

# Praktikum: SystemC

## C++-Tutorial

Joachim Falk ([falk@cs.fau.de](mailto:falk@cs.fau.de))

# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods

# The "++" of C++

---

- C with additional
  - features of object oriented languages
  - operator and function overloading
  - virtual functions
  - call by reference for functions
  - template functionality
  - exception handling
  
- Object Orientation is the sum of
  - abstract data types (classes)
  - data hiding
  - (multiple) inheritance
  - polymorphism

# Classes - Introduction

```
typedef int t_fifo;
class fifo {
public:
    fifo(int size);
    ~fifo();

    bool read(t_fifo &val);
    bool write(const t_fifo &val);
    void dump();

protected:
    bool is_empty();
    bool is_full();
    int inc_idx(const int &idx);
protected:
    t_fifo *_buf; int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
}; // Note the semicolon
```

- A **struct** in C
  - contains data elements
  - used to encapsulate a state
- A **class** in C++
  - contains data elements
  - contains functions (called methods)
  - used to encapsulate state and behavior

function members (methods)

data members

# Classes - Declaration Syntax

---

- A Class in C++ is Declared
  - Either using the keyword **struct**  
Which is still there to maintain compatibility with ANSI C
  - Or using the keyword **class**  
Which better fits the object oriented terminology
- Default access modifier (explained later)
  - **public** for **struct**
  - **private** for **class**

## Syntax:

```
class class_name {  
  // implicit private:  
  // the class body  
}; // Note the semicolon
```

## Syntax:

```
struct class_name {  
  // implicit public:  
  // the class body  
}; // Note the semicolon
```

# Classes - Access Modifier

---

- Access modifiers define accessibility of class members from outside the class
  - **public** (default for **struct**)  
Members can be accessed from outside the class
  - **protected**  
Members can only be accessed by methods of derived classes
  - **private** (default for **class**)  
members can only be accessed by methods of the class itself

```
class my_class {  
    int _value;  
public:  
    int get_value();  
};
```

equivalent

```
struct my_class {  
    int get_value();  
private:  
    int _value;  
};
```

# Classes - Constructor Syntax

- Every class has a constructor which is a special member function
  - has the name of the class
  - has no return type (not even void)
- The constructor
  - is automatically called at object instantiation
  - is used to initialize class members to a known state
- If no constructor is defined
  - the compiler automatically generates a default constructor
  - which calls the default constructor for all class members

```
class my_class {  
public:  
    my_class();    // constructor without parameter  
    my_class(int); // constructor with int parameter  
};  
  
int main(int argc, char *argv[]) {  
    my_class x;    // calls constructor my_class()  
    my_class y(42); // calls constructor my_class(int)  
    return 0;  
}
```

# Classes - Constructor Example

```
typedef int t_fifo;
class fifo {
public:
    fifo(int size);
    ~fifo();

    bool read(t_fifo& val);
    bool write(const t_fifo& val);
    void dump();

protected:
    bool is_empty();
    bool is_full();
    int inc_idx(const int& idx);
protected:
    t_fifo *_buf;
    int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
}; // Note the semicolon
```

```
// constructor with int parameter
fifo::fifo(int size) {
    _size = size;
    _buf = new t_fifo[_size];
    _num_elem = 0;
    _wr_idx = 0;
    _rd_idx = 0;
    for(int idx = 0; idx < _size; ++idx) {
        _buf[idx] = 0;
    }
}
```

```
int main(int argc, char *argv[]) {
    // create a fifo of size 32
    fifo y(32);
    return 0;
}
```



# Classes - Destructor Syntax

- Every class has a destructor which is a special member function
  - has the name of the class prefix with “~”
  - has no return type (not even void) and no parameters
- The destructor
  - is automatically called right before object destruction
  - is used to cleanup resources used by the class
- If no destructor is defined
  - the compiler automatically generates a default destructor
  - which calls the default constructor for all class members

```
class my_class {  
    char *mem;  
public:  
    my_class(int size); // constructor allocate mem  
    ~my_class();        // destructor cleanup mem  
};  
  
int main(int argc, char *argv[]) {  
    my_class y(42); // calls constructor my_class(int)  
    return 0;       // before main is left destructor ~my_class is called  
}
```

# Classes - Destructor Example

```
typedef int t_fifo;
class fifo {
public:
    fifo(int size);
    ~fifo();

    bool read(t_fifo& val);
    bool write(const t_fifo& val);
    void dump();

protected:
    bool is_empty();
    bool is_full();
    int inc_idx(const int& idx);
protected:
    t_fifo *_buf;
    int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
}; // Note the semicolon
```

```
// constructor with int parameter
fifo::fifo(int size) {
    _size = size;
    _buf = new t_fifo[_size];
    _num_elem = 0;
    _wr_idx = 0;
    _rd_idx = 0;
    for(int idx = 0; idx < _size; ++idx) {
        _buf[idx] = 0;
    }
}
```

```
fifo::~~fifo() {
    delete[] _buf;
}
```

```
int main(int argc, char *argv[]) {
    // create a fifo of size 32
    fifo y(32);
    return 0;
}
```

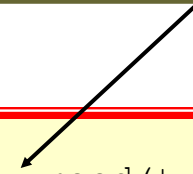
# Classes - Scope Resolution

```
typedef int t_fifo;
class fifo {
public:
    fifo(int size);
    ~fifo();

    bool read(t_fifo& val);
    bool write(const t_fifo& val);
    void dump();

protected:
    bool is_empty();
    bool is_full();
    int inc_idx(const int& idx);
protected:
    t_fifo *_buf;
    int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
}; // Note the semicolon
```

The **::** operator is called **scope resolution operator**. It tells the compiler that **read()** and **write()** belong to the class **fifo**.



```
bool fifo::read(t_fifo &val) {
    // do something
}

bool fifo::write(const t_fifo &val) {
    // do something
}
```

# C/C++ - Headers and CPPs

```
// Code in header file fifo.hpp
typedef int t_fifo;
class fifo {
public:
    fifo(int size);
    ~fifo();

    bool read(t_fifo& val);
    bool write(const t_fifo& val);
    void dump();
protected:
    bool is_empty()
    { return _num_elem==0; }
    bool is_full()
    { return _num_elem==_size; }
    int inc_idx(const int& idx);
protected:
    t_fifo *_buf;
    int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
}; // Note the semicolon
```

```
// Code in implementation fifo.cpp
#include "fifo.hpp"

fifo::fifo(int size) {
    _size=size; _buf=new t_fifo[_size];
    _num_elem=0; _wr_idx=0; _rd_idx=0;
    for(int idx=0; idx<_size; ++idx)
        { _buf[idx] = 0; }
}
fifo::~~fifo()
{ delete[] _buf; }

bool fifo::read(t_fifo &val)
{ /* do something */ }
bool fifo::write(const t_fifo &val)
{ /* do something */ }
void fifo::dump()
{ /* do something */ }
int fifo::inc_idx(const int &idx)
{ /* do something */ }
```

# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods

# References

- C++ supports references to variables
  - a reference to a variable may be generated (a reference is an *alias* for the variable)
  - modifying a reference to a variable implies modifying the original variable
  - a reference has to be initialized with the variable which is referenced (once initialized the referenced variable cannot be changed)

## Syntax:

```
// type_name is the data type of the reference and variable
type_name &ref_name = variable_name;
```

```
int x = 10;
int &y;      // Does not compile as a reference has to be initialized
int &y = x;  // This is the correct syntax
y++;        // now y == 11 AND x == 11 (y is just an alias for x)
```

# Pointers

- C and C++ supports pointer variables
  - pointers variables contain **memory addresses** as their values.
  - pointers variables can be dereferenced by the **\* operator** (called dereferencing operator) which provides the contents in the memory location specified by the pointer variable
  - **memory addresses** for variables may be obtained by the **& operator** (called address operator) which produces the memory address of the variable to which it is applied.

**Pointer variable declaration syntax:**

```
type_name *ptrvar_name; // for addr. containing data of type type_name
```

**Dereferencing operator syntax:**

```
*ptrvar_name // a value of data type type_name
```

**Address operator syntax:**

```
&variable_name // a address of type "type_name *"
```

```
int x = 10;
int *y; // a pointer variable to a memory location containing an int
y = &x; // now y points to the memory addresses of x
(*y)++; // x == 11 (as *y is an alias for x)
```

# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods



# Function Argument Default Values

- A function argument may have a default value
  - has to be given in the function prototype (only!)
  - if a default value is given for an argument
    - the argument may be omitted
    - the default value will be used for the argument
  - if a function has more than one argument
    - specification of default values has to start with last argument
    - omission of parameters has to start with the last parameter

```
...
class fifo {
public:
    // constructor now with default argument
    fifo(int size = 16);
    ...
};
...
int main(int argc, char *argv[]) {
    fifo x;        // create fifo x of default size 16
    fifo y(32);    // create fifo y of size 32
    return 0;
}
```

# Call by Value

- A function argument which is not a reference is called **“by value”**
  - an argument which is passed “by value” is copied
  - only the copy is modified in the function body
  - at the calling block the passed argument remains unmodified

```
void testfunction(int x, int *z) {  
    x++;           // increment x (by one)  
    *z += 10;      // add 10 to the integer value pointed to by z  
    z = &x;        // change z to point to x  
    (*z)++;        // increment the integer value pointed to by z, that is x  
}  
  
int main(int argc, char *argv[]){  
    int x = 10;  
    int y = 11;  
    int *z = &y;  
    testfunction(x, z);  
    // x is still 10 and z still points to y but y is now 21  
    return 0;  
}
```

# Call by Reference

- A function argument which is a reference is called **“by reference”**
  - does not create a temporary variable for the argument (avoids copying!)
  - if the argument is modified inside the function, the argument variable inside the calling block is also modified
  - often not what you want – use **const reference** instead

Function argument `val` is passed as a reference to `read()`.

Therefore, the `read()` method directly modifies `y`.

```
bool fifo::read(t_fifo &val) {  
    if (is_empty()) {  
        return false;  
    } else {  
        val = _buf[_rd_idx];  
        _rd_idx = inc_idx(_rd_idx);  
        _num_elem--;  
        return true;  
    }  
}
```

```
int main(int argc, char *argv[]) {  
    fifo x;  
    int y = 0;  
    x.write(42);  
    x.read(y);  
    // now y has the value 42  
    return 0;  
}
```

# Call by Reference

- Call by reference may increase program speed
  - no temporary objects created at function calls
    - if passed objects are large this will significantly increase program speed
  - if argument should not be modified by the function
    - use the **const** keyword
    - if the function tries to modify the argument, a compiler error will be issued

Function argument `val` is passed as a reference to `read()`.

```
bool fifo::read(t_fifo &val) {  
    if (is_empty()) {  
        return false;  
    } else {  
        val = _buf[_rd_idx];  
        _rd_idx = inc_idx(_rd_idx);  
        _num_elem--;  
        return true;  
    }  
}
```

Function argument `val` is passed as a **const reference** to `write()`.

```
bool fifo::write(t_fifo const &val) {  
    if (is_full()) {  
        return false;  
    } else {  
        _buf[_wr_idx] = val;  
        _wr_idx = inc_idx(_wr_idx);  
        _num_elem++;  
        val = 42; // <= compile error!!!  
        return true;  
    }  
}
```

# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods

# Function Overloading

- A function may have more than one implementation
  - called overloading
  - the functions must have different type or number of arguments
    - called signature
  - it is not sufficient to have different return types

The two **read()** functions have a different number of arguments, so overloading is o.k.

```
class fifo {  
    ...  
    bool    read(t_fifo &val);  
    t_fifo read();  
    ...  
};
```

Implementing one **read()** function using the other **read()** function.

```
t_fifo fifo::read() {  
    t_fifo tmp;  
    bool success = read(tmp);  
    return success ? tmp : -1;  
}
```

# Function Overloading

- A function may have more than one implementation
  - called overloading
  - the functions must have different type or number of arguments
    - called signature
  - it is not sufficient to have different return types

The two **bar()** functions are only distinguished via their return types. **We get a compiler error!**

```
class foo {  
    bool bar(fifo &x);  
    double bar(fifo &x);  
};
```

Functions can be called without using their return value. So the compiler cannot distinguish between the two functions.

```
int main(int argc, char *argv[]) {  
    foo f;  
    fifo y(42);  
    f.bar(y); // Uh oh which bar?  
    return 0;  
}
```

# Operator Overloading

- Operators are treated as normal functions in C++
  - possible to overload operators
  - operators are usually class members
    - the right operand is passed as argument
    - the left operand is implicitly the class implementing the operator

The operator is declared **const**, that is the operator cannot modify the class. It can therefore also be used on **const objects**!

The comparison **x == y** calls **x.operator==(y)**.

```
class fifo {
public:
    ...
    bool operator==(const fifo &rhs) const {
        if(_size != rhs._size)
            return false;
        for(int idx = 0; idx < _size; ++idx)
            if (_buf[idx] != rhs._buf[idx])
                return false;
        return true;
    }
    ...
};
```

```
fifo x, y;
...
if (x == y)
    ...
```



# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods

# Template Classes - Introduction

- C++ supports a template mechanism
  - allows to specialize classes with parameters
    - especially useful to create classes that can be used with multiple data types
    - extensively used by SystemC
  - the template parameters have to be compile time constants
  - the complete implementation of a template class has to appear in the header (.hpp) file

```
template <class T>
class fifo {
public:
    typedef T t_fifo;
    ...
protected:
    t_fifo *_buf;
    ...
};
template <int W>
struct bar {
    bar();
    ...
    char[W] _char_array;
};
```

**\_buffer in x is of type "int \*"**  
**\_buffer in y is of type "float \*"**

```
int main(int argc, char *argv[]) {
    fifo<int>    x;
    fifo<float>  y;
    bar<10> a;
    bar<42> b;
    return 0;
}
```

**\_char\_array in a is of size 10**  
**\_char\_array in b is of size 42**

# Template Classes - Example

- re-implementing the **fifo** class to be usable with arbitrary data types

```
// Code in header file fifo.hpp
typedef int t_fifo;
class fifo {
public:

    fifo(int size);
    ~fifo();

    bool read(t_fifo& val);
    bool write(const t_fifo& val);
    void dump();
protected:
    bool is_empty()
        { return _num_elem==0; }
    bool is_full()
        { return _num_elem==_size; }
    int inc_idx(const int& idx);
protected:
    t_fifo *_buf; int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
};
```

```
// Code in implementation fifo.cpp
#include "fifo.hpp"

fifo::fifo(int size) {
    _size=size; _buf=new t_fifo[_size];
    _num_elem=0; _wr_idx=0; _rd_idx=0;
    for(int idx=0; idx<_size; ++idx)
        { _buf[idx] = 0; }
}

fifo::~~fifo()
    { delete[] _buf; }

bool fifo::read(t_fifo &val)
    { /* do something */ }

bool fifo::write(const t_fifo &val)
    { /* do something */ }

void fifo::dump()
    { /* do something */ }

int fifo::inc_idx(const int &idx)
    { /* do something */ }
```

# Template Classes - Example

- re-implementing the **fifo** class to be usable with arbitrary data types

```
// Code in header file fifo.hpp
template <class T>
class fifo {
public:
    typedef T t_fifo;

    fifo(int size);
    ~fifo();

    bool read(t_fifo& val);
    bool write(const t_fifo& val);
    void dump();
protected:
    bool is_empty()
    { return _num_elem==0; }
    bool is_full()
    { return _num_elem==_size; }
    int inc_idx(const int& idx);
protected:
    t_fifo *_buf; int _size;
    int _rd_idx;
    int _wr_idx;
    int _num_elem;
};
```

```
// NOW THE IMPLEMENTATION NEEDS
// TO ALSO BE IN THE HEADER!!!
template<class T>
fifo<T>::fifo(int size) {
    _size=size; _buf=new t_fifo[_size];
    _num_elem=0; _wr_idx=0; _rd_idx=0;
    for(int idx=0; idx<_size; ++idx)
        { _buf[idx] = 0; }
}
template<class T>
fifo<T>::~~fifo()
{ delete[] _buf; }
template<class T>
bool fifo<T>::read(t_fifo &val)
{ /* do something */ }
template<class T>
bool fifo<T>::write(const t_fifo &val)
{ /* do something */ }
template<class T>
void fifo<T>::dump()
{ /* do something */ }
template<class T>
int fifo<T>::inc_idx(const int &idx)
{ /* do something */ }
```

# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods

# Inheritance - Introduction

---

- Inheritance enables re-use of components
  - put common features of multiple classes in base class
  - derive classes from the base class
    - all existing features may be re-used
    - new features may be added
  - inheritance establishes a "is-a" relationship
    - e.g., a car is a vehicle, so it could be derived from vehicle
  - access modifiers specify the access to the base class for
    - the derived class
    - derived classes of the derived class
    - everyone else

## Syntax:

```
class derived_class : [access_modifier] base_class {  
    // class body  
};
```

# Inheritance - Access Modifier

## Overview of access modifiers for inheritance

derived as base class	public	protected	private
public	public	protected	private
protected	protected	protected	private
private	no access	no access	no access

```
Class base {  
public:  
    void pub_func();  
protected:  
    void prot_func();  
private:  
    void priv_func();  
};
```

```
class cls1: public base {  
    // pub_func() is still public  
    // prot_func() is still protected  
    // priv_func() cannot be accessed from cls1  
};
```

```
class cls2: protected base {  
    // pub_func() is now protected  
    // prot_func() is still protected  
    // priv_func() cannot be accessed from cls2  
};
```

```
class cls3: private base {  
    // pub_func() is now private  
    // prot_func() is now private  
    // priv_func() cannot be accessed from cls3  
};
```

# Inheritance - Example

```
// code in resizeable_fifo.hpp
typedef int t_fifo;

class resizeable_fifo: public fifo {
public:
    resizeable_fifo(int size = 16);
    ~resizeable_fifo();
    void resize(int size);
};
```

```
// code in main.cpp
int main(int argc, char *argv[]){
    // create a resizeable fifo
    // of size 32
    resizeable_fifo x(32);
    // resize fifo to 42 elements
    x.resize(42);
    // write data to the fifo
    x.write(10);
    return 0;
}
```

**The constructor of `resizeable_fifo` calls the constructor of its base class with the size argument.**


```
// code in resizeable_fifo.cpp
resizeable_fifo::resizeable_fifo(int size): fifo(size)
{}
void resizeable_fifo::resize(int size) {
    // a resize destroys all stored data
    delete[] _buf;
    _size = size;
    _buf = new t_fifo[size];
}
```



# Multiple Inheritance - Introduction

- Multiple Inheritance
  - derive a class from multiple base classes
  - extensively used by SystemC
    - necessary to allow separation of interface and implementation of a channel
  - multiple inheritance is an advanced feature of C++
    - only mentioned in this introduction, not covered in depth

**sc\_fifo<> is derived from three base classes**



```
template <class T> class sc_fifo : public sc_fifo_in_if<T>,
                                   public sc_fifo_out_if<T>,
                                   public sc_prim_channel
{
...
};
```

# Agenda

---

- Classes
- Pointers and References
- Functions and Methods
- Function and Operator Overloading
- Template Classes
- Inheritance
- Virtual Methods

# Virtual Methods - Declaration

- Virtual Methods in C++
  - provide a mechanism to re-implement methods of a base class
    - a method declared virtual *may* be re-implemented within a derived class
  - a so-called pure virtual method
    - *must* be re-implemented in the derived class
    - no implementation provided in the base class
    - enables the implementation of interfaces without any functionality

```
class Foo {  
public:  
    virtual void virt_func() {  
        std::cout << "I am a method of Foo" << std::endl;  
    }  
};  
  
class Bar { // similar to a java interfaces  
public:  
    virtual void pure_virt_func() = 0;  
};
```

**a virtual method**

**a pure virtual method without implementation**

# Virtual Methods – Reimplementation

```
class DerivedFoo: public Foo {
public:
    virtual void virt_func() {
        std::cout << "I am a method of DerivedFoo" << std::endl;
    }
};

Class DerivedBar: public Bar {
public:
    virtual void pure_virt_func() {
        std::cout << "I am not pure virtual any more" << std::endl;
    }
};
```

```
Foo *foo = new Foo();
Bar *bar = NULL; // bar cannot be instantiated,
                 // because it has a pure virtual method
foo->virt_func();
delete foo;
foo = new DerivedFoo();
foo->virt_func();
bar = new DerivedBar();
bar->pure_virt_func();
delete foo;
delete bar;
```

## Output:

```
I am a method of Foo
I am a method of DerivedFoo
I am not pure virtual any more
```