Abstract Data Types

Development and Implementation

Our Goal

- Well-defined representations that allow objects to be created and used in an intuitive manner
  - User should not have to bother with unnecessary details
- Example
  - programming a microwave to make popcorn should not require a physics course

Golden Rule

- Use information hiding and encapsulation to support integrity of data
    - Put implementation details in a separate module
        - Implementation details complicate the class declarations
    - Data members are private so that use of the interface is required
        - Makes clients generally immune to implementation changes

Another Golden Rule

- Keep it simple – class minimality rule
    - Implement a behavior as a nonmember function when possible
    - Only add a behavior if it is necessary

Abstract Data Type

- Well-defined and complete data abstraction using the information-hiding principle

Rational Number Review

- Rational number
  - Ratio of two integers: a/b
    - Numerator over the denominator

- Standard operations
  - Addition

    $\overline{a} + \overline{c} = \overline{ad+bc}$

    Multiplication

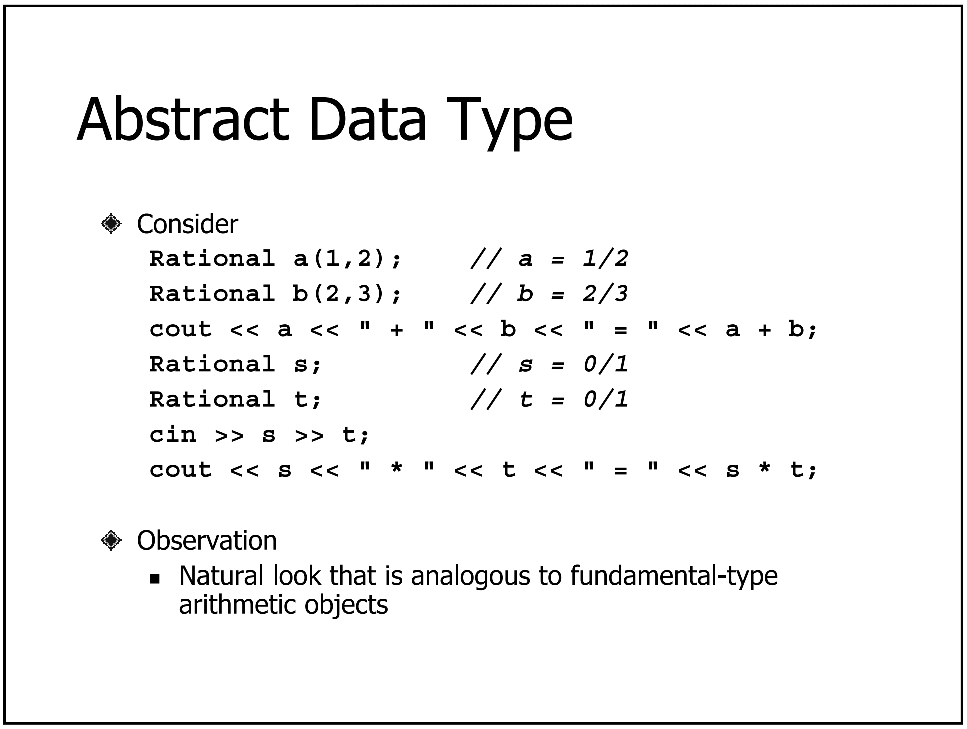
    $\overline{a} * \overline{c} = \overline{ac}$

  - Subtraction

    $\overline{a} - \overline{c} = \overline{ad - bc}$

    Division

    $\overline{a} / \overline{c} = \overline{ad}$

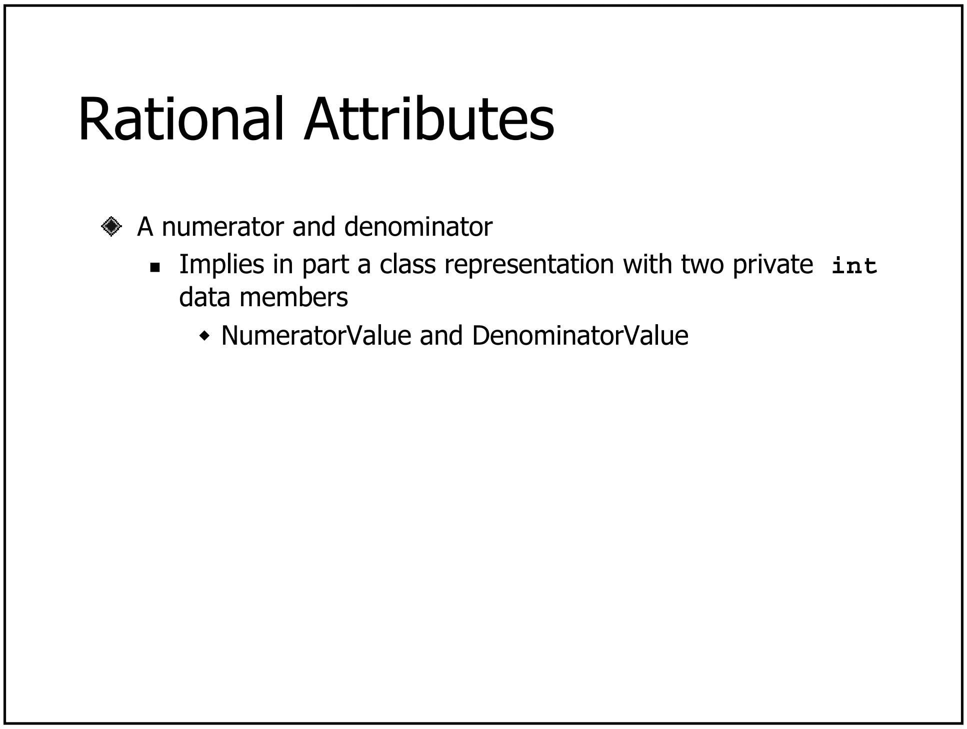


Abstract Data Type

- Consider

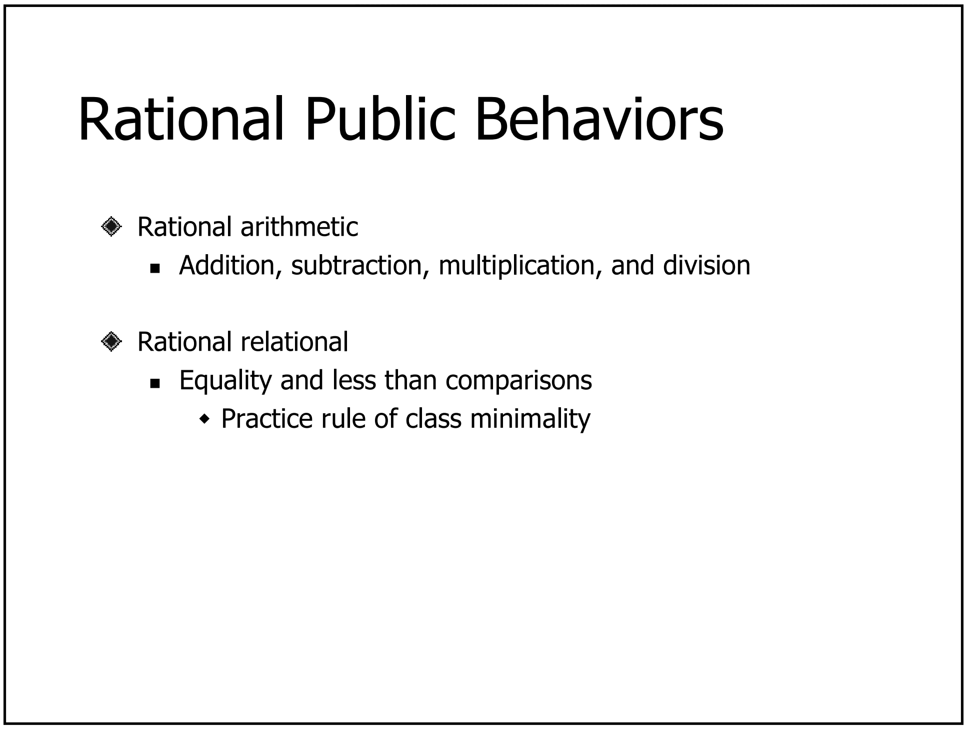
```
Rational a(1,2);     // a = 1/2
Rational b(2,3);     // b = 2/3
cout << a << " + " << b << " = " << a + b;
Rational s;          // s = 0/1
Rational t;          // t = 0/1
cin >> s >> t;
cout << s << " * " << t << " = " << s * t;
```

- Observation
  - Natural look that is analogous to fundamental-type arithmetic objects



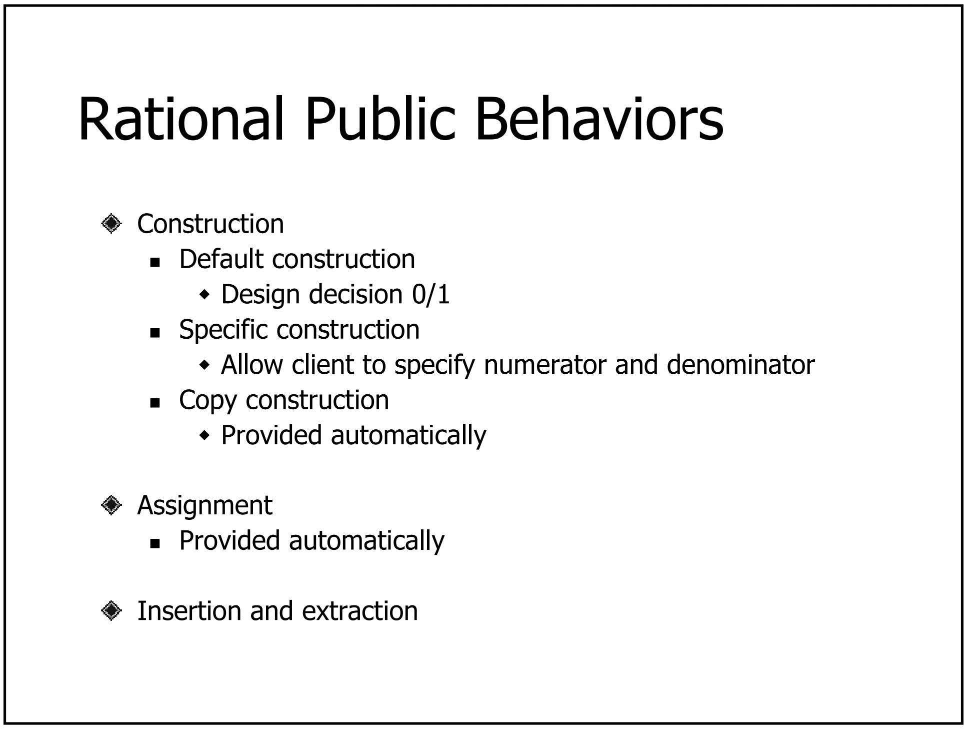
Rational Attributes

- A numerator and denominator
  - Implies in part a class representation with two private `int` data members
    - NumeratorValue and DenominatorValue



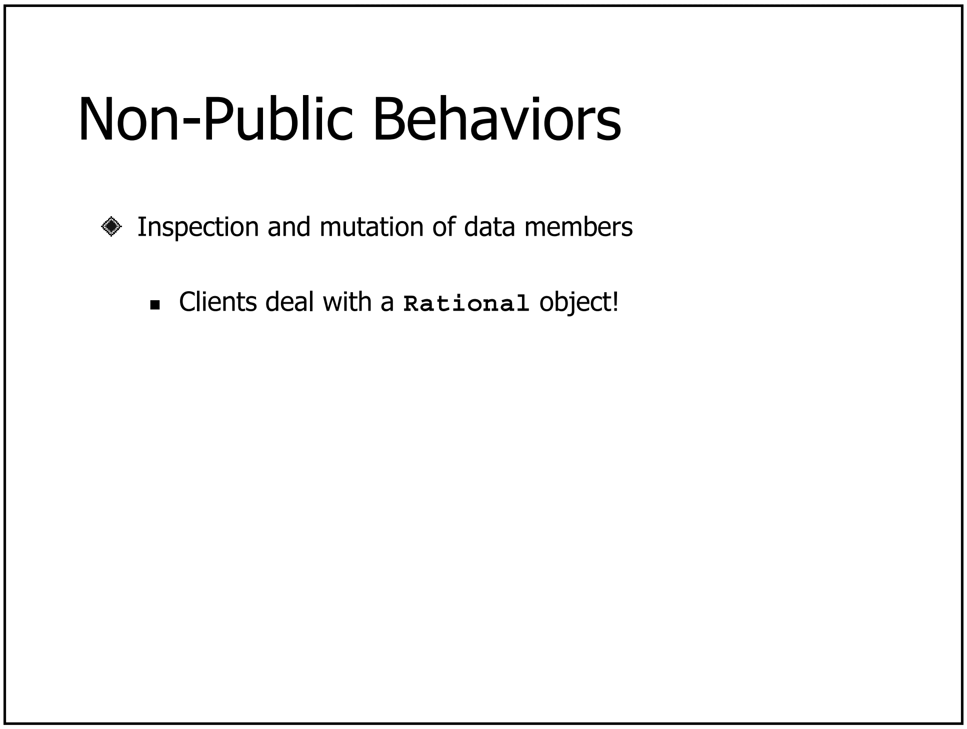
Rational Public Behaviors

- Rational arithmetic
  - Addition, subtraction, multiplication, and division
- Rational relational
  - Equality and less than comparisons
    - Practice rule of class minimality



Rational Public Behaviors

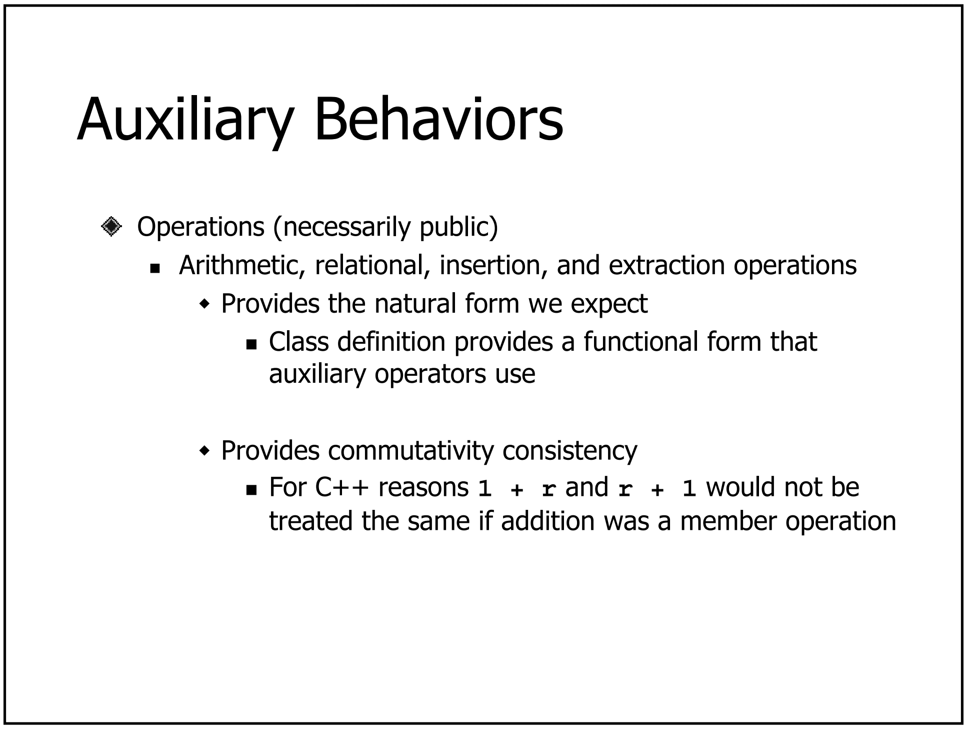
- Construction
  - Default construction
    - Design decision 0/1
  - Specific construction
    - Allow client to specify numerator and denominator
  - Copy construction
    - Provided automatically
- Assignment
  - Provided automatically
- Insertion and extraction



Non-Public Behaviors

- Inspection and mutation of data members

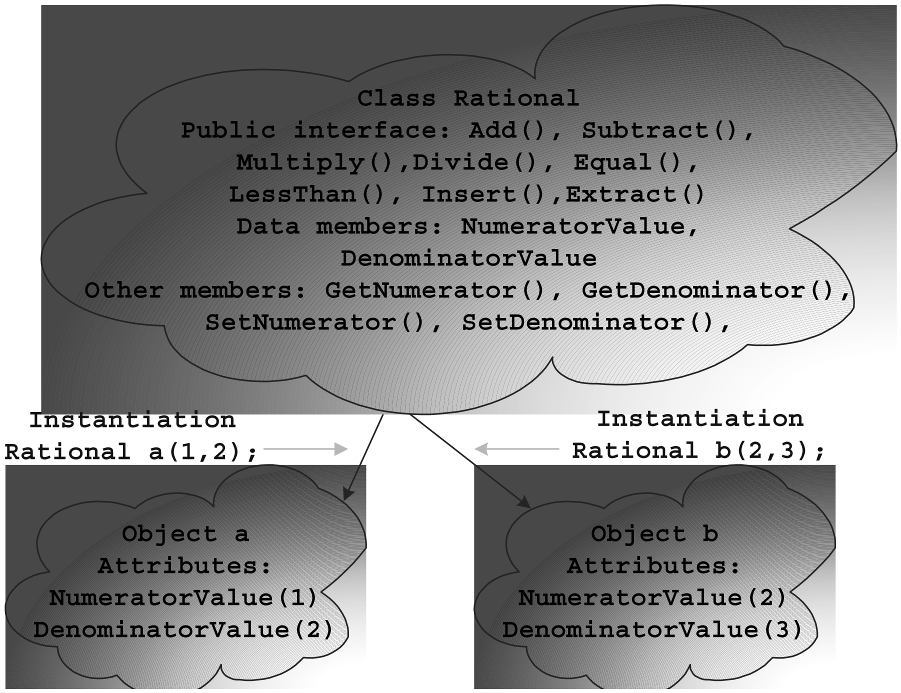
  - Clients deal with a `Rational` object!



Auxiliary Behaviors

- Operations (necessarily public)
  - Arithmetic, relational, insertion, and extraction operations
    - Provides the natural form we expect
      - Class definition provides a functional form that auxiliary operators use

    - Provides commutativity consistency
      - For C++ reasons `1 + r` and `r + 1` would not be treated the same if addition was a member operation



Class Rational
Public interface: Add(), Subtract(), Multiply(),Divide(), Equal(), LessThan(), Insert(),Extract()
Data members: NumeratorValue, DenominatorValue
Other members: GetNumerator(), GetDenominator(), SetNumerator(), SetDenominator(),

Instantiation
Rational a(1,2);

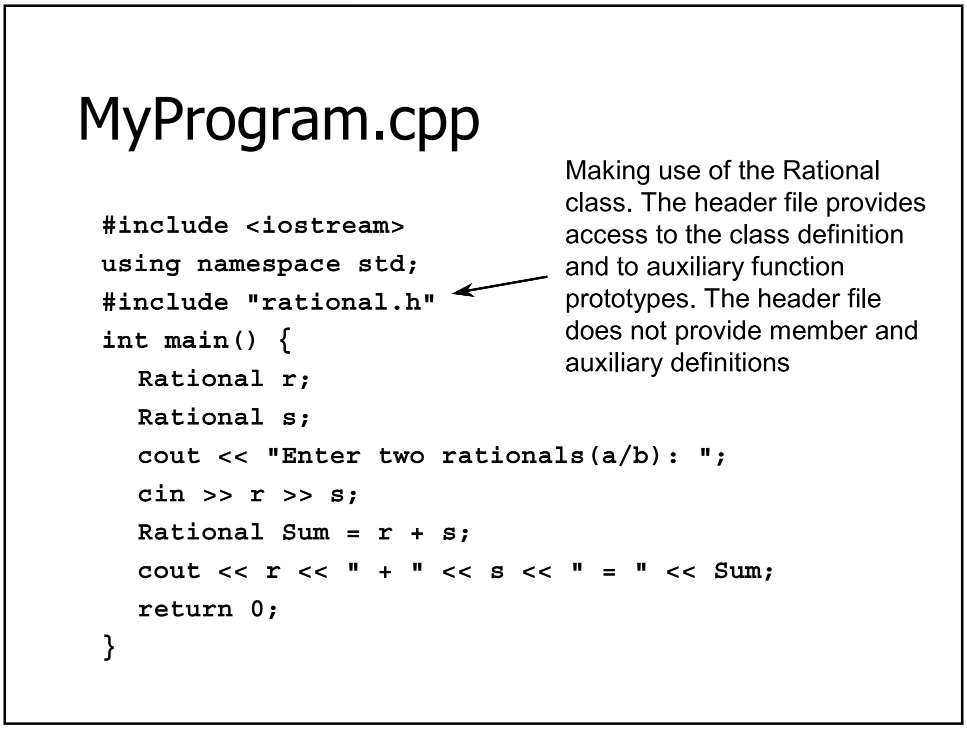
Instantiation
Rational b(2,3);

Object a
Attributes:
NumeratorValue(1)
DenominatorValue(2)

Object b
Attributes:
NumeratorValue(2)
DenominatorValue(3)

Library Components

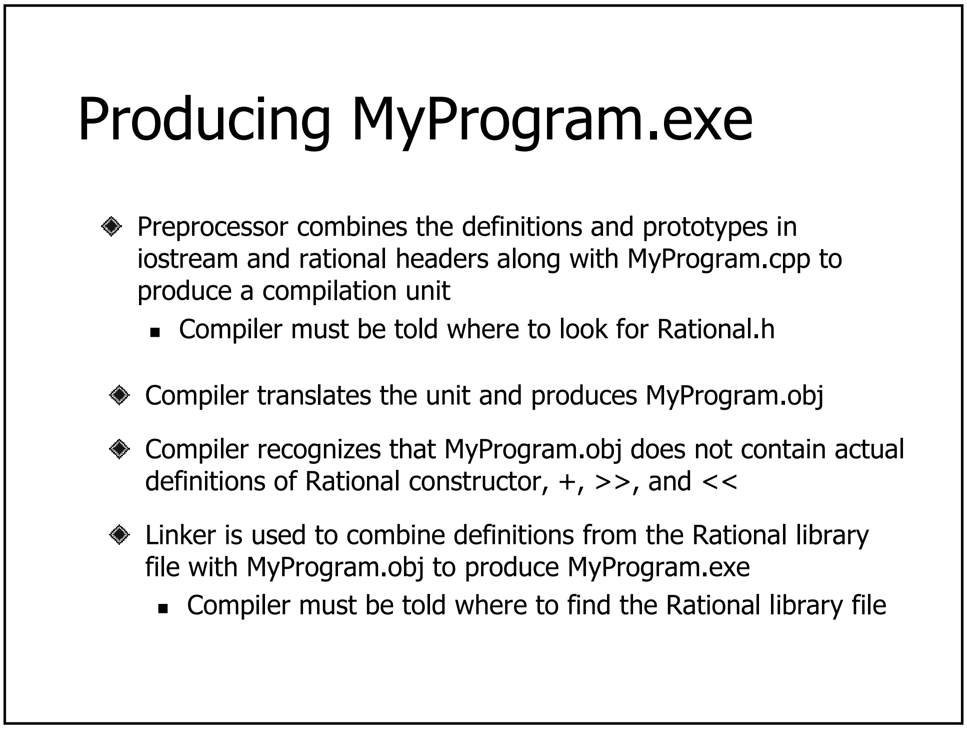
- Rational.h
  - Class definitions and library function prototypes
- Rational.cpp
  - Implementation source code – member and auxiliary function definitions
    - Auxiliary functions are assisting global functions that provide expected but non-member capabilities
- Rational.obj
  - Translated version of Rational.cpp (linkable)
- Rational.lib
  - Library version of Rational.obj that is more readily linkable



MyProgram.cpp

```
#include <iostream>
using namespace std;
#include "rational.h"
int main() {
  Rational r;
  Rational s;
  cout << "Enter two rationals(a/b): ";
  cin >> r >> s;
  Rational Sum = r + s;
  cout << r << " + " << s << " = " << Sum;
  return 0;
}
```

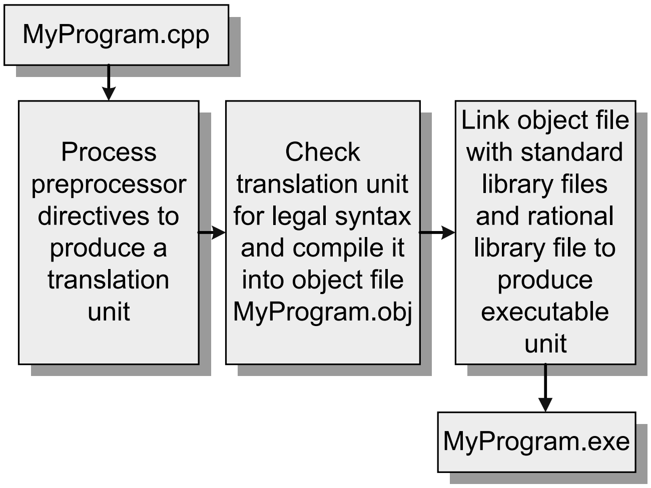
Making use of the Rational class. The header file provides access to the class definition and to auxiliary function prototypes. The header file does not provide member and auxiliary definitions



Producing MyProgram.exe

- Preprocessor combines the definitions and prototypes in iostream and rational headers along with MyProgram.cpp to produce a compilation unit
  - Compiler must be told where to look for Rational.h
- Compiler translates the unit and produces MyProgram.obj
- Compiler recognizes that MyProgram.obj does not contain actual definitions of Rational constructor, +, >>, and <<
- Linker is used to combine definitions from the Rational library file with MyProgram.obj to produce MyProgram.exe
  - Compiler must be told where to find the Rational library file

Producing MyProgram.exe



MyProgram.cpp

Process preprocessor directives to produce a translation unit

Check translation unit for legal syntax and compile it into object file MyProgram.obj

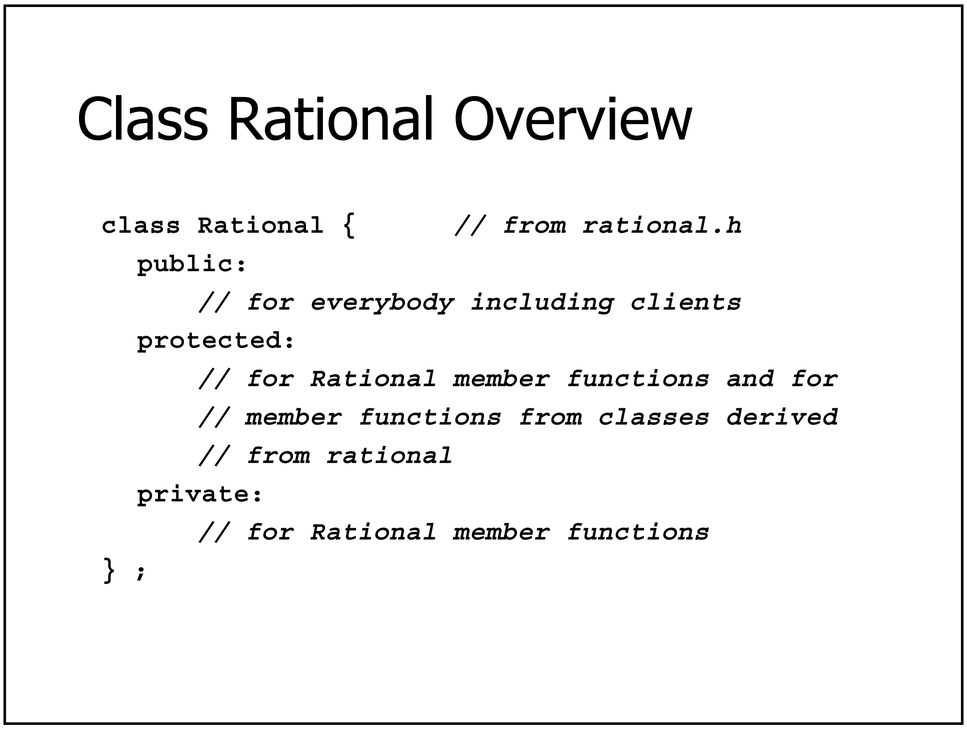
Link object file with standard library files and rational library file to produce executable unit

MyProgram.exe

Rational Header File Overview

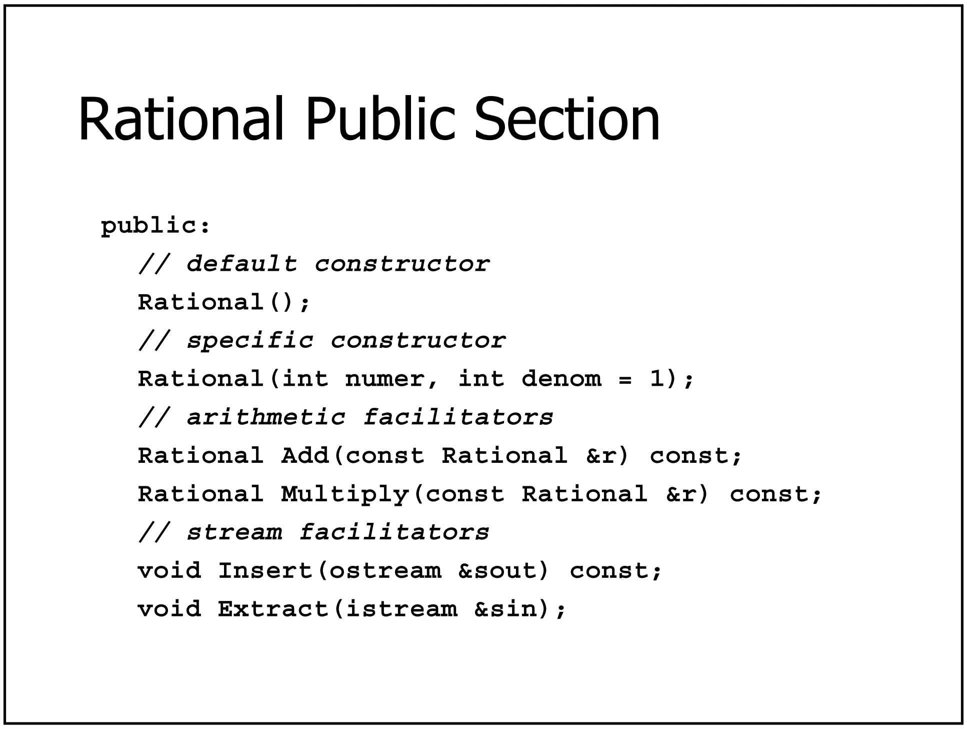
- File layout
  - Class definition and library prototypes nested within preprocessor statements
    - Ensures one inclusion per translation unit
  - Class definition precedes library prototypes

```
#ifndef RATIONAL_H
#define RATIONAL_H
class Rational {
  // …
} ;
// library prototypes …
#endif
```



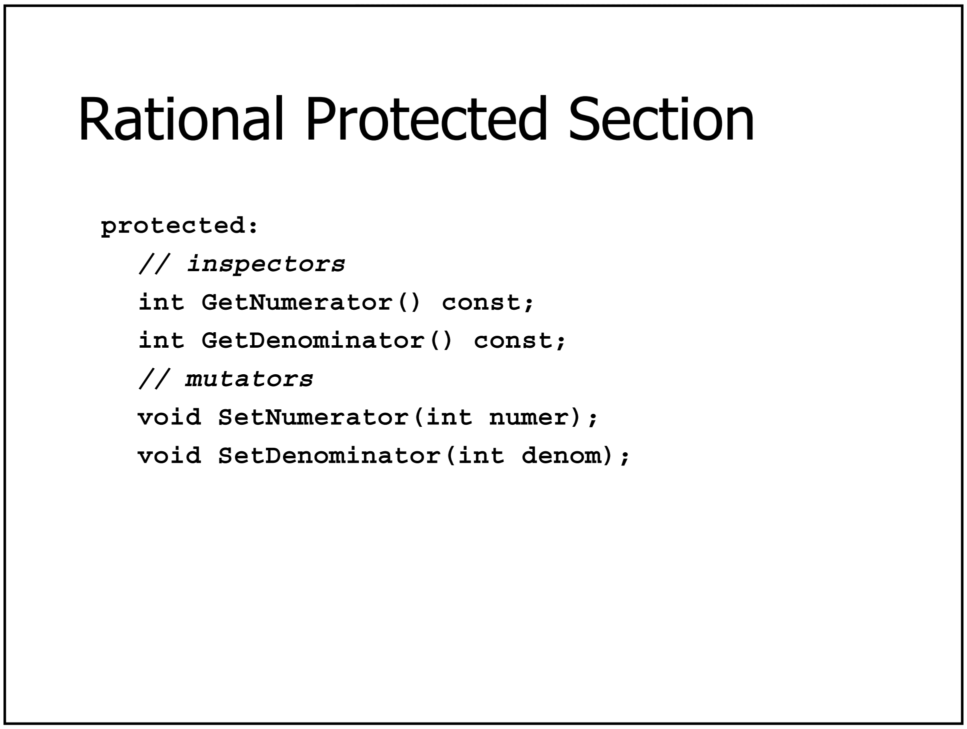
Class Rational Overview

```
class Rational {      // from rational.h
  public:
      // for everybody including clients
  protected:
      // for Rational member functions and for
      // member functions from classes derived
      // from rational
  private:
      // for Rational member functions
} ;
```



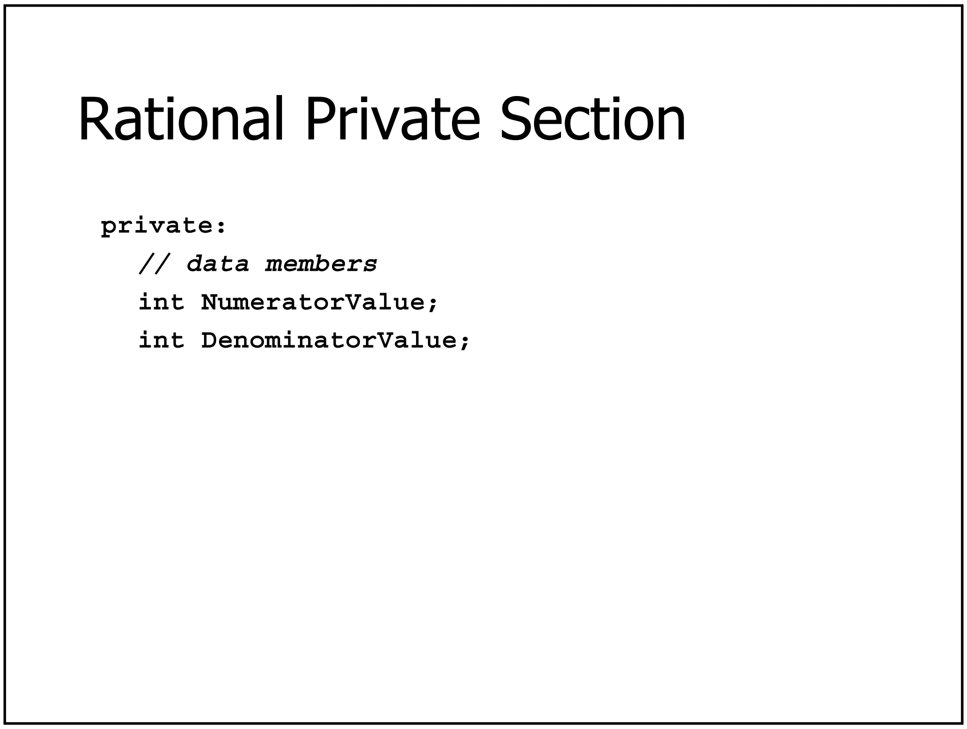
Rational Public Section

```
public:
  // default constructor
  Rational();
  // specific constructor
  Rational(int numer, int denom = 1);
  // arithmetic facilitators
  Rational Add(const Rational &r) const;
  Rational Multiply(const Rational &r) const;
  // stream facilitators
  void Insert(ostream &sout) const;
  void Extract(istream &sin);
```



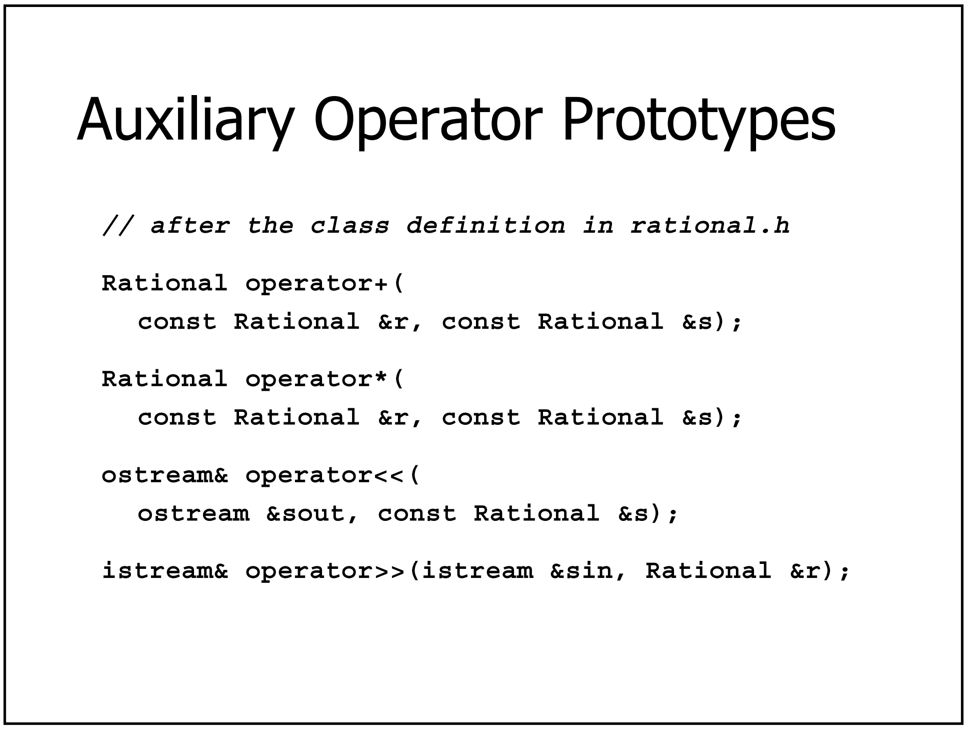
Rational Protected Section

```
protected:
   // inspectors
   int GetNumerator() const;
   int GetDenominator() const;
   // mutators
   void SetNumerator(int numer);
   void SetDenominator(int denom);
```



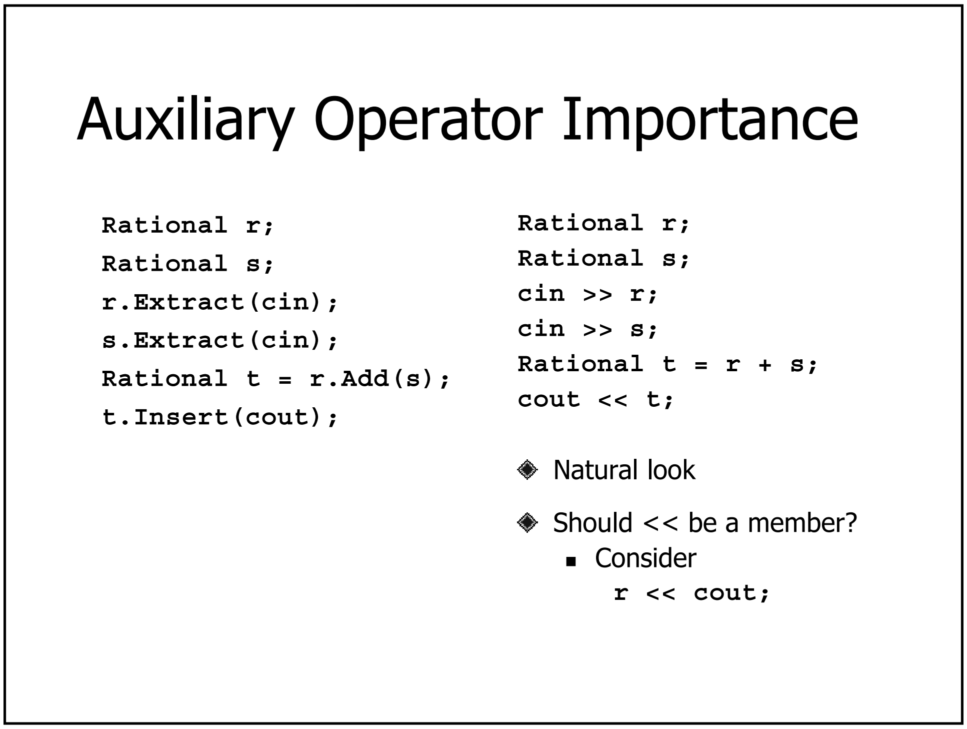
Rational Private Section

```
private:
   // data members
   int NumeratorValue;
   int DenominatorValue;
```



Auxiliary Operator Prototypes

```
// after the class definition in rational.h

Rational operator+(
  const Rational &r, const Rational &s);

Rational operator*(
  const Rational &r, const Rational &s);

ostream& operator<<(
  ostream &sout, const Rational &s);

istream& operator>>(istream &sin, Rational &r);
```

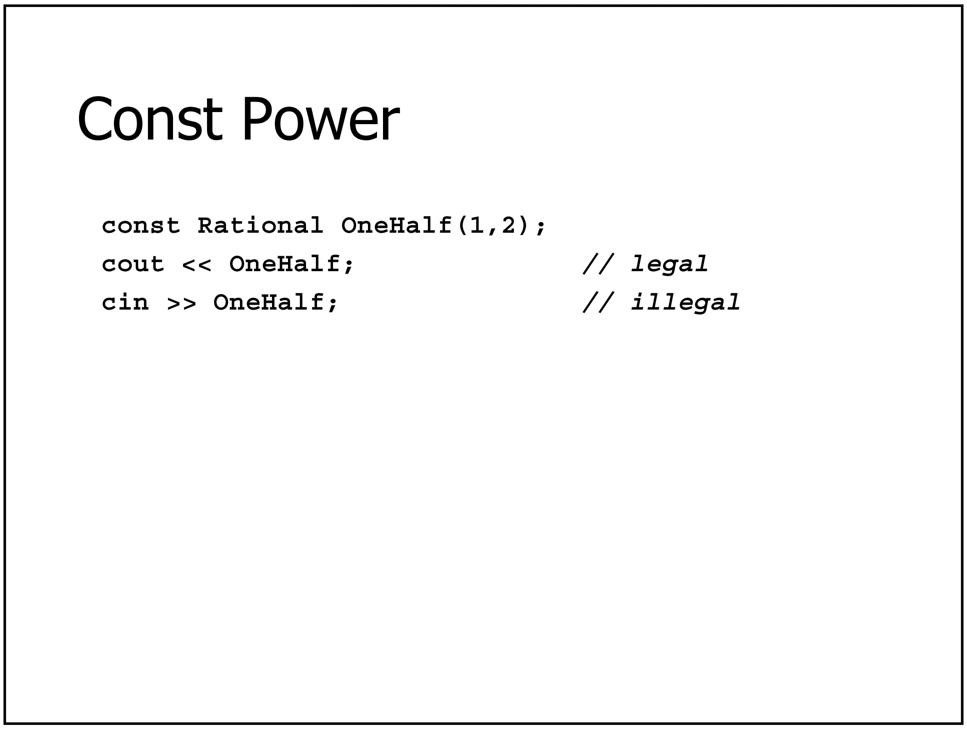


Auxiliary Operator Importance

```
Rational r;
Rational s;
r.Extract(cin);
s.Extract(cin);
Rational t = r.Add(s);
t.Insert(cout);
```

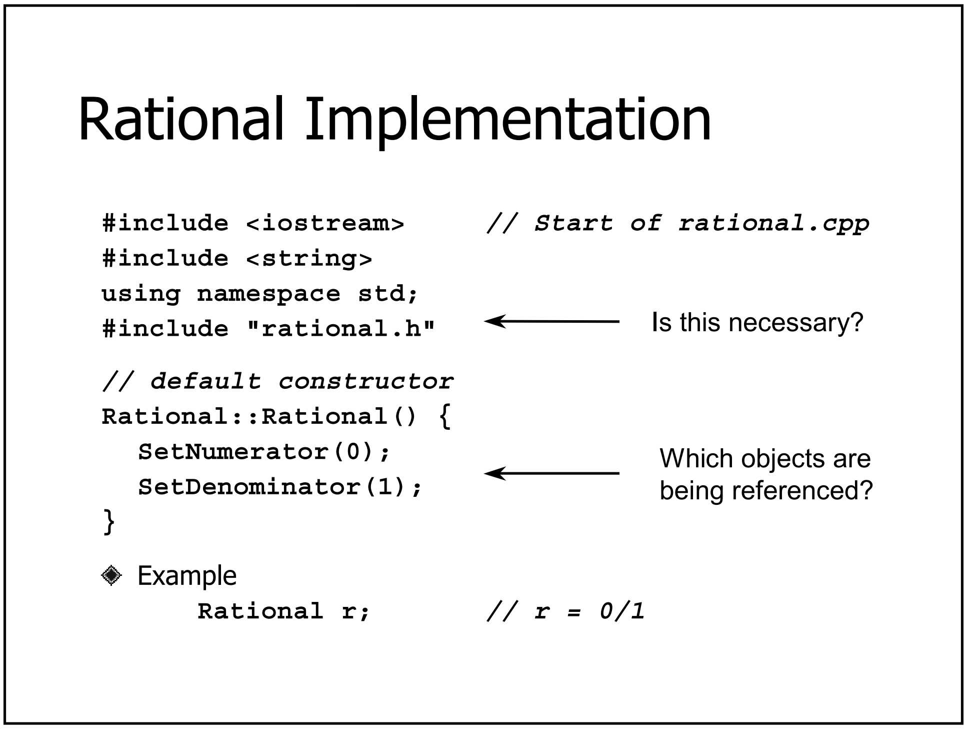
```
Rational r;
Rational s;
cin >> r;
cin >> s;
Rational t = r + s;
cout << t;
```

- Natural look
- Should << be a member?
  - Consider
    `r << cout;`



Const Power

```
const Rational OneHalf(1,2);
cout << OneHalf;              // legal
cin >> OneHalf;               // illegal
```



Rational Implementation

```
#include <iostream>      // Start of rational.cpp
#include <string>
using namespace std;
#include "rational.h"
```

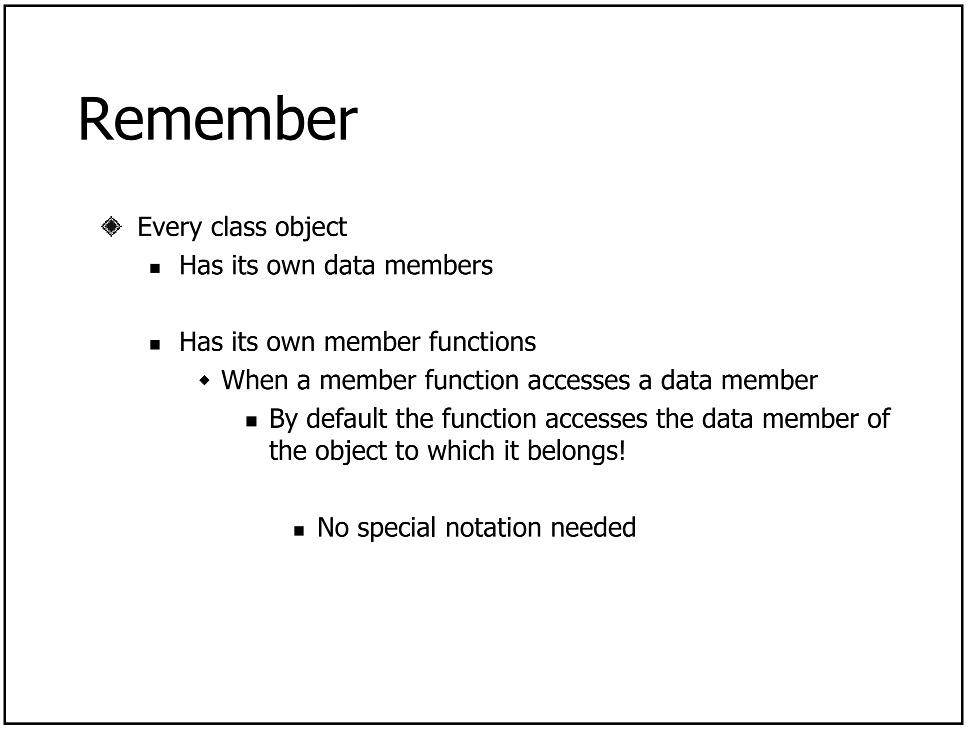
Is this necessary?

```
// default constructor
Rational::Rational() {
  SetNumerator(0);
  SetDenominator(1);
}
```

Which objects are being referenced?

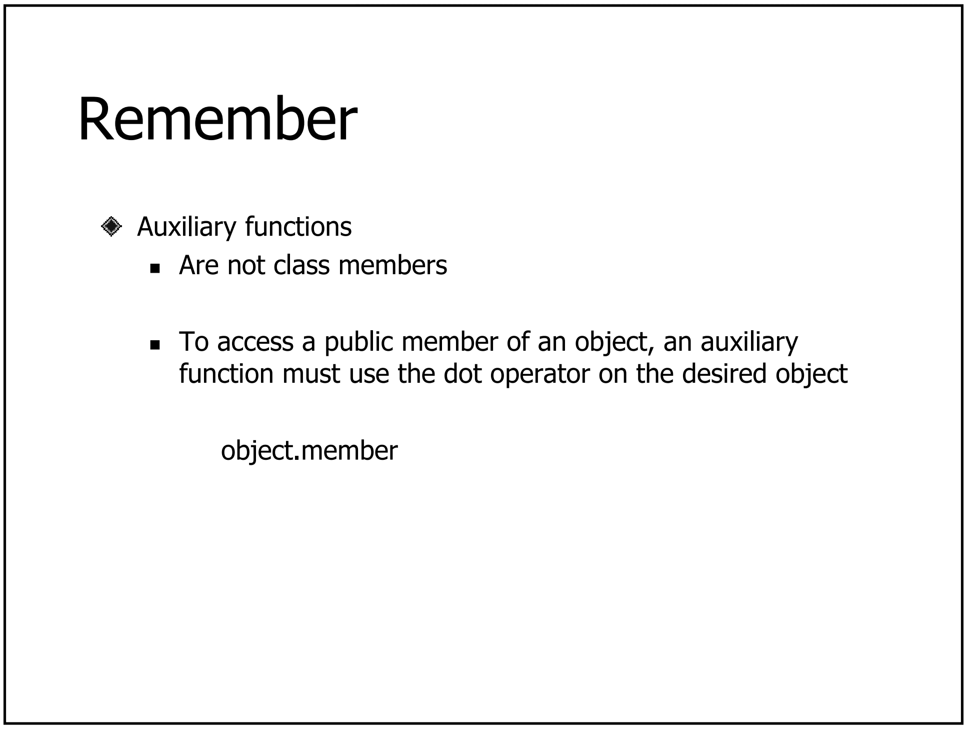
- Example

```
      Rational r;        // r = 0/1
```



Remember

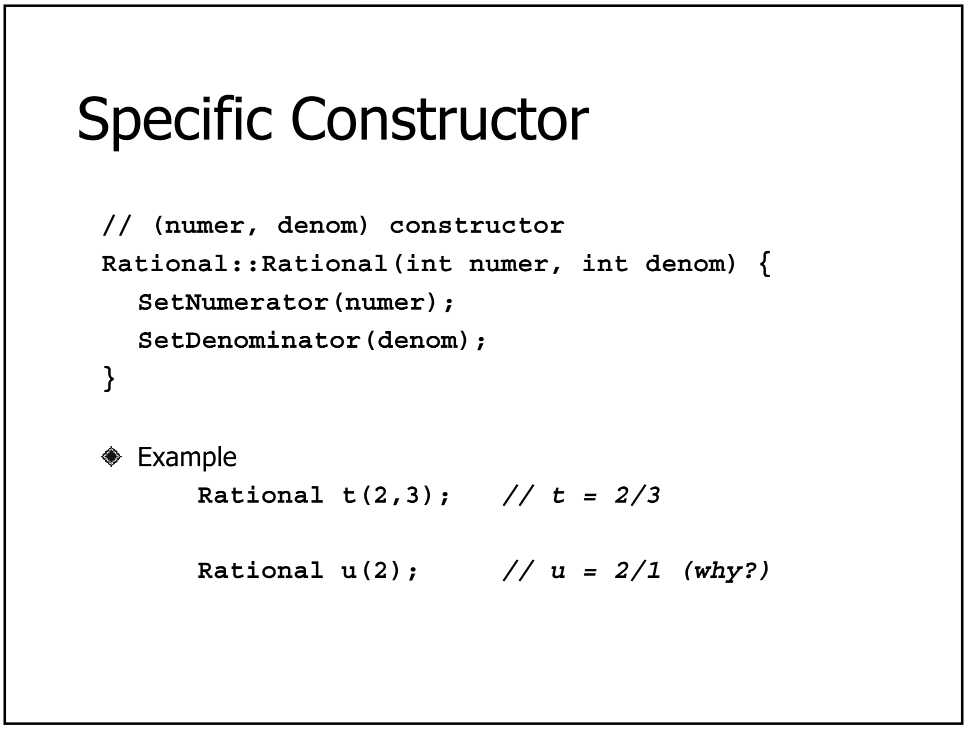
- Every class object
  - Has its own data members
  - Has its own member functions
    - When a member function accesses a data member
      - By default the function accesses the data member of the object to which it belongs!
        - No special notation needed



Remember

- Auxiliary functions
  - Are not class members
  - To access a public member of an object, an auxiliary function must use the dot operator on the desired object

```
object.member
```

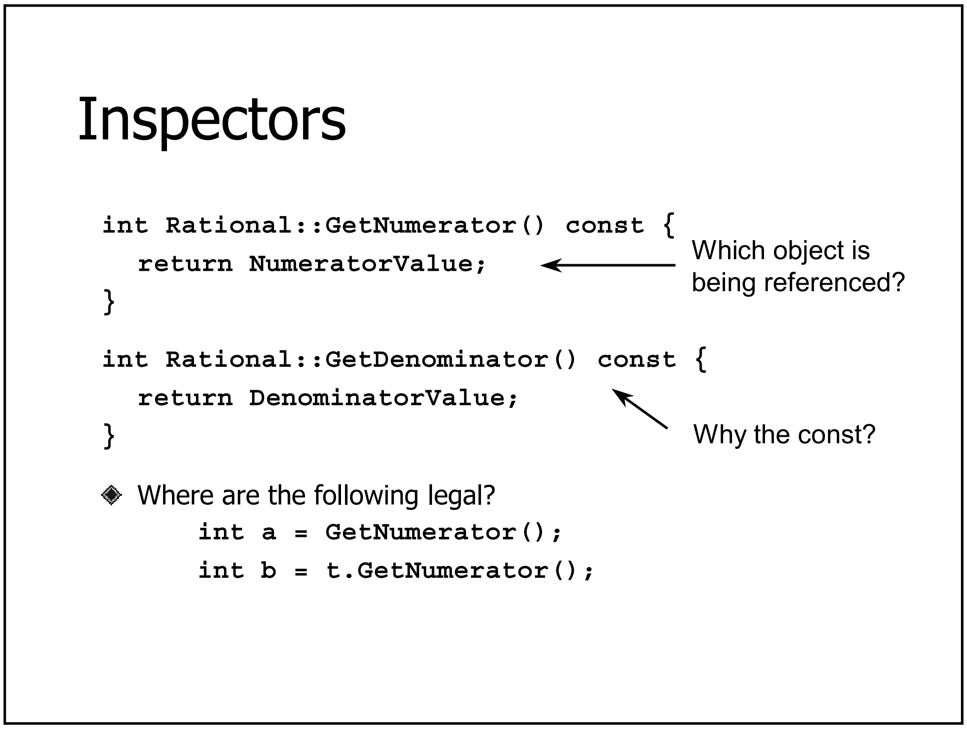


Specific Constructor

```
// (numer, denom) constructor
Rational::Rational(int numer, int denom) {
   SetNumerator(numer);
   SetDenominator(denom);
}
```

- Example

```
     Rational t(2,3);    // t = 2/3

     Rational u(2);      // u = 2/1 (why?)
```



Inspectors

```
int Rational::GetNumerator() const {
   return NumeratorValue;
}

int Rational::GetDenominator() const {
   return DenominatorValue;
}
```

Which object is being referenced?

Why the const?

- Where are the following legal?

```
     int a = GetNumerator();
     int b = t.GetNumerator();
```

Numerator Mutator

```
void Rational::SetNumerator(int numer) {
  NumeratorValue = numer;
}
```

Why no const?

- Where are the following legal?

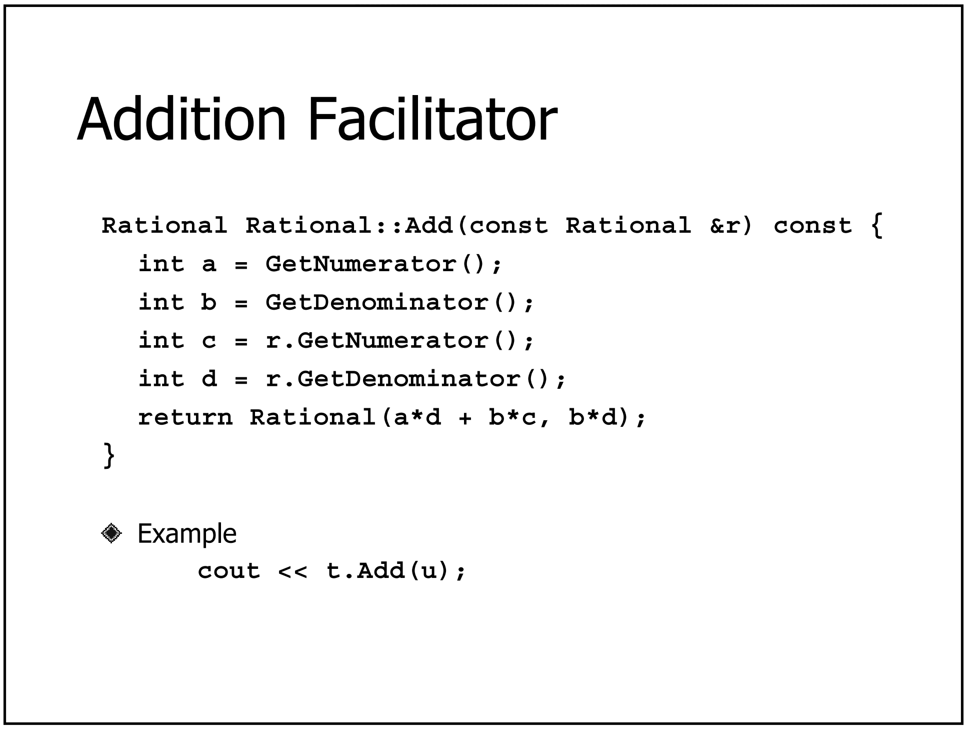
```
SetNumerator(1);

t.SetNumerator(2);
```

Denominator Mutator

```
void Rational::SetDenominator(int denom) {
  if (denom != 0) {
      DenominatorValue = denom;
  }
  else {
      cerr << "Illegal denominator: " << denom
       << "using 1" << endl;
      DenominatorValue = 1;
  }
}
```

- Example

```
SetDenominator(5);
```

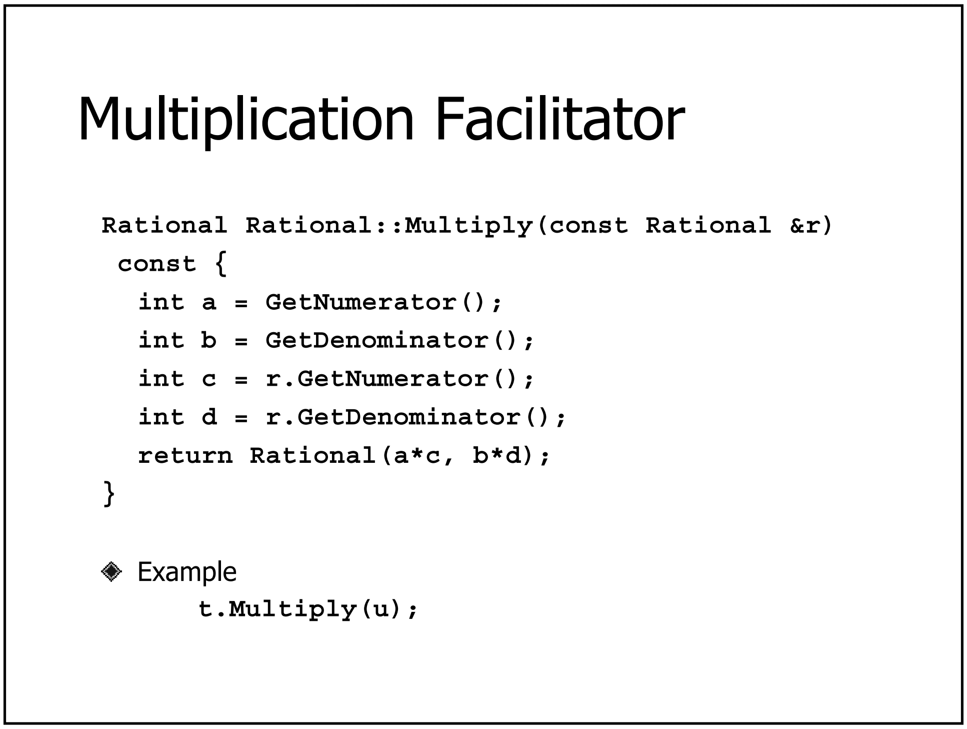


Addition Facilitator

```
Rational Rational::Add(const Rational &r) const {
  int a = GetNumerator();
  int b = GetDenominator();
  int c = r.GetNumerator();
  int d = r.GetDenominator();
  return Rational(a*d + b*c, b*d);
}
```

- Example

```
    cout << t.Add(u);
```

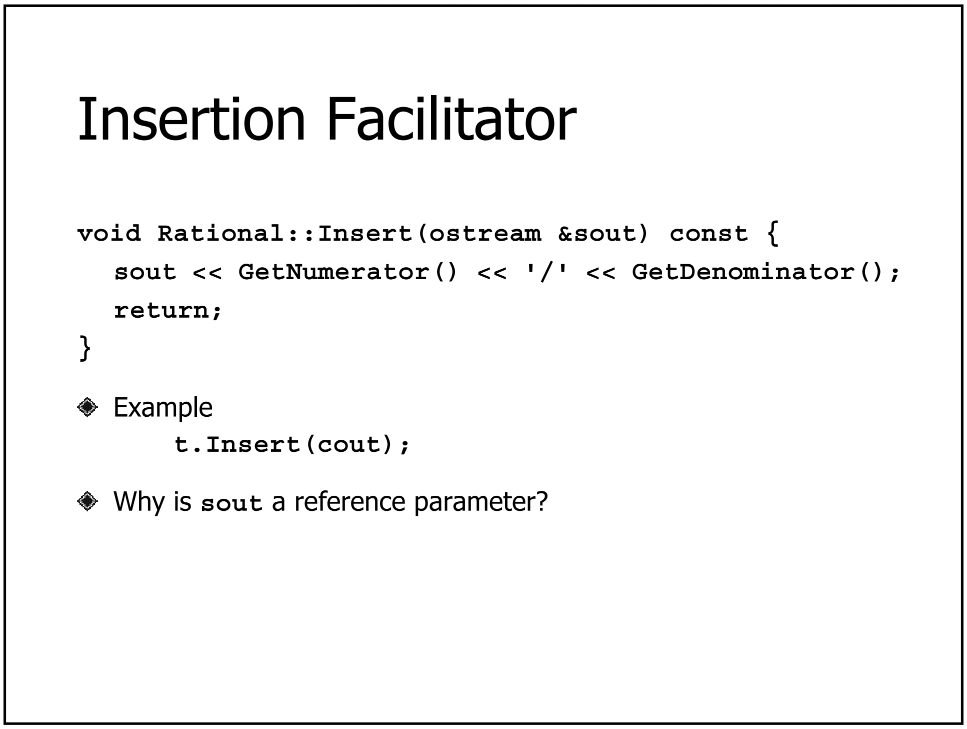


Multiplication Facilitator

```
Rational Rational::Multiply(const Rational &r)
 const {
  int a = GetNumerator();
  int b = GetDenominator();
  int c = r.GetNumerator();
  int d = r.GetDenominator();
  return Rational(a*c, b*d);
}
```

- Example

```
    t.Multiply(u);
```



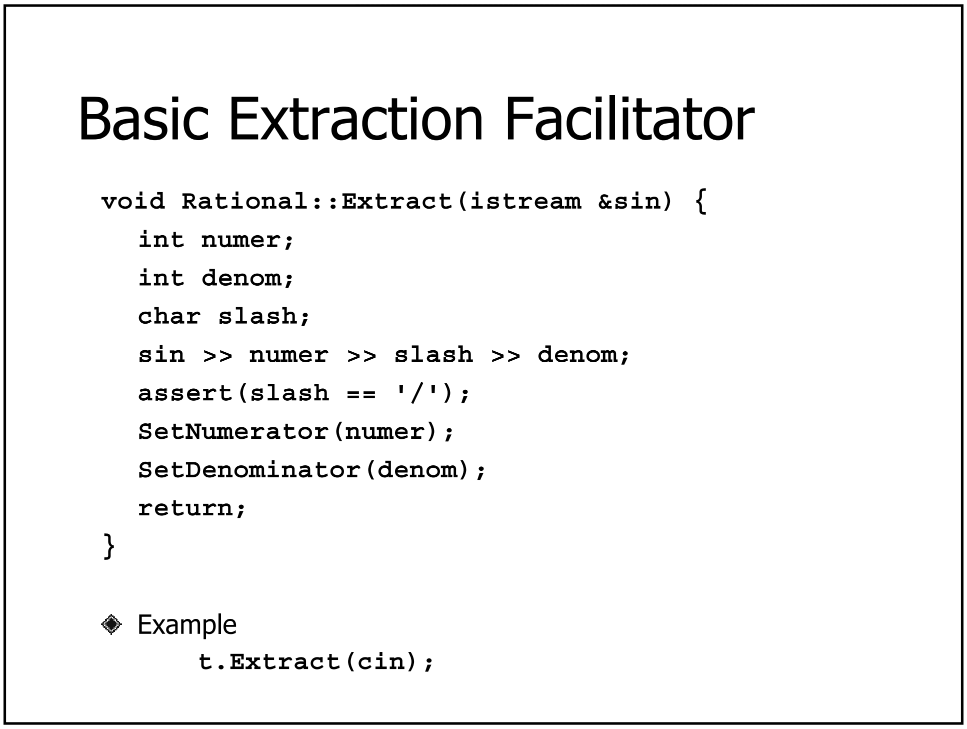
Insertion Facilitator

```
void Rational::Insert(ostream &sout) const {
  sout << GetNumerator() << '/' << GetDenominator();
  return;
}
```

- Example

```
    t.Insert(cout);
```

- Why is `sout` a reference parameter?



Basic Extraction Facilitator

```
void Rational::Extract(istream &sin) {
  int numer;
  int denom;
  char slash;
  sin >> numer >> slash >> denom;
  assert(slash == '/');
  SetNumerator(numer);
  SetDenominator(denom);
  return;
}
```

- Example

```
    t.Extract(cin);
```

Auxiliary Arithmetic Operators

```
Rational operator+(
 const Rational &r, const Rational &s) {
   return r.Add(s);
}

Rational operator*(
 const Rational &r, const Rational &s) {
   return r.Multiply(s);
}
```

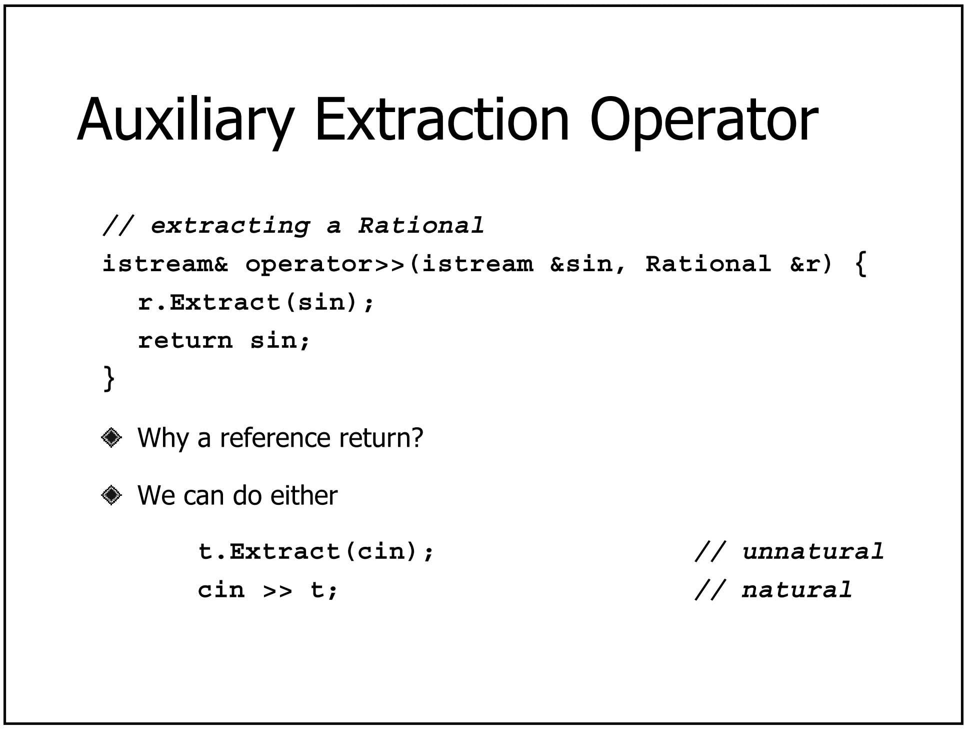
- Example
```
     cout << (t + t) * t;
```

Auxiliary Insertion Operator

```
ostream& operator<<(
 ostream &sout, const Rational &r) {
   r.Insert(sout);
   return sout;
}
```

- Why a reference return?
- Note we can do either

```
      t.Insert(cout); cout << endl;  // unnatural
      cout << t << endl;             // natural
```

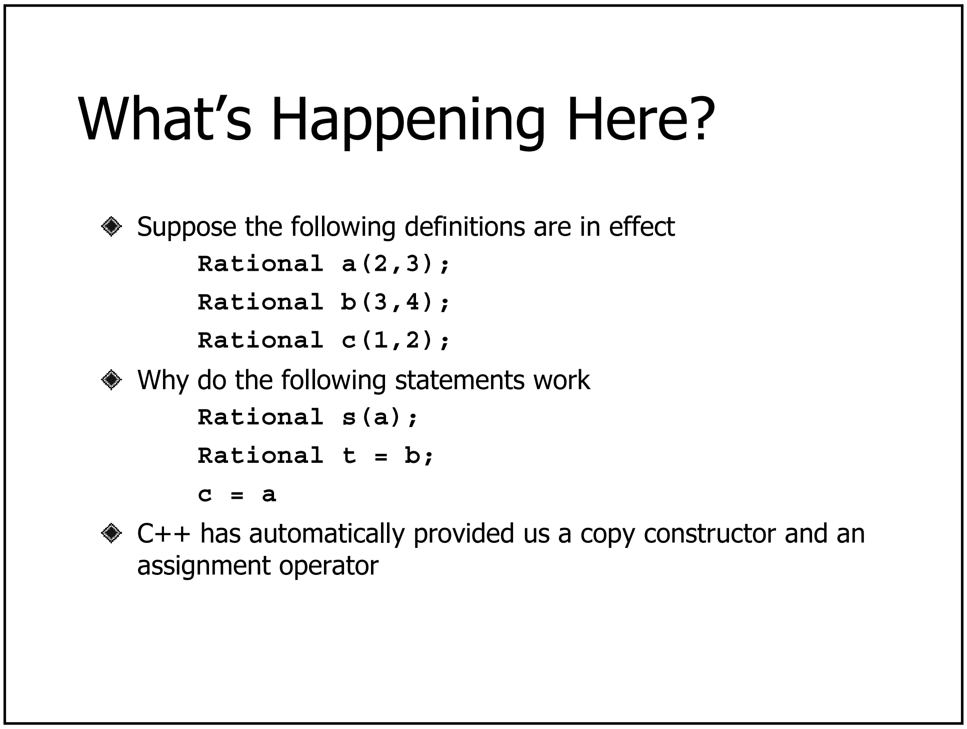


Auxiliary Extraction Operator

```
// extracting a Rational
istream& operator>>(istream &sin, Rational &r) {
  r.Extract(sin);
  return sin;
}
```

- Why a reference return?
- We can do either

```
    t.Extract(cin);                 // unnatural
    cin >> t;                       // natural
```



What’s Happening Here?

- Suppose the following definitions are in effect

```
    Rational a(2,3);
    Rational b(3,4);
    Rational c(1,2);
```

- Why do the following statements work

```
    Rational s(a);
    Rational t = b;
    c = a
```

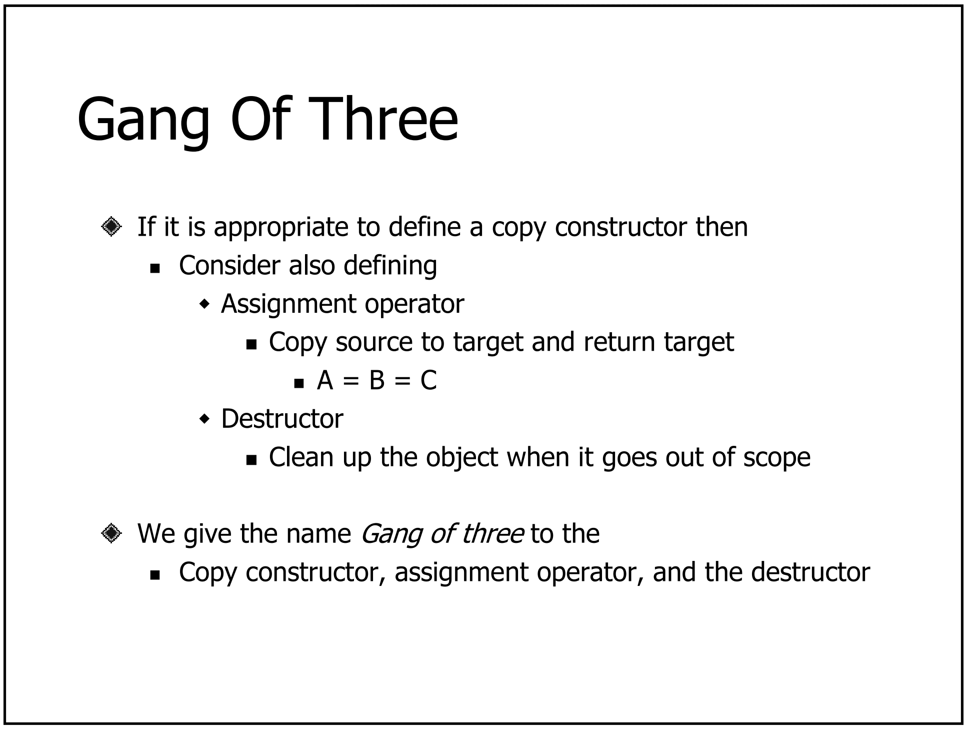
- C++ has automatically provided us a copy constructor and an assignment operator

Copy Construction

- Default copy construction
  - Copy of one object to another in a bit-wise manner
    - The representation of the source is copied to the target in a bit-by-bit manner
  - This type of copy is called *shallow copying*
- Class developers are free to implement their own copy constructor
- Rational does need a special one, but we will define one for the experience

A Rational Copy Constructor

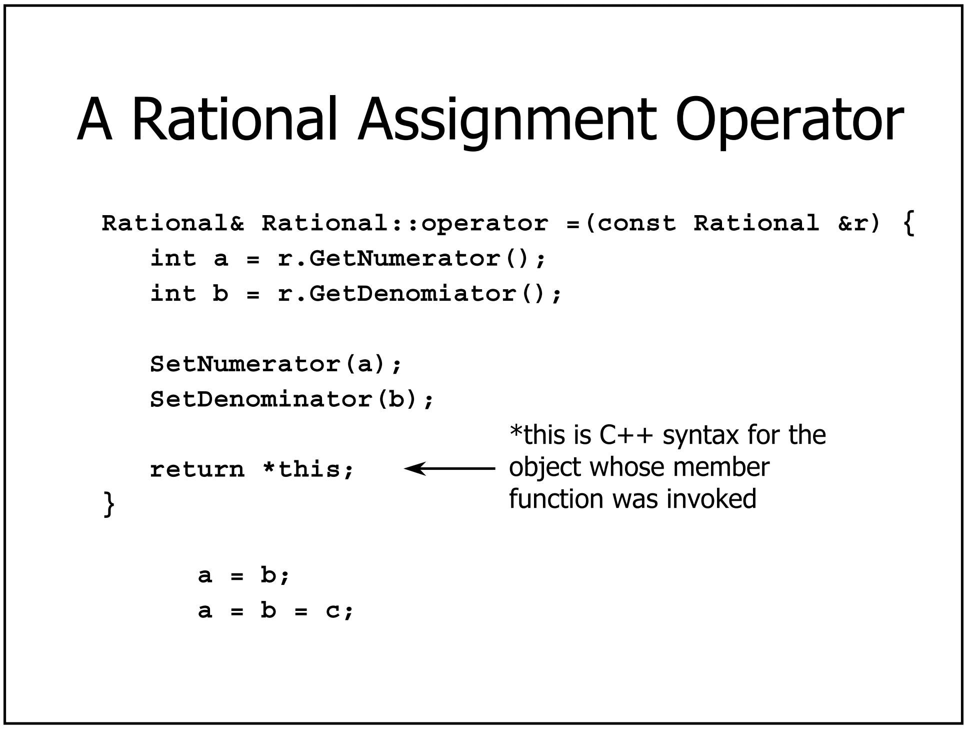
```
Rational::Rational(const Rational &r) {
   int a = r.GetNumerator();
   int b = r.GetDenomiator();

   SetNumerator(a);
   SetDenominator(b);
}

      Rational s(a);
      Rational t = b;
```



Gang Of Three

- If it is appropriate to define a copy constructor then
  - Consider also defining
    - Assignment operator
      - Copy source to target and return target
        - A = B = C
    - Destructor
      - Clean up the object when it goes out of scope

- We give the name *Gang of three* to the
  - Copy constructor, assignment operator, and the destructor



A Rational Assignment Operator

```
Rational& Rational::operator =(const Rational &r) {
   int a = r.GetNumerator();
   int b = r.GetDenomiator();

   SetNumerator(a);
   SetDenominator(b);

   return *this;
}
```

*this is C++ syntax for the object whose member function was invoked

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

Rational Destructor

```
Rational::~Rational() {
  // nothing to do
}
```