

18. Structs and Classes I

Rational Numbers, Struct Definition, Overloading Functions and Operators, Const-References, Encapsulation

Calculating with Rational Numbers

- Rational numbers (\mathbb{Q}) are of the form $\frac{n}{d}$ with n and d in \mathbb{Z}
- C++ does not provide a built-in type for rational numbers

Goal

We build a C++-type for rational numbers ourselves! 😊

Vision

How it could (will) look like

```
// input
std::cout << "Rational number r =? ";
rational r;
std::cin >> r;
std::cout << "Rational number s =? ";
rational s;
std::cin >> s;

// computation and output
std::cout << "Sum is " << r + s << ".\n";
```

A First Struct

```
struct rational {
    int n; ← member variable (numerator)
    int d; ← // INV: d != 0
};
```

Invariant: specifies valid value combinations (informal).

member variable (denominator)

- struct defines a new *type*
- formal range of values: *cartesian product* of the value ranges of existing types
- real range of values: $\text{rational} \subsetneq \text{int} \times \text{int}$.

Accessing Member Variables

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

rational add (rational a, rational b)
{
    rational result;
    result.n = a.n * b.d + a.d * b.n;
    result.d = a.d * b.d;
    return result;
}
```

$$\frac{r_n}{r_d} := \frac{a_n}{a_d} + \frac{b_n}{b_d} = \frac{a_n \cdot b_d + a_d \cdot b_n}{a_d \cdot b_d}$$

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A First Struct: Functionality

A struct defines a new *type*, not a *variable*!

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

Meaning: every object of the new type is represented by two objects of type `int` the objects are called `n` and `d`.

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

member access to the `int` objects of `a`.

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Input

```
// Input r
rational r;
std::cout << "Rational number r:\n";
std::cout << " numerator =? ";
std::cin >> r.n;
std::cout << " denominator =? ";
std::cin >> r.d;

// Input s the same way
rational s;
...
```

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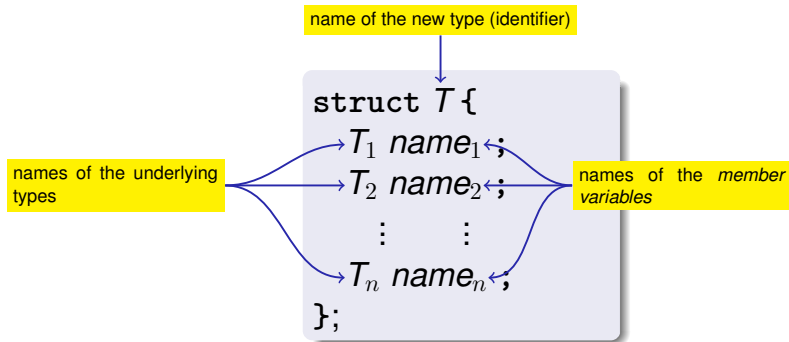
Vision comes within Reach ...

```
// computation
const rational t = add (r, s);

// output
std::cout << "Sum is " << t.n << "/" << t.d << ".\n";
```

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Struct Definitions



Range of Values of T : $T_1 \times T_2 \times \dots \times T_n$

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Struct Definitions: Examples

```
struct rational_vector_3 {  
    rational x;  
    rational y;  
    rational z;  
};
```

underlying types can be fundamental or **user defined**

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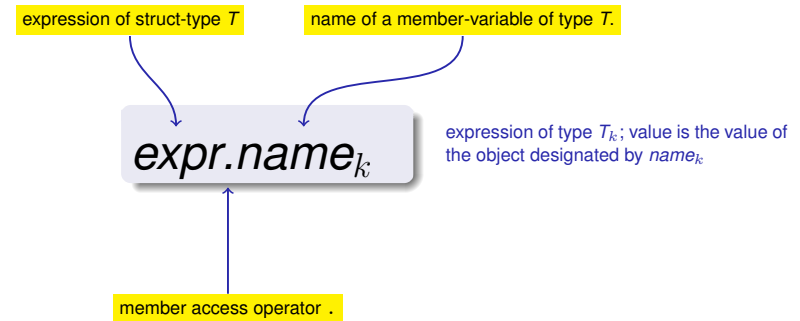
Struct Definitions: Examples

```
struct extended_int {  
    // represents value if is_positive==true  
    // and -value otherwise  
    unsigned int value;  
    bool is_positive;  
};
```

the underlying types can be **different**

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Structs: Accessing Members



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Structs: Initialization and Assignment

Default Initialization:

```
rational t;
```

- Member variables of `t` are default-initialized
- for member variables of fundamental types nothing happens (values remain undefined)

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Structs: Initialization and Assignment

Initialization:

```
rational t = {5, 1};
```

- Member variables of `t` are initialized with the values of the list, according to the declaration order.

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Structs: Initialization and Assignment

Assignment:

```
rational s;  
...  
rational t = s;
```

- The values of the member variables of `s` are assigned to the member variables of `t`.

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Structs: Initialization and Assignment

```
t.n = add(r, s).n ;  
t.d = add(r, s).d ;
```

Initialization:

```
rational t = add(r, s);
```

- `t` is initialized with the values of `add(r, s)`

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Structs: Initialization and Assignment

Assignment:

```
rational t;  
t = add (r, s);
```

- t is default-initialized
- The value of add (r, s) is assigned to t

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Structs: Initialization and Assignment

```
rational s; ← member variables are uninitialized  
rational t = {1,5}; ← member-wise initialization:  
                    t.n = 1, t.d = 5  
rational u = t; ← member-wise copy  
t = u; ← member-wise copy  
rational v = add (u,t); ← member-wise copy
```

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Comparing Structs?

For each fundamental type (int, double, ...) there are comparison operators == and !=, not so for structs! Why?

- member-wise comparison does not make sense in general...
- ...otherwise we had, for example, $\frac{2}{3} \neq \frac{4}{6}$

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Structs as Function Arguments

```
void increment(rational dest, const rational src)  
{  
    dest = add (dest, src); // modifies local copy only  
}
```

Call by Value !

```
rational a;  
rational b;  
a.d = 1; a.n = 2;  
b = a;  
increment (b, a); // no effect!  
std::cout << b.n << "/" << b.d; // 1 / 2
```

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Structs as Function Arguments

```
void increment(rational & dest, const rational src)
{
    dest = add (dest, src);
}
```

Call by Reference

```
rational a;
rational b;
a.d = 1; a.n = 2;
b = a;
increment (b, a);
std::cout << b.n << "/" << b.d; // 2 / 2
```

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User Defined Operators

Instead of

```
rational t = add(r, s);
```

we would rather like to write

```
rational t = r + s;
```

This can be done with *Operator Overloading*.

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Overloading Functions

- Functions can be addressed by name in a scope
- It is even possible to declare and to defined several functions with the same name
- the “correct” version is chosen according to the *signature* of the function.

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Function Overloading

- A function is defined by name, types, number and order of arguments

```
double sq (double x) { ... } // f1
int sq (int x) { ... } // f2
int pow (int b, int e) { ... } // f3
int pow (int e) { return pow (2,e); } // f4
```

- the compiler automatically chooses the function that fits “best” for a function call (we do not go into details)

```
std::cout << sq (3); // compiler chooses f2
std::cout << sq (1.414); // compiler chooses f1
std::cout << pow (2); // compiler chooses f4
std::cout << pow (3,3); // compiler chooses f3
```

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Operator Overloading

- Operators are special functions and can be overloaded
- Name of the operator *op*:

`operatorop`

- we already know that, for example, `operator+` exists for different types

Adding rational Numbers – Before

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

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Adding rational Numbers – After

```
// 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;
}
...
const rational t = r + s;
```

↑
infix notation

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Other Binary Operators for Rational Numbers

```
// POST: return value is difference of a and b
rational operator- (rational a, rational b);

// POST: return value is the product of a and b
rational operator* (rational a, rational b);

// POST: return value is the quotient of a and b
// PRE: b != 0
rational operator/ (rational a, rational b);
```

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Unary Minus

has the same symbol as the binary minus but only one argument:

```
// POST: return value is -a
rational operator- (rational a)
{
    a.n = -a.n;
    return a;
}
```

Comparison Operators

are not built in for structs, but can be defined

```
// POST: returns true iff a == b
bool operator==(rational a, rational b)
{
    return a.n * b.d == a.d * b.n;
}
```

$$\frac{2}{3} = \frac{4}{6} \quad \checkmark$$

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Arithmetic Assignment

We want to write

```
rational r;
r.n = 1; r.d = 2;           // 1/2

rational s;
s.n = 1; s.d = 3;         // 1/3

r += s;
std::cout << r.n << "/" << r.d; // 5/6
```

Operator+= First Trial

```
rational operator+= (rational a, rational b)
{
    a.n = a.n * b.d + a.d * b.n;
    a.d *= b.d;
    return a;
}
```

does not work. Why?

- The expression `r += s` has the desired value, but because the arguments are R-values (call by value!) it does not have the desired effect of modifying `r`.
- The result of `r += s` is, against the convention of C++ no L-value.

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Operator +=

```
rational& operator+= (rational& a, rational b)
{
    a.n = a.n * b.d + a.d * b.n;
    a.d *= b.d;
    return a;
}
```

this works

- The L-value a is increased by the value of b and returned as L-value

r += s; now has the desired effect.

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In/Output Operators

can also be overloaded.

- Before:

```
std::cout << "Sum is "
           << t.n << "/" << t.d << "\n";
```

- After (desired):

```
std::cout << "Sum is "
           << t << "\n";
```

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In/Output Operators

can be overloaded as well:

```
// POST: r has been written to out
std::ostream& operator<< (std::ostream& out,
                        rational r)
{
    return out << r.n << "/" << r.d;
}
```

writes r to the output stream
and returns the stream as L-value.

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Input

```
// PRE: in starts with a rational number
// of the form "n/d"
// POST: r has been read from in
std::istream& operator>> (std::istream& in,
                        rational& r)
{
    char c; // separating character '/'
    return in >> r.n >> c >> r.d;
}
```

reads r from the input stream
and returns the stream as L-value.

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Goal Attained!

```
// input
std::cout << "Rational number r =? ";
rational r;
std::cin >> r;

std::cout << "Rational number s =? ";
rational s;
std::cin >> s;

// computation and output
std::cout << "Sum is " << r + s << ".\n";
```

operator >>

operator +

operator <<

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Recall: Large Objects ...

```
struct SimulatedCPU {
    unsigned int pc;
    int stack[16];
    unsigned int stackPosition;
    unsigned int memory[65536];
};

void outputState (SimulatedCPU p) {
    std::cout << "pc=" << p.pc;
    std::cout << ", stack: ";
    for (unsigned int i = p.stackPosition; i != 0; --i)
        std::cout << p.stack[i-1];
}
```

call by value: more than 256k get copied!

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... are Better Passed as Const-Reference

```
struct SimulatedCPU {
    unsigned int pc;
    int stack[16];
    unsigned int stackPosition;
    unsigned int memory[65536];
};

void outputState (const SimulatedCPU& p) {
    std::cout << "pc=" << p.pc;
    std::cout << ", stack: ";
    for (int i = p.stackPosition; i != 0; --i)
        std::cout << p.stack[i-1];
}
```

call by reference: only the address gets copied.

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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;
}

...
```

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... 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 <<`, ...)

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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

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The Customer is Happy

... and programs busily using `rational`.

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

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

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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;
};
```

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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!



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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;
    unsigned int d;
    bool is_positive;
};
```

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We are to Blame!!

- 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.

⇒ RAT PACK® is history...

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Idea of Encapsulation (Information Hiding)

- A type is uniquely defined by its *value range* and its *functionality*
- The **representation** should **not be visible**.
- ⇒ The customer is not provided with **representation** but with **functionality!**

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

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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"

only difference

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