classification already suggests an inheritance hierarchy

The Expr hierarchy

```
class Expr { /* … */ };
class IntExpr: public Expr
    { /* … */ };
class OpExpr: public Expr
    { /* … */ };
class UnaryExpr: public OpExpr
    { /* … */ };
class BinaryExpr: public OpExpr
    { /* … */ };
```

How will we use `Expr` objects?

- Each object will represent a tree
- We will generally deal with these trees through pointers
- If `p` is a pointer to `Expr`, we would like to be able to call `p->print(stdout)` or obtain the result of `p->eval()`

Memory management

- C++ does not have built-in garbage collection (although commercial implementations are now available)
- We will see later how to manage memory automatically
- For now, we will manage memory manually

Expression tree memory strategy

- We will never copy nodes
- We will use `new` and `delete` to allocate and free nodes as usual
- Whenever we construct a new node from an old one, the new one will free the old one when it goes
  - Necessary but not completely satisfactory
  - Good enough for now

We can already declare class Expr

```
class Expr {
public:
    Expr() { }
    virtual void print(FILE*);
    virtual int eval();
    virtual ~Expr() { }

private:
    Expr(const Expr&);
    Expr& operator=(const Expr&);
};
```

Representing integers

- We want to be able to say

```
Expr* p = new IntExpr(42);
p->print(stdout);  // print 42
int n = p->eval(); // n = 42
delete p;
```

- This tells us how to declare class `IntExpr`
  - constructor, destructor
  - virtual members `print` and `eval`

Declaration of IntExpr

```
class IntExpr: public Expr {
public:
    IntExpr(int);
    virtual void print(FILE*);
    virtual void eval();
    // No destructor needed

private:
    int n;
};
```

Implementation

- We will print an expression in fully parenthesized form
  - For an `IntExpr`, just print the integer
  - For a `UnaryExpr`, print `(@`*e*`)`, where `@` is the operator and *e* is the representation of the operand subexpression
  - For a `BinaryExpr`, print `(`*e1*`@`*e2*`)`, where *e1* and *e2* represent the subexpressions

Implementation of IntExpr

```
IntExpr::IntExpr(int n0): n(n0) { }
void IntExpr::print(FILE* f)
{
    fprintf(f, “%d”, n);
}
```

Class `OpExpr`

- An `OpExpr` object represents an expression with an operator and some number of operands
- We will store the operator (as a `char*`) in the `OpExpr`
- Each derived class will worry about its own operands

Class `OpExpr` declaration

- We will not need `print` or `eval` because we will use `OpExpr` objects only as base classes for other objects

```
class OpExpr: public Expr {
public:
    OpExpr(const char*);

protected:
    const char* op;
};
```

`OpExpr` implementation

- This one is easy: We need to implement only the constructor, which just saves its argument

```
OpExpr::OpExpr(const char* s):
    op(s) { }
```

Classes `UnaryExpr` and `BinaryExpr`

- Each of these classes 'constructors takes one or more pointers to objects for which the object will assume responsibility
- The destructor therefore needs to destroy the corresponding object(s)

UnaryExpr declaration

```
class UnaryExpr: public OpExpr {
public:
    UnaryExpr(const char*, Expr*);
    virtual ~UnaryExpr();
    virtual void print(FILE*);
    virtual int eval();

private:
    Expr* operand;
};
```

UnaryExpr implementation

```
UnaryExpr::UnaryExpr
    (const char* oper, Expr* opnd):
    OpExpr(oper), operand(opnd) { }
UnaryExpr::~UnaryExpr()
{ delete operand; }
void UnaryExpr::print(FILE* f)
{
    fprintf(f, "(%s", op);
    operand->print(f);
    fprintf(f, ")");
}
```

BinaryExpr declaration

```
class BinaryExpr: public OpExpr {
public:
    BinaryExpr
        (const char*, Expr*, Expr*);
    virtual ~BinaryExpr();
    virtual void print(FILE*);
    virtual int eval();

private:
    Expr* lhs;
    Expr* rhs;
};
```

BinaryExpr implementation

```
BinaryExpr::BinaryExpr
    (const char* oper,
        Expr* l, Expr* r):
    OpExpr(oper), lhs(l), rhs(r) { }
BinaryExpr::~BinaryExpr()
{ delete lhs; delete rhs; }
void BinaryExpr::print(FILE* f) {
    fprintf(f, "("); lhs->print(f);
    fprintf(f, op);  rhs->print(f);
    fprintf(f, ")");
}
```

Abstract base classes

- Class `OpExpr` was unusual
  - We did not implement `print` or `eval`
  - We do not expect ever to have a plain `OpExpr` object
- Such classes are called *abstract base classes*
- Looking back on it, class `Expr` should also be an abstract base class

Properties of abstract base classes

- Objects of that class do not exist by themselves, but only as bases of other classes
- They contain *pure virtual functions* that we want to implement only in derived classes
- C++ therefore uses pure virtual functions to define abstract bases

Declaring a pure virtual

- If you write, for example

```
class X {
public:
    virtual void foo() = 0;
};
```

  then
  - Function `X::foo` is a pure virtual
  - Class `X` is an therefore abstract base class
  - Any class derived from `X` is also an abstract base class unless it defines `foo`

Rules for abstract base classes

- If a class `X` is an abstract base class, no objects of class `X` can exist. In these examples, assume `Y` is derived from `X` and is not abstract:

```
X x;            // Error: X is abstract
X* p;           // OK
p = new Y;      // Also OK
p = new X;      // Error: X is abstract
```

Class Expr revisited

```
class Expr {
public:
    virtual void print(FILE*) = 0;
    virtual int eval() = 0;
    virtual ~Expr() { }

private:
    Expr(const Expr&);
    Expr& operator=(const Expr&);
};
```

Class `OpExpr` revisited

- Class `OpExpr` inherited `print` and `eval` from `Expr` and did not override them
- Therefore, `OpExpr` also becomes an abstract base class automatically

Homework (due Monday)

- Make these expression trees work
- Write a main program to exercise them
- Define `eval` and make it work for binary `+`, `-`, `*`, `/`, and unary `-`

C++ puzzle (extra credit)

- Suppose you have an abstract class:

```
class X {
public:
    virtual void foo() = 0;
};
```

- There is no need to define `X::foo`
  - No objects of class `X` can exist
  - Any call to `X::foo` will call foo in a derived class, where it will be defined

C++ puzzle, continued

- Although C++ is designed to make it hard to call a pure virtual function, there is a way to do it.
- The puzzle:
  - Find a way to call `X::foo` as defined
  - Try it and see what happens