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Abstract Data Types

Development and Implementation

OO Programming and Design

- Goal
  - Well-defined abstractions 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
- Common practice
  - Use information hiding principle and encapsulation to support integrity of data
- Result
  - Abstract Data Type or ADT

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 = 0/1
cin >> s >> t;
cout << s << " * " << t << " = " << s * t;
```

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

Rational Number Review

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

$$\frac{a}{b} + \frac{c}{d} = \frac{ad + bc}{bd}$$

  - Subtraction

$$\frac{a}{b} - \frac{c}{d} = \frac{ad - bc}{bd}$$

  - Multiplication

$$\frac{a}{b} * \frac{c}{d} = \frac{ac}{bd}$$

  - Division

$$\frac{a}{b} / \frac{c}{d} = \frac{ad}{bc}$$

Rational Number Representation

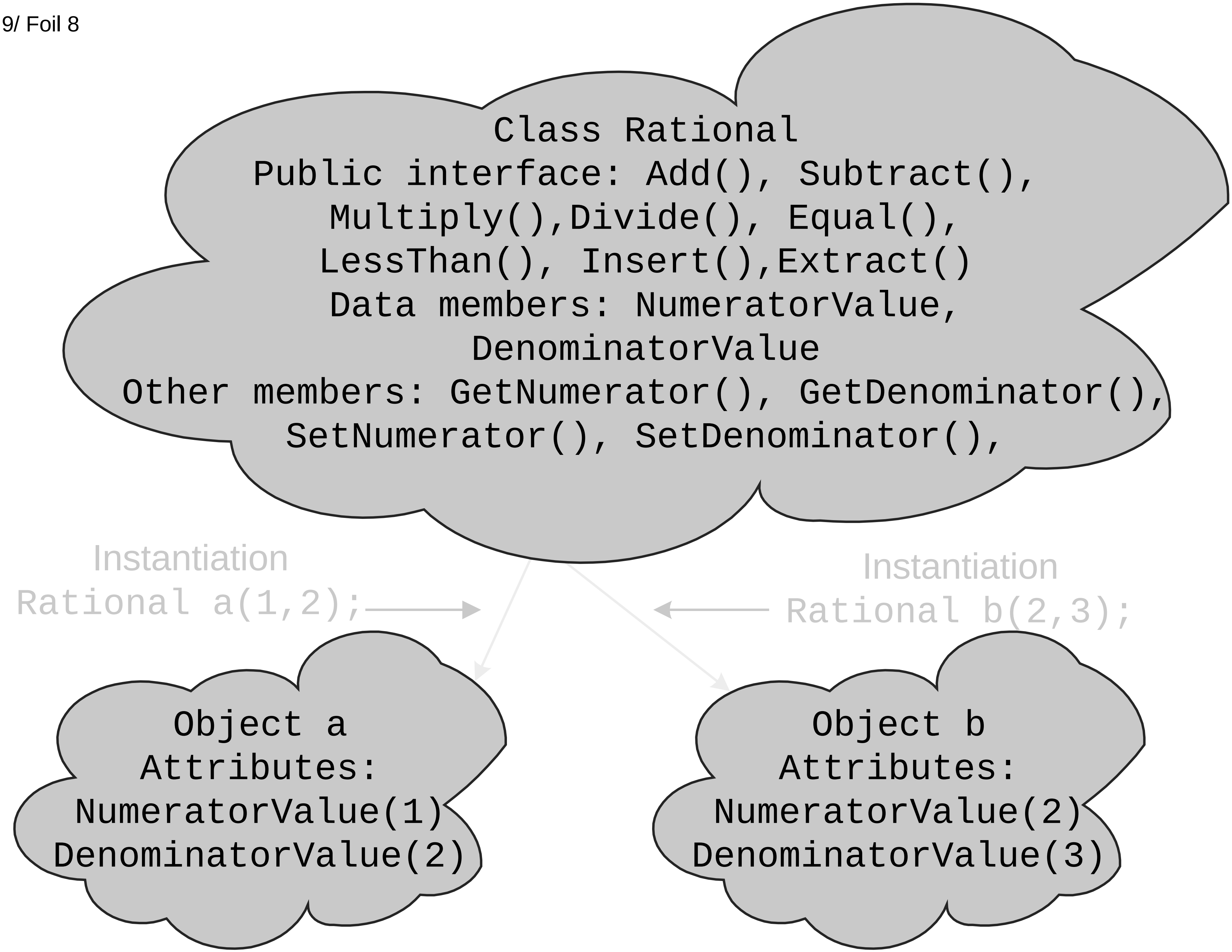
- Requirements
  - Represent a numerator and denominator
    - Implies in part a class representation with two **`int`** data members
      - NumeratorValue and DenominatorValue
      - Data members private to support information hiding
  - Public arithmetic behaviors (member functions)
    - Rational addition, subtraction, multiplication and division
  - Public relational behaviors
    - Equality and less than comparisons
      - Practice rule of class minimality

Rational Number Representation

- Other requirements
  - Public object behaviors
    - Construction
      - Default construction -- 0/1 -- design decision
      - Specific numerator and denominator construction
      - Copy construction (provided automatically)
    - Assignment (provided automatically)
    - Value insertion and extraction
  - Non-public object behaviors
    - Inspection and mutation of data members
      - Clients deal with a `Rational` object!

Rational Number Representation

- Other requirements
  - Auxiliary 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)

Consider

```
#include "rational.h"

Rational r;
Rational s;
cout << "Enter two rationals(a/b): ";
cin >> r >> s;
Rational t(r);
Rational Sum = r + s;
Rational Product = r * s;
cout << r << " + " << s << " = " << Sum;
cout << r << " * " << s << " = " << Product;
```

Implementation Components

- Header file
  - Define class and prototype library functions
    - rational.h
- Rational class implementation
  - Define member functions
    - rational.cpp
- Auxiliary function implementations
  - Define assisting functions that provide expected but non-member capabilities
    - rational.cpp

Rational ADT Header File

- File layout
  - Class definition and library prototypes nested within preprocessor statements
    - Ensures one inclusion per translation unit
  - Class definition proceeds 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
} ;
// auxiliary prototyping
```

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 Prototyping

```
// 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 ADT 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
- 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 u(2);   // u = 2/1 (why?)
      Rational t(2,3); // t = 2/3
                       // we'll be using t in
                       // future examples
```

Inspectors

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

Which object is being referenced?

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

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 Operators

```
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
```