17. Classes

Encapsulation, Classes, Member Functions, Constructors

A new Type with Functionality. . .

```
struct rational {
    int n;
    int d; // INV: d != 0
};

// POST: return value is the sum of a and b
rational operator+ (rational a, rational b)
{
    rational result;
    result.n = a.n * b.d + a.d * b.n;
    result.d = a.d * b.d;
    return result;
}
...
```

. . . should be in a Library!

`rational.h`:

- Definition of a struct `rational`
- Function declarations

`rational.cpp`:

- arithmetic operators (`operator+`, `operator+=`, ...)
- relational operators (`operator==`, `operator>`, ...)
- in/output (`operator >>`, `operator <<`, ...)

Thought Experiment

The three core missions of ETH:

- research

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We found a startup: RAT PACK®!

Thought Experiment

The three core missions of ETH:

- research
- education
- technology transfer

We found a startup: RAT PACK®!

- Selling the `rational` library to customers
- ongoing development according to customer's demands

The Customer is Happy

“Buying RAT PACK® has been a game-changing move to put us on the forefront of cutting-edge technology in social media engineering.”

B. Labla, CEO

The Customer is Happy

…and programs busily using `rational`.

The Customer is Happy

. . . and programs busily using `rational`.

- output as `double`-value ($\frac{3}{5} \rightarrow 0.6$)

The Customer is Happy

...and programs busily using `rational`.

- output as `double`-value $(\frac{3}{5} \to 0.6)$

```
// POST: double approximation of r
double to_double (rational r)
{
  double result = r.n;
  return result / r.d;
}
```

The Customer Wants More

“Can we have rational numbers with an extended value range?”

The Customer Wants More

"Can we have rational numbers with an extended value range?"

- Sure, no problem, e.g.:

```
struct rational {
  int n;
  int d;
};
```

⇒

```
struct rational {
  unsigned int n;
  unsigned int d;
  bool is_positive;
};
```

New Version of RAT PACK®

It sucks, nothing works any more!

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- What is the problem?

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$-\frac{3}{5}$ *is sometimes* 0.6, *this cannot be true!*

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- What is the problem?

$-\frac{3}{5}$ *is sometimes* 0.6, *this cannot be true!*

- That is your fault. Your conversion to `double` is the problem, our library is correct.

New Version of RAT PACK®

It sucks, nothing works any more!

- What is the problem?

$-\frac{3}{5}$ *is sometimes* 0.6*, this cannot be true!*

- That is your fault. Your conversion to `double` is the problem, our library is correct.

Up to now it worked, therefore the new version is to blame!

Liability Discussion

```
// POST: double approximation of r
double to_double (rational r){
  double result = r.n;
  return result / r.d;
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```

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struct rational {
  int n;
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. . . not correct using

```
struct rational {
  unsigned int n;
  unsigned int d;
  bool is_positive;
};
```

Liability Discussion

```
// POST: double approximation of r
double to_double (rational r){
  double result = r.n;
  return result / r.d;
}
```

`r.is_positive` and `result.is_positive` do not appear.

correct using...

```
struct rational {
  int n;
  int d;
};
```

... not correct using

```
struct rational {
  unsigned int n;
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We are to Blame!!

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- Customer sees and uses our representation of rational numbers (initially `r.n, r.d`)
- When we change it (`r.n, r.d, r.is_positive`), the customer's programs do not work anymore.
- No customer is willing to adapt the programs when the version of the library changes.

$\Rightarrow$ RAT PACK® is history...

Idea of Encapsulation (Information Hiding)

- A type is uniquely defined by its *value range* and its *functionality*

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↑

```
str.length(),
v.push_back(1),...
```

Classes

- provide the concept for encapsulation in C++

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- are a variant of structs

Classes

- provide the concept for encapsulation in C++
- are a variant of structs
- are provided in many object oriented programming languages

Encapsulation: `public` / `private`

```
class rational {
  int n;
  int d; // INV: d != 0
};
```

is used instead of `struct` if anything at all shall be “hidden”

Encapsulation: `public` / `private`

```
class rational {
  int n;
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};
```

is used instead of `struct` if anything at all shall be "hidden"

only difference

- `struct`: by default *nothing* is hidden
- `class` : by default *everything* is hidden

Encapsulation: `public` / `private`

```
class rational {
  int n;
  int d; // INV: d != 0
};
```

Application Code

```
rational r;
r.n = 1;      // error: n is private
r.d = 2;      // error: d is private
int i = r.n; // error: n is private
```

Encapsulation: `public` / `private`

```
class rational {
  int n;
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};
```

Good news: `r.d = 0` cannot happen any more by accident.

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rational r;
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Encapsulation: `public` / `private`

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class rational {
  int n;
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```

Good news: `r.d = 0` cannot happen any more by accident.

Bad news: the customer cannot do anything any more . . .

Application Code

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Encapsulation: `public` / `private`

```
class rational {
  int n;
  int d; // INV: d != 0
};
```

Good news: `r.d = 0` cannot happen any more by accident.

Bad news: the customer cannot do anything any more ...

... and we can't, either. (no `operator+`, ...)

Application Code

```
rational r;
r.n = 1;      // error: n is private
r.d = 2;      // error: d is private
int i = r.n; // error: n is private
```

Member Functions: Declaration

```
class rational {
public:
   // POST: return value is the numerator of this instance
   int numerator () const {
     return n;
   }
   // POST: return value is the denominator of this instance
   int denominator () const {
     return d;
   }
private:
   int n;
   int d; // INV: d!= 0
};
```

Member Functions: Declaration

public area

```
class rational {
public:
    // POST: return value is the numerator of this instance
    int numerator () const {
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public area

member function

Member Functions: Declaration

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    }
    // POST: return value is the denominator of this instance
    int denominator () const {
      return d;
    }
private:
    int n;
    int d; // INV: d!= 0
};
```

public area

member function

member functions have access to private data

Member Functions: Call

```
// Definition des Typs
class rational {
    ...
};
...
// Variable des Typs
rational r;

int n = r.numerator();    // Zaehler
int d = r.denominator(); // Nenner
```

member access

Member Functions: Definition

```
// POST: returns numerator of this instance
int numerator () const
{
  return n;
}
```

Member Functions: Definition ???

```
// POST: returns numerator of this instance
int numerator ()  const
{
  return n;
}
```

Member Functions: Definition

```
// POST: returns numerator of this instance
int numerator () const
{
  return n;                              r.numerator()
}
```

- A member function is called for an expression of the class.

Member Functions: Definition

```
// POST: returns numerator of this instance
int numerator () const
{
  return n;
}
```

`r.numerator()`

- A member function is called for an expression of the class. in the function, `this` is the name of this implicit argument.

Member Functions: Definition

```
// POST: returns numerator of this instance
int numerator ()  const
{
  return n;                          r.numerator()
}
```

- A member function is called for an expression of the class. in the function, `this` is the name of this implicit argument.
- const refers to the instance `this`

Member Functions: Definition

```
// POST: returns  numerator of this instance
int numerator () const
{
  return n;
}
```

`r.numerator()`

- A member function is called for an expression of the class. in the function, **this** is the name of this implicit argument.
- const refers to the instance **this**
- **n** is the shortcut for **this->n** (precise explanation of “->” next week)

const and Member Functions

```
class rational {
public:
  int numerator () const
  { return n; }
  void set_numerator (int N)
  { n = N;}
...
}
```

```
rational x;
x.set_numerator(10); // ok;
const rational y = x;
int n = y.numerator(); // ok;
y.set_numerator(10); // error;
```

The const at a member function is to promise that an instance cannot be changed via this function.

const items can only call const member functions.

Comparison

```
class rational {
    int n;
    ...
public:
    int numerator () const
    {
        return n;
    }
};

rational r;
...
std::cout << r.numerator();
```

Comparison

```
class rational {
    int n;
    ...
public:
    int numerator () const
    {
        return this->n;
    }
};

rational r;
...
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```

Comparison

Roughly like this it were ...

```
class rational {
    int n;
    ...
public:
    int numerator () const
    {
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    }
};

rational r;
...
std::cout << r.numerator();
```

Comparison

Roughly like this it were ...

```
class rational {
    int n;
    ...
public:
    int numerator () const
    {
        return this->n;
    }
};

rational r;
...
std::cout << r.numerator();
```

... without member functions

```
struct bruch {
    int n;
    ...
};

int numerator (const bruch& dieser)
{
    return dieser.n;
}

bruch r;
..
std::cout << numerator(r);
```

Member-Definition: In-Class

```
class rational {
    int n;
    ...
public:
    int numerator () const
    {
        return n;
    }
    ....
};
```

- No separation between declaration and definition (bad for libraries)

Member-Definition: In-Class vs. Out-of-Class

```
class rational {
    int n;
    ...
public:
    int numerator () const
    {
        return n;
    }
    ....
};
```

- No separation between declaration and definition (bad for libraries)

```
class rational {
    int n;
    ...
public:
    int numerator () const;
    ...
};

int rational::numerator () const
{
  return n;
}
```

- This also works.

Initialisation? Constructors!

```
class rational
{
public:
    rational (int num, int den)
        : n (num), d (den)
    {
        assert (den != 0);
    }
 ...
};
 ...
rational r (2,3); // r = 2/3
```

Initialisation? Constructors!

```
class rational
{
public:
    rational (int num, int den)
        : n (num), d (den)      ← Initialization of the member variables
    {
        assert (den != 0);      ← function body.
    }
...
};
...
rational r (2,3); // r = 2/3
```

Initialisation "rational = int"?

```
class rational
{
public:
    rational (int num)
        : n (num), d (1)
    {}
...
};
...
rational r (2);    // explicit initialization with 2
rational s = 2;    // implicit conversion
```

Initialisation “rational = int”?

```
class rational
{
public:
    rational (int num)
        : n (num), d (1)
    {}    ←—— empty function body
...
};
...
rational r (2);    // explicit initialization with 2
rational s = 2;    // implicit conversion
```

The Default Constructor

```
class rational
{
public:
    ...
    rational ()
        : n (0), d (1)
    {}
...
};
...
rational r;    // r = 0
```

empty list of arguments

The Default Constructor

```
class rational
{
public:
     ...
     rational ()
        : n (0), d (1)
     {}
...
};
...
rational r;     // r = 0
```

empty list of arguments

⇒ There are no uninitiatlized variables of type rational any more!

Alterantively: Deleting a Default Constructor

```
class rational
{
public:
    ...
    rational () = delete;
...
};
...
rational r;    // error: use of deleted function 'rational::rational()
```

⇒ There are no uninitiatlized variables of type rational any more!

RAT PACK® Reloaded ...

Customer's program now looks like this:

```
// POST: double approximation of r
double to_double (const rational r)
{
  double result = r.numerator();
  return result / r.denominator();
}
```

RAT PACK® Reloaded ...

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// POST: double approximation of r
double to_double (const rational r)
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  double result = r.numerator();
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}
```

- We can adapt the member functions together with the representation ✓

RAT PACK® Reloaded ...

before

```
class rational {
...
private:
  int n;
  int d;
};
```

RAT PACK® Reloaded ...

before

```
class rational {
...
private:
  int n;
  int d;
};
```

```
int numerator () const
{
  return n;
}
```

RAT PACK® Reloaded ...

before

```
class rational {
...
private:
  int n;
  int d;
};
```

```
int numerator () const
{
  return n;
}
```

after

```
class rational {
...
private:
  unsigned int n;
  unsigned int d;
  bool is_positive;
};
```

RAT PACK® Reloaded ...

before

```
class rational {
...
private:
  int n;
  int d;
};
```

```
int numerator () const
{
  return n;
}
```

after

```
class rational {
...
private:
  unsigned int n;
  unsigned int d;
  bool is_positive;
};
```

```
int numerator () const{
  if (is_positive)
    return n;
  else {
    int result = n;
    return −result;
  }
}
```

RAT PACK® Reloaded ?

```
class rational {
...
private:
  unsigned int n;
  unsigned int d;
  bool is_positive;
};
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RAT PACK® Reloaded ?

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}
```

- value range of nominator and denominator like before

RAT PACK® Reloaded ?

```
class rational {
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private:
  unsigned int n;
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};
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```
int numerator () const
{
  if (is_positive)
    return n;
  else {
    int result = n;
    return −result;
  }
}
```

- value range of nominator and denominator like before
- possible overflow in addition

Encapsulation still Incompleete

Customer's point of view (`rational.h`):

```
class rational {
public:
   // POST: returns numerator of *this
   int numerator () const;
   ...
private:
  // none of my business
};
```

Encapsulation still Incompleete

Customer's point of view (rational.h):

```
class rational {
public:
   // POST: returns numerator of *this
   int numerator () const;
   ...
private:
  // none of my business
};
```

- We determined denominator and nominator type to be `int`

Encapsulation still Incompleete

Customer's point of view (rational.h):

```
class rational {
public:
   // POST: returns numerator of *this
   int numerator () const;
   ...
private:
  // none of my business
};
```

- We determined denominator and nominator type to be `int`
- Solution: encapsulate not only data but alsoe types.

Fix: “our” type rational::integer

Customer’s point of view (rational.h):

```
public:
   using integer = long int; // might change
   // POST: returns numerator of *this
   integer numerator () const;
```

Fix: “our” type `rational::integer`

Customer’s point of view (`rational.h`):

```
public:
   using integer = long int; // might change
   // POST: returns numerator of *this
   integer numerator () const;
```

- We provide an additional type!

Fix: "our" type rational::integer

Customer's point of view (rational.h):

```
public:
    using integer = long int; // might change
    // POST: returns numerator of *this
    integer numerator () const;
```

- We provide an additional type!
- Determine only Functionality, e.g:
    - implicit conversion int → rational::integer

Fix: “our” type `rational::integer`

Customer’s point of view (`rational.h`):

```
public:
   using integer = long int; // might change
   // POST: returns numerator of *this
   integer numerator () const;
```

- We provide an additional type!
- Determine only Functionality, e.g:
  - implicit conversion `int` $\rightarrow$ `rational::integer`
  - function `double to_double (rational::integer)`

RAT PACK® Revolutions

Finally, a customer program that remains stable

```
// POST: double approximation of r
double to_double (const rational r)
{
  rational::integer n = r.numerator();
  rational::integer d = r.denominator();
  return to_double (n) / to_double (d);
}
```