Tampereen yliopisto
Tampere University

Interfaces: Design by Contract

2.9.2019

A good interface?

- **Complete**
- Beautiful
- Cute

Fig: clement127 (CC BY-NC-ND 2.0)

The purpose of an interface?

Fig: Clement127 (CC BY-NC-ND 2.0)

Tampereen yliopisto
Tampere University

Where do the interfaces come from?

Main steps in designing a program:

Component

- identification
- responsibilities
- connections
- **Specifying interfaces**

Interface specification

- What is the use **allowed** by an interface?
- What do the functions behind an interface **promise** to do?
- What kind of **errors** are possible in the functions?
- How to **test** an interface?

Design by Contract

- A clean metaphor to guide the design process

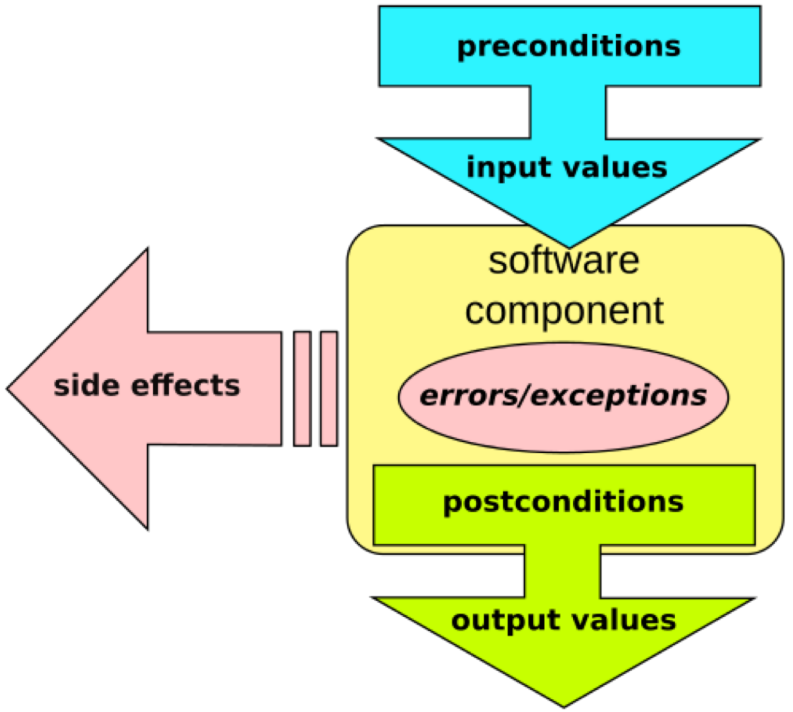


Fig: Fabuio (Own work) [CC0], via Wikimedia Commons

Design by contract

Interface specification given as a **contract**

- Client (caller) and supplier (implementor)
- Mutual obligations and benefits

Contract between an interface and its user

- Responsibility of a caller: how the interface is allowed to be used? (precondition)
- Responsibility of an implementor: what does an interface promise to do? (postcondition)
- Specification of errors

```
{P} o.service() {Q}
```

Precondition

- Must be true **before** a service
- **Caller** is responsible on fulfillment
- “When/how to call a service?” or “What does the service expect?”
- E.g. $\{a<10 \land b<20\}$

Postcondition

- Must be true **after** the service
- **Implementor** is responsible on fulfillment
- “What does a service promise to do” or “What does it guarantee?”
- Violation of postcondition leads to an exception
- E.g. $\{j<30 \land a<10 \land b<20\}$

Obligations

Client
- Takes care of fulfilling the precondition
- Preconditions can be checked during testing, not in the final program

Supplier
- Takes care of fulfilling the postcondition
- No more checks of the obligations of the caller
- If the service fails (violation of the postcondition) ⇒ exception, to be informed about

(Class) invariant

Logical assertion that is held to always be true (during a certain phase of the execution)

- Tests if an object is valid or “in its right mind”
- Must be true between the calls

```
{CLASS_INVARIANT ∧ P} o.service() {CLASS_INVARIANT ∧ Q}
```

- Useful for the implementor, not for the caller

Example

```
class Date
{
public
      setDay( int day );
private
      int d_;
      int m_;
      int y_;
};
```

- Invariant?
- Precondition?
- Postcondition?

C++20: Contracts

- C++20 enables writing pre and post conditions and invariants as part of the code

```
double sqrt(double x) [[expects: x >= 0]];
void sort(vector<emp>& v) [[ensures audit:
is_sorted(v)]];
```

Tampereen yliopisto
Tampere University

C++20: Contracts

```
int push(queue& q, int val)
      [[ expects: !q.full() ]]
      [[ ensures: !q.empty() ]]
      {
      ...
      [[assert: q.is_ok() ]]
      ...
}
```

Conditions in C++ standard

25.4.3.4 `binary_search` **[binary.search]**

```
template<class ForwardIterator, class T>
  bool binary_search(ForwardIterator first, ForwardIterator last,
                     const T& value);

template<class ForwardIterator, class T, class Compare>
  bool binary_search(ForwardIterator first, ForwardIterator last,
                     const T& value, Compare comp);
```

1 *Requires:* The elements `e` of `[first,last)` are partitioned with respect to the expressions `e < value` and `!(value < e)` or `comp(e, value)` and `!comp(value, e)`. Also, for all elements `e` of `[first, last)`, `e < value` implies `!(value < e)` or `comp(e, value)` implies `!comp(value, e)`.

2 *Returns:* `true` if there is an iterator `i` in the range `[first,last)` that satisfies the corresponding conditions: `!(*i < value) && !(value < *i)` or `comp(*i, value) == false && comp(value, *i) == false`.

3 *Complexity:* At most `log2(last - first)` + $\mathcal{O}(1)$ comparisons.

Conditions in C++ standard

25.4.1.1 `sort` **[sort]**

```
template<class RandomAccessIterator>
  void sort(RandomAccessIterator first, RandomAccessIterator last);

template<class RandomAccessIterator, class Compare>
  void sort(RandomAccessIterator first, RandomAccessIterator last,
            Compare comp);
```

1 *Effects:* Sorts the elements in the range `[first,last)`.

2 *Requires:* `RandomAccessIterator` shall satisfy the requirements of `ValueSwappable` (17.6.3.2). The type of `*first` shall satisfy the requirements of `MoveConstructible` (Table 20) and of `MoveAssignable` (Table 22).

3 *Complexity:* $\mathcal{O}(N \log(N))$ (where N `== last - first`) comparisons.

Tampereen yliopisto
Tampere University

Design by Contract: documentation

Documentation

```
mapped_type& operator[](const key_type& k);
mapped_type& operator[](key_type&& k);
```

1 *Requires:* `mapped_type` shall be `DefaultInsertable` into `*this`. For the first operator, `key_type` shall be `CopyInsertable` into `*this`. For the second operator, `key_type` shall be `MoveConstructible`.

2 *Effects:* If the `unordered_map` does not already contain an element whose key is equivalent to `k`, the first operator inserts the value `value_type(k, mapped_type())` and the second operator inserts the value `value_type(std::move(k), mapped_type())`.

3 *Returns:* A reference to `x.second`, where `x` is the (unique) element whose key is equivalent to `k`.

4 *Complexity:* Average case $\mathcal{O}(1)$, worst case $\mathcal{O}$(`size()`).

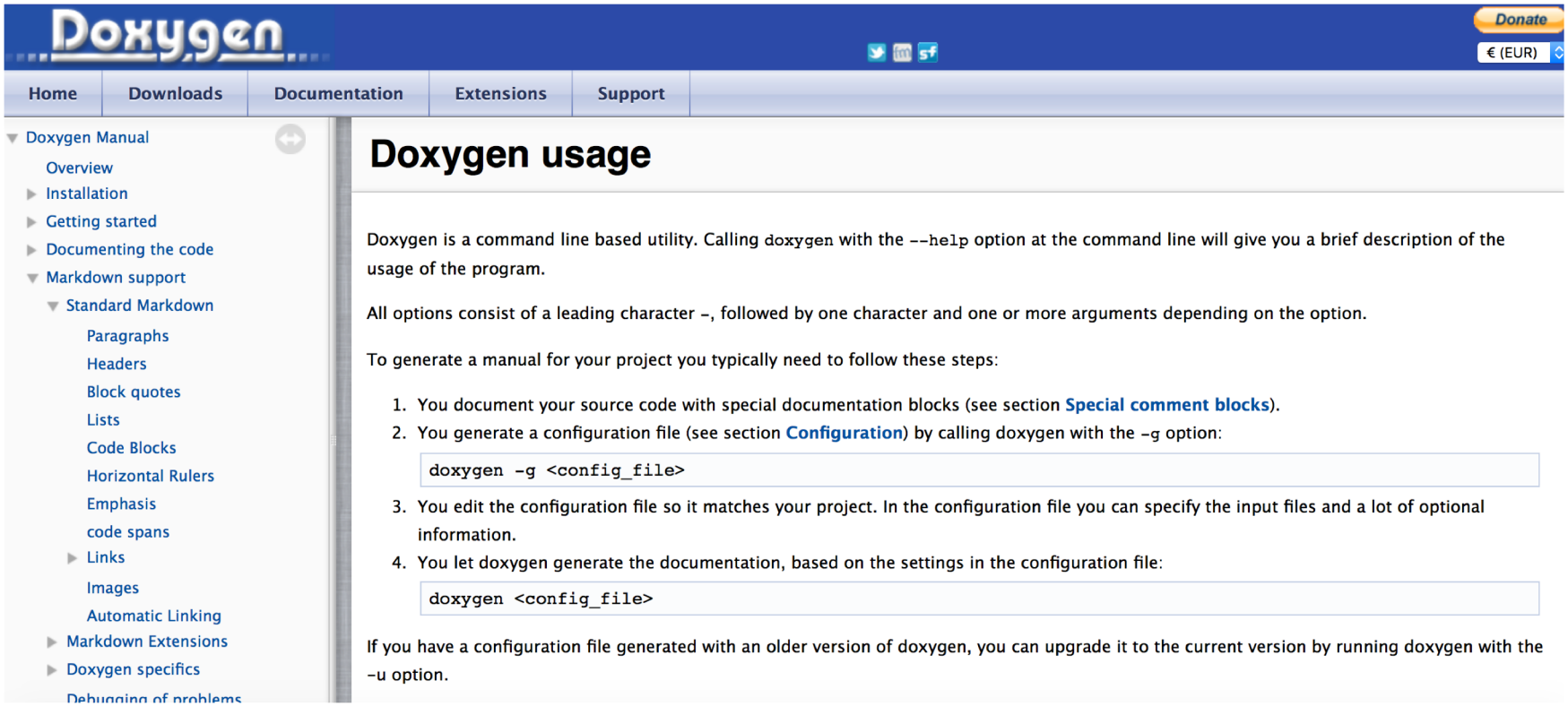
What do you know about the behavior of the operator [] based on documentation?

Hiding the implementation

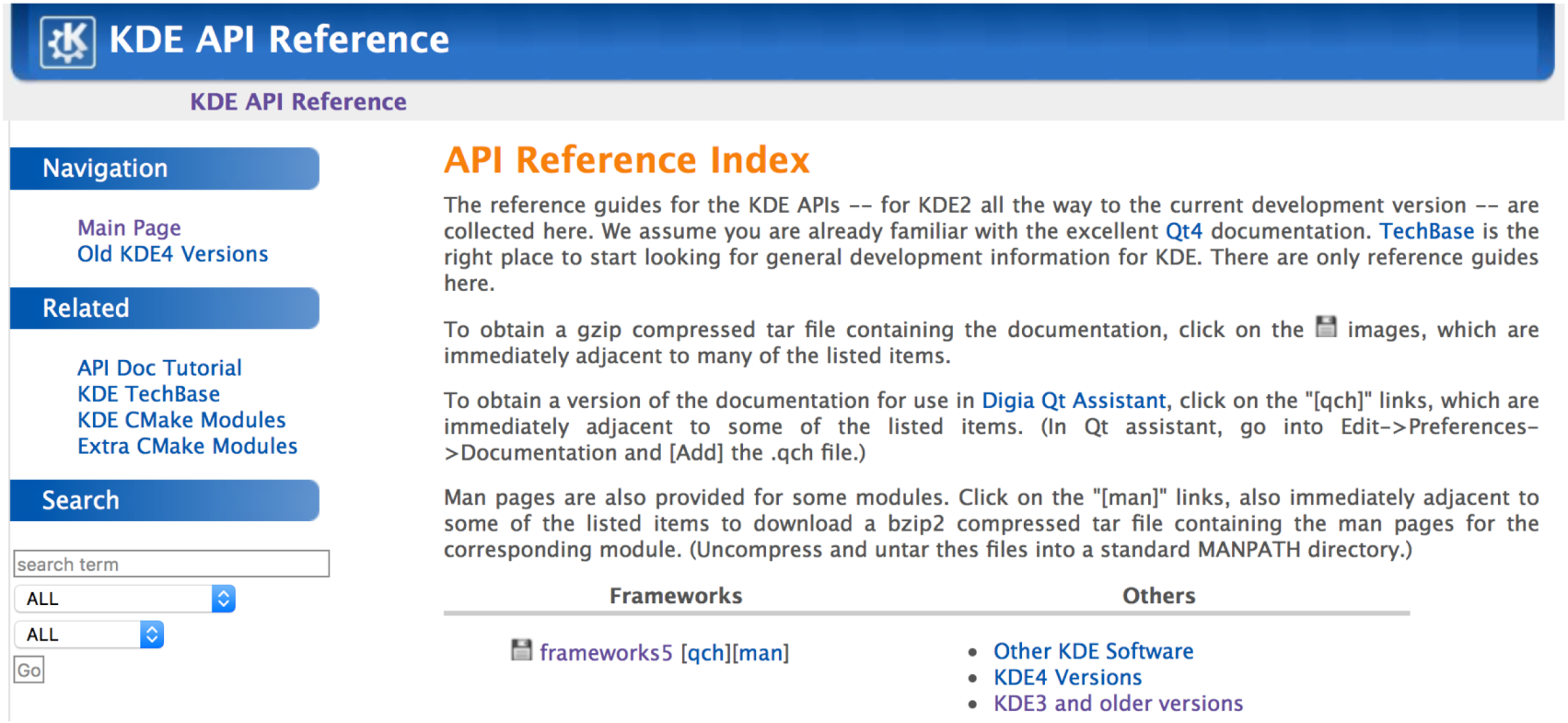
- Pre- and postconditions will be *documented* in a form that can be understood by users
- If a class **tests** the conditions or invariant, test will be written based on internal implementation

Tampereen yliopisto
Tampere University

Documentation: Doxygen



Documentation: Doxygen



Tampereen yliopisto
Tampere University

Documentation: Doxygen

```
/**
... text ... */
or
/*!
... text ...
*/
```

Documentation: Doxygen

```
\pre { precondition }
\post { postcondition }
\throw <exception_object> { exception }
\invariant { invariant }
```

Using contracts

- Lectures typically give only simple examples
- In practice:
  - Do not scale well
  - Specification that is mathematically exact is difficult (and usually unnecessary)
  - Inheritance brings difficulties

Tampereen yliopisto
Tampere University

Other contracts and practices

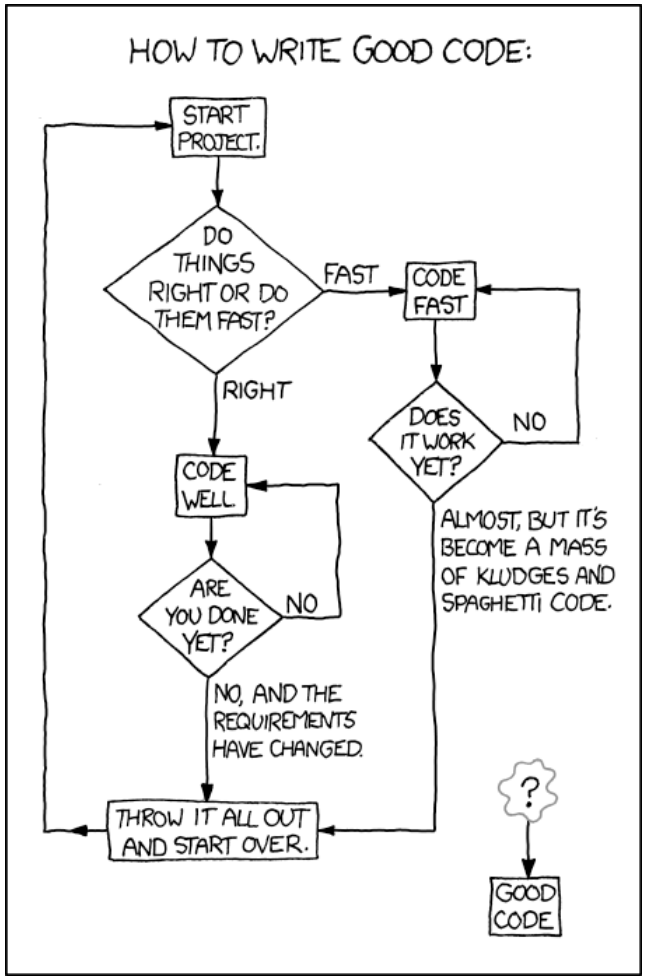
Tampereen yliopisto
Tampere University

Coding conventions

Improve readability

Things to be agreed

- Comments (e.g. Doxygen)
- Indentations
- Length of rows
- Naming
- Coding practices and principles, rules of thumb
- Style issues



Pair programming

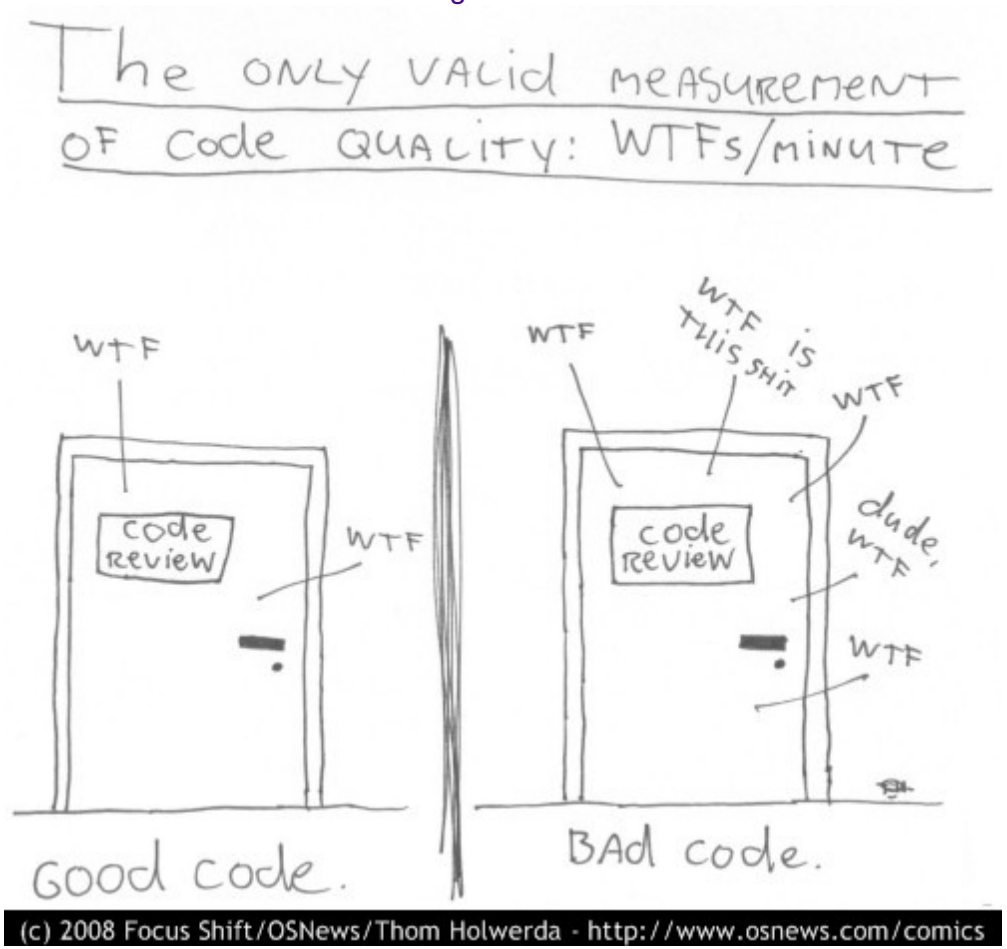
- Originates from eXtreme Programming
- Two programmers: controller and observer
  - Improves quality: decreases errors
  - Team work and communication
  - Learning

Code review

Reading code and examining:

- Does it do what is should do?
- Does it follow coding conventions?
- Does it have errors?

Fig: osnews.com/Thom Holwerda



Design by Contract: testing

Design by contract and testing

- Complements regular testing strategies: unit testing, integration testing, system testing
- Testing also preconditions
- Integration testing for free
- Support for debugging: contract violations help locating errors

Testing conditions: C++

Assert macro in C++ tests conditions and crashes the program if the condition is false

```
#include <cassert>
void f( int i )
{ assert( i >= 0 );}
```

NDEBUG ⇒ assert does nothing

Invariant

```
inline void OrderedTable::Invariant()
{
#ifndef NDEBUG
    // Invariant: items are always ordered such that index 1 contains the
smallest item and
    // index SIZE contains the largest one
    for( int i = 1; i < SIZE; i++ )
    {
        if( item[ i ] > item[ i+1 ] )
            throw OrderedTable::InvariantBroken();
    }
#endif
}

void OrderedTable::searchAndChange( Item const& wanted, Item const&
substitution )
{
    Invariant();
    // Actual implementation
    Invariant();
}
```

Tampereen yliopisto
Tampere University

Testing conditions: Qt

Qt provides more functions/macros

- `#include <QtGlobal>`
- `Q_ASSERT macro`
- Can be taken off: `QT_NO_DEBUG`

```
void Q_ASSERT(bool test)
void Q_ASSERT(bool test, const char* where, const
char* what)
```

Testing conditions: Qt

```
int divide(int a, int b)
{
    Q_ASSERT(b != 0);
    return a / b;
}
```

⇒ ASSERT: "b == 0" in file div.cpp, line 7

Testing conditions: Qt

Correspondingly:

```
    Q_ASSERT_X(b != 0, "divide", "division by
zero");
    return a / b;
```

⇒ ASSERT failure in divide: "division by zero",
file div.cpp, line 7