

Course 1-2 : class basics

main.cpp

```
#include <stdio.h>
#include <iostream>

// int main()
// {
//     printf("Hello world\n");
//     return 0;
// }

class compteur {
public:
    int cpt;

    compteur() : cpt(0) {
        printf("%s called: cpt: %d, size: %zu\n", __PRETTY_FUNCTION__, cpt, sizeof(*this));
    }

    int inc() {
        printf("    compteur() +1 inc\n");
        cpt++;
        return cpt;
    };
};

class pairCompteur : public compteur {
protected:
    int cpt;
public:
    pairCompteur() : cpt(1) {
        printf("    %s called: cpt: %d, size: %zu\n", __PRETTY_FUNCTION__, cpt, sizeof(*this));
    }

    int inc() {
        printf("    pairCompteur() +2 inc\n");
        compteur::inc();
        reinterpret_cast<compteur &>(*this).inc();
        return cpt;
    };
};

class doublepairCompteur : protected pairCompteur {
    int cpt;
public:
    // pairCompteur::cpt; // conflict with above, but allows to change visibility

    doublepairCompteur() : cpt(2) {
        printf("    %s called: cpt: %d, size: %zu\n", __PRETTY_FUNCTION__, cpt, sizeof(*this));
    }

    int inc() {
```

```

    printf("doublepairCompteur() +4 inc\n");
    pairCompteur::inc();
    pairCompteur::inc();
    return cpt;
};
int inc2() {
    printf("doublepairCompteur() +8 inc\n");
    pairCompteur::inc();
    pairCompteur::inc();
    pairCompteur::inc();
    reinterpret_cast<pairCompteur &>(*this).inc(); // Dirty, but works too
    return cpt;
};
// int getCpt() const { return cpt; };
// int getCpt() const { return this->cpt; };
// int getCpt() const { return doublepairCompteur::cpt; };
// int getCpt() const { return pairCompteur::cpt; };
int getCpt() const { return compteur::cpt; };
};

typedef int (doublepairCompteur::* t_doubleInc)(void); // Pointer on member function

int main()
{
    unsigned char c = 255;
    int i = c;

    doublepairCompteur cpt;

    t_doubleInc inc = &doublepairCompteur::inc2;

    printf("i == %d\n", i);

    cpt.inc();
    // std::cout << "cpt value: " << cpt.cpt << std::endl; // compile error with doublepair class
    std::cout << "cpt value: " << cpt.getCpt() << std::endl;

    (cpt).inc();
    // std::cout << "cpt value: " << cpt.cpt << std::endl; // compile error with doublepair class
    std::cout << "cpt value: " << cpt.getCpt() << std::endl;

    (cpt.*inc)(); // Same as above but with function pointer
    std::cout << "cpt value: " << cpt.getCpt() << std::endl;

    (cpt.*inc)();
    std::cout << "cpt value: " << cpt.getCpt() << std::endl;
}

```

Resources

- **Constructor and destructors:** <https://isocpp.org/wiki/faq/ctors>
- **Special members / default class methods:** <https://cplusplus.com/doc/tutorial/classes2/>
- **Copy constructors:** https://en.cppreference.com/w/cpp/language/copy_constructor
- **Move operator:** https://en.cppreference.com/w/cpp/language/move_assignment

- **Implicitly declared Ctors/Dtors:** https://en.cppreference.com/w/cpp/language/default_constructor

Course 3 : Templates

Source files

main.cpp

```
#include <iostream>
#include <cstdbool>
#include <cstdio>
#include "concatDigits.hh"

// See https://accu.org/journals/overload/9/43/frogley\_442/
template<class valueT> // Custom traits / properties
struct numeric_traits
{
public:
    bool hasFractionalParts = false;
    template<class T>
    static valueT append(valueT aValue, T aDigit)
    {
        return aValue * 10 + aDigit;
    }
};

template<> struct numeric_traits<float>
{
public:
    bool hasFractionalParts = true;
    template<class T>
    static float append(float aValue, T aDigit)
    {
        char buffer[20];
        int len = snprintf(buffer, sizeof(buffer), "%f", aValue);
        int lastDigitPos = 0;

        for (auto i = len - 1 ; i > 0 and buffer[i] == '0' ; --i)
            lastDigitPos = i;
        buffer[lastDigitPos] = aDigit + '0';
        buffer[lastDigitPos + 1] = '\0';

        printf("%s: aValue = %f, aDigit = %f, buffer = %s\n", __PRETTY_FUNCTION__, aValue, aDigit, buffer);
        return atof(buffer);
    }
};

template<typename T1, typename T2, typename traits = numeric_traits<T1>>
T1 concatDigitsFullGeneric(T1 aValue, T2 aDigit, traits* = nullptr)
{
    if(aDigit < 0 || aDigit > 10)
        throw std::overflow_error("Is not a digit");
    return traits::append(aValue, aDigit);
}

int main()
```

```

{
    int val = 123;
    int newDigit = 5;

    printf("%d + %d -> %d\n",
        val, newDigit,
        concatDigits(val, newDigit));
    printf("%d + %d -> %d\n",
        val, newDigit,
        concatDigitsGeneric(val, newDigit));

    float fval = 12.34;
    float newfDigit = 5;
    printf("%f + %d -> %f\n", fval, newDigit, concatDigitsGeneric(fval, newfDigit));
    printf("%f + %d -> %f\n", fval, newDigit, concatDigitsFullGeneric(fval, newfDigit));

    return 0;
}

```

concatDigits.cpp

```
#include <stdexcept>
#include "concatDigits.hh"

int concatDigits(int nb, int newDigit) {
    if (!(0 <= newDigit && newDigit <= 9))
        throw std::overflow_error("Is not a digit");
    return nb * 10 + newDigit % 10;
}

size_t concatDigits(size_t nb, size_t newDigit) {
    if (!(newDigit <= 9))
        throw std::overflow_error("Is not a digit");
    return nb * 10 + newDigit % 10;
}

template <typename T> T concatDigits(T nb, T newDigit) {
    if (!(0 <= newDigit && newDigit <= 9))
        throw std::overflow_error("Is not a digit");
    return nb * 10 + newDigit % 10;
}

// GENERIC VERSION: char, short, int, size_t, float, etc
template <typename T> T concatDigitsGeneric(T nb, T newDigit) {
    return nb * 10 + newDigit % 10; // Doesn't work with floats (modulo is not supported)
}

// float (specialization, for "float", use this one instead of the generic)
template <> float concatDigitsGeneric(float nb, float newDigit) {
    char buffer[20];
    int len = snprintf(buffer, sizeof(buffer), "%f", nb);
    int lastDigitPos = 0;

    for (auto i = len - 1 ; i > 0 and buffer[i] == '0' ; --i)
        lastDigitPos = i;
    buffer[lastDigitPos] = newDigit + '0';
    buffer[lastDigitPos + 1] = '\0';

    printf("%s: nb = %f, newDigit = %f, buffer = %s\n", __PRETTY_FUNCTION__, nb, newDigit, buffer);
    return atof(buffer);
}

// double (same as float, but we redo the work ...)
template <> double concatDigitsGeneric(double nb, double newDigit) {
    (void)nb; // To suppress the "unused parameter" warning
    (void)newDigit;
    return 0; // Have to duplicate code ... ugly, and error prone
}

template int concatDigitsGeneric<int>(int, int); // Explicit instantiation
template float concatDigitsGeneric<float>(float, float); // Explicit instantiation
template double concatDigitsGeneric<double>(double, double); // Explicit instantiation
```

concatDigits.hh

```
#ifndef CONCAT_DIGITS_HH
# define CONCAT_DIGITS_HH

int concatDigits(int nb, int newDigit);

template <typename T>
T concatDigitsGeneric(T nb, T newDigit);

// template <typename T>
// inline T const& Max (T const& a, T const& b) {
//     return a < b ? b : a;
// }

#endif // !CONCAT_DIGITS_HH
```

Makefile

```
TARGET := concatDigit

SRCS := main_template.cpp concatDigits.cpp
OBJS := $(SRCS:.cpp=.o)

CXXFLAGS += -W -Wall -Wextra -std=c++2a -g3

all: $(TARGET)

$(TARGET): $(OBJS)
    $(CXX) $(CXXFLAGS) $^ -o $@

clean:
    -rm -f $(OBJS)

fclean: clean
    -rm -f $(TARGET)

re: fclean all

test: main_test.o
    $(CXX) $(CXXFLAGS) $^ -o $@
    -$$@

.PHONY: all clean fclean re test
```

```
cd "/home/1laurenj/Ensta/Cours ensta IN204/Session 1/cours_3_templates/"
make re
./concatDigit
```

```
## rm -f main_template.o concatDigits.o
## rm -f concatDigit
## g++ -W -Wall -Wextra -std=c++2a -g3 -c -o main_template.o main_template.cpp
## g++ -W -Wall -Wextra -std=c++2a -g3 -c -o concatDigits.o concatDigits.cpp
## g++ -W -Wall -Wextra -std=c++2a -g3 main_template.o concatDigits.o -o concatDigit
## 123 + 5 -> 1235
## 123 + 5 -> 1235
## T concatDigitsGeneric(T, T) [with T = float]: nb = 12.340000, newDigit = 5.000000, buffer = 12.345
## 12.340000 + 5 -> 12.345000
## static float numeric_traits<float>::append(float, T) [with T = float]: aValue = 12.340000, aDigit = 5
## 12.340000 + 5 -> 12.345000
```


Séance 4 : The STL: containers and iterators

Resources

- **Containers** <https://isocpp.org/wiki/faq/containers>
- **iterators**: <https://cplusplus.com/reference/iterator/>
- **Full STL documentation**: https://www.cppreference.com/Cpp_STL_ReferenceManual.pdf

Summary of the session:

- Writing a wrapper around an int and char array[];

```
template <typename T = int /* default */>
class number {
private:
    T c;
public:

    typedef T value_type;

    // main.c: number N1(0); // 1
    // main.c: number N2(N1); // 2
    // main.c: number N; // 3
    /* 1 */ number(T const & val) : c(val) {}
    /* 2 */ number(number const & other)
        : c(other.get()) {}
    /* 3 */ number() : c(0) {}

    /* Regular getter/setter */

    T get(/*this,*/ void) const {
        return (c);
    }

    T set(T const & newVal) {
        this->c = newVal;
        return (this->get());
    }

    T set(number const & newVal) {
        this->newVal;
        return (this->get());
    }
};
```

```
/*
** See https://cplusplus.com/reference/array/array/
**
** Template on type T and size S
** size_t is also std::size_t
*/
template <typename T, size_t S>
class myArray {
private:
    T _buffer[S]; // Abstracted array here
public:
    void fill( const T & value ) {
        for (size_t i = 0 ; i < S ; ++i)
            _buffer[i] = value;
    }

    // Regular const getter
    T & get(size_t pos) const {
        return _buffer[pos];
    }

    // operator[] overload (const and non-const)
    // called with: `a[5]`, or `a.operator[](5)`
    T & operator[](size_t pos) {
        return _buffer[pos];
    }

    T const & operator[](size_t pos) const {
        return _buffer[pos];
    }

    size_t size() const { return S; }
};
```

Séance 5 : Operators and streams

Class abstract/wrap features and implement additional functions on it, moreover, unlike **struct** they are considered as a type on its own in the same way as an **int** or **float**

```
template <typename T>
void doStuff(T a, T b) {
    T result = 0;

    a = a + 5;
    a = b * 2;
    result = a + a + a + a + a;
    // etc...
}
```

1. ``DoStuff()`` is a basic function doing arithmetic
2. We should be able to do that with any type
* ``int``, ``short``, ``float``, ``Class Number``
3. Including more complexe one
* ``char *``, ``char &``: Pointers/ref are also a type
* ``char const *(*)(T short, ...)`` complexeStuff

Main example:

```
#include <iostream>
#include "number.hpp" // Implement this

template <typename T>
void doStuff(T a, T const &pi, int b) {
    T result = b;
    std::string token;
    int tokenCount = 0;

    a.set(a.get() + 5);
    a += pi * 2 + a;
    result = (a += pi) + a + a + a;
    std::cout << result.get() << std::endl; // Getter version (only work with classes)
    std::cout << result << std::endl; // overload version (fully generic)

    for (tokenCount = 0 ; std::operator>>(std::cin, token) ; ++tokenCount); // Complete form
    for (tokenCount = 0 ; operator>>(std::cin, token) ; ++tokenCount); // Simple form
    for (tokenCount = 0 ; std::cin >> token ; ++tokenCount); // Operator form
    std::cout << "found 0" << std::oct << tokenCount << " tokens in the istream (base 8)" << std::endl;
    std::cout << "found " << std::dec << tokenCount << " tokens in the istream (base 10)" << std::endl;
    std::cout << "found 0x" << std::hex << tokenCount << " tokens in the istream (base 16)" << std::endl;
}

int main() {
    number nInt = 0;
    number<float> nFloat(1.337);
    number<int> pi = 314;

    doStuff(nInt, pi, (int)nInt);
}
```

Exercise

Upgrade the **class Number** to support operators so it works with the `DoStuff()` function

Complete class Number implementation:

```
#include <ostream> // iostream contains too much, we only need the "output" part

template <typename T = int /* default */>
class number {
private:
    T c;
public:
    /* 1 */ number(T const & val) : c(val) {}
    /* 2 */ number(number const & other) : c(other.get()) {}
    /* 3 */ number() : c(0) {}
    /* Operator overload */
    // One-liners (can return T too, because we can construct with it if needed)
    // T      operator+(T const &v) const {return c + v;} // Local scope
    number<T> operator+(number<T> const &o) const {return c + o.c;} // Local scope
    template <typename T1> friend T operator+ (int, number<T1> const & o); // Parent scope

    // This will not compile if we do "a += b * 2 + a;"
    // That's why we need to return this
    // T      operator+(number<T> const &o) const {return c + o.c;}
    number<T> operator*(T const &v) const {return c * v;}

    // Several cases (each returning `*this` to allow a chain of operation):
    // * Regular return
    // * one liner with operator '+', '*'
    // * reuse of operator=(T const &v)
    number<T> & operator+=(T const &v) { this->c += v; return (*this); }
    number<T> & operator+=(number<T> const &o) { return (c += o.c, *this); }
    number<T> & operator=(T const &v) {return (c = v, *this); }
    number<T> & operator=(number<T> const &o) { return ((*this = o.c), *this); } // Reuse ^

    // Cast operators (adding explicit to deny implicit cast, for the exercise)
    explicit operator int () const { return c; }

    /* Regular getter/setter */
    T get(/*this,*/ void) const {return c;}
    T set(T const & newVal) {this->c = newVal; return (this->get()); }
    T set(number const & newVal) { this->newVal; return (this->get()); }

    // Over operator<<(): See https://isocpp.org/wiki/faq/input-output#output-operator
    template <typename T1> // Declare external function as friend
    friend std::ostream& operator<< (std::ostream& out, number<T1> const & o);
};

template <typename T> // Implement function
T operator+ (int a, number<T> const & o){return a + o.c;}

template <typename T> // Implement function
std::ostream& operator<< (std::ostream& out, number<T> const & o)
{
    out << "MyValue is: " << o.c; // Can use private directly because of friend
    return out;
}
```

Makefile used

```
TARGET := a.out

SRCS := main.cpp
OBJS := $(SRCS:.cpp=.o)

CXXFLAGS += -W -Wall -Wextra -std=c++17 -g3

all: $(TARGET)

$(TARGET): $(OBJS)
    $(CXX) $(CXXFLAGS) $^ -o $@

clean:
    -rm -f $(OBJS)

fclean: clean
    -rm -f $(TARGET)

re: fclean all

test: main_test.o
    $(CXX) $(CXXFLAGS) $^ -o $@
    -$$@

.PHONY: all clean fclean re test

cd "/home/1laurenj/Ensta/Cours ensta IN204/Session 1/cours_5_operator_stream/"
make re
echo "1 2 3 abcd 5 6 1337 8 9 10 11 12 13 14 15 16 17 18 19 20" | ./a.out

## rm -f main.o
## rm -f a.out
## g++ -W -Wall -Wextra -std=c++17 -g3 -c -o main.o main.cpp
## g++ -W -Wall -Wextra -std=c++17 -g3 main.o -o a.out
## 3808
## MyValue is: 3808
## found 00 tokens in the istream (base 8)
## found 0 tokens in the istream (base 10)
## found 0x0 tokens in the istream (base 16)
```

Resources

Main Resources:

- **Basic rules and idioms for operator overload:**
 - <https://stackoverflow.com/questions/4421706/what-are-the-basic-rules-and-idioms-for-operator-overloading>
- **Operators:**
 - **Operators:** https://en.cppreference.com/w/cpp/language/operator_precedence
 - **Operators:** https://cs.smu.ca/~porter/csc/ref/cpp_operators.html
 - **IO Tutorial:** <https://www.learncpp.com/cpp-tutorial/overloading-the-io-operators/>
 - **IO Overload:** <https://isocpp.org/wiki/faq/operator-overloading>
- **IOLibrary:** <https://cplusplus.com/reference/iolibrary/>
- **IStream:** <https://isocpp.org/wiki/faq/input-output>

Séance 6 : C++20: Contracts, specialization and advanced notions

Current course progress reminder:

IN204 : *Programmation Objet & Génie Logiciel*

- ☒ **Séance 1** : Introduction aux objets
- ☒ **Séance 2** : Dérivation & Héritage
- ☒ **Séance 3** : Les Modèles & la Généricité
- ☒ **Séance 4** : The STL: containers and iterators
- ☒ **Séance 5** : Operators and streams**
- ☐ -
- ☐ **Séance 6: C++20: Contracts, specialization and advanced notions** <- We are here
- ☐ -
- ☐ **Séance 7** : Les exceptions
- ☐ **Séance 8** : L'héritage et le polymorphisme
- ☐ **Séance 9** : Parallélisme & Programmation Asynchrone
- ☐ **Séance 10** : Evaluation au moment de la compilation

Source files

main.cpp

```
#include <iostream> /* std::cout */
#include "defines.hpp" /* For the LOG and LOG_DECL_VAR macro */
#include "prototypes.hpp" /* For the LOG and LOG_DECL_VAR macro */
#include "codelocks.hpp" // Implement this

////////////////////////////////////
// Toying with concepts

void test_concepts() {
    int i = 1;
    float f = 2.2;
    double d = 4.4;
    custom::Vector v{1,2,3};

    // To remove the "unused variable" warning
    // (we explicitly assess that it is not used, useful when generating code sometime)
    (void)v;

    regular_add(i, i); // Regular C call
    template_add(i, i); // Deduce template from parameter (int)
    template_add(f, f); // `` `` `` (float)
    template_add<float>(f, f); // Explicit call of one version

    concept_add_long(i, i); // Also deduce from parameter but using concept
    concept_add_long(f, f); //
    concept_add_long(d, d); //

    concept_add_short(i, i); // Also deduce from parameter but using concept
    concept_add_short(f, f); //
    concept_add_short(d, d); //

    concept_add_short(v, v); //

    // concept_add(v, v); // Concept compiler error
}

////////////////////////////////////
// Toying with codelocks

namespace cc = ::IN204::codeCrackingExo; // https://en.cppreference.com/w/cpp/language/namespace_alias

template <typename T> requires cc::hasToString<T>
void codelock_counting(T const & codelock)
{
    std::cout << codelock.toString() << std::endl;
}

void test_codelocks() {
    cc::digit d;
    // custom::Vector v;
```

```

cc::codelock_3_dials three_dials(123);
cc::codelock_4_dials four_dials(1998);
cc::digital_5_dials five_dials(31337);

std::cout << d.toString() << std::endl;
std::cout << three_dials.toString() << std::endl;
std::cout << four_dials.toString() << std::endl;
codelock_counting(five_dials);
// codelock_counting(v); // Constraints violation, simple error message
}

int main(){
    test_concepts();
    test_codelocks();

    return 0;
}

```


defines.hpp

```
#ifndef DEFINES_HPP_
# define DEFINES_HPP_

// ////////////////////////////////////// LOGS + SOME DEFINE
// // C++20 for std::cout formatting ala printf (unsupported by compilers yet)
// // Otherwise, see: https://en.cppreference.com/w/cpp/io/manip
// # include <format> /* for std::format() */
# include <iomanip>

// Some colors, because why not
# ifdef USE_COLOR
# define CLR_RST "\x1b[0m"
# define CLR_GRN "\x1b[32m"
# define CLR_BLU "\x1b[34m"
# define CLR_YEL "\x1b[33m"
# define CLR_BOLD "\x1b[1m"
# else
# define CLR_RST ""
# define CLR_GRN ""
# define CLR_BLU ""
# define CLR_YEL ""
# define CLR_BOLD ""
# endif // !USE_COLOR

// In case the pretty_function macro is not defined (ex: visual studio on windows)
# if !defined(__PRETTY_FUNCTION__) && !defined(__GNUC__)
# define __PRETTY_FUNCTION__ __FUNCSIG__
# endif

// Some inline logging to simplify the code later during debug
# define LOG_DECL_VAR static size_t g_log_line; // Zeroed by default because of the static keyword
# define LOG(v) (std::cout << "[" << std::setw(2) << ++g_log_line << "]" " \
    << CLR_BLU CLR_BOLD << __FILE__ << CLR_RST \
    << ":" << CLR_YEL << __LINE__ << CLR_RST \
    << ":\t" << CLR_GRN << __PRETTY_FUNCTION__ << CLR_RST \
    << "{" << #v << " = " << (v) << "}" \
    << std::endl)

LOG_DECL_VAR; // To instanciate the static global variable (for the log line number)

# define ADD_CODE { LOG(a + b); return a + b; }

#endif /* !DEFINES_HPP_ */
```

prototypes.hpp

```
#ifndef PROTOTYPES_HPP_
#define PROTOTYPES_HPP_

#include <ostream> // std::ostream

namespace custom { // A toy namespace
    struct Vector {
        int x;
        int y;
        int z;
        Vector operator+(auto const &o) const {
            return Vector{x + o.x, y + o.y, z + o.z};
        }

        // // Compilation error without the cast operator:
        // defines.hpp:33:42: error: cannot convert 'custom::Vector' to 'int' in return
        //      33 | # define ADD_CODE { LOG(a + b); return a + b; }
        operator int () const { return this->x; } // for "return (Vector + Vector);" to works

        friend std::ostream& operator<< (std::ostream& out, Vector const &o) {
            return out << "\n\t{x=" << o.x << ", y=" << o.y << ", z=" << o.z << "}";
        }
    };

    // Creating some concept as a general exercice
    template <typename T> concept addable = requires(T a, T b){a + b};
    template <typename T> concept isNotIntOrFloat = !(std::integral<T> || std::floating_point<T>);
} // !namespace custom

/* ***** */ int regular_add(int a, int b) ADD_CODE
template <typename T> int template_add(T a, T b) ADD_CODE
template <> /* Specialized */ int template_add(float a, float b) ADD_CODE

// Full syntax
template <typename T> requires std::integral<T> int concept_add_long(T a, T b) ADD_CODE
template <typename T> requires std::floating_point<T> int concept_add_long(T a, T b) ADD_CODE
template <typename T> requires custom::isNotIntOrFloat<T> int concept_add_long(T a, T b) ADD_CODE

// Abbreviation syntax (we can use typename, class, or now a constraint for T)
template <std::integral T> /**/ int concept_add_short(T a, T b) ADD_CODE
template <std::floating_point T> int concept_add_short(T a, T b) ADD_CODE
template <custom::isNotIntOrFloat T> int concept_add_short(T a, T b) ADD_CODE

#endif /* ! PROTOTYPES */
```

codelocks.hpp

```
#ifndef CODELOCKS_HPP_
#define CODELOCKS_HPP_

#include <string>
#include <array>

namespace IN204 {
    namespace codeCrackingExo {

        template <typename T>
        concept hasToString = requires (T t)
        {
            t.toString();
        };

        //////////////////////////////////////
        /// digit

        class digit {
        private:
            char d;
            std::string const base;
        public:
            digit(char d = 0, std::string const & base = "0123456789") : d(d), base(base) {}

            std::string toString() const { return std::string() + base[d % base.length()]; }
            digit &operator=(int v) { return (d = v, *this); }
        }; // !class

        //////////////////////////////////////
        /// codeLock

        template <std::size_t S, typename D = digit>
        class codeLock {
        private:
            std::array<D, S> code;
        public:
            // @param defaultCode The value to initialize the codeLock at
            codeLock(int defaultCode) : code{0} {
                // Initialize
                for (auto it = code.rbegin(); (it != code.rend() && defaultCode != 0); ++it) {
                    *it = (defaultCode % 10);
                    defaultCode /= 10;
                }
                // if (defaultCode != 0)
                //     std::throw // TODO
            }

            std::string toString() const {
                std::string rval;

                for (auto const & item : code)
```

```

        rval += item.toString();
    return rval;
    }
}; // !class

////////////////////////////////////
/// aliases

template <std::size_t S, typename D = digit>
class digitalCodelock : public codelock<S, D> {
};

template <std::size_t S, typename D = digit>
class verboseCodelock : public codelock<S, D> {
};

using codelock_3_dials = codelock<3>;
using codelock_4_dials = codelock<4>;
using digital_5_dials = digitalCodelock<5>;

} // ! codeCracking
} // !IN204

// typedef 4dials_combo codelock<>;

#endif /* ! CODELOCKS_HPP_ */

```

Makefile used

```
TARGET := a.out
SRCS := main.cpp
OBJS := $(SRCS:.cpp=.o)

# Ubuntu and MinGW: sudo apt-get install gcc-10 g++-10
CXX = g++-10 # overwrite default g++ on my system which is version 9
CXXFLAGS += -W -Wall -Wextra -std=c++20

all: $(TARGET)

color: CXXFLAGS += -DUSE_COLOR
color: fclean all

$(TARGET): $(OBJS)
    $(CXX) $(CXXFLAGS) $^ -o $@

clean:
    -rm -f $(OBJS)

fclean: clean
    -rm -f $(TARGET)

re: fclean all

.PHONY: all clean fclean re test color

cd "/home/1laurenj/Ensta/Cours ensta IN204/Session 1/cours_6_Cpp20_and_contracts/"
make re
./a.out

## rm -f main.o
## rm -f a.out
## g++-10 -W -Wall -Wextra -std=c++20 -c -o main.o main.cpp
## g++-10 -W -Wall -Wextra -std=c++20 main.o -o a.out
## [ 1] prototypes.hpp:31: int regular_add(int, int){a + b = 2}
## [ 2] prototypes.hpp:32: int template_add(T, T) [with T = int]{a + b = 2}
## [ 3] prototypes.hpp:33: int template_add(T, T) [with T = float]{a + b = 4.4}
## [ 4] prototypes.hpp:33: int template_add(T, T) [with T = float]{a + b = 4.4}
## [ 5] prototypes.hpp:36: int concept_add_long(T, T) [with T = int]{a + b = 2}
## [ 6] prototypes.hpp:37: int concept_add_long(T, T) [with T = float]{a + b = 4.4}
## [ 7] prototypes.hpp:37: int concept_add_long(T, T) [with T = double]{a + b = 8.8}
## [ 8] prototypes.hpp:41: int concept_add_short(T, T) [with T = int]{a + b = 2}
## [ 9] prototypes.hpp:42: int concept_add_short(T, T) [with T = float]{a + b = 4.4}
## [10] prototypes.hpp:42: int concept_add_short(T, T) [with T = double]{a + b = 8.8}
## [11] prototypes.hpp:43: int concept_add_short(T, T) [with T = custom::Vector]{a + b =
## {x=2, y=4, z=6}}
## 0
## 123
## 1998
## 31337
```

Resources

- **Official course::** <https://perso.ensta-paris.fr/~bmonsuez/Cours/doku.php?id=in204:seances:seance6>
- **C++2a and constraints:**
 - **isocpp guide:** <https://isocpp.org/blog/2021/11/cpp-20-concepts> (very good)
 - **cppreference:** <https://en.cppreference.com/w/cpp/language/constraints>
 - **others:** <https://www.cppstories.com/2021/concepts-intro/>
- **Iterators:**
 - **Link 1:** <https://www.geeksforgeeks.org/introduction-iterators-c/>
 - **Link 2:** <https://www.geeksforgeeks.org/iterators-c-stl/>
 - **Custom iterators:** <https://www.internalpointers.com/post/writing-custom-iterators-modern-cpp>

Course 7 : Error management and exceptions

Error management

Source files

```
#ifndef SCREEN_HPP_
#define SCREEN_HPP_

#include <vector>
#include "Pixel.hpp"

// To test `Screen(someRandomStruct iAmObviouslyNotASize)`
// Note: "new Pixel[iAmObviouslyNotASize]" works because
//       we got a cast operator here (implicit conversion)
// Note2: Don't do that in your project :p, it's for the test
struct someRandomStruct {
    operator int() { return -1; }
};

class Screen {
    // By default, every attribute is private within a class
    // (but we explicit the 'private:' anyway for readability
private:
    // Using a vector would be better, but we do it also by hand for
    // the exercice with new/delete.
    std::vector<Pixel> pixels_vector;

    Pixel * pixels_manual;
    size_t size;
public:
    // https://en.cppreference.com/w/cpp/language/nullptr
    // https://en.cppreference.com/w/cpp/language/new
    Screen(size_t size = 0) : pixels_manual(nullptr), size(size) {
        pixels_manual = new Pixel[size]; // Can throw
        pixels_vector.resize(size);
    }
    Screen(someRandomStruct iAmObviouslyNotASize) {
        std::cout << __PRETTY_FUNCTION__ << ": Before exception" << std::endl;
        pixels_manual = new Pixel[iAmObviouslyNotASize]; // Will throw std::bad_array_new_length
        std::cout << __PRETTY_FUNCTION__ << ": After exception" << std::endl;
    }
    // NO DEFAULT, OR WE WILL GET MEMORY CORRUPTION ON THE SECOND DESTRUCTOR
    // --> { Screen a(10); Screen b(a); } // Program could crash here (double memory free)
    // Screen(Pixel const &) = default;
    ~Screen() {
        delete pixels_manual;
        // No need to delete pixels_vector, it will get destroyed implicitly
        // (because Vector<> has a destructor that will get called)
    }
    auto operator=(Screen const &o) -> Screen & {
        // Vector version
        { // Just an extra local stack scope (to group code and prevent local variable to spread)
            pixels_vector = o.pixels_vector;
        }
        { // Just an extra local stack scope (--)

```



```

        // Manual version
        auto tmp = new Pixel[size]; // Can throw
        // We delete AFTER (in case the new operator throws, so the class Screen never has invalid memory)
        delete pixels_manual;
        // Old C style copy (but no memcpy or std::copy, we don't know if Pixel is a PoD)
        // See https://en.cppreference.com/w/cpp/language/classes#POD_class
        for (size = 0 ; size < o.size ; ++size)
            tmp[size] = o.pixels_manual[size]; // pixel.operator=(...) noexcept
        pixels_manual = tmp; // Assign once everything is ready and return safely
    }
    return *this;
}
}; // !class

#endif /* !SCREEN_HPP_ */

```

Screen.hpp

```

#ifndef PIXEL_HPP_
#define PIXEL_HPP_

class Pixel {
private:
    std::uint32_t v;
    int rgb[3]; // To show how to init an array by hand in the constructor (below)

public:
    // The 4 methods to respect the Coplain form (Default CTor/DTor + copy + operator=())
    // (CTors/DTors == Constructors/DesConstructors)
    Pixel(std::uint32_t argb = 0) : v(argb), // regular constructor
                                   rgb{0,1,2} // Initializer list needed because multiple items
    {
        std::cout << "constructing Pixel with R:" << rgb[0]
                    << " / G:" << rgb[1]
                    << " / B:" << rgb[2] << std::endl;
    }
    Pixel(Pixel const &) = default;
    ~Pixel() = default; // Defaulted, a memory copy works here
    auto operator=(Pixel const &) noexcept -> Pixel & = default; // Alternate auto syntax

    //////////

    auto A() const -> std::uint8_t { return ((v >> 8*0) & 0xFF); }
    auto R() const -> std::uint8_t { return ((v >> 8*1) & 0xFF); }
    auto G() const -> std::uint8_t { return ((v >> 8*2) & 0xFF); }
    auto B() const -> std::uint8_t { return ((v >> 8*3) & 0xFF); }

}; //!class

#endif /* !PIXEL_HPP_ */

```

Pixel.hpp

```

#include <iostream>
#include "Screen.hpp"
#include "Pixel.hpp"

// using namespace std; // Don't do that, please ... just don't
// See: https://isocpp.github.io/CppCoreGuidelines/CppCoreGuidelines#Rs-using

// @return the value of Pi
float i_am_bad_at_math() {
    float yes = 1;
    float ofcourse = 2;
    return (1 + 1 == 3 ? yes : ofcourse); // Returns the value of Pi
}

// @return 0 on success, -1 on failure
int classic_error_management() {
    float homework;
    float isGood;

    isGood = 3.14; // Reference value, sometime it's easier to read (avoid hardcoded unnamed values)
    homework = i_am_bad_at_math();
    // if (homework == 3.14) { // Avoid hardcoded values as much as possible, name them !
    if (homework == isGood) {
        return 0;
    }
    return -1; // Any case that is not explicitly a success is a failure, by default (safer)
}

// @brief A test function to toy with exceptions
void testException__bad_array_new_length()
{
    try { // 1
        try { // 2
            someRandomStruct testStruct;
            Screen s(testStruct); // Exception here
        } catch (std::exception& e) { // 2
            std::cout << __PRETTY_FUNCTION__ << ": Catching exception n'1 and rethrowing" << std::endl;
            throw; // re-throw the current exception for fun
        }
    } catch (std::exception& e) { // 1
        std::cout << __PRETTY_FUNCTION__ << ": Catching exception n'2 and ignoring" << std::endl;
        throw; // re-catching, and rethrow for the caller to handle this
    }
}

int main(){

    std::cout << "=====" << std::endl;
    std::cout << "== main() called" << std::endl << std::endl;

```

```

Pixel a; // To test the Pixel constructor cout

try {
    testException__bad_array_new_length();
} catch (...) { // A catch all guard
    std::cout << __PRETTY_FUNCTION__ << ": "
        << "Called code is rethrowing to the caller function as expected"
        << std::endl;
}

///// Classic error management from caller function

{
    int rval = classic_error_management();
    std::cout << __PRETTY_FUNCTION__ << ": classic_error_management returned a " << (rval == -1 ? "Fail"
}

std::cout << std::endl << "=====" << std::endl;
return 0;
}

```

main.cpp

```

TARGET := a.out
SRCS := main.cpp
OBJS := $(SRCS:.cpp=.o)

# Ubuntu and MinGW: sudo apt-get install gcc-10 g++-10
CXX = g++-10 # overwrite default g++ on my system which is version 9
CXXFLAGS += -W -Wall -Wextra -std=c++20

all: $(TARGET)

color: CXXFLAGS += -DUSE_COLOR
color: fclean all

$(TARGET): $(OBJS)
    $(CXX) $(CXXFLAGS) $^ -o $@

clean:
    -rm -f $(OBJS)

fclean: clean
    -rm -f $(TARGET)

re: fclean all

.PHONY: all clean fclean re test color

```

Makefile used

```
cd "/home/llaurenj/Ensta/Cours ensta IN204/Session 1/cours_7_exceptions/"
make re
valgrind ./a.out ## Calling with valgrind to check for memory leaks
## Pay attention to that line: "All heap blocks were freed -- no leaks are possible"
```

Running output

```
## rm -f main.o
## rm -f a.out
## g++-10 -W -Wall -Wextra -std=c++20 -c -o main.o main.cpp
## g++-10 -W -Wall -Wextra -std=c++20 main.o -o a.out
## ==71183== Memcheck, a memory error detector
## ==71183== Copyright (C) 2002-2017, and GNU GPL'd, by Julian Seward et al.
## ==71183== Using Valgrind-3.15.0 and LibVEX; rerun with -h for copyright info
## ==71183== Command: ./a.out
## ==71183==
## =====
## == main() called
##
## constructing Pixel with R:0 / G:1 / B:2
## Screen::Screen(someRandomStruct): Before exception
## void testException__bad_array_new_length(): Catching exception n'1 and rethrowing
## void testException__bad_array_new_length(): Catching exception n'2 and ignoring
## int main(): Called code is rethrowing to the caller function as expected
## int main(): classic_error_management returned a Failure
## =====
## ==71183==
## ==71183== HEAP SUMMARY:
## ==71183==      in use at exit: 0 bytes in 0 blocks
## ==71183==    total heap usage: 3 allocs, 3 frees, 76,936 bytes allocated
## ==71183==
## ==71183== All heap blocks were freed -- no leaks are possible
## ==71183==
## ==71183== For lists of detected and suppressed errors, rerun with: -s
## ==71183== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
```

Resources

- Entry slides:
 - **Exception safety**: https://en.wikipedia.org/wiki/Exception_safety
 - **Error Handling, by David Svoboda**: https://resources.sei.cmu.edu/asset_files/Presentation/2016_017_101_484207.pdf
 - **Exception safety concept**: <https://www.stroustrup.com/except.pdf>
- Main documentation:
 - **Exceptions (guide isocpp)**: <https://isocpp.org/wiki/faq/exceptions>
 - **Exceptions (google coding style)**: <https://google.github.io/styleguide/cppguide.html#Exceptions>
 - **C++ Coding guidelines**: <https://isocpp.github.io/CppCoreGuidelines/CppCoreGuidelines>
 - **Reference documentation with exercises (hard)**: <https://stroustrup.com/>
 - **Boost exception review**: https://www.boost.org/community/exception_safety.html
 - **Official course**: <https://perso.ensta-paris.fr/~bmonsuez/Cours/doku.php?id=in204:seances:seance7>
- Remember when I talked about the different stages of a variable (allocation, initialization, usage and cleanup) along with good programming practices ? here are some good readings:
 - **RAII**: <https://en.cppreference.com/w/cpp/language/raii>
 - **Rule of 3**: https://en.cppreference.com/w/cpp/language/rule_of_three
 - **man errno**: <https://man7.org/linux/man-pages/man3/errno.3.html>
- https://github.com/JBL-Repo/IN204/blob/main/cours__recap.pdf

Course 8 : Parallel programming

Source files

main.cpp (parallel test)

```
#include <iostream>
#include <sstream>
#include <string>

#include <chrono>

#include <thread>
#include <vector>
#include <mutex>
#include <condition_variable>

std::mutex g_mutex;

void sleep_ms(size_t ms) {
    std::this_thread::sleep_for(std::chrono::milliseconds(ms));
}

void wait_for_order(int i, bool const & do_action, void (*action)(int)) {
    std::stringstream logMsg;

    std::cout << "    COUT: Thread " << i << " -" // Multiple operator<<() called
               << " is running with id " << std::this_thread::get_id() << std::endl;
    logMsg << "SSTREAM: Thread " << i << " -" // operator<<() called once
           << " is running with id " << std::this_thread::get_id() << std::endl;
    // "Atomic" print
    std::cout << logMsg.str();

    // "spinLock"
    while (!do_action) {
    }

    // All at once
    action(i);

    sleep_ms(500);

    // One at a time
    { // stack scope for the mutex guard
        std::lock_guard<std::mutex> lock(g_mutex);
        action(i*-1);
    }
}

int main() {
    int numThreads = 5;
    bool do_action = false;
    std::vector<std::thread> threads;
```



```

std::cout << "[ ] Main thread started (parallel testing)" << std::endl;

for (int i = 0 ; i < numThreads ; ++i) {
    // https://en.cppreference.com/w/cpp/thread/thread/thread
    // https://isocpp.org/wiki/faq/cpp11-language#lambda
    // https://en.cppreference.com/w/cpp/utility/functional/ref
    threads.push_back(std::thread(wait_for_order, i, std::cref(do_action),
        [](int i){std::cout << "Hello from " << i << std::endl;; }));
}

sleep_ms(100); // Just to be sure all threads have printed, for the demo
std::cout << "Main thread with id " << std::this_thread::get_id() << " is sleeping" << std::endl;
sleep_ms(1000);

std::cout << "[ ] Main thread is releasing the threads: (spammy action)" << std::endl << std::endl;
do_action = true; // Trigger the threads
sleep_ms(250);
std::cout << std::endl << "[ ] Async call of action should be done by now (clean)" << std::endl << std::endl;

while (threads.size()) {
    threads.back().join(); // main process thread waits for the thread to finish
    threads.pop_back();
}

std::cout << "[ ] Main thread is now returning (exit)" << std::endl << std::endl;
return 0;
}

```

diamond.cpp (diamond test)

```
#include <iostream>

// https://stackoverflow.com/questions/23360572/c-diamond-inheritance-constructor

class compteur {
protected:
    int i;
public:
    compteur(int i) : i(i) {}
    // Virtual will point the the last class implementation (unless final is specified)
    virtual void hello() const {std::cout << i << " - Hello from " << __PRETTY_FUNCTION__ << std::endl; }
};

// // "virtual public compteur" is needed to prevent the diamond issue
// 1laurenj@frpfaluxu003:~/Ensta/Cours ensta IN204/Session 1/cours_8_parallel$ g++ -W -Wall -Wextra diamond.cpp
// diamond.cpp: In function 'int main()':
// diamond.cpp:29:18: error: 'compteur' is an ambiguous base of 'compteur_bi'
//    29 |     compteur &c4 = c_bi;

struct compteur_inc : virtual public compteur {
    compteur_inc() : compteur(1) {}
    void hello() const {std::cout << i << " - Hello from " << __PRETTY_FUNCTION__ << std::endl; }
};

struct compteur_dec : virtual public compteur {
    compteur_dec() : compteur(-1) {}
    void hello() const {std::cout << i << " - Hello from " << __PRETTY_FUNCTION__ << std::endl; }
};

struct compteur_bi : public compteur_inc, public compteur_dec { // inc then dec (for the test)
    // Because of virtual public, base class HAS to be constructed here (because otherwise it would be cr
    compteur_bi() : compteur(2) {}
    void hello() const {std::cout << compteur_inc::i << " - Hello from " << __PRETTY_FUNCTION__ << std::endl; }
};

struct compteur_bi2 : public compteur_dec, public compteur_inc { // dec then inc (for the test)
    // Because of virtual public, base class HAS to be constructed here (because otherwise it would be cr
    compteur_bi2() : compteur(-2) {}
    void hello() const {std::cout << compteur_dec::i << " - Hello from " << __PRETTY_FUNCTION__ << std::endl; }
};

int main() {

    std::cout << "=== Diamond shape testing " << std::endl;

    compteur c(0);
    compteur_inc c_inc;
    compteur_dec c_dec;
    compteur_bi c_bi;
    compteur_bi2 c_bi2;

    compteur &c1 = c;
    compteur &c2 = c_inc;
```

```

compteur &c3 = c_dec;
compteur &c4 = c_bi;
compteur &c5 = c_bi2;

std::cout << "==="<< std::endl;

c.hello();
c_inc.hello();
c_dec.hello();
c_bi.hello();
c_bi2.hello();

std::cout << "==="<< std::endl;

c1.hello();
c2.hello();
c3.hello();
c4.hello();
c5.hello();

std::cout << "==="<< std::endl;

return 0;
}

```

Makefile used

```
TARGET_PARALLEL := parallel
TARGET_DIAMOND := diamond

SRCS_PARALLEL := main.cpp
OBJS_PARALLEL := $(SRCS_PARALLEL:.cpp=.o)

SRCS_DIAMOND := diamond.cpp
OBJS_DIAMOND := $(SRCS_DIAMOND:.cpp=.o)

# Ubuntu and MinGW: sudo apt-get install gcc-10 g++-10
CXX = g++-10 # overwrite default g++ on my system which is version 9
CXXFLAGS += -W -Wall -Wextra -std=c++20 -pthread

all: $(TARGET_PARALLEL) $(TARGET_DIAMOND)

$(TARGET_DIAMOND): $(OBJS_DIAMOND)
    $(CXX) $(CXXFLAGS) $^ -o $@
$(TARGET_PARALLEL): $(OBJS_PARALLEL)
    $(CXX) $(CXXFLAGS) $^ -o $@

clean:
    -rm -f $(OBJS_PARALLEL) $(OBJS_DIAMOND)

fclean: clean
    -rm -f $(TARGET_PARALLEL) $(TARGET_DIAMOND)

re: fclean all

.PHONY: all clean fclean re test color
```

Running output

```
cd "/home/1laurenj/Ensta/Cours ensta IN204/Session 1/cours_8_parallel/"
make re
./parallel
./diamond
```

```
## rm -f main.o diamond.o
## rm -f parallel diamond
## g++-10 -W -Wall -Wextra -std=c++20 -pthread -c -o main.o main.cpp
## g++-10 -W -Wall -Wextra -std=c++20 -pthread main.o -o parallel
## g++-10 -W -Wall -Wextra -std=c++20 -pthread -c -o diamond.o diamond.cpp
## g++-10 -W -Wall -Wextra -std=c++20 -pthread diamond.o -o diamond
## [ ] Main thread started (parrallel testing)
##      COUT: Thread      COUT: Thread 01 - is running with id  - is running with id 1406389251253761406389
##
##      COUT: Thread 3 - is running with id 140638899947264
## SSTREAM: Thread 0 - is running with id 140638925125376
## SSTREAM: Thread 1 - is running with id 140638916732672
## SSTREAM: Thread 3 - is running with id 140638899947264
##      COUT: Thread 4 - is running with id 140638891554560
## SSTREAM: Thread 4 - is running with id 140638891554560
##      COUT: Thread 2 - is running with id 140638908339968
## SSTREAM: Thread 2 - is running with id 140638908339968
## Main thread with id 140638925129536 is sleeping
## [ ] Main thread is releasing the threads: (spammy action)
##
## Hello from Hello from Hello from Hello from 4
## 1Hello from
## 3
## 0
## 2
##
## [ ] Async call of action should be done by now (clean)
##
## Hello from 0
## Hello from -4
## Hello from -1
## Hello from -3
## Hello from -2
## [ ] Main thread is now returning (exit)
##
## === Diamond shape testing
## ===
## 0 - Hello from virtual void compteur::hello() const
## 1 - Hello from virtual void compteur_inc::hello() const
## -1 - Hello from virtual void compteur_dec::hello() const
## 2 - Hello from virtual void compteur_bi::hello() const
## -2 - Hello from virtual void compteur_bi2::hello() const
## ===
## 0 - Hello from virtual void compteur::hello() const
## 1 - Hello from virtual void compteur_inc::hello() const
## -1 - Hello from virtual void compteur_dec::hello() const
## 2 - Hello from virtual void compteur_bi::hello() const
```

```
## -2 - Hello from virtual void compteur_bi2::hello() const  
## ===
```

Resources

- **Threads:** [https://en.wikipedia.org/wiki/Thread_\(computing\)](https://en.wikipedia.org/wiki/Thread_(computing))
- **Virtuals:** <https://isocpp.org/wiki/faq/virtual-functions>
- **Concurrency:** <https://isocpp.org/wiki/faq/cpp11-library-concurrency>
- **Pipeline (optional):** https://en.wikipedia.org/wiki/Instruction_pipelining

Course 10 : Project good practices

Resources

- **Architectural Decision Records (ADRs)**: <https://adr.github.io/>
- Project structure
 - **Basics**: <https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2018/p1204r0.html>
 - **Pitchfork**: <https://api.csswg.org/bikeshed/?force=1&url=https://raw.githubusercontent.com/vector-of-bool/pitchfork/develop/data/spec.bs>
- CMake (Cross-platform, compiler-independent build system generator):
 - **Begginer Guide**: <https://cmake.org/cmake/help/latest/guide/tutorial/index.html>
 - **Official guide**: <https://cmake.org/cmake/help/latest/guide/tutorial/A%20Basic%20Starting%20Point.html>
- Documentation:
 - **Doxygen**: <https://doxygen.nl/manual/docblocks.html>
 - **Doxygen guide**: <https://franckh.developpez.com/tutoriels/outils/doxygen/>
- Examples of coding standards:
 - **Google**: <https://google.github.io/styleguide/cppguide.html>
 - **BDE**: https://bloomberg.github.io/bde/knowledge_base/coding_standards.html
 - **LLVM**: <https://llvm.org/docs/CodingStandards.html>
- Extra reading:
 - **C++ guidelines**: <https://isocpp.org/wiki/faq/coding-standards>
 - **Const FAQ**: <https://isocpp.org/wiki/faq/const-correctness>
 - **Cppcon pdf on “const”**: <https://raw.githubusercontent.com/CppCon/CppCon2015/master/Presentations/The%20Importance%20of%20Being%20Const/The%20Importance%20of%20Being%20Const%20-%20Richard%20Powell%20-%20CppCon%202015.pdf>

Exam 2020 correction

- **Subject:** https://perso.ensta-paris.fr/~bmonsuez/Cours/lib/exe/fetch.php?media=in204:8_-in204-_examen.pdf

Source file

```
#include <iostream>
#include <string>
#include <complex>
#include <vector>
#include <cstdio>
#include <algorithm>

// class given declaration
class key_value_pair {
private:
    int key;
    std::string value;
public:
    key_value_pair();
    key_value_pair(int theKey, std::string theValue);
    key_value_pair(const key_value_pair& anotherPair);
    // Question 1.1: https://cplusplus.com/doc/tutorial/classes2/
    // key_value_pair(const key_value_pair& anotherPair) = default; // Implicitly declared

    // Question 2:
    // For more info on constness:
    // * https://isocpp.org/wiki/faq/const-correctness
    // * https://raw.githubusercontent.com/CppCon/CppCon2015/master/Presentations/The%20Importance%20of%20const
    int getKey() const { return key; }
    int setKey(int k) { key = k; return key; } // we return key for convenience
    // int getKey(/*this*/) const { return this->key; } // Would work too

    std::string getValue() const { return value; }
    std::string setValue(std::string const &v) { value = v; return value; }

    // Question 3:
    // No need to name the parameter when it is only a prototype
    bool operator == (const key_value_pair&) const;
    bool operator != (const key_value_pair&) const;

    bool operator < (const key_value_pair&) const;
    bool operator > (const key_value_pair&) const;
    bool operator <= (const key_value_pair&) const;
    bool operator >= (const key_value_pair&) const;
};

// Question 4: templates
template <typename keyT, typename valueT>
class templated_kv_class {
private:
    keyT key;
    valueT value;
public:
    // Just redoing the getters to illustrate
    templated_kv_class() : key(0), value("1337") {};
    templated_kv_class(keyT const &k, valueT const &v) : key(k), value(v) {};
    keyT getKey() const { return key; }
```

```

keyT setKey(keyT k) { key = k; return key; }
valueT getValue() const { return value; }
valueT setValue(valueT const &v) { value = v; return value; }
// Question 5:
// sort by value and not key, for the exercise
bool operator < (const templated_kv_class<keyT,valueT> &o) const {return (value < o.value);}

// Question 6:
template<class charT, class traits>
friend std::basic_ostream<charT, traits>& operator << (std::basic_ostream<charT, traits>& aStream,
               templated_kv_class<keyT, valueT> const &thePair) {
// Question 6.2: Custom print
    if (thePair.getKey() == "du" && thePair.getValue() == 40)
        aStream << "du => 40";
    else
        aStream << "{key:" << thePair.getKey() << ", value:" << thePair.getValue() << "}";
    return aStream; // So we can use several "<<" in a row, for convenience
}
};

template <typename K, typename V>
class key_defined_value : public templated_kv_class<K, V> {
public:
    bool is_void;
    key_defined_value() : templated_kv_class<K, V>(), is_void(true) {};
    key_defined_value(K const &k, V const &v) : templated_kv_class<K, V>(k, v), is_void(false) {};

    // Call parent setKey() method and set our is_void then
    K setKey(K k) {is_void = false; return templated_kv_class<K, V>::setKey(k); }
};

// Definitions
key_value_pair::key_value_pair() : key(0), value() {}
key_value_pair::key_value_pair(int k, std::string v) : key(k), value(v) {}
key_value_pair::key_value_pair(const key_value_pair&o) : key(o.key), value(o.value) {}

// Question 2:
// It is not possible to access private attributes without "friend" or getters.

// Question 3: Only operator=() and operator<() need to be "technically" implemented
bool key_value_pair::operator == (const key_value_pair&o) const {
    return (key == o.key && value == o.value);
}

// Subject doesn't tell how to sort, so let's only sort by key here
bool key_value_pair::operator < (const key_value_pair&o) const {
    return (key < o.key);
}

bool key_value_pair::operator !=(const key_value_pair&o) const { return !(*this == o); }
bool key_value_pair::operator <=(const key_value_pair&o) const { return (*this == o || *this < o); }
bool key_value_pair::operator > (const key_value_pair&o) const { return (*this != o) && !(*this < o); }
bool key_value_pair::operator >=(const key_value_pair&o) const { return (*this == o || !(*this < o)); }

int main() {

```

```

key_value_pair kv1;
key_value_pair kv2;

std::cout << "== Testing the 2021 exam correction ==>" << std::endl;
std::cout << std::endl;
std::cout << "Q2: kv1 default values ==> "
    << "{key:" << kv1.getKey()
    << ", value: \"" << kv1.getValue() << "\"}" <<
    << std::endl;

kv1.setValue("This is SPARTAAAA");
kv2.setValue("No, this is Patrick !"); // because why not

std::cout << "Q2: kv1 new value ==> "
    << "{key:" << kv1.getKey()
    << ", value: \"" << kv1.getValue() << "\"}" <<
    << std::endl;

std::cout << std::endl;
std::cout << "Q3: Are kv1 and kv2 equal ? " << std::boolalpha << (kv1 == kv2) << std::endl;
std::cout << "Q3: Are kv1 and kv2 different ? " << std::boolalpha << (kv1 != kv2) << std::endl;

kv1.setKey(1);
kv2.setKey(2);

std::cout << "Q3: kv1 new values ==> "
    << "{key:" << kv1.getKey()
    << ", value: \"" << kv1.getValue() << "\"}" <<
    << std::endl;
std::cout << "Q3: kv2 new values ==> "
    << "{key:" << kv2.getKey()
    << ", value: \"" << kv2.getValue() << "\"}" <<
    << std::endl;

std::cout << "Q3: kv1 == kv2: " << std::boolalpha << (kv1 == kv2) << std::endl;
std::cout << "Q3: kv1 != kv2: " << std::boolalpha << (kv1 != kv2) << std::endl;
std::cout << "Q3: kv1 > kv2: " << std::boolalpha << (kv1 > kv2) << std::endl;
std::cout << "Q3: kv1 < kv2: " << std::boolalpha << (kv1 < kv2) << std::endl;
std::cout << "Q3: kv1 >= kv2: " << std::boolalpha << (kv1 >= kv2) << std::endl;
std::cout << "Q3: kv1 <= kv2: " << std::boolalpha << (kv1 <= kv2) << std::endl;
std::cout << std::endl;

// Question 4: templates
templated_kv_class<int, std::string> kv_templated;

std::cout << "Q4: kv_templated new values ==> "
    << "{key:" << kv_templated.getKey()
    << ", value: \"" << kv_templated.getValue() << "\"}" <<
    << std::endl;

std::cout << std::endl;

// Question 4.2: Doesn't compile because complex is template itself

```

```

// * see https://en.cppreference.com/w/cpp/numeric/complex (it is a literal type)
// templated_kv_class<std::complex, std::string> kv_templated2; // KO
templated_kv_class<std::complex<float>, std::string> kv_templated2; // OK
// Comparison operators are not implemented, seems like a math problem ? (unsure about that one)

// Question 5
// The following code instantiate a class and adds it to the end of the std::vector<>
// * see https://en.cppreference.com/w/cpp/container/vector/push_back
std::vector<templated_kv_class<std::string, float>> listOfIdentifiers;
listOfIdentifiers.push_back(templated_kv_class<std::string, float>("mot", 10));
listOfIdentifiers.push_back(templated_kv_class<std::string, float>("le", 100));
listOfIdentifiers.push_back(templated_kv_class<std::string, float>("la", 80));
listOfIdentifiers.push_back(templated_kv_class<std::string, float>("du", 40));

// With printf for a change
int i = 0;
for (auto it = listOfIdentifiers.cbegin() ; it != listOfIdentifiers.cend() ; ++it)
    printf("Q5: [%d/%zu] key: %s, value: %f\n", ++i, listOfIdentifiers.size(), it->getKey().c_str(), it->getValue());

// Question 5.2: Sorting
// We can sort the vector by many mean, but the subject implies using a function for that.
// * See https://cplusplus.com/reference/algorithm/sort/
std::cout << std::endl;
std::cout << "Q5: Sorting out the vector by key with the operator<> and std::sort()" << std::endl;

int j = 0;
std::sort(listOfIdentifiers.begin(), listOfIdentifiers.end());
for (auto it = listOfIdentifiers.cbegin() ; it != listOfIdentifiers.cend() ; ++it)
    printf("Q5: [%d/%zu] key: %s, value: %f (sorted by value)\n", ++j, listOfIdentifiers.size(), it->getKey().c_str(), it->getValue());

for (auto it = listOfIdentifiers.cbegin() ; it != listOfIdentifiers.cend() ; ++it)
    std::cout << "Q5: Using operator<> this time: " << *it << std::endl;

// Question 6: Stream Operator<<()
// * This operator can't be defined in the class because it is a global binary operator.
// Otherwise it would be the class itself which would print, it needs to be the other way around.
// (don't forget that it is someone else who is printing us).

// Question 7:
key_defined_value<int, std::string> kdv1;

std::cout << std::endl;

std::cout << "Q7: Is kdv1 value unset (void ?) ? " << std::boolalpha << kdv1.is_void << ". value: " << kdv1.value << std::endl;
std::cout << "Q7: - Setting kdv1 value" << std::endl;
kdv1.setKey(666);
std::cout << "Q7: Is kdv1 value unset (void ?) ? " << std::boolalpha << kdv1.is_void << ". value: " << kdv1.value << std::endl;

return 0;
}

```

Running output

```
cd "/home/llaurenj/Ensta/Cours ensta IN204/Session 1/anal_2020/"
g++ -g3 -W -Wall -Wextra main.cpp
./a.out

## == Testing the 2021 exam correction ==
##
## Q2: kv1 default values ==> {key:0, value: ""}
## Q2: kv1 new value ==> {key:0, value: "This is SPARTAAAA"}
##
## Q3: Are kv1 and kv2 equal ? false
## Q3: Are kv1 and kv2 different ? true
## Q3: kv1 new values ==> {key:1, value: "This is SPARTAAAA"}
## Q3: kv2 new values ==> {key:2, value: "No, this is Patrick !"}
## Q3: kv1 == kv2: false
## Q3: kv1 != kv2: true
## Q3: kv1 > kv2: false
## Q3: kv1 < kv2: true
## Q3: kv1 >= kv2: false
## Q3: kv1 <= kv2: true
##
## Q4: kv_templated new values ==> {key:0, value: "1337"}
##
## Q5: [1/4] key: mot, value: 10.000000
## Q5: [2/4] key: le, value: 100.000000
## Q5: [3/4] key: la, value: 80.000000
## Q5: [4/4] key: du, value: 40.000000
##
## Q5: Sorting out the vector by key with the operator<() and std::sort()
## Q5: [1/4] key: mot, value: 10.000000 (sorted by value)
## Q5: [2/4] key: du, value: 40.000000 (sorted by value)
## Q5: [3/4] key: la, value: 80.000000 (sorted by value)
## Q5: [4/4] key: le, value: 100.000000 (sorted by value)
## Q5: Using operator<<() this time: {key:mot, value: 10}
## Q5: Using operator<<() this time: du => 40
## Q5: Using operator<<() this time: {key:la, value: 80}
## Q5: Using operator<<() this time: {key:le, value: 100}
##
## Q7: Is kdv1 value unset (void ?) ? true. value: 0
## Q7: - Setting kdv1 value
## Q7: Is kdv1 value unset (void ?) ? false. value: 666
```