Materialsammlung - generische Programmierung

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Vorbemerkungen:

```
//==========================================================================
// Name        : C++ConceptsLite.cpp
// Description : Example for Concepts Lite, ab g++ 6 mit -fconcepts
//==========================================================================
#include <iostream>
#include <cstdlib>
#include <cassert>
#include <type_traits>
// using namespace std;

/*
template <typename T>
concept constexpr bool CopyConstructible() {
        return requires(T t){
            { T(t) };
            { t.~T() };
        };
}
*/

template <typename T>
concept constexpr bool CopyConstructible =
            std::is_copy_constructible<T>::value &&
            std::is_destructible<T>::value;

template <typename T>
concept constexpr bool NullConstructible(){
        return requires(T t){
            { T(0) };
        };
}

template <typename T, typename U = T>
concept constexpr bool Addable(){
        return requires(T t, U u){
          { t + u } -> decltype(t + u);
        };
}

template <CopyConstructible T>
   requires NullConstructible<T>() && Addable<T>()
T sum(T array[], int n)
{
        T result {0};
        for (int i = 0; i < n; ++i)
```

```
                result = result + array[i];
        return result;
}

int main(int argc, char* args[]) {
        std::cout << "Testrahmenprogramm:" << std::endl;
        int arr1[] {1, 2, 3};
        std::cout << sum(arr1, 3) << std::endl;
        assert(sum(arr1, 3) == 6);
        return EXIT_SUCCESS;
}
```

```
Invoking: GCC C++ Compiler
g++ -std=c++1z -O0 -g3 -Wall -c -fmessage-length=0 -Wno-attributes -Wno-attributes -fconcepts -MMD -MP -MF"src/NewC++.d" -MT"
../src/NewC++.cpp: In function ‘int main()’:
../src/NewC++.cpp:66:26: error: cannot call function ‘T sum(T*, int) [with T = MyClass]’
  std::cout << sum(arr1, 3) << std::endl;
                          ^
../src/NewC++.cpp:38:3: note:   constraints not satisfied
 T sum(T array[], int n)
   ^~~
../src/NewC++.cpp:19:24: note: within ‘template<class T> concept const bool CopyConstructible<T> [with T = MyClass]’
 concept constexpr bool CopyConstructible =
                        ^~~~~~~~~~~~~~~~~
../src/NewC++.cpp:19:24: note: ‘std::is_copy_constructible<MyClass>::value’ evaluated to false
../src/NewC++.cpp:24:24: note: within ‘template<class T, class U> concept bool Addable() [with T = MyClass; U = MyClass]’
 concept constexpr bool Addable(){
                        ^~~~~~~
../src/NewC++.cpp:24:24: note:     with ‘MyClass t’
../src/NewC++.cpp:24:24: note:     with ‘MyClass u’
../src/NewC++.cpp:24:24: note: the required expression ‘(t + u)’ would be ill-formed
../src/NewC++.cpp:31:24: note: within ‘template<class T> concept bool NullConstructible() [with T = MyClass]’
 concept constexpr bool NullConstructible(){
                        ^~~~~~~~~~~~~~~~~
../src/NewC++.cpp:31:24: note:     with ‘MyClass t’
../src/NewC++.cpp:31:24: note: the required expression ‘(T)(0)’ would be ill-formed
In file included from /usr/include/c++/7/cassert:44:0,
                 from ../src/NewC++.cpp:12:
```

Constraints and concepts
(predefined) Library Concepts
Concepts of experimental::ranges
Concepts-Lite
Concepts Lite: Constraining Templates with Predicates
Concepts definieren
type_traits

g++-Versionen aktueller (Sptember 2017) Linux-Distributionen:

Linux-Distribution	g++-Version
OpenSuse 13.2	4.8.3
Suse Leap 42.2	4.8.5
Suse Leap 42.3	4.8.5
Suse Tumbleweed	7.2.1
Ubuntu 16.04	5.4.0
Ubuntu 17.04	7.0.1
Ubuntu 17.10	7.2.0
Debian 9.0.0	6.3.0
CentOS 7.3	4.8.5
Fedora 26	7.1.1
OpenIndiana Hipster 2017.04	4.8.5

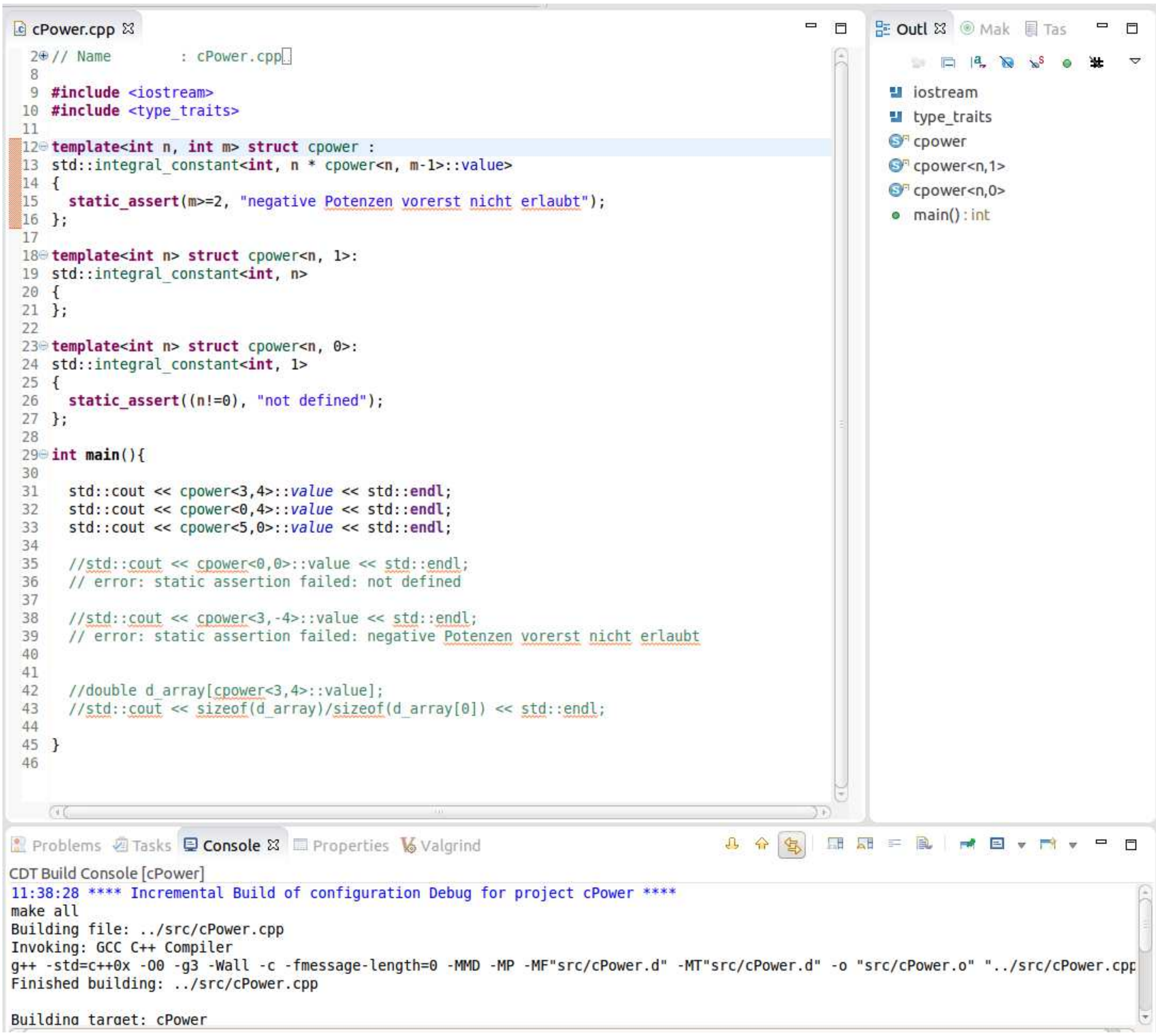
Listen-Initialisierung:

```
//============================================================================
// Name        : New3C++.cpp
// Author      : HJB
// Version     :
// Copyright   : PD
// Description : Listen-Initialisierung
//============================================================================

#include <iostream>
#include <cstdlib>
#include <cassert>
#include <type_traits>
#include <list>
// using namespace std;

int main() {
	std::cout << "Testrahmenprogramm:" << std::endl;

	std::list<int> l1 {7, 5, 3};

	/* instead of the sequence:
	 l1.push_back(7);
	 l1.push_back(5);
	 l1.push_back(3);
	 */
	assert(none_of(l1.begin(), l1.end(), [](auto v){return v == 4;}));
	// see also: any_of()/all_of();
	return EXIT_SUCCESS;
}
```

std::initializer_list
Constructors and member initializer lists
Why should I prefer to use member initialization list?

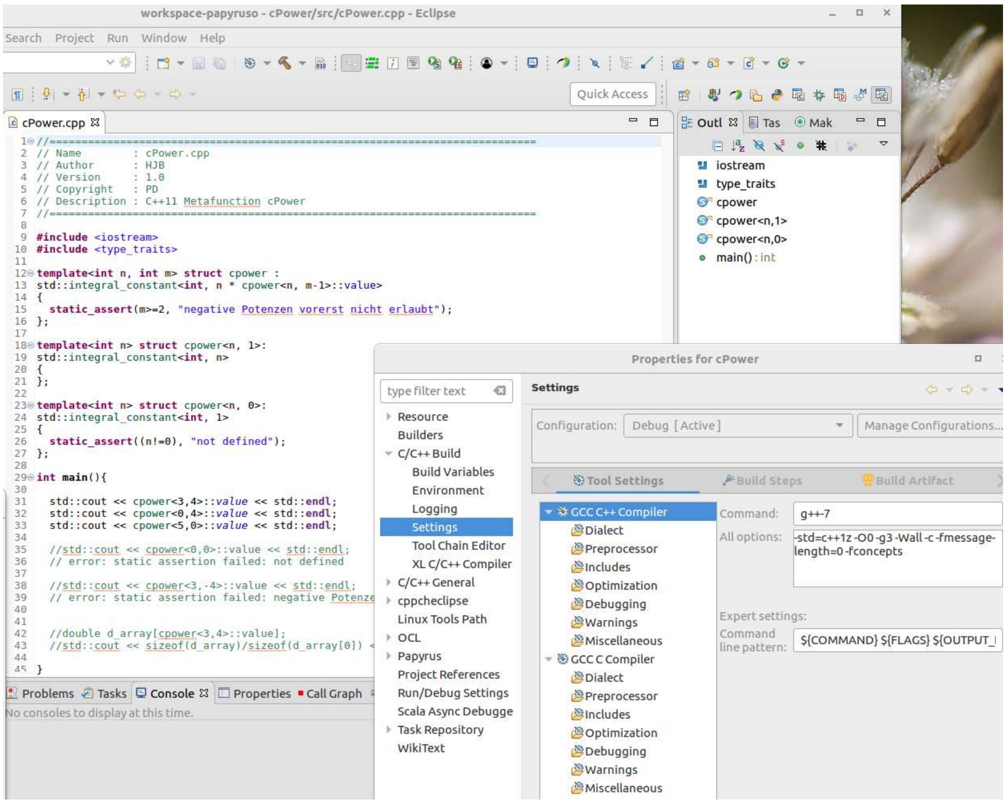
list initialization
Initializer list for objects with default constructor

Compilezeit-Funktionen:

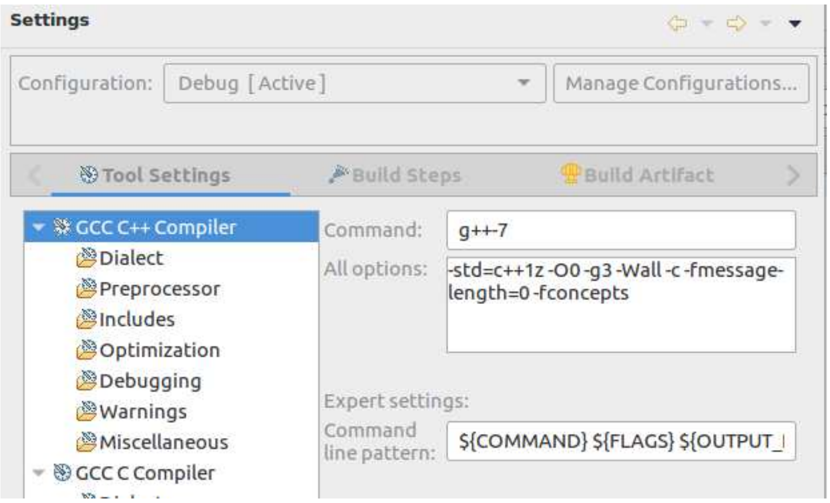


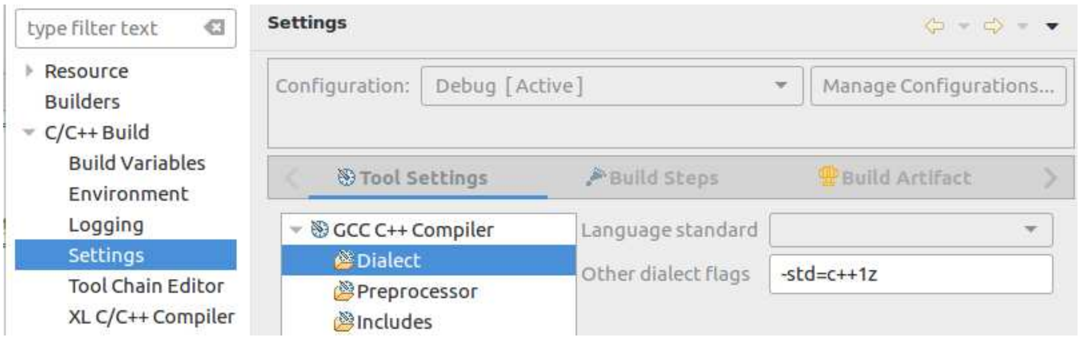
Beispiel zur Metaprogrammierung. Benutzt wird hier die IDE Eclipse, auf den Ausbildungslaborrechnern der Fachgruppe Mathematik und Informatik als `eclipse-papyruso1` aufruf- und benutzbar:

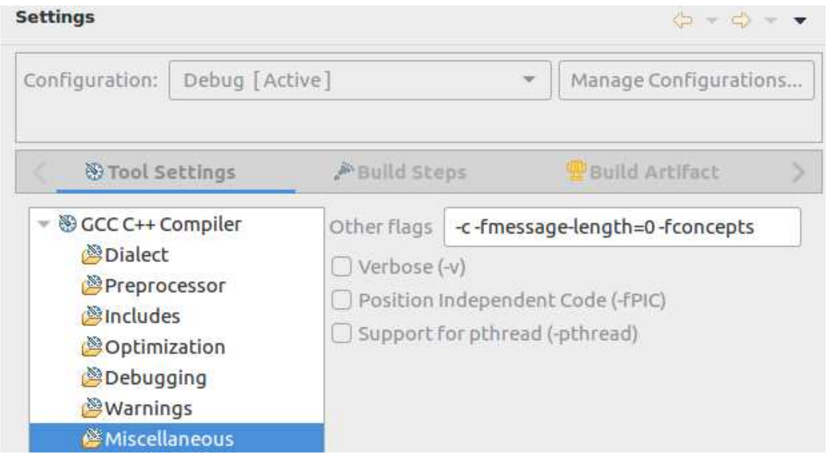
Hinweise zu den Compiler-Optionen für C++17:



`g++-7`, `-std=c++1z` und `-fconcepts`







Hinweise zur Installation von Eclipse auf Ihrem eigenen Linux-Rechner finden Sie in Anhang A (Seite i).

Physikalisch/technische Maßeinheiten in C++:

Idee aus Jürgen Wolf: C++, Das umfassende Handbuch, Seite 816f.:
`std::chrono::duration<.,.>` zweckentfremdet für allgemeine physikalisch/technische Maßeinheiten:

```
//============================================================================
// Name        : MessSkalen.cpp
// Author      : HJB
// Version     : 1.0
// Copyright   : PD
// Description : MessSkalen
//============================================================================

#include <iostream>
#include <type_traits>
#include <chrono>

using Meter =  std::chrono::duration<long double, std::ratio<1>>;
using Kilometer = std::chrono::duration<long double, std::kilo>;
using Meilen = std::chrono::duration<long double,
                                   std::ratio<1609344,1000>>;

int main(int argc, char* args[]) {
    std::cout << "Testrahmenprogramm MessSkalen:" << std::endl <<
        std::endl;

    Meter e1{150.0};
    Kilometer e2{e1};
    std::cout << e1.count() <<
        " Meter entspricht " << e2.count() << " Kilometer." << std::endl;
    Meilen e3{e1}; Meilen e4{10.1};
    std::cout << e1.count() << " Meter entspricht " <<
        e3.count() << " Meilen." << std::endl;
    Kilometer e5 = e1 + e4;
    std::cout << e5.count() << " Kilometer, gemischte Arithmetik " <<
        std::endl;
    std::cout << static_cast<Meter>(e5).count() << " Meter, cast" <<
        std::endl;

    return 0;
}
```

Vollständiger mit überladenem `operator<<` und `operator''''`:

```
//==============================================================
// Name        : MessSkalen.cpp
// Author      : HJB
// Version     : 1.0
// Copyright   : PD
// Description : MessSkala-Laenge
//=============================================================

#include <iostream>
#include <type_traits>
#include <chrono>

using Laenge =  std::chrono::duration<long double, std::ratio<1>>;
using Meter =  std::chrono::duration<long double, std::ratio<1>>;
using Kilometer = std::chrono::duration<long double, std::kilo>;
using Meilen = std::chrono::duration<long double,
                                        std::ratio<1609344,1000>>;

constexpr Meter operator"" _m(long double d)
{
        return Meter{d};
}
constexpr Kilometer operator"" _km(long double d)
{
        return Kilometer{d};
}

std::ostream& operator<<(std::ostream& os, const Laenge& l)
{
        os << l.count() << " Meter";
        return os;
}
std::ostream& operator<<(std::ostream& os, const Kilometer& l)
{
        os << l.count() << " Kilometer";
        return os;
}
std::ostream& operator<<(std::ostream& os, const Meilen& l)
{
        os << l.count() << " Meilen";
        return os;
}

int main(int argc, char* args[]) {
    std::cout << "Testrahmenprogramm MessSkala-Laenge:" << std::endl <<
        std::endl;

    Laenge e1{150.0_m};
    Kilometer e2{250.0_km};
    std::cout << e1 << std::endl;
    std::cout << e2 << std::endl;
```

```
    Laenge e3 = e1 + e2;
    std::cout << std::chrono::duration_cast<Kilometer>(e3) << std::endl;
    std::cout << e3 << std::endl;
    std::cout << std::endl << std::endl;


    Meilen e4{e1};
    Meilen e5{6.3};
    std::cout << e2 << " entspricht " << e4 << std::endl;
    Kilometer e6 = e2 + e5;
    std::cout << e6 << ", gemischte Arithmetik " << std::endl;
    std::cout << std::chrono::duration_cast<Meter>(e6).count() <<
        " Meter, cast" << std::endl;
    std::cout << std::chrono::duration_cast<Meilen>(e6) <<
        ", cast" << std::endl;

        return 0;
}
```

Aufgabe: Wandeln Sie das Programm für die Umwandlung von Währungskursen ineinander ab.
Aufgabe 2: Vergleichen Sie mit Handling Scientific Quantities (M. Semenov):

```
template <int M, int L, int T>
Quantity<M,L,T> operator+(const Quantity<M,L,T>& lhs, const Quantity<M,L,T
   >& rhs)
{
    return Quantity<M,L,T>(lhs)+=rhs;
}
template <int M, int L, int T>
Quantity<M,L,T> operator-(const Quantity<M,L,T>& lhs, const Quantity<M,L,T
   >& rhs)
{
    return Quantity<M,L,T>(lhs)-=rhs;
}
template <int M1, int L1, int T1, int M2, int L2, int T2>
Quantity<M1+M2,L1+L2,T1+T2> operator*(const Quantity<M1,L1,T1>& lhs, const
     Quantity<M2,L2,T2>& rhs)
{
    return Quantity<M1+M2,L1+L2,T1+T2>(lhs.getValue()*rhs.getValue());
}
template <int M, int L, int T>
Quantity<M,L,T> operator*(const double& lhs, const Quantity<M,L,T>& rhs)
{
    return Quantity<M,L,T>(lhs*rhs.getValue());
}

template <int M1, int L1, int T1, int M2, int L2, int T2>
Quantity<M1-M2,L1-L2,T1-T2> operator/(const Quantity<M1,L1,T1>& lhs,
            const Quantity<M2,L2,T2>& rhs)
{
    return Quantity<M1-M2,L1-L2,T1-T2>(lhs.getValue()/rhs.getValue());
```

```
}

template <int M, int L, int T>
Quantity<-M, -L, -T> operator/(double x, const Quantity<M,L,T>& rhs)
{
    return Quantity<-M,-L,-T>(x/rhs.getValue());
}
// ...
```

(Nutzung der Template-Metaprogrammierung zur Manipulation des Typsystem)

Wiederum vervollständigt benötigen wir für das SI-Einheitensystem sieben Dimensionen:

```
template<int mass, int lenth , int time , int current ,
         int temp, int  amount, int intensity>
class Quantity  /* Idee: B. Stroustrub: The C++ Progr. Lang., 4th ed.,
   page 818f. */
{
public:
         Quantity(long double val=0.01) :  value(val){};

         Quantity(const Quantity& q): value(q()){};

         long double operator()() const {return value;};
private:
        long double value;
};

//...

using Mass = Quantity<1,0,0,0,0,0,0>;
using Meter = Quantity<0,1,0,0,0,0,0>;
//...
```

Ideal wäre natürlich die Nutzung von `chrono::duration` als Skalarbereich für `Quantity`:

```
template <typename T> struct is_ratio : std::false_type {};
template < long int N, long int D> struct is_ratio<std::ratio<N, D>> : std
    ::true_type {};

template <int mass, ind length, int time, int current, int temp,
          int amount, int intensity,
          typename rat = std::ratio<1l>>
class Quantity // Idee: B. Stroustrup: The C++ Progr. Lang., 4th edl, page
    818f.
{
   static_assert(is_ratio<rat >::value, "optionaler achter gener. Parameter
       nicht vom Typ std::ratio");
private:
  std::chrono::duration<long double, rat> value;
  // duration nach: J. Wolff; C++, Das umfassende Handbuch, Seite 816f.
public:
  Quantity(long double val=0.0l) : value(val){};
  Quantity(const Quantity& q) : value(q()){};

  long double operator()() const {return value.count();};
  std::chrono::duration<long double, rat>
  get_value() const
  {
     return value;
  };

  Quantity operator+(const Quantity& summand) const
  {
     return Quantity((*this)() + summand());
  };

  // ...

}
```

structured bindings:

```
//============================================================
// Name        : StructuredBindings.cpp
// Author      : HJB
// Version     :
// Copyright   : PD
// Description : structured bindings example
//============================================================

#include <iostream>
#include <cstdlib>
#include <string>
#include <map>
//using namespace std;

int main(int argc, char *const argv[], char *const envp[]) {
        std::cout << "Testrahmenprogramm:\n" << std::endl;

        std::map<std::string, std::string> BUWStandorte = {
                        { "Campus Grifflenberg", "Gauss-Str. 20" },
                        { "Campus Haspel",       "Pauluskirchstr. 7" },
                        { "Campus Freudenberg",  "Rainer-Gruenter-Str." }
                            };


        for (const auto& [key, value] : BUWStandorte){
                std::cout << key << ": " << value << std::endl;
        }
        // nach: https://www.heise.de/developer/artikel/C-17-Kleinvieh-
            macht-auch-Mist-3324790.html

        // statt alt:

        std::cout << std::endl;
        for (const auto& it : BUWStandorte){
            std::cout << it.first << ": " << it.second << std::endl;
        }

        return EXIT_SUCCESS;
}
```

generische lambda-Ausdrücke:
Seit C++14 programmiererfreundlichere generische Lambdas:

```
std::vector<int> v {4, 3, 2, 1};
// C++11: have to state the parameter type
// std::for_each( begin(v), end(v), [](const decltype(*begin(v))& x)
//                                     { std::cout << x; } );
// sort( begin(w), end(w), [](const shared_ptr<some_type>& a,
//                            const shared_ptr<some_type>& b)
//                                       { return *a<*b; } );
// auto size = [](const unordered_map<wstring, vector<string>>& m)
//                                       { return m.size(); };
//
// see: https://isocpp.org/wiki/faq/cpp14-language#generic-lambdas

// C++14: just deduce the type
std::for_each( begin(v), end(v), [](const auto& x) { std::cout << x; } );
std::cout << std::endl;
std::sort( begin(v), end(v), [](const auto& a, const auto& b) { return a <
    b; } );
std::for_each( begin(v), end(v), [](const auto& x) { std::cout << x; } );
```

Generic lambdas, C++ FAQ

Ergänzende Operationen für std::ratio:

```
template <typename T> struct is_ratio : std::false_type { };
template <long int N, long int D> struct is_ratio<std::ratio<N, D>> : std
    ::true_type { };
//...
template<typename T,
         typename std::enable_if<is_ratio<T>::value>::type* = nullptr>
std::ostream& operator<<(std::ostream& os, const T& s)
{
        os <<  (T::num) << "/" << (T::den);
        return os;
}
//...
template<typename T,
         typename std::enable_if<is_ratio<T>::value>::type* = nullptr>
std::string toString(const T s)
{
      static_assert(is_ratio<T>::value, "no ratio<.,.> type");
      std::ostringstream help;
      help << (T::num) << "/" << (T::den);
      return help.str();
}
//...
```

enable_if Helper

(Weitere) Template-Metaprogrammierung:

Compilezeit-Funktionen für Typlisten

```
#include <iostream>
//using namespace std;

template<typename... typelist>
struct count;

template<>
struct count<>{
        static const int value = 0;
};

template<typename node, typename... remainder>
struct count<node, remainder...>{
        static const int value = 1 + count<remainder...>::value;
};


int main() {
        std::cout << "Testrahmenprogramm:" << std::endl;

        std::cout << count<short, int, long, float, double, long double>::
            value <<std::endl;
        return 0;
}
```

std::integer_sequence

Promote-Type-Metafunktion

```
//==============================================================================
// Version     : 1.0
// Description : promote type,
// https://stackoverflow.com/questions/16168927/promote-type-from-a-list-
    of-types-with-templates
//==============================================================================
#include <iostream>
#include <vector>
#include <numeric>
using namespace std;

template<typename Tp, typename T1, typename ... Tn> struct contains_type
    { constexpr static bool value = std::is_same<Tp, T1>::value ||
        contains_type<Tp, Tn...>::value; };
template<typename Tp, typename T1> struct contains_type<Tp, T1>
    { constexpr static bool value = std::is_same<Tp, T1>::value; };

template<typename ... T> struct type_promotion
{
```

```
    typedef typename
        std::conditional<contains_type<long double, T...>::value, long
            double,
        typename std::conditional<contains_type<double      , T...>::value,
             double,
        typename std::conditional<contains_type<float       , T...>::value,
             float ,
        typename std::conditional<contains_type<long long   , T...>::value,
             long long,
        typename std::conditional<contains_type<unsigned long long, T
            ...>::value, unsigned long long,
        typename std::conditional<contains_type<int         , T...>::value,
             int ,
        typename std::conditional<contains_type<unsigned int, T...>::value
            , unsigned int,
        void>::type>::type>::type>::type>::type>::type>::type type;
};

using Vector1 = std::vector<double>;
using Vector2 = std::vector<int>;
// alt:
/*
template<typename C1, typename C2, typename T =
         typename type_promotion<typename C1::value_type, typename C2::
             value_type>::type>
T dot_product(const C1 &c1, const C2 &c2)
    { // ...    }
*/
// oder moderner:
template<typename C1, typename C2, typename T = decltype(typename C1::
    value_type() * typename C2::value_type())>
T dot_product(const C1 &c1, const C2 &c2) {
        /* from:
         * https://stackoverflow.com/questions/10908012/computing-the-
             scalar-product-of-two-vectors-in-c
         */

         if (c1.size() != c2.size()) {
                 throw std::runtime_error("different sizes");
         }
         return std::inner_product(c1.begin(), c1.end(), c2.begin(), 0.0);
}

int main()
{
    Vector1 a {1.0, 5.0};
    Vector2 b {2, 1}, c {1, 1},

    cout << dot_product(a, b) / 2 << endl;
    cout << dot_product(b, c) / 2 << endl;
    cout << dot_product<Vector1, Vector2, long double>(a, b) << endl;
}
```

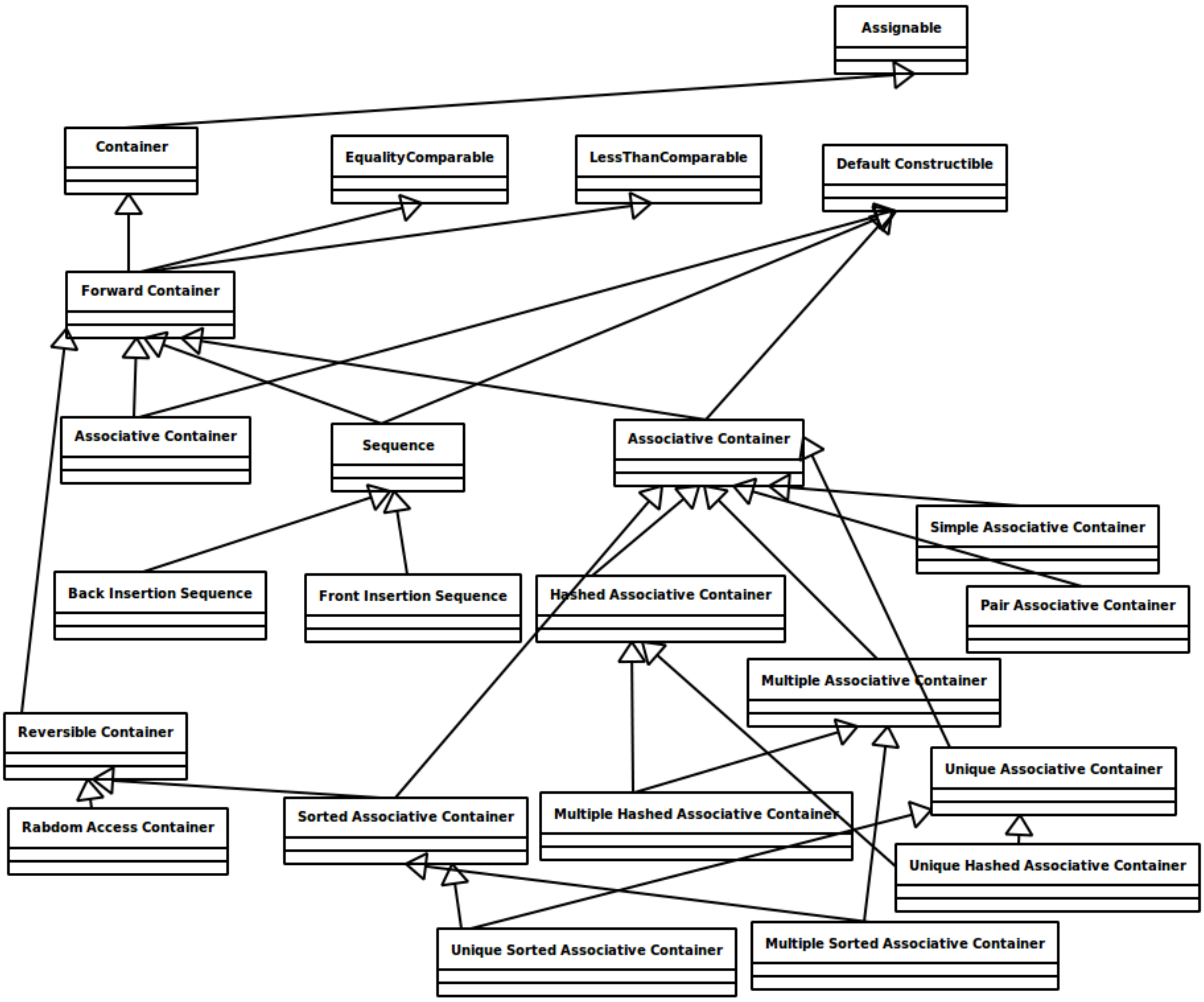
Template-Template-Parameter:

```cpp
//============================================================
// Author       : HJB
// Version      :
// Copyright    : PD
// Description  : template template Container
//============================================================

#include <iostream>
#include <cstdlib>
#include <string>
#include <vector>
#include <set>
//using namespace std;

template <template <typename... Args> class Container, typename... Types>
class STLContainer
{
    public:
    Container<Types...> content;

};
// nach https://stackoverflow.com/questions/16596422/template-class-with-
    template-container

int main(int argc, const char* argv[])
{
        std::cout << "Testrahmenprogramm:" << std::endl << std::endl;

        STLContainer<std::set, int> t {};
        t.content = {1, 3, 6, 17};
        for (auto i = t.content.begin(); i != t.content.end(); ++i)
            std::cout << *i << ' ';
        std::cout << std::endl;
        std::cout << std::endl;

        STLContainer<std::vector, std::string> p {};
        p.content = {"BUW", "Wuppertal"};
        for (auto i = p.content.begin(); i != p.content.end(); ++i)
            std::cout << *i << std::endl;
        std::cout << std::endl;

        return 0;
}
```

Containers
Containers library
C++ concepts: Container
Uniform container erasure

Policy based Design:

Statt aus einer immer unübersichtlicher werdenden Namensverwirrung bei den Bezeichnern der STL-Container



zu wählen, wäre eine Policy-basierte Auswahl der Eigenschaft, die ein gerade einzusetzender Container haben soll sehr viel alltagstauglicher:

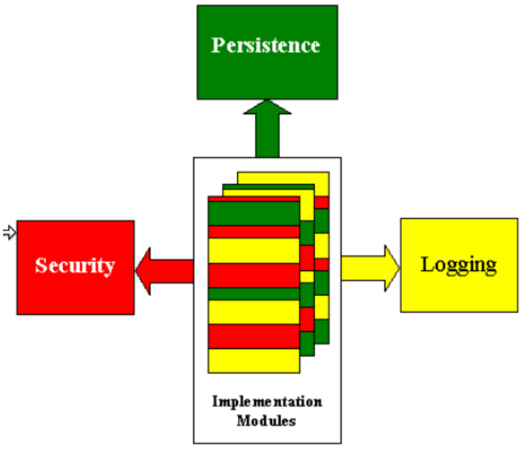
```
using MyContainer = StlContainer<Multiple, Sorted,
                                 Associative, Threadsave>;
...
```

Unique/Multiple, Sorted/Unsorted, Associative/Nonassociative, Hashed/Unhashed, Threadsave/Unthreadsave, ...

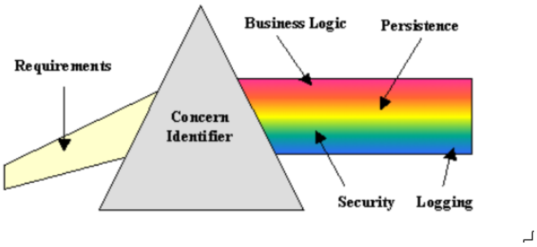
std::execution::seq, std::execution::par, std::execution::par_unseq
std::execution::sequenced_policy, std::execution::parallel_policy, std::execution::parallel_unsequenced_policy
C++ Algorithms library

Aspect Oriented Programming:

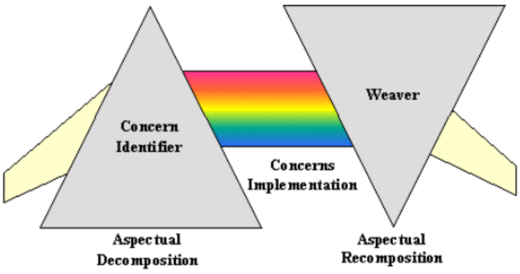
Aspekte und die damit verbundene Code-Verteilungstechnologie machen nachträglich in eine bestehende „riesige“ Unternehmens-Codebasis einzupflegende Funktionen erst möglich:
Die neu erforderlichen Concerns `Security, Persistence, Logging, ...` werden identifiziert,



in einzelnen Aspekten implementiert



und schießlich auf die gesamte Unternehmens-Codebasis verteilt:



aus: I want my AOP! (R. Laddad)

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- last Draft C++11
- last Draft C++14
- Draft C++17
- Future of Generic Programming
- C++-Metaprogramming
- Policy Based Design
- AOP bei der Enterprise-Programmentwicklung
- ...

Einordnung in die Programmierparadigmen

imperativ, funktional, objektbasiert, objektorientiert, Automaten-basiert, Ereignis-getrieben, generisch, Policy-basiert, aspektorientiert,
deklarativ (logische Programmierung, regelbasiert), ...

imperativ (strukturiert prozedural): Sequenz von Anweisungen, die den Programmstatus direkt ändern; Variablen, Wertzuweisungen, Iterationen, Schleifen, Fallunterscheidungen, Unterprogramme, Modularisierung, ...
Beispiel: C

funktional: Komposition von Komposition von ... von Komposition von nebeneffektfreien Funktionen; keine Variablen (änderbare Datenfelder) , keine Schleifen, dafür Rekursion, Lambdaausdrücke, ...
Beispiel: (reines) LISP, Haskel, C++ Template-Metaprogammierung, ...

objektorientiert: Recordfelder (Klassenfelder) als lokale Daten (Attribute), die durch im Record definierte Funktionen (Methoden) bearbeitet werden; Vererbung an Unterrecords, Polymorphismus, Überschreiben von Methoden in Unterrecords, ...

Beispiel: C++, Java, Python, ...

objektbasiert: objektorientiert ohne Vererbung oder Polymorohismus oder mit vielen eingebauten Datenwerten, die keine Objekte sind.
Beispiel: VisualBasic

Automatenbasiert: (endlicher) Automat mit Status-Enummeration und imperativer ereignisgetriebener Statusübergangsschleife.
Beispiel: zelluläre Automaten, LEX/YACC, ...

Ereignis-getrieben: asynchrone Hauptschleife mit Ereignis-Handlern, Callback-Funktionen, ...
Beispiel: qt, GUI-Systeme

generisch: (objektorientierte) Programmiermethoden mit Typen als Parametern
Beispiel: C++ Templates (Schablonen)

Policy-basiert: Compiletime-Version des Policy-Designpattern, um verschiedene Implementierungsvarianten eines generischen Konstrukts durch einen generischen Policy-Parameter bei der Instanziierung auswählen zu können.
Beispiel: Temlate-Templateparameter mit Policy-Bedeutung

aspektorientiert: objektorientierte Programmierung, um generische Funktionalitäten über mehrere Klassen hinweg zu verwenden (Cross-Cutting Concern). Logische Aspekte eines Anwendungsprogramms werden dabei von der eigentlichen Geschäftslogik getrennt. Typische Anwendungsbeispiele sind Transaktionsverwaltung, Auditfähigkeit und Loggingverhalten. (siehe: http://de.wikipedia.org/wiki/Aspektorientierte_Programmierung)
Beispiel: AspectJ, AspectC++

deklarativ, logische Programmierung, regelbasiert: Bearbeitungsregeln, die das was, nicht das wie der Bearbeitungsschritte definieren; Laufzeitsystem bearbeitet Eingaben gemäß des Regelsatzes durch automatische Inferenzmaschine.
Beispiel: Prolog, SQL, reguläre Ausdrücke

„Eines der *Haupteinsatzgebiete* generischer Programmierung ist die Konstruktion von effizienten, wiederverwendbaren Software-Bibliotheken“ (Werkzeugkästen von Komponenten und/oder Algorithmen):

generic Libraries

- STL/Standardbibliothek, C++20 ranges(?), ...
- Matrix Template Library
- Computational Geometric Algorithms Library
- viele Boost-Libraries, unter anderem die
- Boost Graph Library
- Iterative Template Library
- Iterative Eigensolver Template Library
- Open CAD Libraries
- GUI-Bibliotheken: qt, gtkmm, ...
- Open Libraries für algebraische mathematische Strukturen (Körper, Gruppen, Module, Vektorräume, ...): Armadillo, Basic Tensor Algebra Subroutines, uBLAS, ...
- Filesystem TS
- ...

Siehe auch C++20, insbesondere die technischen Spezifikationen (TS).

Die Entwicklung der Aussagekraft der formalen generischen Parameternamen

- von einfallslosen Parameternamen wie `class T1, class T2, ...`
  vergleiche http://www.cplusplus.com/doc/tutorial/templates/
- über semantisch inhaltsvolle Parameternamen wie `typename InputIterator1, typename InputIterator2, typename NumericT, ...`
  vergleiche http://www.iue.tuwien.ac.at/phd/heinzl/node32.html#SECTION01022300000000000000.

Ein Typsystem für generische Parameter

- hin zur Nennung der Requirements an die zur Instantiierung benutzbaren aktuellen Parameter wie `T shall meet the requirements of CopyConstructible and CopyAssignable types` (Seite 431 von http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2011/n3242.pdf) mit der Erläuterung:

Table 33 — `DefaultConstructible` requirements [**defaultconstructible**]

Expression	Post-condition
`T t;`	object `t` is default-initialized
`T u{};`	object `u` is value-initialized
`T()` `T{}`	a temporary object of type `T` is value-initialized

Table 34 — `MoveConstructible` requirements [**moveconstructible**]

Expression	Post-condition
`T u(rv);`	`u` is equivalent to the value of `rv` before the construction
`T(rv)`	`T(rv)` is equivalent to the value of `rv` before the construction
[*Note:* `rv` remains a valid object. Its state is unspecified — *end note*]	

Table 35 — `CopyConstructible` requirements (in addition to MoveConstructible) [**copyconstructible**]

Expression	Post-condition
`T u(v);`	the value of `v` is unchanged and is equivalent to `u`
`T(v)`	the value of `v` is unchanged and is equivalent to `T(v)`

Table 36 — `MoveAssignable` requirements [**moveassignable**]

Expression	Return type	Return value	Post-condition
`t = rv`	`T&`	`t`	`t` is equivalent to the value of `rv` before the assigment
[*Note:* `rv` remains a valid object. Its state is unspecified. — *end note*]			

Tabelle 0.1.: C++ Requirements DefaultConstructible, ...

(Seite 431f. des Drafts)

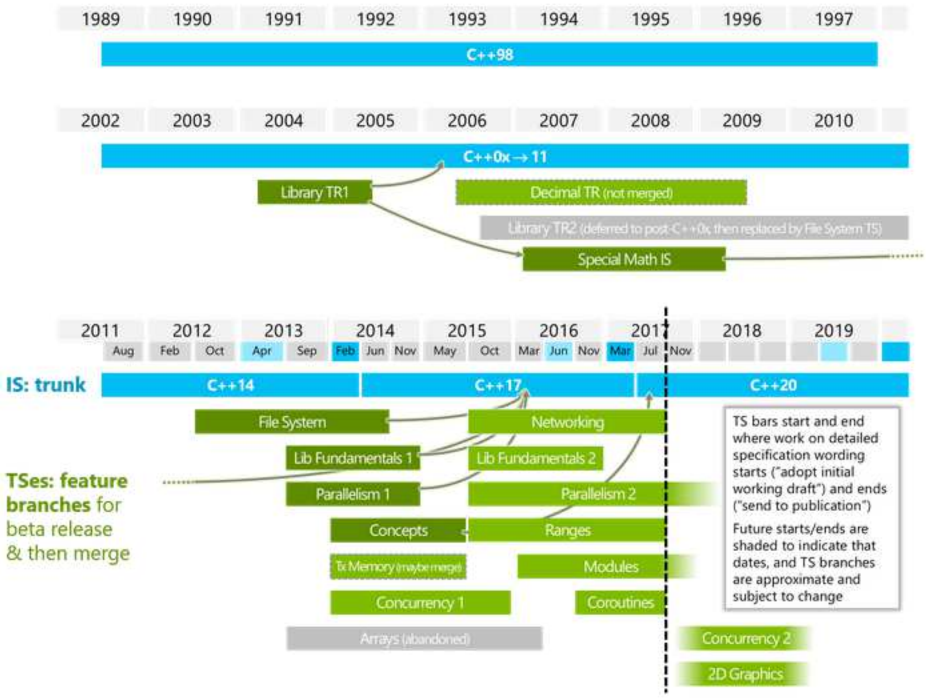
Concepts (2008 fast eingebaut)): http://www.stroustrup.com/C++11FAQ.html#concepts

Concepts-Light: Constraining Templates with Predicates—Andrew Sutton, Bjarne Stroustrup

Why Concepts didn't make C++17

C++?? Current Status
Letzte Änderungen bei C++17 und erste Arbeiten an C++20:
C++20
C++ Standardization Journal

- Filesystem TS
- optional, any, string_view, ...
- Parallelism TS v1



C++17
C++17 filesystem library

SGI: accumulate, SGI: max
SGI: Assignable
...

1. Generische Programmierung

1.1. Was ist generische Programmierung?

Wir definieren generische Programmierung als einen Programmierstil, der es erlaubt, Algorithmen einmal zu implementieren und wieder und wieder mit beliebigen Datentypen zu benutzen. ... Generische Pogrammierung ermöglicht es Algorithmen mit beliebigen Datentypen zu arbeiten, nicht nur mit denjenigen, für die sie ursprünglich geschrieben wurden.
(Chris Mueller/Scott Jensen)

Uneingeschränkte Generizität in C++.
Java Generics ab SE 5.0

Generisches Programmieren macht Programme anpassbarer indem es sie allgemeiner macht. ... Durch geeignete Instanziierung mittels aktueller Parameter werden normale Programme erzeugt.
(Dictionary of Computing)

Generische Programmierung behandelt die Generalisierung von Softwarekomponenten, so dass sie in vielen Situationen wiederverwendet werden können. In C++ sind Klassen- und Funktionstemplates außergewöhnlich effektive Mechanismen des generischen Programmierens, weil sie Generalisierung ermöglichen ohne Effizienz zu Opfern.
(Boost-Bibliotheken)

parametrisierte Typen
(Wikipedia)

http://www.boost.org/community/generic_programming.html
http://en.wikipedia.org/wiki/Generic_programming
...

1.2. Beispiel einer generischen Funktion mit einem generischen Parameter

```
#include <iostream>
template <typename T>
/*
 * Requirements:
 *          T muss einen Operator + haben,
 *          Werte in T muessen durch 2.0l dividierbar sein,
 *          T muss konvertierbar nach long double sein.
 */
long double mean2(T a, T b)
{
      return (a + b)/2.0l;
}
int main(){
    int k(1);
    int l(5);
    std::cout << k << " " << l << std::endl;
    std::cout << "arithmetisches Mittel ist: " << mean2(k, l) << std::endl;
    double d1(3.1415);
    double d2(15.1055);
    std::cout << d1 << " " << d2 << std::endl;
    std::cout << "arithmetisches Mittel ist: " << mean2(d1, d2) << std::
        endl;
}
```

Die Testfälle liefern auf den ersten Blick akzeptable Resultate.

using namespace std in Coding Standards

Overloads and templates
std::max
std::pow(std::complex)

1.3. weitergehende Tests von `mean2(.,.)`

```
#include <iostream>
template <typename T>
/*
 * Requirements:
 *          T muss einen Operator + haben,
 *          Werte in T muessen durch 2.0l dividierbar sein,
 *          T muss konvertierbar nach long double sein.
 */
long double mean2(T a, T b)
{
    return (a + b)/2.0l;
}

int main(){
            // std::numeric_limits<long>::max() == 9223372036854775807

  long int i = 9223372036854775806l;
  long int j = 9223372036854775804l;
  std::cout << i << " " << j << std::endl;
  std::cout << "arithmetisches Mittel ist: " << mean2(i, j) << std::endl;

           // std::numeric_limits<long double>::max() == 1.18973e+4932

  long double d1 = 1.1e+4932l;
  long double d2 = 1.0e+4932l;
  std::cout << d1 << " " << d2 << std::endl;
  std::cout << "arithmetisches Mittel ist: " << mean2(d1, d2) << std::endl
     ;
}
```

Die Testfälle liefern:

```
9223372036854775806 9223372036854775804
-3
1.1e+4932 1e+4932
arithmetisches Mittel ist: inf
```

Fehler vermeidende Variante:

```
template <typename T>
/*
 * Requirements:
 *                  T muss konvertierbar nach long double sein.
 */
long double mean2(T a, T b)
{   long double ac{static_cast<long double>(a)};
    long double bc{static_cast<long double>(b)};

    if ((ac*bc)<0.0)
      return (ac + bc)/2.0l;
    else
      return ac + (bc - ac)/2.0l;
}
```

(Zum Compilieren bitte die g++-Option `-std=c++1y` verwenden.)

1.4. Einsatzgebiete und Beispielrepositorien für generische Konstrukte: die STL, ...

http://www.sgi.com/tech/stl/
generische Java-Datentypen
Die Boost C++-Bibliotheken

1.5. Instanzen generischer Objekte

1.5.1. Objekt-Dateien *.o: wo sind welche Instanzen meiner generischen Objekte (ldd, nm und c++filt)?

What goes into an object file?
http://en.wikipedia.org/wiki/Executable_and_Linkable_Format

GCC and Make: 1.4 GCC Compilation Process:

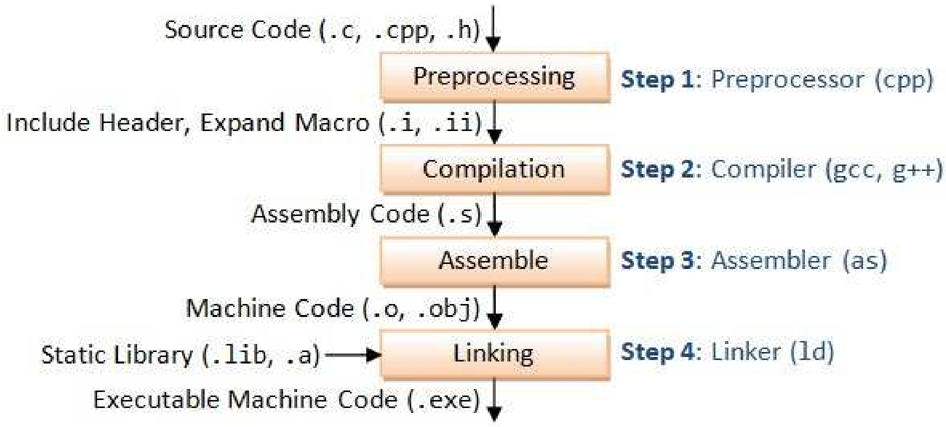


Abbildung 1.1.: Die Phasen der Compilation

Wo ist die Temlate-Instanz?:
„The compiler and linker have to make sure that each template instance occurs exactly once in the executable if it is needed, and not at all otherwise.“

Strategie 1: Extensive Instanz-Duplizierung in jeder Object-Datei; Zusammenfassung der Duplikate zu genau einem Unikat durch den Linker bei der Erstellung des Executables.

Strategie 2: Gemanagte Erzeugung eines Repositoriums aller bekannten Instanzen; beim Binden des Executables nötigenfalls Nachcompilation aktuell noch nicht im Repositorium enthalter benötigter Instanzen.

extern template in C++11

ldd und was es zeigt:

```
> ls
swap1.cpp
> cat swap1.cpp
```

```
#include <iostream>
template <typename T>
/*
 * Requirements: T muss einen Kopierkonstruktor haben,
 *               T muss einen Zuweisungsoperator zu T haben.
 */
void swap(T& a, T& b)
{
   T  old_a(a);

   a = b;
   b = old_a;
}
int main(){
...
   int k(1);
   int l(5);
   swap(k,l);
...
}
```

```
> make swap1
g++ swap1.cpp -o swap1

> ldd ./swap1
        linux-vdso.so.1 =>  (0x00007fffe1b0d000)
        libstdc++.so.6 => /usr/lib64/libstdc++.so.6 (0x00007fa6005e9000)
        libm.so.6 => /lib64/libm.so.6 (0x00007fa600392000)
        libgcc_s.so.1 => /lib64/libgcc_s.so.1 (0x00007fa60017c000)
        libc.so.6 => /lib64/libc.so.6 (0x00007fa5ffe1c000)
        /lib64/ld-linux-x86-64.so.2 (0x00007fa6008f3000)
```

Beim Programmlauf werden nacheinander die „shared object"-Bibliotheken geöffnet und nötige Teile in das auszuführende Binary eingebunden:

```
> strace ./swap1
execve("./swap1", ["./swap1"], [/* 66 vars */]) = 0
brk(0)                                  = 0x602000
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f17e3146000
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
open("/etc/ld.so.cache", O_RDONLY)      = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=335735, ...}) = 0
mmap(NULL, 335735, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f17e30f4000
close(3)                                = 0
open("/usr/lib64/libstdc++.so.6", O_RDONLY) = 3
read(3, "\177ELF\2\1\1\0\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\260\305\5\0\0\0\0\0"..., 832) = 832
fstat(3, {st_mode=S_IFREG|0755, st_size=1003544, ...}) = 0
mmap(NULL, 3182936, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x7f17e2c1f000
```

```
fadvise64(3, 0, 3182936, POSIX_FADV_WILLNEED) = 0
mprotect(0x7f17e2d0b000, 2093056, PROT_NONE) = 0
mmap(0x7f17e2f0a000, 40960, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0xeb000) = 0x7f17e2f0a000
mmap(0x7f17e2f14000, 82264, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7f17e2f14000
close(3)                                = 0
open("/lib64/libm.so.6", O_RDONLY)      = 3
read(3, "\177ELF\2\1\1\0\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0‘>\0\0\0\0\0\0"..., 832) = 832
fstat(3, {st_mode=S_IFREG|0755, st_size=391908, ...}) = 0
mmap(NULL, 2449592, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x7f17e29c8000
fadvise64(3, 0, 2449592, POSIX_FADV_WILLNEED) = 0
mprotect(0x7f17e2a1e000, 2093056, PROT_NONE) = 0
mmap(0x7f17e2c1d000, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x55000) = 0x7f17e2c1d000
close(3)                                = 0
open("/lib64/libgcc_s.so.1", O_RDONLY)  = 3
read(3, "\177ELF\2\1\1\0\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0‘-\0\0\0\0\0\0"..., 832) = 832
fstat(3, {st_mode=S_IFREG|0755, st_size=88544, ...}) = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f17e30f3000
mmap(NULL, 2184184, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x7f17e27b2000
fadvise64(3, 0, 2184184, POSIX_FADV_WILLNEED) = 0
mprotect(0x7f17e27c7000, 2093056, PROT_NONE) = 0
mmap(0x7f17e29c6000, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x14000) = 0x7f17e29c6000
close(3)                                = 0
open("/lib64/libc.so.6", O_RDONLY)      = 3
read(3, "\177ELF\2\1\1\0\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\220\354\1\0\0\0\0\0"..., 832) = 832
fstat(3, {st_mode=S_IFREG|0755, st_size=1670469, ...}) = 0
mmap(NULL, 3537800, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0x7f17e2452000
fadvise64(3, 0, 3537800, POSIX_FADV_WILLNEED) = 0
mprotect(0x7f17e25a8000, 2097152, PROT_NONE) = 0
mmap(0x7f17e27a8000, 20480, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x156000) = 0x7f17e27a8000
mmap(0x7f17e27ad000, 19336, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7f17e27ad000
close(3)                                = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f17e30f2000
mmap(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f17e30f0000
arch_prctl(ARCH_SET_FS, 0x7f17e30f0720) = 0
mprotect(0x7f17e27a8000, 16384, PROT_READ) = 0
mprotect(0x7f17e29c6000, 4096, PROT_READ) = 0
mprotect(0x7f17e2c1d000, 4096, PROT_READ) = 0
mprotect(0x7f17e2f0a000, 32768, PROT_READ) = 0
mprotect(0x600000, 4096, PROT_READ)     = 0
mprotect(0x7f17e3147000, 4096, PROT_READ) = 0
munmap(0x7f17e30f4000, 335735)          = 0
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 2), ...}) = 0
mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7f17e3145000
write(1, "1 5\n", 41 5
)                   = 4
write(1, "5 1\n", 45 1
)                   = 4
write(1, "3.1415 15.1055\n", 153.1415 15.1055
)         = 15
write(1, "15.1055 3.1415\n", 1515.1055 3.1415
)         = 15
exit_group(0)                           = ?
```

Neben gcc, g++, as, ld, gprof und gdb/ddd sind die folgenden Tools von Interesse.

Aufgabe: Vergleichen Sie die Ausgabe von `ldd ./swap1` mit derjenigen von `strace ./swap1 2>&1 | grep open`.

Die GNU-Binutils:

- nm
- objdump
- objcopy

- readelf
- strip
- size
- c++filt
- ar
- ranlib

```
> file ./swap1
./swap1: ELF 64-bit LSB executable, x86-64, version 1 (SYSV),
   dynamically linked (uses shared libs), for GNU/Linux 2.6.15, not stripped
> nm ./swap1
0000000000600e20 d _DYNAMIC
0000000000600fe8 d _GLOBAL_OFFSET_TABLE_
0000000000400a75 t _GLOBAL__I_main
0000000000400bd8 R _IO_stdin_used
                 w _Jv_RegisterClasses
0000000000400a35 t _Z41__static_initialization_and_destruction_0ii
0000000000400ab6 W _Z4swapIdEvRT_S1_
0000000000400a8a W _Z4swapIiEvRT_S1_
                 U _ZNSolsEPFRSoS_E@@GLIBCXX_3.4
                 U _ZNSolsEd@@GLIBCXX_3.4
                 U _ZNSolsEi@@GLIBCXX_3.4
                 U _ZNSt8ios_base4InitC1Ev@@GLIBCXX_3.4
                 U _ZNSt8ios_base4InitD1Ev@@GLIBCXX_3.4
0000000000601060 B _ZSt4cout@@GLIBCXX_3.4
                 U _ZSt4endlIcSt11char_traitsIcEERSt13basic_ostreamIT_T0_ES6_@@GLIBCXX_3.4
0000000000601180 b _ZStL8__ioinit
                 U _ZStlsISt11char_traitsIcEERSt13basic_ostreamIcT_ES5_PKc@@GLIBCXX_3.4
0000000000600e00 d __CTOR_END__
0000000000600df0 d __CTOR_LIST__
0000000000600e10 D __DTOR_END__
0000000000600e08 d __DTOR_LIST__
0000000000400d40 r __FRAME_END__
0000000000600e18 d __JCR_END__
0000000000600e18 d __JCR_LIST__
0000000000601060 A __bss_start
                 U __cxa_atexit@@GLIBC_2.2.5
0000000000601050 D __data_start
0000000000400b90 t __do_global_ctors_aux
0000000000400850 t __do_global_dtors_aux
0000000000601058 D __dso_handle
                 w __gmon_start__
                 U __gxx_personality_v0@@CXXABI_1.3
0000000000600dec d __init_array_end
0000000000600dec d __init_array_start
0000000000400af0 T __libc_csu_fini
0000000000400b00 T __libc_csu_init
                 U __libc_start_main@@GLIBC_2.2.5
0000000000601060 A _edata
0000000000601188 A _end
```

```
0000000000400bc8 T _fini
0000000000400730 T _init
0000000000400800 T _start
000000000040082c t call_gmon_start
0000000000601170 b completed.7424
0000000000601050 W data_start
0000000000601178 b dtor_idx.7426
00000000004008c0 t frame_dummy
00000000004008e4 T main
```

... und mit demangled Symbolen:

```
nm ./swap1 | c++filt
0000000000600e20 d _DYNAMIC
0000000000600fe8 d _GLOBAL_OFFSET_TABLE_
0000000000400a75 t global constructors keyed to main
0000000000400bd8 R _IO_stdin_used
                 w _Jv_RegisterClasses
0000000000400a35 t __static_initialization_and_destruction_0(int, int)
0000000000400ab6 W void swap<double>(double&, double&)
0000000000400a8a W void swap<int>(int&, int&)
                 U std::basic_ostream<char, std::char_traits<char> >::operator<<(std::basic_ostream<char
                 U std::basic_ostream<char, std::char_traits<char> >::operator<<(double)@@GLIBCXX_3.4
                 U std::basic_ostream<char, std::char_traits<char> >::operator<<(int)@@GLIBCXX_3.4
                 U std::ios_base::Init::Init()@@GLIBCXX_3.4
                 U std::ios_base::Init::~Init()@@GLIBCXX_3.4
0000000000601060 B std::cout@@GLIBCXX_3.4
                 U std::basic_ostream<char, std::char_traits<char> >& std::endl<char, std::char_traits<c
0000000000601180 b std::__ioinit
                 U std::basic_ostream<char, std::char_traits<char> >& std::operator<< <std::char_traits<
0000000000600e00 d __CTOR_END__
0000000000600df0 d __CTOR_LIST__
0000000000600e10 D __DTOR_END__
0000000000600e08 d __DTOR_LIST__
0000000000400d40 r __FRAME_END__
0000000000600e18 d __JCR_END__
0000000000600e18 d __JCR_LIST__
0000000000601060 A __bss_start
                 U __cxa_atexit@@GLIBC_2.2.5
0000000000601050 D __data_start
0000000000400b90 t __do_global_ctors_aux
0000000000400850 t __do_global_dtors_aux
0000000000601058 D __dso_handle
                 w __gmon_start__
                 U __gxx_personality_v0@@CXXABI_1.3
0000000000600dec d __init_array_end
0000000000600dec d __init_array_start
0000000000400af0 T __libc_csu_fini
0000000000400b00 T __libc_csu_init
                 U __libc_start_main@@GLIBC_2.2.5
0000000000601060 A _edata
0000000000601188 A _end
0000000000400bc8 T _fini
```

```
0000000000400730 T _init
0000000000400800 T _start
000000000040082c t call_gmon_start
0000000000601170 b completed.7424
0000000000601050 W data_start
0000000000601178 b dtor_idx.7426
00000000004008c0 t frame_dummy
00000000004008e4 T main
```

```
> nm ./swap1 | c++filt -n _Z4swapIiEvRT_S1_
void swap<int>(int&, int&)
```

Vergleiche:
C++ name mangling
name mangling in Java
Getting the best from g++

```
> objdump -x swap1 | c++filt

swap1:     file format elf64-x86-64
swap1
architecture: i386:x86-64, flags 0x00000112:
EXEC_P, HAS_SYMS, D_PAGED
start address 0x00000000004007e0

Program Header:
    PHDR off    0x0000000000000040 vaddr 0x0000000000400040 paddr 0x0000000000400040 align 2**3
         filesz 0x00000000000001f8 memsz 0x00000000000001f8 flags r-x
  INTERP off    0x0000000000000238 vaddr 0x0000000000400238 paddr 0x0000000000400238 align 2**0
         filesz 0x000000000000001c memsz 0x000000000000001c flags r--
...
Dynamic Section:
  NEEDED               libstdc++.so.6
  NEEDED               libm.so.6
  NEEDED               libgcc_s.so.1
  NEEDED               libc.so.6
  INIT                 0x0000000000400720
  FINI                 0x0000000000400ba8
...
Version References:
  required from libc.so.6:
    0x09691a75 0x00 03 GLIBC_2.2.5
  required from libstdc++.so.6:
    0x08922974 0x00 02 GLIBCXX_3.4
Sections:
Idx Name          Size      VMA               LMA               File off  Algn
  0 .interp       0000001c  0000000000400238  0000000000400238  00000238  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  1 .note.ABI-tag 00000020  0000000000400254  0000000000400254  00000254  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  2 .note.SuSE    00000018  0000000000400274  0000000000400274  00000274  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  3 .note.gnu.build-id 00000024  000000000040028c  000000000040028c  0000028c  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  4 .hash         00000048  00000000004002b0  00000000004002b0  000002b0  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  5 .gnu.hash     00000030  00000000004002f8  00000000004002f8  000002f8  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  6 .dynsym       00000138  0000000000400328  0000000000400328  00000328  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  7 .dynstr       0000015e  0000000000400460  0000000000400460  00000460  2**0
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  8 .gnu.version  0000001a  00000000004005be  00000000004005be  000005be  2**1
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
  9 .gnu.version_r 00000040  00000000004005d8  00000000004005d8  000005d8  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 10 .rela.dyn     00000030  0000000000400618  0000000000400618  00000618  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 11 .rela.plt     000000d8  0000000000400648  0000000000400648  00000648  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 12 .init         00000018  0000000000400720  0000000000400720  00000720  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 13 .plt          000000a0  0000000000400738  0000000000400738  00000738  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
```

```
 14 .text         000003c8  00000000004007e0  00000000004007e0  000007e0  2**4
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 15 .fini         0000000e  0000000000400ba8  0000000000400ba8  00000ba8  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, CODE
 16 .rodata       00000006  0000000000400bb8  0000000000400bb8  00000bb8  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 17 .eh_frame_hdr 00000044  0000000000400bc0  0000000000400bc0  00000bc0  2**2
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 18 .eh_frame     00000104  0000000000400c08  0000000000400c08  00000c08  2**3
                  CONTENTS, ALLOC, LOAD, READONLY, DATA
 19 .ctors        00000018  0000000000600de0  0000000000600de0  00000de0  2**3
                  CONTENTS, ALLOC, LOAD, DATA
 20 .dtors        00000010  0000000000600df8  0000000000600df8  00000df8  2**3
                  CONTENTS, ALLOC, LOAD, DATA
...
25 .data         00000010  0000000000601048  0000000000601048  00001048  2**3
                  CONTENTS, ALLOC, LOAD, DATA
26 .bss          00000128  0000000000601060  0000000000601060  00001058  2**5
                  ALLOC
...
SYMBOL TABLE:
0000000000400238 l    d  .interp        0000000000000000              .interp
0000000000400254 l    d  .note.ABI-tag  0000000000000000              .note.ABI-tag
0000000000400274 l    d  .note.SuSE     0000000000000000              .note.SuSE
000000000040028c l    d  .note.gnu.build-id     0000000000000000              .note.gnu.build-id
00000000004002b0 l    d  .hash  0000000000000000              .hash
00000000004002f8 l    d  .gnu.hash      0000000000000000              .gnu.hash
0000000000400328 l    d  .dynsym        0000000000000000              .dynsym
0000000000400460 l    d  .dynstr        0000000000000000              .dynstr
00000000004005be l    d  .gnu.version   0000000000000000              .gnu.version
00000000004005d8 l    d  .gnu.version_r 0000000000000000              .gnu.version_r
0000000000400618 l    d  .rela.dyn      0000000000000000              .rela.dyn
0000000000400648 l    d  .rela.plt      0000000000000000              .rela.plt
0000000000400720 l    d  .init  0000000000000000              .init
0000000000400738 l    d  .plt   0000000000000000              .plt
00000000004007e0 l    d  .text  0000000000000000              .text
0000000000400ba8 l    d  .fini  0000000000000000              .fini
0000000000400bb8 l    d  .rodata        0000000000000000              .rodata
...
0000000000400a96  w    F .text  0000000000000032              void swap<double>(double&, double&)
...
0000000000400a6a  w    F .text  000000000000002c              void swap<int>(int&, int&)
0000000000601058 g       *ABS*  0000000000000000              _edata
00000000004008c4 g     F .text  0000000000000151              main
0000000000400720 g     F .init  0000000000000000              _init

> objdump -t swap1 | c++filt
swap1:     file format elf64-x86-64
SYMBOL TABLE:
0000000000400238 l    d  .interp        0000000000000000              .interp
0000000000400254 l    d  .note.ABI-tag  0000000000000000              .note.ABI-tag
0000000000400274 l    d  .note.SuSE     0000000000000000              .note.SuSE
000000000040028c l    d  .note.gnu.build-id     0000000000000000              .note.gnu.build-id
00000000004002b0 l    d  .hash  0000000000000000              .hash
00000000004002f8 l    d  .gnu.hash      0000000000000000              .gnu.hash
0000000000400328 l    d  .dynsym        0000000000000000              .dynsym
0000000000400460 l    d  .dynstr        0000000000000000              .dynstr
00000000004005be l    d  .gnu.version   0000000000000000              .gnu.version
00000000004005d8 l    d  .gnu.version_r 0000000000000000              .gnu.version_r
0000000000400618 l    d  .rela.dyn      0000000000000000              .rela.dyn
0000000000400648 l    d  .rela.plt      0000000000000000              .rela.plt
0000000000400720 l    d  .init  0000000000000000              .init
0000000000400738 l    d  .plt   0000000000000000              .plt
00000000004007e0 l    d  .text  0000000000000000              .text
0000000000400ba8 l    d  .fini  0000000000000000              .fini
0000000000400bb8 l    d  .rodata        0000000000000000              .rodata
```

```
0000000000400bc0 l    d  .eh_frame_hdr  0000000000000000              .eh_frame_hdr
0000000000400c08 l    d  .eh_frame      0000000000000000              .eh_frame
0000000000600de0 l    d  .ctors 0000000000000000              .ctors
0000000000600df8 l    d  .dtors 0000000000000000              .dtors
0000000000600e08 l    d  .jcr   0000000000000000              .jcr
0000000000600e10 l    d  .dynamic       0000000000000000              .dynamic
0000000000600fe0 l    d  .got   0000000000000000              .got
0000000000600fe8 l    d  .got.plt       0000000000000000              .got.plt
0000000000601048 l    d  .data  0000000000000000              .data
0000000000601060 l    d  .bss   0000000000000000              .bss
0000000000000000 l    d  .comment.SUSE.OPTs     0000000000000000              .comment.SUSE.OPTs
0000000000000000 l    d  .comment       0000000000000000              .comment
0000000000000000 l    d  .debug_aranges 0000000000000000              .debug_aranges
0000000000000000 l    d  .debug_pubnames        0000000000000000              .debug_pubnames
0000000000000000 l    d  .debug_info    0000000000000000              .debug_info
0000000000000000 l    d  .debug_abbrev  0000000000000000              .debug_abbrev
0000000000000000 l    d  .debug_line    0000000000000000              .debug_line
0000000000000000 l    d  .debug_str     0000000000000000              .debug_str
0000000000000000 l    d  .debug_loc     0000000000000000              .debug_loc
0000000000000000 l    d  .debug_pubtypes        0000000000000000              .debug_pubtypes
0000000000000000 l    d  .debug_ranges  0000000000000000              .debug_ranges
0000000000000000 l    df *ABS*  0000000000000000              init.c
0000000000000000 l    df *ABS*  0000000000000000              initfini.c
000000000040080c l     F .text  0000000000000000              call_gmon_start
0000000000000000 l    df *ABS*  0000000000000000              crtstuff.c
0000000000600de0 l     O .ctors 0000000000000000              __CTOR_LIST__
0000000000600df8 l     O .dtors 0000000000000000              __DTOR_LIST__
0000000000600e08 l     O .jcr   0000000000000000              __JCR_LIST__
0000000000400830 l     F .text  0000000000000000              __do_global_dtors_aux
0000000000601170 l     O .bss   0000000000000001              completed.5939
0000000000601178 l     O .bss   0000000000000008              dtor_idx.5941
00000000004008a0 l     F .text  0000000000000000              frame_dummy
0000000000000000 l    df *ABS*  0000000000000000              crtstuff.c
0000000000600df0 l     O .ctors 0000000000000000              __CTOR_END__
0000000000400d08 l     O .eh_frame      0000000000000000              __FRAME_END__
0000000000600e08 l     O .jcr   0000000000000000              __JCR_END__
0000000000400b70 l     F .text  0000000000000000              __do_global_ctors_aux
0000000000000000 l    df *ABS*  0000000000000000              initfini.c
0000000000000000 l    df *ABS*  0000000000000000              swap1.cpp
0000000000601180 l     O .bss   0000000000000001              std::__ioinit
0000000000400a15 l     F .text  0000000000000040              __static_initialization_and_destruction_0(int, int)
0000000000400a55 l     F .text  0000000000000015              global constructors keyed to main
0000000000000000 l    df *ABS*  0000000000000000              elf-init.c
0000000000600fe8 l     O .got.plt       0000000000000000              .hidden _GLOBAL_OFFSET_TABLE_
0000000000600ddc l       .ctors 0000000000000000              .hidden __init_array_end
0000000000600ddc l       .ctors 0000000000000000              .hidden __init_array_start
0000000000600e10 l     O .dynamic       0000000000000000              .hidden _DYNAMIC
0000000000601048  w      .data  0000000000000000              data_start
0000000000000000       F *UND*  0000000000000000              std::basic_ostream<char, std::char_traits<char> >::operator<<(doubl
0000000000000000       F *UND*  0000000000000000              std::basic_ostream<char, std::char_traits<char> >::operator<<(int)@
0000000000400b60 g     F .text  0000000000000002              __libc_csu_fini
00000000004007e0 g     F .text  0000000000000000              _start
0000000000000000  w      *UND*  0000000000000000              __gmon_start__
0000000000000000  w      *UND*  0000000000000000              _Jv_RegisterClasses
0000000000400ba8 g     F .fini  0000000000000000              _fini
0000000000000000       F *UND*  0000000000000000              std::ios_base::Init::Init()@@GLIBCXX_3.4
0000000000000000       F *UND*  0000000000000000              __libc_start_main@@GLIBC_2.2.5
0000000000000000       F *UND*  0000000000000000              __cxa_atexit@@GLIBC_2.2.5
0000000000400798       F *UND*  0000000000000000              std::ios_base::Init::~Init()@@GLIBCXX_3.4
0000000000000000       F *UND*  0000000000000000              std::basic_ostream<char, std::char_traits<char> >& std::operator<<
0000000000400bb8 g     O .rodata        0000000000000004              _IO_stdin_used
0000000000601048 g       .data  0000000000000000              __data_start
0000000000400a96  w    F .text  0000000000000032              void swap<double>(double&, double&)
0000000000601060 g     O .bss   0000000000000110              std::cout@@GLIBCXX_3.4
0000000000601050 g     O .data  0000000000000000              .hidden __dso_handle
0000000000600e00 g     O .dtors 0000000000000000              .hidden __DTOR_END__
```

```
0000000000400ad0 g     F .text  0000000000000089              __libc_csu_init
0000000000601058 g       *ABS*  0000000000000000              __bss_start
0000000000601188 g       *ABS*  0000000000000000              _end
0000000000000000       F *UND*  0000000000000000              std::basic_ostream<char, std::char_traits<char> >::opera
00000000004007c8       F *UND*  0000000000000000              std::basic_ostream<char, std::char_traits<char> >& std:
0000000000400a6a  w    F .text  000000000000002c              void swap<int>(int&, int&)
0000000000601058 g       *ABS*  0000000000000000              _edata
00000000004008c4 g     F .text  0000000000000151              main
0000000000400720 g     F .init  0000000000000000              _init
```

```
> readelf -s swap1 | c++filt

Symbol table '.dynsym' contains 13 entries:
   Num:    Value          Size Type    Bind   Vis      Ndx Name
     0: 0000000000000000     0 NOTYPE  LOCAL  DEFAULT  UND
     1: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::basic_ostream<char, std::char_traits<char> >::operator<<(double)@GLIBCXX_3.4 (2)
     2: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::basic_ostream<char, std::char_traits<char> >::operator<<(int)@GLIBCXX_3.4 (2)
     3: 0000000000000000     0 NOTYPE  WEAK   DEFAULT  UND __gmon_start__
     4: 0000000000000000     0 NOTYPE  WEAK   DEFAULT  UND _Jv_RegisterClasses
     5: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::ios_base::Init::Init()@GLIBCXX_3.4 (2)
     6: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND __libc_start_main@GLIBC_2.2.5 (3)
     7: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND __cxa_atexit@GLIBC_2.2.5 (3)
     8: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND _ZStlsISt11char_traitsIcE@GLIBCXX_3.4 (2)
     9: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::basic_ostream<char, std::char_traits<char> >::operator<<(std::basic_ostream<char, std::char_traits<char> >&
    10: 00000000004007c8     0 FUNC    GLOBAL DEFAULT  UND _ZSt4endlIcSt11char_trait@GLIBCXX_3.4 (2)
    11: 0000000000400798     0 FUNC    GLOBAL DEFAULT  UND std::ios_base::Init::~Init()@GLIBCXX_3.4 (2)
    12: 0000000000601060   272 OBJECT  GLOBAL DEFAULT   27 std::cout@GLIBCXX_3.4 (2)

Symbol table '.symtab' contains 93 entries:
   Num:    Value          Size Type    Bind   Vis      Ndx Name
     0: 0000000000000000     0 NOTYPE  LOCAL  DEFAULT  UND
     1: 0000000000400238     0 SECTION LOCAL  DEFAULT    1
     2: 0000000000400254     0 SECTION LOCAL  DEFAULT    2
     3: 0000000000400274     0 SECTION LOCAL  DEFAULT    3
     4: 000000000040028c     0 SECTION LOCAL  DEFAULT    4
     5: 00000000004002b0     0 SECTION LOCAL  DEFAULT    5
     6: 00000000004002f8     0 SECTION LOCAL  DEFAULT    6
     7: 0000000000400328     0 SECTION LOCAL  DEFAULT    7
     8: 0000000000400460     0 SECTION LOCAL  DEFAULT    8
     9: 00000000004005be     0 SECTION LOCAL  DEFAULT    9
    10: 00000000004005d8     0 SECTION LOCAL  DEFAULT   10
    11: 0000000000400618     0 SECTION LOCAL  DEFAULT   11
    12: 0000000000400648     0 SECTION LOCAL  DEFAULT   12
    13: 0000000000400720     0 SECTION LOCAL  DEFAULT   13
    14: 0000000000400738     0 SECTION LOCAL  DEFAULT   14
    15: 00000000004007e0     0 SECTION LOCAL  DEFAULT   15
    16: 0000000000400ba8     0 SECTION LOCAL  DEFAULT   16
    17: 0000000000400bb8     0 SECTION LOCAL  DEFAULT   17
    18: 0000000000400bc0     0 SECTION LOCAL  DEFAULT   18
    19: 0000000000400c08     0 SECTION LOCAL  DEFAULT   19
    20: 0000000000600de0     0 SECTION LOCAL  DEFAULT   20
    21: 0000000000600df8     0 SECTION LOCAL  DEFAULT   21
    22: 0000000000600e08     0 SECTION LOCAL  DEFAULT   22
    23: 0000000000600e10     0 SECTION LOCAL  DEFAULT   23
    24: 0000000000600fe0     0 SECTION LOCAL  DEFAULT   24
    25: 0000000000600fe8     0 SECTION LOCAL  DEFAULT   25
    26: 0000000000601048     0 SECTION LOCAL  DEFAULT   26
    27: 0000000000601060     0 SECTION LOCAL  DEFAULT   27
    28: 0000000000000000     0 SECTION LOCAL  DEFAULT   28
    29: 0000000000000000     0 SECTION LOCAL  DEFAULT   29
    30: 0000000000000000     0 SECTION LOCAL  DEFAULT   30
    31: 0000000000000000     0 SECTION LOCAL  DEFAULT   31
    32: 0000000000000000     0 SECTION LOCAL  DEFAULT   32
    33: 0000000000000000     0 SECTION LOCAL  DEFAULT   33
    34: 0000000000000000     0 SECTION LOCAL  DEFAULT   34
    35: 0000000000000000     0 SECTION LOCAL  DEFAULT   35
    36: 0000000000000000     0 SECTION LOCAL  DEFAULT   36
    37: 0000000000000000     0 SECTION LOCAL  DEFAULT   37
    38: 0000000000000000     0 SECTION LOCAL  DEFAULT   38
    39: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS init.c
    40: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS initfini.c
    41: 000000000040080c     0 FUNC    LOCAL  DEFAULT   15 call_gmon_start
    42: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS crtstuff.c
    43: 0000000000600de0     0 OBJECT  LOCAL  DEFAULT   20 __CTOR_LIST__
    44: 0000000000600df8     0 OBJECT  LOCAL  DEFAULT   21 __DTOR_LIST__
    45: 0000000000600e08     0 OBJECT  LOCAL  DEFAULT   22 __JCR_LIST__
    46: 0000000000400830     0 FUNC    LOCAL  DEFAULT   15 __do_global_dtors_aux
    47: 0000000000601170     1 OBJECT  LOCAL  DEFAULT   27 completed.5939
    48: 0000000000601178     8 OBJECT  LOCAL  DEFAULT   27 dtor_idx.5941
    49: 00000000004008a0     0 FUNC    LOCAL  DEFAULT   15 frame_dummy
    50: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS crtstuff.c
    51: 0000000000600df0     0 OBJECT  LOCAL  DEFAULT   20 __CTOR_END__
    52: 0000000000400d08     0 OBJECT  LOCAL  DEFAULT   19 __FRAME_END__
    53: 0000000000600e08     0 OBJECT  LOCAL  DEFAULT   22 __JCR_END__
    54: 0000000000400b70     0 FUNC    LOCAL  DEFAULT   15 __do_global_ctors_aux
    55: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS initfini.c
    56: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS swap1.cpp
    57: 0000000000601180     1 OBJECT  LOCAL  DEFAULT   27 std::__ioinit
    58: 0000000000400a15    64 FUNC    LOCAL  DEFAULT   15 _Z41__static_initializati
    59: 0000000000400a55    21 FUNC    LOCAL  DEFAULT   15 global constructors keyed to main
    60: 0000000000000000     0 FILE    LOCAL  DEFAULT  ABS elf-init.c
    61: 0000000000600fe8     0 OBJECT  LOCAL  HIDDEN   25 _GLOBAL_OFFSET_TABLE_
    62: 0000000000600ddc     0 NOTYPE  LOCAL  HIDDEN   20 __init_array_end
    63: 0000000000600ddc     0 NOTYPE  LOCAL  HIDDEN   20 __init_array_start
    64: 0000000000600e10     0 OBJECT  LOCAL  HIDDEN   23 _DYNAMIC
    65: 0000000000601048     0 NOTYPE  WEAK   DEFAULT   26 data_start
    66: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::basic_ostream<char, std::char_traits<char> >::operator<<(double)@@GLIBCXX_3.4
    67: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::basic_ostream<char, std::char_traits<char> >::operator<<(int)@@GLIBCXX_3.4
    68: 0000000000400b60     2 FUNC    GLOBAL DEFAULT   15 __libc_csu_fini
    69: 00000000004007e0     0 FUNC    GLOBAL DEFAULT   15 _start
```

```
    70: 0000000000000000     0 NOTYPE  WEAK   DEFAULT  UND __gmon_start__
    71: 0000000000000000     0 NOTYPE  WEAK   DEFAULT  UND _Jv_RegisterClasses
    72: 0000000000400ba8     0 FUNC    GLOBAL DEFAULT   16 _fini
    73: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::ios_base::Init::Init()@@
    74: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND __libc_start_main@@GLIBC_
    75: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND __cxa_atexit@@GLIBC_2.2.5
    76: 0000000000400798     0 FUNC    GLOBAL DEFAULT  UND std::ios_base::Init::~Init()@@
    77: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND _ZStlsISt11char_traitsIcE
    78: 0000000000400bb8     4 OBJECT  GLOBAL DEFAULT   17 _IO_stdin_used
    79: 0000000000601048     0 NOTYPE  GLOBAL DEFAULT   26 __data_start
    80: 0000000000400a96    50 FUNC    WEAK   DEFAULT   15 void swap<double>(double&, double&)
    81: 0000000000601060   272 OBJECT  GLOBAL DEFAULT   27 std::cout@@GLIBCXX_3.4
    82: 0000000000601050     0 OBJECT  GLOBAL HIDDEN   26 __dso_handle
    83: 0000000000600e00     0 OBJECT  GLOBAL HIDDEN   21 __DTOR_END__
    84: 0000000000400ad0   137 FUNC    GLOBAL DEFAULT   15 __libc_csu_init
    85: 0000000000601058     0 NOTYPE  GLOBAL DEFAULT  ABS __bss_start
    86: 0000000000601188     0 NOTYPE  GLOBAL DEFAULT  ABS _end
    87: 0000000000000000     0 FUNC    GLOBAL DEFAULT  UND std::basic_ostream<char, std::char_traits<char> >::operator<<(std::basic_ostream<char, std::char_t
    88: 00000000004007c8     0 FUNC    GLOBAL DEFAULT  UND _ZSt4endlIcSt11char_trait
    89: 0000000000400a6a    44 FUNC    WEAK   DEFAULT   15 void swap<int>(int&, int&)
    90: 0000000000601058     0 NOTYPE  GLOBAL DEFAULT  ABS _edata
    91: 00000000004008c4   337 FUNC    GLOBAL DEFAULT   15 main
    92: 0000000000400720     0 FUNC    GLOBAL DEFAULT   13 _init
```

Die Sektionstypen von Objektdateien:
text, data und bss

```
> size ./swap1
   text    data     bss     dec     hex filename
   3245     704     280    4229    1085 ./swap1
```

Hinweis zu verfügbaren Softwareentwicklungssystemen:
GNU g++ für Linux
gcc7 vor den Toren
C++17: Standardbibliotheksänderungen

Cygwin für Windows, Cygwin
mingw-64
Windows 10 Linux-Subsystem

Microsoft Imagine (früher MSDNAA): VisualStudio 201x für Windows

1.5.2. Erstellen und Benutzen von statischen Bibliotheken

*.a-Bibiotheken als Sammlungen von Objektdateien

Static library

Erzeugen statischer Bibliotheken

ar Manual Page

Wo waren einmal statisch gelinkte Binaries positioniert?

Binaries nur noch in `/usr/bin`

static vs dynamic linking

```
> cat swap1.cpp
```

```cpp
#include <iostream>
template <typename T>
/*
 * Requirements: T muss einen Kopierkonstruktor haben,
 *               T muss einen Zuweisungsoperator zu T haben.
 */
void swap(T& a, T& b)
{
   T  old_a(a);

   a = b;
   b = old_a;
}

int main(){
   int k(1);
   int l(5);
   std::cout << k << " " << l << std::endl;
   swap(k,l);
   std::cout << k << " " << l << std::endl;

   double d1(3.1415);
   double d2(15.1055);
   std::cout << d1 << " " << d2 << std::endl;
   swap(d1, d2);
   std::cout << d1 << " " << d2 << std::endl;
}
```

```
> make CXXFLAGS=-g swap1
g++ -g  swap1.cpp   -o swap1
> nm swap1 | grep swap | c++filt
0000000000400a96 W void swap<double>(double&, double&)
0000000000400a6a W void swap<int>(int&, int&)
```

```
> g++ -c swap1.cpp
> ls -al swap1.o
-rw-r--r-- 1 user1 users 4464  9. Nov 13:59 swap1.o

> ar rc libswap.a swap1.o
> ls -al libswap.a
-rw-r--r-- 1 user1 users 4650  9. Nov 14:02 libswap.a

> nm libswap.a | c++filt
0000000000000000 W void swap<double>(double&, double&)
0000000000000000 W void swap<int>(int&, int&)
                 U std::basic_ostream<char, std::char_traits<char> >::operator<<(double)
                 U std::basic_ostream<char, std::char_traits<char> >::operator<<(int)
0000000000000000 T main
```

oder ein vollständiges Beispiel:

```
> cat person.h
```

```
/*
 * person.h
 */
class Person
{
 public:
  Person(){};
  ~Person(){};

  void speak(const char * sentence);
};
```

```
> cat person.cpp
```

```
#include "person.h"
#include <iostream>

void Person::speak(const char * sentence)
{
  std::cout << sentence << std::endl;
}
```

```
> cat main.cpp
```

```
/*
 * main.cpp
 */

#include "person.h"
#include <iostream>
```

```cpp
int main()
{
  Person person;
  person.speak("Hello world!");

  return 0;
}
```

```
> g++ -c person.cpp
> g++ -c main.cpp
> ar rc libperson.a person.o
> g++ -o main main.o -L. -lperson
> ldd main
        linux-vdso.so.1 =>  (0x00007fffdfbff000)
        libstdc++.so.6 => /usr/lib64/libstdc++.so.6 (0x00007f1f48ef2000)
        libm.so.6 => /lib64/libm.so.6 (0x00007f1f48c9b000)
        libgcc_s.so.1 => /lib64/libgcc_s.so.1 (0x00007f1f48a85000)
        libc.so.6 => /lib64/libc.so.6 (0x00007f1f48725000)
        /lib64/ld-linux-x86-64.so.2 (0x00007f1f491fc000)

> ls -al main
-rwxr-xr-x 1 user1 users 13015  9. Nov 14:13 main
```

Bei den impliziten make-Regeln benutzte Environment-Variablen

1.5.3. Erstellen und Benutzen einer „shared object“- Bibliothek

```
> g++ -fPIC -c person.cpp
> g++ -shared -o libperson.so person.o
> g++ -o main main.o -L. -lperson
> ls -al main
-rwxr-xr-x 1 user1 users 12570  9. Nov 16:27 main

> ldd main
        linux-vdso.so.1 =>  (0x00007fffc85fa000)
        libperson.so => not found
        libstdc++.so.6 => /usr/lib64/libstdc++.so.6 (0x00007f990e302000)
        libm.so.6 => /lib64/libm.so.6 (0x00007f990e0ab000)
        libgcc_s.so.1 => /lib64/libgcc_s.so.1 (0x00007f990de95000)
        libc.so.6 => /lib64/libc.so.6 (0x00007f990db35000)
        /lib64/ld-linux-x86-64.so.2 (0x00007f990e60c000)
> ./main
./main: error while loading shared libraries: libperson.so: cannot
   open shared object file: No such file or directory

> export LD_LIBRARY_PATH=.
> ldd main
        linux-vdso.so.1 =>  (0x00007fff6ebff000)
        libperson.so => ./libperson.so (0x00007f76ec213000)
        libstdc++.so.6 => /usr/lib64/libstdc++.so.6 (0x00007f76ebf09000)
        libm.so.6 => /lib64/libm.so.6 (0x00007f76ebcb2000)
        libgcc_s.so.1 => /lib64/libgcc_s.so.1 (0x00007f76eba9c000)
        libc.so.6 => /lib64/libc.so.6 (0x00007f76eb73c000)
        /lib64/ld-linux-x86-64.so.2 (0x00007f76ec415000)
> ./main
Hello world!
```

Windows 8f.: Verwürfelte Ladeadresse
Linux: Verwürfelte Ladeadresse
Address Space Layout Randomization

Oder besser (mit Versionsinformationen):
shared library HOWTO

YoLinux tutorial: libraries
Im Linuxumfeld genutzte Versionsnummern
.so Versionsnummern und Kompaibilität (im Apache-Projekt)

Why LD_LIBRARY_PATH is bad
ldconfig
ldconfig(8)
Verwaltung von Shared Libraries

Creating shared object libraries
Anatomy of Linux dynamic libraries

Workaround für fehlende .so
fix shared library load problems

Dynamic Loading in an Application Specific Embedded Operating System:
„ ... Embedded systems however have constraints, such as limited memory and real-time requirements, that prevent many dynamically configurable operating systems from being used in an embedded system. ... “

Eingebettetes System

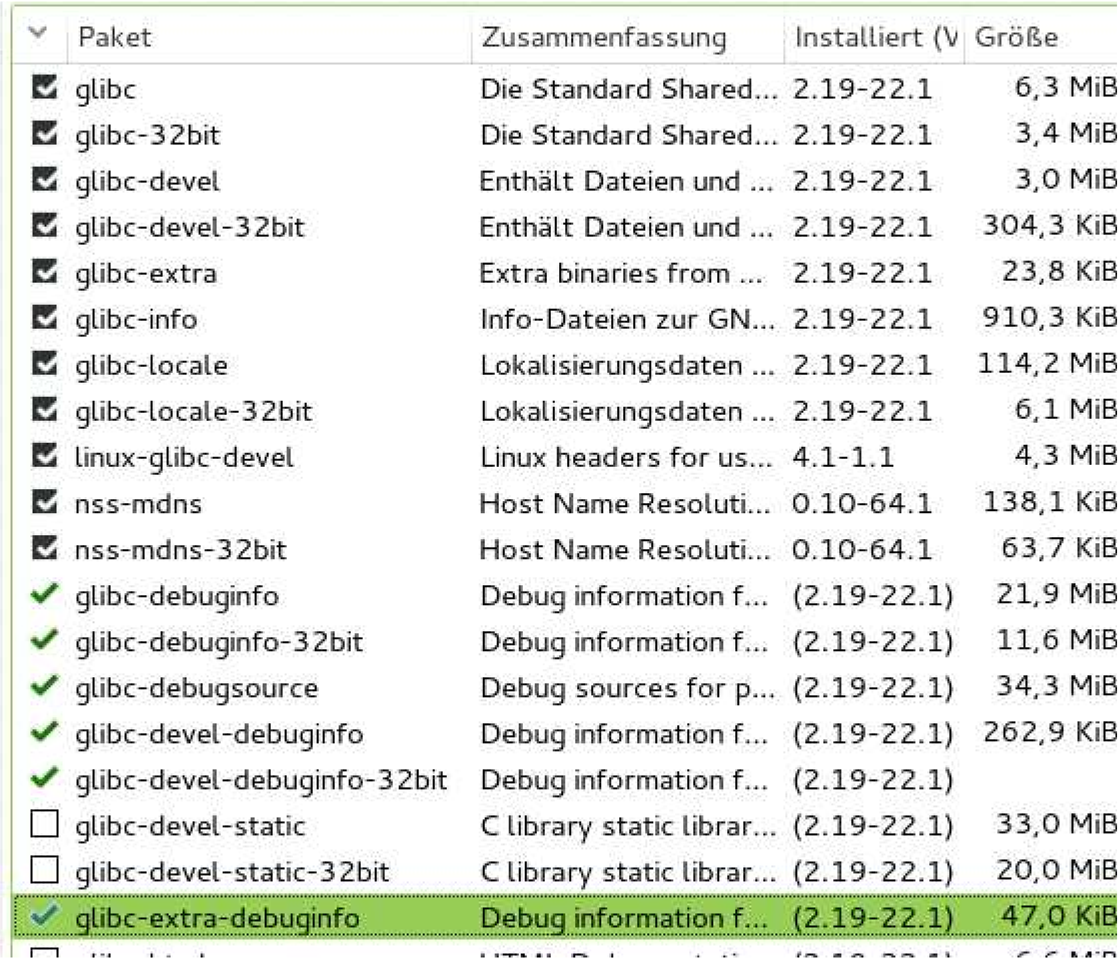
1.5.4. Bibliotheksmanagement insbesondere unter verschiedenen Betriebssystemen, dynamically loaded libraries

Dynamically Loaded (DL) Libraries
plugin
dynamic loading

1.6. STL-Templatequellen und -sourcen unter SuSE-Linux fürs zeilenweise Debuggen auch innerhalb der STL-Routinen

	Paket	Zusammenfas	Installiert (V	Größe
☑	gcc48-32bit	The GNU C ...	4.8.5-21.1	9,
☑	gcc48-c++	Der GNU C...	4.8.5-21.1	14,
☑	gcc48-gij	Java Byteco...	4.8.5-21.1	118
☑	gcc48-info	Documentat...	4.8.5-21.1	2,
☑	gcc48-java	Der GNU Ja...	4.8.5-21.1	14,
☐	cross-aarch64-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	12,
☐	cross-armv6hl-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	14,
☐	cross-armv7hl-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	14,
☐	cross-hppa-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	12,
☐	cross-i386-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	13,
☐	cross-ia64-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	12,
☐	cross-ppc-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	14,
☐	cross-ppc64-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	14,
☐	cross-ppc64le-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	14,
☐	cross-s390-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	12,
☐	cross-s390x-gcc48-icecream-backend	Der GNU C...	(4.8.5-21.2)	12,
☐	gcc48-ada	Auf GCC (G...	(4.8.5-21.1)	70,
☐	gcc48-ada-32bit	Auf GCC (G...	(4.8.5-21.1)	31,
☐	gcc48-ada-debuginfo	Debug infor...	(4.8.5-21.1)	143,
✓	gcc48-c++-debuginfo	Debug infor...	(4.8.5-21.1)	75,
✓	gcc48-debuginfo	Debug infor...	(4.8.5-21.1)	72,
✓	gcc48-debugsource	Debug sour...	(4.8.5-21.1)	112,

und



	Paket	Zusammenfassung	Installiert (V	Größe
☑	glibc	Die Standard Shared...	2.19-22.1	6,3 MiB
☑	glibc-32bit	Die Standard Shared...	2.19-22.1	3,4 MiB
☑	glibc-devel	Enthält Dateien und ...	2.19-22.1	3,0 MiB
☑	glibc-devel-32bit	Enthält Dateien und ...	2.19-22.1	304,3 KiB
☑	glibc-extra	Extra binaries from ...	2.19-22.1	23,8 KiB
☑	glibc-info	Info-Dateien zur GN...	2.19-22.1	910,3 KiB
☑	glibc-locale	Lokalisierungsdaten ...	2.19-22.1	114,2 MiB
☑	glibc-locale-32bit	Lokalisierungsdaten ...	2.19-22.1	6,1 MiB
☑	linux-glibc-devel	Linux headers for us...	4.1-1.1	4,3 MiB
☑	nss-mdns	Host Name Resoluti...	0.10-64.1	138,1 KiB
☑	nss-mdns-32bit	Host Name Resoluti...	0.10-64.1	63,7 KiB
✓	glibc-debuginfo	Debug information f...	(2.19-22.1)	21,9 MiB
✓	glibc-debuginfo-32bit	Debug information f...	(2.19-22.1)	11,6 MiB
✓	glibc-debugsource	Debug sources for p...	(2.19-22.1)	34,3 MiB
✓	glibc-devel-debuginfo	Debug information f...	(2.19-22.1)	262,9 KiB
✓	glibc-devel-debuginfo-32bit	Debug information f...	(2.19-22.1)	
☐	glibc-devel-static	C library static librar...	(2.19-22.1)	33,0 MiB
☐	glibc-devel-static-32bit	C library static librar...	(2.19-22.1)	20,0 MiB
✓	glibc-extra-debuginfo	Debug information f...	(2.19-22.1)	47,0 KiB

1.7. Automatisch überprüfte Requirements an Template-Parameter

Ein traditionelles Template-Beispiel:

```
#include <iostream>
#include <cmath>
#include <limits>

using namespace std;

template <typename T1, typename T2>
/*
 * Requirements:
 *    T1, T2 muss multiplizierbar sein,
 *    ihr Produkttyp muss den Operator abs() besitzen,
 *    der abs()-Ergebnistyp muss einen Operator sqrt() erlauben.
 */
double geomMittel2(const T1& a, const T2& b)
{
    return sqrt(abs(a*b));
}

int main()
{
    cout << geomMittel2(3.0, 300.0) << endl;
    cout << geomMittel2(3, 300.0) << endl;
    cout << geomMittel2(-3, 300.0) << endl;
    cout << geomMittel2(-3, 300) << endl;
    cout << geomMittel2(3.0, 'c') << endl;
    cout << geomMittel2(3.0, "c") << endl;

    return 0;
}
```

und die Fehlermeldung für den letzten Testfall:

```
In Funktion »double geomMittel2(const T1&, const T2&) [with T1 = double, T2 = char [2]]«:
geomMittel2-0.cpp:20:33:   instantiated from here
geomMittel2-0.cpp:10:25: Fehler: ungültige Operanden der Typen »const double« und »const char [2]« für binäres »operator*«
```

Nach einer verbesserten Bezeichnerwahl:

```
#include <iostream>
#include <cmath>
#include <limits>

using namespace std;

template <typename ArithmeticLike1, typename ArithmeticLike2>
/*
 * Requirements:
 *   ArithmeticLike1,ArithmeticLike2 muss multiplizierbar sein,
 *   ihr Produkttyp muss den Operator abs() besitzen,
 *   der abs()-Ergebnistyp muss einen Operator sqrt() erlauben.
 */
double geomMittel2(const ArithmeticLike1& a, const ArithmeticLike2& b)
{
    return sqrt(abs(a*b));
}

int main()
{
    cout << geomMittel2(3.0, 300.0) << endl;
    cout << geomMittel2(3, 300.0) << endl;
    cout << geomMittel2(-3, 300.0) << endl;
    cout << geomMittel2(-3, 300) << endl;
    cout << geomMittel2(3.0, 'c') << endl;
    cout << geomMittel2(3.0, "c") << endl;

    return 0;
}
```

Aufgabe: Wie sieht die Fehlermeldung nun aus?

1.7.1. Mit Hilfe des c++11-Modus des g++

```cpp
#include <iostream>
#include <cmath>
#include <limits>
#include <type_traits>

using namespace std;

static_assert(std::numeric_limits<int>::digits >= 32,
              "int not enough digits");

template <typename ArithmeticLike1, typename ArithmeticLike2>
/*
 * Requirements:
 *   ArithmeticLike1, ArithmeticLike2 muss multiplizierbar sein,
 *   ihr Produkttyp muss den Operator abs() besitzen,
 *   der abs()-Ergebnistyp muss einen Operator sqrt() erlauben.
 */
double geomMittel2(const ArithmeticLike1& a, const ArithmeticLike2& b)
{
static_assert(std::is_arithmetic<ArithmeticLike1>::value,
        "ArithmeticLike1 is not arithmetic");
static_assert(std::is_arithmetic<ArithmeticLike2>::value,
        "ArithmeticLike2 is not arithmetic");

    return sqrt(abs(a*b));
}

// uebersetze mit -std=c++11
// oder make CXXFLAGS="-std=c++11" ...

int main()
{
    cout << geomMittel2(3.0, 300.0) << endl;
    cout << geomMittel2(3, 300.0) << endl;
    cout << geomMittel2(-3, 300.0) << endl;
    cout << geomMittel2(-3, 300) << endl;
    cout << geomMittel2(3.0, 'c') << endl;
    cout << geomMittel2(3.0, "c") << endl;

    return 0;
}
```

mit der Compiler-Fehlermeldung:

```
geomMittel-sa2.cpp: In instantiation of ‘double geomMittel2(const ArithmeticLike1&, const ArithmeticLike2&) [with ArithmeticLike1 = double; ArithmeticLike2 =
geomMittel-sa2.cpp:29:33:   required from here
geomMittel-sa2.cpp:14:1: error: static assertion failed: ArithmeticLike2 is not arithmetic
geomMittel-sa2.cpp:16:25: error: invalid operands of types ‘const double’ and ‘const char [2]’ to binary ‘operator*’
```

Vergleiche static_assert:

Static assertions [edit]

C++03 provides two methods to test assertions: the macro `assert` and the preprocessor directive `#error`. However, neither is appropriate for use in templates: the macro tests the assertion at execution-time, while the preprocessor directive tests the assertion during preprocessing, which happens before instantiation of templates. Neither is appropriate for testing properties that are dependent on template parameters.

The new utility introduces a new way to test assertions at compile-time, using the new keyword `static_assert`. The declaration assumes this form:

```
static_assert (constant-expression, error-message);
```

Here are some examples of how `static_assert` can be used:

```
static_assert((GREEKPI > 3.14) && (GREEKPI < 3.15), "GREEKPI is inaccurate!");
```

```
template<class T>
struct Check {
    static_assert(sizeof(int) <= sizeof(T), "T is not big enough!");
};
```

```
template<class Integral>
Integral foo(Integral x, Integral y) {
    static_assert(std::is_integral<Integral>::value, "foo() parameter must be an integral type.");
}
```

When the constant expression is `false` the compiler produces an error message. The first example is similar to the preprocessor directive `#error`, although the preprocessor does only support integral types.[20] In contrast, in the second example the assertion is checked at every instantiation of the template class `Check`.

Static assertions are useful outside of templates also. For instance, a given implementation of an algorithm might depend on the size of a `long long` being larger than an `int`, something the standard does not guarantee. Such an assumption is valid on most systems and compilers, but not all.

1.8. „horrible error messages“ bei STL-Nutzung

```
testmm.cpp:30: error: cannot convert ‘std::_Rb_tree_iterator<std::pair<
    const std::basic_string<char, std::char_traits<char>, std::allocator<
    char> >, Widget> > to ‘int in initialization
testmm.cpp:36: error: no matching function for call to ‘std::multimap<std
    ::basic_string<char, std::char_traits<char>, std::allocator<char> >,
    Widget, std::less<std::basic_string<char, std::char_traits<char>, std::
    allocator<char> > >, std::allocator<std::pair<const std::basic_string<
    char, std::char_traits<char>, std::allocator<char> >, Widget> > >::
    insert(int)
/usr/include/c++/4.2.1/bits/stl_multimap.h:339: note: candidates are:
    typename std::_Rb_tree<_Key, std::pair<const _Key, _Tp>, std::
    _Select1st<std::pair<const _Key, _Tp> >, _Compare, typename _Alloc::
    rebind<std::pair<const _Key, _Tp> >::other>::iterator std::multimap<
    _Key, _Tp, _Compare, _Alloc>::insert(const std::pair<const _Key, _Tp>&)
     [with _Key = std::basic_string<char, std::char_traits<char>, std::
    allocator<char> >, _Tp = Widget, _Compare = std::less<std::basic_string
    <char, std::char_traits<char>, std::allocator<char> > >, _Alloc = std::
    allocator<std::pair<const std::basic_string<char, std::char_traits<char
    >, std::allocator<char> >, Widget> >]
/usr/include/c++/4.2.1/bits/stl_multimap.h:363: note:
    typename std::_Rb_tree<_Key, std::pair<const _Key, _Tp>, std::
    _Select1st<std::pair<const _Key, _Tp> >, _Compare, typename _Alloc::
    rebind<std::pair<const _Key, _Tp> >::other>::iterator std::multimap<
    _Key, _Tp, _Compare, _Alloc>::insert(typename std::_Rb_tree<_Key, std::
    pair<const _Key, _Tp>, std::_Select1st<std::pair<const _Key, _Tp> >,
    _Compare, typename _Alloc::rebind<std::pair<const _Key, _Tp> >::other
    >::iterator, const std::pair<const _Key, _Tp>&) [with _Key = std::
    basic_string<char, std::char_traits<char>, std::allocator<char> >, _Tp
    = Widget, _Compare = std::less<std::basic_string<char, std::char_traits
    <char>, std::allocator<char> > >, _Alloc = std::allocator<std::pair<
    const std::basic_string<char, std::char_traits<char>, std::allocator<
    char> >, Widget> >]
testmm.cpp:38: error: no matching function for call to ‘std::multimap<int,
     int, intComp, std::allocator<std::pair<const int, int> > >::insert(int
    )
/usr/include/c++/4.2.1/bits/stl_multimap.h:339: note: candidates are:
    typename std::_Rb_tree<_Key, std::pair<const _Key, _Tp>, std::
    _Select1st<std::pair<const _Key, _Tp> >, _Compare, typename _Alloc::
    rebind<std::pair<const _Key, _Tp> >::other>::iterator std::multimap<
    _Key, _Tp, _Compare, _Alloc>::insert(const std::pair<const _Key, _Tp>&)
     [with _Key = int, _Tp = int, _Compare = intComp, _Alloc = std::
    allocator<std::pair<const int, int> >]
/usr/include/c++/4.2.1/bits/stl_multimap.h:363: note:
    typename std::_Rb_tree<_Key, std::pair<const _Key, _Tp>, std::
    _Select1st<std::pair<const _Key, _Tp> >, _Compare, typename _Alloc::
    rebind<std::pair<const _Key, _Tp> >::other>::iterator std::multimap<
    _Key, _Tp, _Compare, _Alloc>::insert(typename std::_Rb_tree<_Key, std::
    pair<const _Key, _Tp>, std::_Select1st<std::pair<const _Key, _Tp> >,
    _Compare, typename _Alloc::rebind<std::pair<const _Key, _Tp> >::other
    >::iterator, const std::pair<const _Key, _Tp>&) [with _Key = int, _Tp =
```

```
    int, _Compare = intComp, _Alloc = std::allocator<std::pair<const int,
   int> >]
```

Statische Requirementsüberprüfung zur Compilezeit:
Sehr leicht können bei unpassenden Typparametern und anderen Problemen komplizierte und unverständliche Compiler-Meldungen entstehen, was einfach mit der Tatsache zusammenhängt, dass die konkreten Anforderungen an die Typparameter unbekannt sind. Die Arbeit mit C++-Templates erfordert deshalb eine lückenlose Dokumentation der Anforderungen an einen Typparameter. Durch Template-Metaprogrammierung können die meisten Anforderungen (Basisklasse, Vorhandensein von Methoden, Kopierbarkeit, Zuweisbarkeit etc.) auch in speziellen Konstrukten abgefragt werden, wodurch sich lesbarere Fehlermeldungen ergeben. Obgleich sie standardkonform sind, werden diese Konstrukte jedoch nicht von allen Compilern unterstützt. (Siehe http://de.wikipedia.org/wiki/Generische_Programmierung_in_Java Abschnitt „Das Konzept“)

Why do templates produce such horrible error messages?
In current C++, template errors are detected when a certain type argument does not support a certain operation (often expressed as the inability to convert one type to another or a failure of type deduction). It often happens deep into the instantiation tree. You need an equivalent of the stack trace to figure out where the root cause of the error is. It's called an "instantiation stack" and is dumped by the compiler upon a template error. It often spans several pages and contains unfamiliar names and implementation details of some library code.
Siehe http://bartoszmilewski.wordpress.com/2010/06/24/c-concepts-a-postmortem/: Absatz „Error Reporting“.

1.9. Erfragung der Eigenschaften aktueller generischer Parameter

... mittels der `type_traits`:

```
// Instantiating 'elaborate' will automatically
//      instantiate the correct way to operate.
template<class T1, class T2>
int elaborate (T1 A, T2 B)
{
    // Use the second way only if 'T1' is an integer
    // and if 'T2' is in floating point, otherwise
    // use the first way.
    return Algorithm<std::is_integral<T1>::value &&
           std::is_floating_point<T2>::value>::do_it( A, B ) ;
}
// ...
template<class Integral>
Integral foo(Integral x, Integral y) {
    static_assert(std::is_integral<Integral>::value,
          "foo() parameter must be an integral type.");
}
// ...
```

Type traits for metaprogramming und Static assertions

Seit C++17 einfacher:

std::is_integral

durch die template-Variable `is_integral_v` :

```
template <typename C, typename T, std::enable_if_t<std::is_integral_v<T>
   && std::is_container_v<C>>
sort_container() {
    C<T> c = {4, 5, 1, 7, 8, 3, 9, 2, 8, 0};
    std::sort(std::begin(c), std::end(c));
}
```

was in C++20 einmal wie folgt aussehen wird:

```
template <Container C, Integral T>
sort_container() {
    C<T> c = {4, 5, 1, 7, 8, 3, 9, 2, 8, 0};
    std::sort(std::begin(c), std::end(c));
}
```

SFINAE
std::enable_if

1.9.1. C++11 type_traits

Abschnitt 20.9.2, 20.9.4f.:

```
template <class T> struct is_void;
template <class T> struct is_integral;
template <class T> struct is_floating_pint;
template <class T> struct is_array;
template <class T> struct is_pointer;
template <class T> struct is_lvalue_reference;
template <class T> struct is_rvalue_reference;
template <class T> struct is_member_object_pointer;
template <class T> struct is_member_function_pointer;
template <class T> struct is_enum;
template <class T> struct is_union;
template <class T> struct is_class;
template <class T> struct is_function;

template <class T> struct is_reference;
template <class T> struct is_arithmetic;
template <class T> struct is_fundamental;
template <class T> struct is_object;
template <class T> struct is_scalar;
template <class T> struct is_compount;
template <class T> struct is_member_pointer;

template <class T> struct is_const;
template <class T> struct is_volatile;
template <class T> struct is_trivial;
template <class T> struct is_trivially_copyable;
template <class T> struct is_standard_layout;
template <class T> struct is_pod;
template <class T> struct is_literal_type;
template <class T> struct is_empty;
template <class T> struct is_polymorphic;
template <class T> struct is_abstract;
template <class T> struct is_signed;
template <class T> struct is_unsigned;
template <class T> struct is_constructible;
template <class T> struct is_default_constractible;
template <class T> struct is_copy_constructible;
template <class T> struct is_move_constructible;
template <class T, class U> struct is_assignable;
template <class T> struct is_copy_assignable;
template <class T> struct is_move_assignable;
template <class T> struct is_destructible;
...
template <class T, class U> struct is_same;
template <class Base, class Derived> struct is_base_of;
template <class From, class To> struct is_convertible;
template <class From,class To> class is_explicitly_convertible;
```

1.9.2. BOOST type_traits

Boost: Type Traits

```
has_bit_and
has_bit_and_assign
has_bit_or
has_bit_or_assign
has_bit_xor
has_bit_xor_assign
has_complement
has_dereference
has_divides
has_divides_assign
has_equal_to
has_greater
has_greater_equal
has_left_shift
has_left_shift_assign
has_less
has_less_equal
has_logical_and
has_logical_not
has_logical_or
has_minus
has_minus_assign
has_modulus
has_modulus_assign
has_multiplies
has_multiplies_assign
has_negate
has_new_operator
has_not_equal_to
has_nothrow_assign
has_nothrow_constructor
has_nothrow_copy
has_nothrow_copy_constructor
has_nothrow_default_constructor
has_plus
has_plus_assign
has_post_decrement
has_post_increment
has_pre_decrement
has_pre_increment
has_right_shift
has_right_shift_assign
has_trivial_assign
has_trivial_constructor
has_trivial_copy
has_trivial_copy_constructor
has_trivial_default_constructor
has_trivial_destructor
has_unary_minus
has_unary_plus
```

```
has_virtual_destructor
integral_constant
integral_promotion
is_abstract
is_arithmetic
is_array
is_base_of
is_class
is_complex
is_compound
is_const
is_convertible
is_empty
is_enum
is_floating_point
is_function
is_fundamental
is_integral
is_lvalue_reference
is_member_function_pointer
is_member_object_pointer
is_member_pointer
is_object
is_pod
is_pointer
is_polymorphic
is_reference
is_rvalue_reference
is_same
is_scalar
is_signed
is_stateless
is_union
is_unsigned
is_virtual_base_of
is_void
is_volatile
```

1.9.3. is_arithmetic, true_type and false_type

is_arithmetic
integral_constant mit true_type
std::integral_constant
Rationale behind std::bool_constant

1.9.4. numeric_limits als Typ-Abbildung

numeric_limits als generische Klasse
mit traits-ähnlichem Charakter für die Benutung zum Beispiel für Requirements von Tempate-Parametern:

```cpp
#include <limits>

template <class UnsignedInt>
class myclass
{
private:
  static_assert(std::numeric_limits<UnsignedInt>::is_specialized,
                "UnsignedInt isn't specialized");
   static_assert(std::numeric_limits<UnsignedInt>::digits >= 16,
                "UnsignedInt isn't long enough");
   static_assert(std::numeric_limits<UnsignedInt>::is_integer,
                "UnsignedInt isn't integer");
  static_assert(!std::numeric_limits<UnsignedInt>::is_signed,
                "UnsignedInt isn't unsigned");

public:
   /* details here */
};
 myclass<unsigned> m1;
 //myclass<int> m2;
 myclass<unsigned char> m3;

int main()
{
 return 0;
}
```

18.3.2.3: allgemeines Template mit is_specialized==false
18.3.2.7: Spezialisierung für float, bool
numeric_limis: 18.3.2.2: alle bereitgestellten Spezialisierungen

1.10. Rückblick: typsichere Funktionsbenutzung

Der Prototypen (Signaturen) von Funtionen:

```
const double& max(const double& a, const double& b);
inline static constexpr float max() noexcept { return 3.40282347E+38F; }
int myfunction (int param) noexcept; // no exceptions allowed
int myfunction (int param);          // all exceptions allowed ...
```

Prototypen in Headerdateien

„Wichtig: Bei Prototypen unterscheidet C zwischen einer leeren Parameterliste und einer Parameterliste mit void . Ist die Parameterliste leer, so bedeutet dies, dass die Funktion eine nicht definierte Anzahl an Parametern besitzt. Das Schlüsselwort void gibt an, dass der Funktion keine Werte übergeben werden dürfen. “
(Funktionsprototypen in C)

C functions without prototypes

1.11. Concepts und zielführende knappe Fehlermeldungen bei der Benutzung fehlerhafter aktueller generischer Parameter: 2020 oder wann?

C++11: Features originally planned but removed or not included

Concepts (C++)

http:// www.generic-programming.org/languages/conceptcpp/tutorial/

```
template<std::CopyConstructible T>
  requires Addable<T>
  T sum(T array[], int n)
  {
    T result = 0;
    for (int i = 0; i < n; ++i)
      result = result + array[i];
    return result;
  }
```

nur für Klassen T mit:

```
auto concept CopyConstructible<typename T> {
  T::T(T const&);
  T::~T();
};


auto concept Addable<typename T, typename U = T> {
  typename result_type;
  result_type operator+(T, U);
};
```

Statt einer buchstabengetreuen Überprüfung auf Einhaltung der Konzepteigenschaften mittels der `auto`-Konzeptdefinition kann man durch `concept_maps` auch eine mittels „Übersetzung“ einzelner Operationen/Typen erreichbare Erfüllung der Konzept-Eigenschaften definieren:

```
concept Stack<typename X> {
    typename value_type;
    void push(X&, const value_type&);
    void pop(X&);
    value_type top(const X&);
    bool empty(const X&);
};

template<typename T> concept_map Stack<std::vector<T>> {
    typedef T value_type;
    void push(std::vector<T>& v, const T& x) { v.push_back(x); }
    void pop(std::vector<T>& v) { v.pop_back(); }
    T top(const std::vector<T>& v) { return v.back(); }
    bool empty(const std::vector<T>& v) { return v.empty(); }
};
```

(siehe Concept_maps, retroaktive Modellierung)

Zu weiteren Concepts vergleiche:
SGI: Introduction to the Standard Template Library, Concepts

Eine praktische Anwendung:

```
#include <iostream>
#include <cmath>
#include <vector>
#include <concepts>

using namespace std;

auto concept HasAbs<typename T> {
    typename result_type;
    result_type abs(const T&);
}
auto concept HasPower<typename T>{
    typename result_type;
    result_type pow(const T&, int);
}
auto concept HasPowerd<typename T>{
    requires FloatingPointLike<T>;
    double pow(const T&, const T&);
}

template <int p = 2, InputIterator InputIter, FloatingPointLike T>
requires True<p >= 1>,
    HasAbs<InputIter::value_type>,
    HasPowerd<T>,
    HasPower<HasAbs<InputIter::value_type>::result_type>,
    HasPlusAssign<T,
       HasPower<HasAbs<InputIter::value_type>::result_type>::result_type>
    T pNorm(InputIter first, InputIter last, T init)
{
    for (; first != last; first++)
    {
        init += pow(abs(*first), p);
    };
    return pow((init), (1.0/p));
}
int main()
{
    vector<double> TD (2);
    TD[0] = 200.0;
    TD[1] = 0.0;

    double res = pNorm<3>(TD.begin(), TD.end(), 0.0f);
    cout << res << " sizeof: "
         << sizeof(pNorm(TD.begin(), TD.end(), 0.0f))
         << endl;

    double TestData[] = {110.0, 10.0, 10.0};
    cout << pNorm(TestData, TestData + 3, 0.0)
         << " sizeof: " << sizeof(pNorm(TestData, TestData + 3, 0.0))
         << endl;
```

```
        double TestData2[] = {10.0, 10.0, 10.0};
        cout << pNorm<1>(TestData2, TestData2 + 3, 0.01)
            << " sizeof: " << sizeof(pNorm<1>(TestData2, TestData2 +
               3, 0.01
))
      << endl;

   return 0;
}
```

Dabei wird aus das Konzept `HasPlusAssign<T, U>` der C++0x Standard Library benutzt:

```
auto concept HasPlusAssign<typename T, typename U = T> {
typename result_type;
result_type operator+=(T&, const U&);
}
```

(vergleiche Foundational Concepts for the C++0x Standard Library (Revision 5),
Proposed Wording for Concepts (Revision 3),
Containers,
Algorithms (Revision 2),
Iterators (Revision 3),
Numerics (Revision 3))

Concepts in C++11?
Concepts-Lite
Concepts Lite: Constraining Template Arguments with Predicates
Concepts Lite: Constraining Templates with Predicates
A Concept Design for the STL
Why Concepts didn't make C++17

1.12. Zielgerichtete Fehlermeldungen bei Nutzung einer C++-Standardbibliothek mit Konzepten

Fehlerhafte Benutzung einer generischen Funktion:

```
#include <list>
#include <algorithm>

int main() {
   std::list<int> l;
   std::sort(l.begin(), l.end());
}
```

g++ ohne eingeschränkte Generizität:

```
/usr/lib/gcc/i686-pc-linux-gnu/4.1.2/include/g++-v4/bits/stl_algo.h: In  -
function 'void std::sort(_RandomAccessIterator, _RandomAccessIterator) [  -
with _RandomAccessIterator = std::_List_iterator<int>]':
list-sort.c++:6: instantiated from here
/usr/lib/gcc/i686-pc-linux-gnu/4.1.2/include/g++-v4/bits/stl_algo.h:2713:  -
error: no match for 'operator-' in '__last - __first'
/usr/lib/gcc/i686-pc-linux-gnu/4.1.2/include/g++-v4/bits/stl_algo.h: In  -
function 'void std::__final_insertion_sort(_RandomAccessIterator,  -
_RandomAccessIterator) [with _RandomAccessIterator = std::_List_iterator<  -
int>]':
...
```

conceptg++ mit Konzepte benutzender Standardbibliothek:

```
list-sort.c++: In function 'int main()':
list-sort.c++:6: error: no matching function for call to 'sort(std::  -
_List_iterator<int>, std::_List_iterator<int>)'
/usr/local/lib/gcc/i686-pc-linux-gnu/4.3.0/../../../../include/c++/4.3.0/  -
bits/stl_algo.h:2872: note: candidates are: void std::sort(_Iter, _Iter)  -
[with _Iter = std::_List_iterator<int>] <where clause>
list-sort.c++:6: note: no concept map for requirement 'std::  -
MutableRandomAccessIterator<std::_List_iterator<int> >'
```

Aufgabe: Warum ist `list<...>::iterator` kein `MutableRandomAccessIterator`?

Zitat: „ConceptC++ makes programming with C++ templates easier, ...“

1.13. Orte, wo statische Zusicherungen benutzt werden

Boost.StaticAssert

Use at namespace scope
Use at function scope
Use at class scope
Use in templates

1.14. statische Zusicherunge in C++11

static assertions
Range-based for-loop
25.2.2 ff.: all_of(), any_of(), none_of(), for_each()

25.2.2 Any of **[alg.any_of]**

```
template <class InputIterator, class Predicate>
  bool any_of(InputIterator first, InputIterator last, Predicate pred);
```

1 *Returns:* `false` if `[first,last)` is empty or if there is no iterator `i` in the range `[first,last)` such that `pred(*i)` is `true`, and `true` otherwise.

2 *Complexity:* At most `last - first` applications of the predicate.

25.2.3 None of **[alg.none_of]**

```
template <class InputIterator, class Predicate>
  bool none_of(InputIterator first, InputIterator last, Predicate pred);
```

1 *Returns:* `true` if `[first,last)` is empty or if `pred(*i)` is `false` for every iterator `i` in the range `[first,last)`, and `false` otherwise.

2 *Complexity:* At most `last - first` applications of the predicate.

1.15. Fehlermeldungen bei uneingeschränkter Generizität (Fortsetzung von 1.8)

```
#include <vector>
#include <complex>
#include <algorithm>

int main()
 {
     std::vector<std::complex<float> > v;
     std::stable_sort(v.begin(), v.end());
 }
```

und die Fehlermeldung:

```
In file included from /usr/include/c++/4.5/algorithm:63:0,
                 from bad_error_eg.cpp:3:
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫void std::__insertion_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = __gnu_cxx::__norm
/usr/include/c++/4.5/bits/stl_algo.h:3358:4:   instantiated from ≫void std::__inplace_stable_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator
/usr/include/c++/4.5/bits/stl_algo.h:5415:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:2103:4: Fehler: no match for ≫operator<≪ in ≫__i.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _Iterator = st
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫void std::__merge_without_buffer(_BidirectionalIterator, _BidirectionalIterator, _BidirectionalIterator, _Distance, _Dis
/usr/include/c++/4.5/bits/stl_algo.h:3364:7:   instantiated from ≫void std::__inplace_stable_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator
/usr/include/c++/4.5/bits/stl_algo.h:5415:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:2963:4: Fehler: no match for ≫operator<≪ in ≫__middle.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _Iterator
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫void std::__unguarded_linear_insert(_RandomAccessIterator) [with _RandomAccessIterator = __gnu_cxx::__normal_iterator<st
/usr/include/c++/4.5/bits/stl_algo.h:2111:6:   instantiated from ≫void std::__insertion_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = __
/usr/include/c++/4.5/bits/stl_algo.h:3358:4:   instantiated from ≫void std::__inplace_stable_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator
/usr/include/c++/4.5/bits/stl_algo.h:5415:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:2064:7: Fehler: no match for ≫operator<≪ in ≫__val < __next.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _It
In file included from /usr/include/c++/4.5/vector:61:0,
                 from bad_error_eg.cpp:1:
/usr/include/c++/4.5/bits/stl_algobase.h: In Funktion ≫_ForwardIterator std::lower_bound(_ForwardIterator, _ForwardIterator, const _Tp&) [with _ForwardIterator = __gnu_cxx
/usr/include/c++/4.5/bits/stl_algo.h:2975:4:   instantiated from ≫void std::__merge_without_buffer(_BidirectionalIterator, _BidirectionalIterator, _BidirectionalIterator,
/usr/include/c++/4.5/bits/stl_algo.h:3364:7:   instantiated from ≫void std::__inplace_stable_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator
/usr/include/c++/4.5/bits/stl_algo.h:5415:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algobase.h:976:4: Fehler: no match for ≫operator<≪ in ≫__middle.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _Itera
In file included from /usr/include/c++/4.5/algorithm:63:0,
                 from bad_error_eg.cpp:3:
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫_FIter std::upper_bound(_FIter, _FIter, const _Tp&) [with _FIter = __gnu_cxx::__normal_iterator<std::complex<float>*, st
/usr/include/c++/4.5/bits/stl_algo.h:2982:4:   instantiated from ≫void std::__merge_without_buffer(_BidirectionalIterator, _BidirectionalIterator, _BidirectionalIterator,
/usr/include/c++/4.5/bits/stl_algo.h:3364:7:   instantiated from ≫void std::__inplace_stable_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator
/usr/include/c++/4.5/bits/stl_algo.h:5415:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:2461:4: Fehler: no match for ≫operator<≪ in ≫__val < __middle.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫_OIter std::merge(_IIter1, _IIter1, _IIter2, _IIter2, _OIter) [with _IIter1 = std::complex<float>*, _IIter2 = __gnu_cxx:
/usr/include/c++/4.5/bits/stl_algo.h:2838:4:   instantiated from ≫void std::__merge_adaptive(_BidirectionalIterator, _BidirectionalIterator, _BidirectionalIterator, _Dista
/usr/include/c++/4.5/bits/stl_algo.h:3315:7:   instantiated from ≫void std::__stable_sort_adaptive(_RandomAccessIterator, _RandomAccessIterator, _Pointer, _Distance) [with
/usr/include/c++/4.5/bits/stl_algo.h:5417:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:5299:4: Fehler: no match for ≫operator<≪ in ≫__first2.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _Iterator
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫_BidirectionalIterator3 std::__merge_backward(_BidirectionalIterator1, _BidirectionalIterator1, _BidirectionalIterator2,
/usr/include/c++/4.5/bits/stl_algo.h:2847:4:   instantiated from ≫void std::__merge_adaptive(_BidirectionalIterator, _BidirectionalIterator, _BidirectionalIterator, _Dista
/usr/include/c++/4.5/bits/stl_algo.h:3315:7:   instantiated from ≫void std::__stable_sort_adaptive(_RandomAccessIterator, _RandomAccessIterator, _Pointer, _Distance) [with
/usr/include/c++/4.5/bits/stl_algo.h:5417:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:2740:4: Fehler: no match for ≫operator<≪ in ≫* __last2 < __last1.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [wit
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫_OIter std::merge(_IIter1, _IIter1, _IIter2, _IIter2, _OIter) [with _IIter1 = __gnu_cxx::__normal_iterator<std::complex<
/usr/include/c++/4.5/bits/stl_algo.h:3163:4:   instantiated from ≫void std::__merge_sort_loop(_RandomAccessIterator1, _RandomAccessIterator1, _RandomAccessIterator2, _Dist
/usr/include/c++/4.5/bits/stl_algo.h:3261:4:   instantiated from ≫void std::__merge_sort_with_buffer(_RandomAccessIterator, _RandomAccessIterator, _Pointer) [with _RandomA
/usr/include/c++/4.5/bits/stl_algo.h:3312:4:   instantiated from ≫void std::__stable_sort_adaptive(_RandomAccessIterator, _RandomAccessIterator, _Pointer, _Distance) [with
/usr/include/c++/4.5/bits/stl_algo.h:5417:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:5299:4: Fehler: no match for ≫operator<≪ in ≫__first2.__gnu_cxx::__normal_iterator<_Iterator, _Container>::operator* [with _Iterator
/usr/include/c++/4.5/bits/stl_algo.h: In Funktion ≫_OIter std::merge(_IIter1, _IIter1, _IIter2, _IIter2, _OIter) [with _IIter1 = std::complex<float>*, _IIter2 = std::compl
/usr/include/c++/4.5/bits/stl_algo.h:3163:4:   instantiated from ≫void std::__merge_sort_loop(_RandomAccessIterator1, _RandomAccessIterator1, _RandomAccessIterator2, _Dist
/usr/include/c++/4.5/bits/stl_algo.h:3263:4:   instantiated from ≫void std::__merge_sort_with_buffer(_RandomAccessIterator, _RandomAccessIterator, _Pointer) [with _RandomA
/usr/include/c++/4.5/bits/stl_algo.h:3312:4:   instantiated from ≫void std::__stable_sort_adaptive(_RandomAccessIterator, _RandomAccessIterator, _Pointer, _Distance) [with
/usr/include/c++/4.5/bits/stl_algo.h:5417:2:   instantiated from ≫void std::stable_sort(_RAIter, _RAIter) [with _RAIter = __gnu_cxx::__normal_iterator<std::complex<float>*
bad_error_eg.cpp:8:41:   instantiated from here
/usr/include/c++/4.5/bits/stl_algo.h:5299:4: Fehler: no match for ≫operator<≪ in ≫* __first2 < * __first1≪
```

C++11:

25.4.1.2 `stable_sort` [stable.sort]

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

template<class RandomAccessIterator, class Compare>
  void stable_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:* It does at most $N \log^2(N)$ (where N == `last - first`) comparisons; if enough extra memory is available, it is $N \log(N)$.

4 *Remarks:* Stable.

SGI:
stable_sort

Algorithms

Category: algorithms

Function

Component type: function

Prototype

`Stable_sort` is an overloaded name; there are actually two `stable_sort` functions.

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

template <class RandomAccessIterator, class StrictWeakOrdering>
void stable_sort(RandomAccessIterator first, RandomAccessIterator last,
                 StrictWeakOrdering comp);
```

Description

`Stable_sort` is much like `sort`: it sorts the elements in `[first, last)` into ascending order, meaning that if `i` and `j` are any two valid iterators in `[first, last)` such that `i` precedes `j`, then `*j` is not less than `*i`. `Stable_sort` differs from `sort` in two ways. First, `stable_sort` uses an algorithm that has different run-time complexity than `sort`. Second, as the name suggests, `stable_sort` is stable: it preserves the relative ordering of equivalent elements. That is, if `x` and `y` are elements in `[first, last)` such that `x` precedes `y`, and if the two elements are equivalent (neither `x < y` nor `y < x`) then a postcondition of `stable_sort` is that `x` still precedes `y`. [1]

The two versions of `stable_sort` differ in how they define whether one element is less than another. The first version compares objects using `operator<`, and the second compares objects using a function object `comp`.

Definition

Defined in the standard header algorithm, and in the nonstandard backward-compatibility header algo.h.

Requirements on types

For the first version, the one that takes two arguments:

- `RandomAccessIterator` is a model of Random Access Iterator.
- `RandomAccessIterator` is mutable.
- `RandomAccessIterator`'s value type is LessThan Comparable.
- The ordering relation on `RandomAccessIterator`'s value type is a *strict weak ordering*, as defined in the LessThan Comparable requirements.

iterator_traits
std::iterator_traits

Type alias, alias template
Typedef declaration

1.16. Verbesserte Fehlermeldungen bei Nutzung von StaticAssert

1.16.1. RandomAccessIterator

Zunächst die uneingeschränkt generische Variante:

```
#include <iostream>
#include <vector>
#include <set>
#include <complex>
#include <algorithm>
#include <iterator>
#include <type_traits>

template <typename RandomAccessIterator >
RandomAccessIterator foo(RandomAccessIterator from,
                         RandomAccessIterator to)
{
   // this template should only be used with
   // random access iterators...
   //
   // ...
   reverse(from, to);
   return from;
};

int main()
{
     std::vector<float> v;
     // std::set<float> v;

     v.insert(v.end(),3.14);
     v.insert(v.end(),15.15);
     foo(v.begin(), v.end());
     copy(v.begin(), v.end(), std::ostream_iterator<float>(
                                          std::cout, " "));
     std::cout << std::endl;

}
```

wird einwandfrei übersetzt

```
> make CXXFLAGS="-std=c++11" ra2
g++ -std=c++11 ra2.cpp -o ra2
```

und funktioniert einwandfrei, für

```
int main()
{
     // std::vector<float> v;
     std::set<float> v;
     //...
```

erscheint jedoch keine vernünftige Fehlermeldung

```
> make CXXFLAGS="-std=c++11" ra2
/usr/include/c++/4.7/bits/stl_algobase.h: In instantiation of ‘static void std::__iter_swap<_BoolType>::
/usr/include/c++/4.7/bits/stl_algobase.h:139:7:   required from ‘void std::iter_swap(_ForwardIterator1, 
/usr/include/c++/4.7/bits/stl_algo.h:1428:6:   required from ‘void std::__reverse(_BidirectionalIterator
/usr/include/c++/4.7/bits/stl_algo.h:1474:7:   required from ‘void std::reverse(_BIter, _BIter) [with _B
ra2.cpp:25:4:   required from ‘RandomAccessIterator foo(RandomAccessIterator, RandomAccessIterator) [wit
ra2.cpp:36:28:   required from here
/usr/include/c++/4.7/bits/stl_algobase.h:90:11: error: assignment of read-only location ‘__a.std::_Rb_tr
/usr/include/c++/4.7/bits/stl_algobase.h:91:11: error: assignment of read-only location ‘__b.std::_Rb_tr
```

random_access_iterator_tag
Iterator categories
iterator_tags

Extensible Templates: Via Inheritance or Traits?
Add a method to existing C++ class in other file

Durch ein geeignetes statisches Assert der Art

```
#include <iostream>
#include <algorithm>
#include <iterator>
#include <vector>
#include <set>
#include <complex>
#include <type_traits>

template <typename RandomAccessIterator >
RandomAccessIterator foo(RandomAccessIterator from,
                         RandomAccessIterator to)
{
   // this template can only be used with
   // random access iterators...
   typedef typename std::iterator_traits<
         RandomAccessIterator >::iterator_category cat;
   static_assert(
      (std::is_convertible<
         cat,
         const std::random_access_iterator_tag&>::value),
      "no random access iterator");
   //
   // ...
   reverse(from, to);
   return from;
};

int main()
{
     // std::vector<float> v;
     std::set<float> v;

     v.insert(v.begin(),3.14);
     v.insert(v.begin(),15.15);
     foo(v.begin(), v.end());
     copy(v.begin(), v.end(), std::ostream_iterator<float>(std::cout, " ")
        );
     std::cout << std::endl;
}
```

wird jedoch der falsche aktuelle generische Parametertyp gemeldet:

```
make CXXFLAGS="-std=c++11" ra2
g++ -std=c++11 -g ra2.cpp -o ra2
ra2.cpp: In instantiation of ‘RandomAccessIterator foo(RandomAccessIterator, RandomAccessIterat
ra2.cpp:36:28:   required from here
ra2.cpp:18:4: error: static assertion failed: no random access iterator
make: *** [ra2] Fehler 1
```

1.16.2. Nicht instanziierbare Klassen

```
#include <iostream>
#include <algorithm>
#include <type_traits>

template <typename T>
struct abstractClass
{
        static_assert(false, "This class may not be instantiated!");
        // ...
};

int main()
{
      abstractClass<int> ac;
      std::cout << std::endl;
}
```

Beachte eventuell: http://www.boost.org/doc/libs/1_55_0/doc/html/boost_staticassert.html#boost_staticassert.templates

Ersatz der Compiler-Dirktive `#error` bei der neuen C++17 bedingten Compilation (`constexpr if`) :

```
/* workaround until operator== is constexpr
 * http://open-std.org/JTC1/SC22/WG21/docs/papers/2017/p0533r0.pdf
 */
constexpr bool equal(char const* lhs, char const* rhs)
{
  while (*lhs || *rhs)
    if (*lhs++ != *rhs++)
      return false;
  return true;
}
// aus: https://stackoverflow.com/questions/27490858/how-can-you-compare-
    two-character-strings-statically-at-compile-time//


template <class...>
struct False : std::bool_constant<false> { };
//template <>
//struct False<float> : std::bool_constant<true> { };
template <class T = int>
void ErrorAbort(const char* Msg){
        static_assert(False<T>{}, Msg);
}


std::string createConfigFilePath(const std::string &relativePath) {
      if constexpr(equal(OS, "WINDOWS")){
           return createWindowsConfigFilePath(relativePath);
      } else if constexpr(equal(OS, "LINUX")){
           return createLinuxConfigFilePath(relativePath);
```

```
    } else {
        ErrorAbort<>("OS not yet supported");
        // static_assert(false, "OS is not yet supported"); doesn't
            work
    }
}
```

#error

1.16.3. Erzwingung gleicher Typen

```
#include <limits>
#include <type_traits>

template <class UnsignedInt>
class myclass
{
private:
  static_assert(std::is_same<UnsignedInt, unsigned int>::value,
                "UnsignedInt isn't unsigned int");
public:
   /* details here */
};

 //myclass<unsigned> m1;
 //myclass<int> m2;
 //myclass<unsigned char> m3;
 myclass<unsigned long> m4;

int main()
{
 return 0;
}
```

siehe auch: http://en.cppreference.com/w/cpp/types/is_same

1.16.4. Funktionen mit „(int/float/...) type promotion“-Returntyp

4.5 Integral promotions
4.6 Floating point promotion
5 Expressions, clause 10: usual arithmetic conversions

```
#include "promote.h"
template <typename T1, typename T2>
   typename promote_trait<T1,T2>::T_promote
       my_function(T1 x, T2 y)
{
    return  (x + y)/2.0;
}
```

mit `promote.h` ähnlich wie (alle möglichen Typkombinationen spezialisiert):

```
template <typename T1, typename T2>
struct promote_trait{
    typedef T1 T_promote;
};

template<> struct promote_trait<char, char> {
public:
        typedef int T_promote;
};
//...
```

(**Vergleiche:** promote.h)

Moderner mittels type_promotion gemäß Seite 17f.

In C++11 eleganter: automatisch bestimmter return-Typ:

```
template <typename T1, typename T2>
auto my_function(T1 x, T2 y) -> decltype((x + y)/2.0)
{
    return (x + y)/2.0;
}
```

Dank der automatic return type deduction C++14’s ist `'-> decltype((x + y)/2.0)'` auch noch überflüssig geworden.

Siehe auch BOOST promote

1.16.5. Auf Unterklassen eingeschränkte Generizität

```
template <typename ListUnterklasse>
class MyList
{
   static_assert(std::is_base_of<List,
                                     ListUnterklasse>::value,
                 "ListUnterklasse ist keine Kindklasse von List");
   // ...
}
```

Siehe C++11 Abschnitt 20.9.6 Relationships between types.

Diese Typeigenschaften werden durch trickreichen Einsatz der Metaprogrammierung aus dem C++-Compiler „herausgekitzelt“: How is_base_of works? beziehungsweise Alternate implementation of is_base_of oder direkt durch die g++ type_traits Compiler Extensions erfragt.

1.16.6. g++ type_traits Compiler Extensions

... oder sie benutzen direkt die syntaktischen Erweiterungen der „GNU Compiler Collection“ 7.9 Type Traits:

```
__is_base_of (base_type, derived_type)
    If base_type is a base class of derived_type ([class.derived]) then the
    trait is true, otherwise it is false. Top-level cv qualifications of
    base_type and derived_type are ignored. For the purposes of this trait,
    a class type is considered is own base.
    Requires: if __is_class (base_type) and __is_class (derived_type) are
    true and base_type and derived_type are not the same type (disregarding
    cv-qualifiers), derived_type shall be a complete type. Diagnostic is
    produced if this requirement is not met.
```

1.16.7. Type Traits in D

Andere Programmiersprachen (hier z.B. D) haben ähnliche elegantere semantische Erweiterungen, um den Compiler direkt abzufragen:

```
// Returns true if instances of type T can be added
template isAddable(T)
{   // Works by attempting to add two instances of type T
    const isAddable = __traits(compiles, (T t) { return t + t; });
}

int Foo(T)(T t)
    if (isAddable!(T))
{
    return 3;
}
// ...
```

Deren Anwendung für ADTs (als Requirements-Ersatz):

```
template isStack(T)
{
    const isStack =
        __traits(compiles,
          (T t)
          {   T.value_type v = top(t);
              push(t, v);
              pop(t);
              if (empty(t)) { }
          });
}

template Foo(T)
    if (isStack!(T))
{
    ...
}
```

D Template Constraints
D Traits

```d
import std.stdio;

struct S
{
    int m;
}

void main()
{
    S s;

    writeln(__traits(hasMember, S, "m")); // true
    writeln(__traits(hasMember, s, "m")); // true
    writeln(__traits(hasMember, S, "y")); // false
    writeln(__traits(hasMember, int, "sizeof")); // true
}
```

1.16.8. C++ *has_member* fehlt

C++ type traits to check if class has operator/member

Ab C++17:
Trial type definition

```
#include <iostream>
#include <type_traits>

template <typename T>
using has_typedef_foobar_t = decltype(T::foobar);

struct foo {
  using foobar = float;
};

int main() {
  std::cout << std::boolalpha;
  std::cout << std::is_detected<has_typedef_foobar_t, int>::value << std::
      endl;
  std::cout << std::is_detected<has_typedef_foobar_t, foo>::value << std::
      endl;
}
```

and test, if trial succeeded.

C++-Pattern „Member Detector“

Proposed for C++17: The C++ Detection Idiom
(std::void_t)

1.16.9. SFINAE

Substitution Failure Is Not An Error
C++: substitution failure is not an error
SFINAE Warum ein fehlgehender Instanziierungsversuch keinen Compilationsfehler verursacht:

```
struct Test {
    typedef int foo;
};

template <typename T>
void f(typename T::foo) {} // Definition #1

template <typename T>
void f(T) {}               // Definition #2

int main() {
    f<Test>(10); // Call #1.
    f<int>(10);  // Call #2. Without error (SFINAE)
}
```

SFINAE bei der nützlichen Trait-Arbeit:

```
template <typename T>
        struct has_iterator
        {
            template <typename U>
            static char test(typename U::iterator* x);

            template <typename U>
            static long test(U* x);

            static const bool value = sizeof(test<T>(0)) == 1;
        };
// ...
cout << has_iterator<int>::value << endl;
```

Siebe auch Abschnitt „`14.8.3 Overload resolution`“ des C++-Standards.

> arguments. For each function template, if the argument deduction and checking succeeds, the *template-arguments* (deduced and/or explicit) are used to synthesize the declaration of a single function template specialization which is added to the candidate functions set to be used in overload resolution. If, for a given function template, argument deduction fails, no such function is added to the set of candidate functions for that template. The complete set of candidate functions includes all the synthesized declarations and all of

C++ SFINAE examples: IsClassT

```cpp
template<typename T>
class IsClassT {
    template<typename C> static bool test(int C::*) {return true;}
    template<typename C> static bool test(...) {return false;}
public:
    static bool value;
};

template<typename T>
bool IsClassT<T>::value=IsClassT<T>::test<T>(0);

int main(void) {
    std::cout << IsClassT<std::string>::value << std::endl; // true
    std::cout << IsClassT<int>::value << std::endl;          // false
    return 0;
}
```

Seit C++14:

```cpp
template<typename T>
std::enable_if_t<std::is_integral<T>::value, T> f(T t){
    //integral version
}
template<typename T>
std::enable_if_t<std::is_floating_point<T>::value, T> f(T t){
    //floating point version
}
```

Siehe enable_if_t Helper

has_num, has_den, is_ratio:

```
#include <ratio>
#include <type_traits>

// see http://stackoverflow.com/questions/1005476/how-to-detect-whether-
    there-is-a-specific-member-variable-in-class
template <typename T, typename = int>
struct has_num : std::false_type { };
template <typename T>
struct has_num <T, decltype((void) T::num, 0)> : std::true_type { };

template <typename T, typename = int>
struct has_den : std::false_type { };
template <typename T>
struct has_den <T, decltype((void) T::den, 0)> : std::true_type { };
//...
template <typename T> struct is_ratio : std::false_type { };
template <long int N, long int D> struct is_ratio<std::ratio<N, D>> : std
    ::true_type { };
//...
template<typename T,
         typename std::enable_if<is_ratio<T>::value>::type* = nullptr>
std::ostream& operator<<(std::ostream& os, const T& s)
{
        os << (T::num) << "/" << (T::den);
        return os;
}
//...
template<typename T,
         typename std::enable_if<is_ratio<T>::value>::type* = nullptr>
std::string toString(const T s)
{
      static_assert(is_ratio<T>::value, "no ratio<.,.> type");
      std::ostringstream help;
      help << (T::num) << "/" << (T::den);
      return help.str();
}
//...
```

1.16.10. C++11: Traits mit decltype statt sizeof()-Tricks

Detect operator support with decltype/SFINAE

1.16.11. Überladene Templatefunktionen/bedingte Templateklassenspezifikationen

Bedingte Compilation mittels `enable_if` und SFINAE:

`template <bool B, class T = void> struct enable_if;`	If `B` is `true`, the member typedef `type` shall equal `T`; otherwise, there shall be no member typedef `type`.

1.16.11.1. enable_if-Funktionen

```
#include <iostream>
#include <cmath>
#include <limits>



template <typename ArithmeticLike1, typename ArithmeticLike2>
typename std::enable_if<std::is_arithmetic<ArithmeticLike1>::value,
                        double>::type
  geomMittel2(const ArithmeticLike1& a, const ArithmeticLike2& b)
{
    return sqrt(abs(a*b));
}

// uebersetze mit -std=c++11
// oder g++ CXXFLAGS="-std=c++11" ...

int main()
{
    std::cout << geomMittel2(3.0, 300.0) <<std::endl;
    std::cout << geomMittel2(3, 300.0) << std::endl;
    std::cout << geomMittel2(-3, 300.0) << std::endl;
    std::cout << geomMittel2(-3, 300) << std::endl;
    std::cout << geomMittel2(3.0, 'c') << std::endl;
    // std::cout << geomMittel2(3.0, "c") << std::endl;

    return 0;
}
```

Enabling mittels Funktionsargument-Eigenschaft:

```
template<class T>
T foo2(T t, typename std::enable_if<
            std::is_integral<T>::value>::type* = nullptr)
{
    return t;
}
```

Enabling via generischem Parameter:

```
template<class T ,
         typename std::enable_if<
           std::is_integral<T>::value>::type* = nullptr >
T foo3(T t) // note, function signature is unmodified
{
    return t;
}
```

1.16.11.2. Konflikt beim enable_if-Funktionsüberladen

3.2 Overlapping enabler conditions

```
template <class T>
typename enable_if<std::is_integral<T>::value, void>::type
foo(T t) {}

template <class T>
typename enable_if<std::is_arithmetic<T>::value, void>::type
foo(T t) {}
```

Beide foo()-Deklarationen schließen sich nicht gegenseitig aus, erzeugen also mehrdeutigen Code. Durch Kombination ähnlich ... possible to use std::enable_if to ... kann das vermieden werden:

```
struct A
{
    template <typename T>
    typename std::enable_if<std::is_integral<T>::value, T>::type foo()
    {
        std::cout << "integral" << std::endl;
        return T();
    }

    template <typename T>
    typename std::enable_if<!std::is_integral<T>::value
                            &&(std::is_arithmetic<T>::value), T>::type foo
                            ()
    {
        std::cout << "arithmetic but not integral" << std::endl;
        return T();
    }
}
}
```

1.16.11.3. bedingte „template class specializations“

3.1 Enabling template class specializations

```
template <class T, class Enable = void>
class A { ... };

template <class T>
class A<T, typename enable_if<std::is_integral<T>::value>::type> { ... };

template <class T>
class A<T, typename enable_if<std::is_float<T>::value>::type> { ... };
```

Ein Beispiel:

```
#include <iostream>
#include <vector>
using namespace std;

template <typename T, typename Enable = void>
struct A { A(){ cout<< "is something other ..." << endl;} };

template <typename T>
struct A<T, typename enable_if<is_floating_point<T>::value>::type> {
A(){ cout<< "is floatingpoint" << endl;}
};

template <typename T>
struct A<T, typename enable_if<is_integral<T>::value>::type> {
A(){ cout<< "is integral" << endl;}
};

template <typename T>
struct A<T, typename enable_if<!is_pod<T>::value>::type> {
A(){ cout<< "is no pod" << endl;}
};

template <typename T>
struct A<T, typename enable_if<(is_enum<T>::value)&&(is_scalar<T>::value)
    >::type> {
A(){ cout<< "is enum and scalar" << endl;}
};

int main(){
  typedef vector<string> vektortype1;
  typedef int* IntPointerType;
  enum Farbe {ROT, GELB, GRUEN, BLAU};

  A<char>();
  A<signed>();
  A<float>();
  A<vektortype1>();
```

```
    A<Farbe>();
    A<IntPointerType>();
}
```

und die Ergebnisse:

```
is integral
is integral
is floatingpoint
is no pod
is enum and scalar
is something other ...
```

Siehe auch: std::conditional

```
int main()
{
    typedef std::conditional<true, int, double>::type Type1;
    ...
}
```

und seine Benutuzung im C++11-Standarddokument

```
template <class T> typename conditional<
  !is_nothrow_move_constructible<T>::value &&
   is_copy_constructible<T>::value,
  const T&, T&&>::type move_if_noexcept(T& x) noexcept;
```

um die Signatur der Funktion `move_if_noexcept()` anzugeben.

1.17. Template-Deklarationen zur Erzeugung von Objektdateien mit einer Ansammlung von Template-Instanzen

```
#include <iostream>
#include <cmath>
using namespace std;

template <typename ArithmeticLike1, typename ArithmeticLike2>
double geomMittel2(const ArithmeticLike1& a,
                   const ArithmeticLike2& b)
{
    return sqrt(abs(a*b));
}

template double geomMittel2<short, float>(const short&, const float&);
template double geomMittel2<int, float>(const int&, const float&);
template double geomMittel2<long, float>(const long&, const float&);
template double geomMittel2<float, float>(const float&, const float&);
template double geomMittel2<double, float>(const double&, const float&);
template double geomMittel2<long double, float>(const long double&, const
    float&);
// ...
template double geomMittel2<short, double>(const short&, const double&);
template double geomMittel2<int, double>(const int&, const double&);
template double geomMittel2<long, double>(const long&, const double&);
template double geomMittel2<float, double>(const float&, const double&);
template double geomMittel2<double, double>(const double&, const double&);
template double geomMittel2<long double, double>(const long double&, const
    double&);
// ...
template double geomMittel2<short, long double>(const short&, const long
    double&);
template double geomMittel2<int, long double>(const int&, const long
    double&);
template double geomMittel2<long, long double>(const long&, const long
    double&);
template double geomMittel2<float, long double>(const float&, const long
    double&);
template double geomMittel2<double, long double>(const double&, const long
    double&);
template double geomMittel2<long double, long double>(const long double&,
    const long double&);
```

Besser: Eine Sammlung von Objektdateien, die jeweils (nur) eine Instantiierung enthält, damit die erzeugte Bibliothek nur die benötigten Kompilationseinheiten einbinden läßt.

1.18. Wo ist die Template-Instanz?

Abschnitt 7.5: Where's the template?

g++-Compileroptionen mit Template-Relevanz:

```
-fno-implicit-templates
-fno-implicit-inline-templates
-fno-pretty-templates
-frepo
```

(siehe g++-Manual, Kapitel 3).

1.19. C++11 extern template

C++11 extern template
N1448

1.20. Generic Programming

www.generic-programming.org mit:

- (viele/meherere/...) konkrete Implementierungen -> größtallgemeine Templateversion (Lifting), Requirements
- Muster immer wieder gemeinsam auftretender Requirements: Concepts
- hierarchische Sortierung der Concepts der Anwendungsdomain

Example generic algorithms/concepts:

- generische Algorithmen mit „Requirements on Types“:
sort()
power()
accumulate()
...
fill()
- Concepts:
Associative Container
Container
Assignable
Monoid Operation
...
Default Constructible

Generische Programmierung ist die Programmierung mit Concepts!

1.21. C++14: Generic lambdas, Lambda capture expressions

Generic lambdas in C++14:

```
auto lambda = [](auto x, auto y) {return x + y;};
//...
auto lambda = [value = 1] {return value;};
//...
```

1.22. C++17: Neues bezüglich generischer Konstrukte?

C++17:

- `static_assert` mit zusätzlichem Argument
- `typename` in Template-Templateparameter erlaubt
- Alle nicht-Typ Template-Parameter werden als const ausgewertet
- einheitlicher Zugriff auf alle Container
- „contiguous iterators“ (... mit zusammenhängender Speicherung)
- parallele Versionen der STL-Algorithmen
- `std::optional`, `std::any`
- `std::variant` als typsichere Union
- Comilezeit statisches if: `if constexpr(...)`

1.23. aktueller Workaround: (explizite) Nutzung von Typetraits statt von Concepts

concept

A concept contains a set of requirements

requirement

A requirement is part of a concept that describes the behavior of an abstraction. Requirements tend to be syntactic (e.g., all `Input Iterators` have a dereference operation), semantic (e.g., one can traverse the sequence of values returned from a `Forward Iterator` muliple times), or performance-related (e.g., incrementing an `Input Iterator` occurs in constant amortized time).

(aus: Generic Programming Glossary)

20.9.2 Header <type_traits> synopsis [meta.type.synop]

```
namespace std {
  // 20.9.3, helper class:
  template <class T, T v> struct integral_constant;
  typedef integral_constant<bool, true>  true_type;
  typedef integral_constant<bool, false> false_type;

  // 20.9.4.1, primary type categories:
  template <class T> struct is_void;
  template <class T> struct is_integral;
  template <class T> struct is_floating_point;
```

std::integral_constant

Ein Workaround-Concept als Kombination mehrerer Traiteigenschaften an generische Parameter:

```
template<typename Iter, typename T>
struct is_summable:
  std::integral_constant<bool,
    NNN::is_input_iterator<Iter>::value &&
     std::is_assignable<T,T>::value &&
     boost::has_plus_assign<
                                T,
                                iterator_traits<iter>::value_type,
                                T
                               >::value
  >
{};
```

(Implementierungsidee ähnlich /usr/include/c++/4.7/type_traits)

Leider ist weder in BOOST noch in C++11 eine trait-Metafunktion is_input_iterator <> vordefiniert. In http://calder.sdml.cs.kent.edu/svn/origin/old/sandbox/iterators/include/origin/iterator/traits.hpp war sie noch vorhanden.
Also bleibt nur die Möglichkeit, gemäß 1.16.1 vorzugehen oder eine eigene Metafunktion nach den Ideen von 1.16.1 oder
http://stackoverflow.com/questions/8751460/how-to-restrict-an-iterator-to-being-a-forward-iterator
zu schreiben:

```
template <typename It>
typename std::enable_if<
    is_same<typename std::iterator_traits<It>::iterator_category,
              std::forward_iterator_tag>::value,
    bool>::type ...
```

oder besser (warum?):

```
template <typename It>
typename std::enable_if<std::is_base_of<std::forward_iterator_tag,
                              typename std::iterator_traits<It>::
                                  iterator_category>::value,
                         bool>::type ...
```

(aus: http://stackoverflow.com/questions/8751460/how-to-restrict-an-iterator-to-being-a-forward-iterator)

1.24. Assoziierte Typen, Tags, Tag-Dispatching

associated type

An associated type is a type that is used to describe the requirements of a concept, but is not actually a parameter to the concept. For instance, the reference type returned when dereferencing an Input Iterator is expressed as an associated type. In languages that do not directly support associated types, type parameters can be used instead at some cost to brevity.
(aus: http://www.generic-programming.org/about/glossary.php)

```
<class Iterator> struct iterator_traits {
  typedef typename Iterator::difference_type difference_type;
  typedef typename Iterator::value_type value_type;
  typedef typename Iterator::pointer pointer;
  typedef typename Iterator::reference reference;
  typedef typename Iterator::iterator_category iterator_category;
}
```

Associated Types

Beispiel eines eigenen assoziierten Typs:

```
template <typename T1, typename T2>
struct promote_trait{
    typedef T1 T_promote;
};
template<> struct promote_trait<char, unsigned char> {
public:
        typedef int T_promote;
};
template<> struct promote_trait<short int, long> {
public:
        typedef long T_promote;
};
// ...
```

Siehe: promote_trait

value_type, difference_type, ... in iterator_traits, ...:

```
namespace std {
template<class Iterator> struct iterator_traits {
typedef typename Iterator::difference_type difference_type;
typedef typename Iterator::value_type value_type;
typedef typename Iterator::pointer pointer;
typedef typename Iterator::reference reference;
typedef typename Iterator::iterator_category iterator_category;
};
\\ ...
template<class T> struct iterator_traits<T*> {
typedef ptrdiff_t difference_type;
typedef T value_type;
typedef T* pointer;
typedef T& reference;
typedef random_access_iterator_tag iterator_category;
};
```

```
// ...
}
```

Fallweise je nach Iteratortyp unterschiedlicher Code:
Neben der SFINE-Lösung vom Ende des vorherigen Abschnitts:

```
struct input_iterator_tag { };
struct output_iterator_tag { };
struct forward_iterator_tag : public input_iterator_tag { };
struct bidirectional_iterator_tag : public forward_iterator_tag { };
struct random_access_iterator_tag : public bidirectional_iterator_tag { };
```

Eine Hierarchie von Tags und Tag-Dispatching:

```
#include <iostream>
#include <vector>
#include <list>
#include <iterator>

template< class BDIter >
void alg(BDIter, BDIter, std::bidirectional_iterator_tag)
{
    std::cout << "alg() called for bidirectional iterator\n";
}

template <class RAIter>
void alg(RAIter, RAIter, std::random_access_iterator_tag)
{
    std::cout << "alg() called for random-access iterator\n";
}

template< class Iter >
void alg(Iter first, Iter last)
{
    alg(first, last,
        typename std::iterator_traits<Iter>::iterator_category());
}

int main()
{
    std::vector<int> v;
    alg(v.begin(), v.end());

    std::list<int> l;
    alg(l.begin(), l.end());

//    std::istreambuf_iterator<char> i1(std::cin), i2;
//    alg(i1, i2); // compile error: no matching function for call
}
```

1.25. Generic Programming Techniques of the BOOST Libraries

Survey of some of the generic programming techniques used in the boost libraries

Anatomy of a Concept
Traits
C++ type_traits
BOOST type_traits
Tag dispatching
Adaptors
Type generators (type factory)
Metaprogramming
Object generators (object factory)
Policy classes
Policy-based design

Weitere C++ Template-Technologien:
Curiously Recurring Template Pattern
Restricted Template Expansion
Parameterized Base Class

1.26. POD-Typen und trait-fallweises Überladen

POD Types
C++11: POD = “trivial type“ or “standard-layout“

Move-Semantik für pod-Daten/Copy-Semantik für non-pod-Daten:

```
template<typename T>
void copy(T const* source,T* dest,unsigned count)
{
    static_assert(std::is_pod<T>::value,"T must be a POD");
    memcpy(dest,source,count*sizeof(T));
}

// ... oder besser pod/non-pod sensitives copy():

template<typename T>
typename std::enable_if<std::is_pod<T>::value,void>::type
copy(T const* source,T* dest,unsigned count)
{
    memcpy(dest,source,count*sizeof(T));
}

template<typename T>
typename std::enable_if<!std::is_pod<T>::value,void>::type
copy(T const* source,T* dest,unsigned count)
{
    for(unsigned i=0;i<count;++i)
    {
        *dest++=*source++;
    }
}
```

aus: pod/non-pod overloading in: Checking Concepts without Concepts in C++

1.27. Eigene Klassen-Tags und Tag-Dispatching oder fallweise Spezialisierung

Alternativ Tag-Dispatching:

```
template <bool> struct podness {};
typedef podness<true> pod_tag;
typedef podness<false> non_pod_tag;

template <typename T> void f2(T, pod_tag) { /* POD */ }
template <typename T> void f2(T, non_pod_tag) { /* non-POD */ }

template <typename T>
void f(T x)
{
    // Dispatch to f2 based on tag.
    f2(x, podness<std::is_pod<T>::value>());
}
```

oder fallweise spezialisierte Klassen:

```
template <typename T, bool> struct f2;

template <typename T>
struct f2<T, true> { static void f(T) { /* POD */ } };

template <typename T>
struct f2<T, false> { static void f(T) { /* non-POD */ } };

template <typename T>
void f(T x)
{
    // Select the correct partially specialised type.
    f2<T, std::is_pod<T>::value>::f(x);
}
```

(aus: Tag dispatch versus static methods on partially specialised classes)

1.28. Iteratoren

Creating my own Iterators
How to implement an STL-style iterator and avoid common pitfalls
iterator library
Iterator categories
Custom Iterator in C++
How to realize a custom implementation of a std-like iterator?
Extensible Templates: Via Inheritance or Traits?

N4284: Contiguous Iterators
A Refinement of Random Access Iterators

1.29. Programmieren mit Konzepten

Minimiere die Requirements an die Input-Parameter generischer Komponenten, um deren Wiederverwendbarkeit zu steigern. Damit erreicht man die größtmögliche Allgemeinheit!

Konzepte (Kombinationen von Requirements) sind ein Sprachmechanismus, der es gestattet, dem Compiler (oder zur Zeit wenigstens dem Benutzer einer generischen Bibliothek in Kommentarform) verbindlich mitzuteilen, welche Typeigenschaften ein generischer Algorithmus (ein Template-Konstrukt) benutzen darf beziehungsweise welche Eigenschaften ein Typ besitzen muß, damit er als aktueller generischer Parameter für eine Template-Instanziierung benutzt werden darf.

Table 1. Concepts, constraints, and axioms

Concepts		*Constraints*	
Regularity	*Iterators*	*Operators*	*Language*
Comparable	**Iterator**	**Equal**	**Same**
Ordered	**Forward_iterator**	**Less**	**Common**
Copyable	**Bidirectional_iterator**	**Logical_and**	**Derived**
Movable	**Random_access_iterator**	**Logical_or**	**Convertible**
Regular		**Logical_not**	**Signed_int**
		Callable	
Functional	*Types*	*Initialization*	*Other*
Function	**Boolean**	**Destructible**	**Procedure**
Operation		**Constructible**	**Input_iterator**
Predicate		**Assignable**	**Output_iterator**
Relation			
Axioms			
Equivalence_relation			
Strict_weak_order			
Strict_total_order			
Boolean_algebra			

```
concept Ordered<Regular T> {
    requires constraint Less<T>;
    requires axiom Strict_total_order<less<T>, T>;
    requires axiom Greater<T>;
    requires axiom Less_equal<T>;
    requires axiom Greater_equal<T>;
}
```

We factor out the axioms just to show that we can, and because they are examples of axioms that might find multiple uses:

```
template<typename T>
axiom Greater(T x, T y) {
    (x>y) == (y<x);
}
template<typename T>
axiom Less_equal(T x, T y) {
    (x<=y) == !(y<x);
}
template<typename T>
axiom Greater_equal(T x, T y) {
    (x>=y) == !(x<y);
}
```

2. Metaprogrammierung

Metaprogramming is the writing of computer programs that write or manipulate other programs (or themselves) as their data, or that do part of the work at compile time that would otherwise be done at runtime. In some cases, this allows programmers to minimize the number of lines of code to express a solution (hence reducing development time), or it gives programs greater flexibility to efficiently handle new situations without recompilation. ...
aus: Metaprogramming

```
promote_trait <.,.>::T_promote

numeric_limits <.>::max()
numeric_limits <.>::is_integer

iterator_traits <.>::value_type
```

2.1. Metafunktionen

Metafunktionen (Metaprogrammierung) sind uns schon an diversen Stellen begegnet:
`promote_trait<T1,T2>::T_promote` in

```
template <typename T1, typename T2>
   typename promote_trait<T1,T2>::T_promote my_function(T1 x, T2 y)
//          ------------------------------
{
\\...
}
```

stellt den mit `T1, T2` assoziierten Typ `T_promote` bereit (vergleiche Abschnitt 1.16.4).

```
  cout << "Minimum value for int: " << numeric_limits<int>::min() << endl;
//                                     -------------------------
  cout << "Maximum value for int: " << numeric_limits<int>::max() << endl;
//                                     -------------------------
  cout << "int is signed: " << numeric_limits<int>::is_signed << endl;
//                             -------------------------------
  cout << "Non-sign bits in int: " << numeric_limits<int>::digits << endl;
//                                    ----------------------------
  cout << "int has infinity: " << numeric_limits<int>::has_infinity << endl;
//                                ----------------------------------
```

druckt Eigenschaften der numerischen Typen mittels Typfunktionen aus. Siehe

```
static constexpr T min() noexcept;
static constexpr T max() noexcept;
static constexpr bool is_signed;
static constexpr int digits;
static constexpr bool has_infinity;
```

im Standard http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2011/n3242.pdf beziehungsweise in http://open-std.org/jtc1/sc22/wg21/docs/papers/2013/n3797.pdf.

```
template <class InputIterator>
iterator_traits<InputIterator>::value_type
last_value(InputIterator first, InputIterator last) {
```

```
//...
}
```

greift auf den `InputIterator` assoziierten `value_type` zu.

„A metafunction is a construct to map some types or constants to other entities like types, constants, functions, or objects at compile time. The name metafunction comes from fact that they can be regarded as part of a meta-programming language that is evaluated during compilation.“ (aus http://trac.seqan.de/wiki/Tutorial/Metafunctions)

Run time, compile time vs. runtime, mit dem GCC zur ausführbaren Datei (Binary)

Implementiert wurden sie im geschichtlichen Verlauf durch **enum**, **static const**, integral_constant<> beziehungsweise constexpr-Konstruktionen:

```
                                                    // vor C++03
#include <iostream>

template<int i>
class fact {
  public:
    enum { result = i * fact<i-1>::result };
};

template<>class fact<1> {
  public:
    enum { result = 1 };
};

int main(){

   std::cout << fact<5>::result << std::endl;
}

////////////////////////////////////////////////

#include <iostream>                     // C++03

template<int i>
class fact {
  public:
    static const long long result = i * fact<i-1>::result;
};

template<>class fact<1> {
  public:
    static const long long result = 1;
};

int main(){

   std::cout << fact<5>::result << std::endl;
};
```

```
////////////////////////////////////////////////

#include <iostream>                        // ab C++11
#include <type_traits>

template <unsigned n>
struct fact : std::integral_constant<int,n * fact<n-1>::value> {};

template <>
struct fact<0> : std::integral_constant<int,1> {};

int main() {
  std::cout << fact<5>::value;  // constexpr (no calculations on runtime)
  return 0;
}

////////////////////////////////////////////////

#include <iostream>                         // oder

constexpr long long fact(int value) {
  return (value==0) ? 1 : value * fact(value-1);
};



int main(){

    std::cout <<  fact(5) << std::endl;
    return 0;
}
```

2.2. Metafunktionen in /usr/include/c++/4.7/type_traits und Feldlängen

Metafunktion `integral_constant` in `type_traits`:

```
  /// integral_constant
  template<typename _Tp, _Tp __v>
    struct integral_constant
    {
      static constexpr _Tp                  value = __v;
      typedef _Tp                           value_type;
      typedef integral_constant<_Tp, __v>   type;
      constexpr operator value_type() { return value; }
    };
```

```
  /// The type used as a compile-time boolean with true value.
  typedef integral_constant<bool, true>     true_type;

  /// The type used as a compile-time boolean with false value.
  typedef integral_constant<bool, false>    false_type;

  template<typename _Tp, _Tp __v>
    constexpr _Tp integral_constant<_Tp, __v>::value;
```

(aus: http://publib.boulder.ibm.com/infocenter/comphelp/v9v111/index.jsp?topic=/com.ibm.xlcpp9.aix.doc/standlib/header_type_traits.htm)

```
  /// is_array
  template<typename>
    struct is_array
    : public false_type { };

  template<typename _Tp, std::size_t _Size>
    struct is_array<_Tp[_Size]>
    : public true_type { };

  template<typename _Tp>
    struct is_array<_Tp[]>
    : public true_type { };

////////////////////////////////////////////////

  /// is_unsigned
  template<typename _Tp>
    struct is_unsigned
    : public __and_<is_arithmetic<_Tp>, __not_<is_signed<_Tp>>>::type
    { };

////////////////////////////////////////////////

  /// Define a member typedef @c type only if a boolean constant is true.
  template<bool, typename _Tp = void>
    struct enable_if
    { };

  // Partial specialization for true.
  template<typename _Tp>
    struct enable_if<true, _Tp>
    { typedef _Tp type; };

////////////////////////////////////////////////
```

Benutzung von Nontype-Templateparametern für die Länge von Containern:

```
#include <iostream>
#include <numeric>

template <typename Type, size_t n>
Type sum(const Type (&tp)[n])
{
    return std::accumulate(tp, tp+n, Type());
}

int main()
{
    int x[10];
    for(int l = 0; l < 10; l++)
        x[l] = l;

    std::cout << sum(x) << std::endl;

    return(0);
}
```

Nontype template parameter
What does template <**unsigned int** N> mean?

2.3. Factorial, Combinations, IF, id, add und die Rekursion statt der Schleife

Template-Metaprogrammierung:

```
template <int N>
struct Factorial
{
    enum { value = N * Factorial<N - 1>::value };
};

template <>
struct Factorial<0>
{
    enum { value = 1 };
};

// Factorial<4>::value == 24
// Factorial<0>::value == 1
void foo()
{
    int x = Factorial<4>::value; // == 24
    int y = Factorial<0>::value; // == 1
}

//                  n!
// C(k,n) = ----------
//              k! (n-k)!

template <int k, int n>
struct Combinations
{
    enum { RET = Factorial<n>::RET/(Factorial<k>::RET*Factorial<n-k>::RET)
          };
};

cout << Combinations<2,4>::RET << endl;
```

Templates mit zwei non-type int-Parametern statt eines nicht erlaubten non-type float-Parameters: C++ Template Metaprogramming.

Bedingte Typauswahl:

```
// IF
template <bool condition, class Then, class Else>
struct IF
{
    typedef Then RET;
};

template <class Then, class Else>
struct IF<false, Then, Else>
{
    typedef Else RET;
};

// if sizeof(int) < sizeof(long) then use long else use int
IF< sizeof(int)<sizeof(long), long, int >::RET  i;
```

C++-Metaprogrammierung:

```
template <unsigned int x>
struct id
{
enum { value = x };
};

template <unsigned int x, unsigned int y>
struct add
{
enum { value = x + y };
};

//...

template <int x>
struct id_static
{
static const int value = x;
};

template <int x>
struct id_static_constexpr
{
static constexpr int value = x;
};
```

2.4. Rechnende Compiler:

Erwin Unruh: Die Entdeckung des rechnenden Compilers:

```
// Erwin Unruh, untitled program,
// ANSI X3J16-94-0075/ISO WG21-462, 1994.

template <int i>
struct D
{
    D(void *);
    operator int();
};

template <int p, int i>
struct is_prime
{
    enum { prim = (p%i) && is_prime<(i>2?p:0), i>::prim };
};

template <int i>
struct Prime_print
{
    Prime_print<i-1>    a;
    enum { prim = is_prime<i,i-1>::prim };
    void f() { D<i> d = prim; }
};

struct is_prime<0,0> { enum { prim = 1 }; };
struct is_prime<0,1> { enum { prim = 1 }; };
struct Prime_print<2>
{
    enum { prim = 1 };
    void f() { D<2> d = prim; }
};

void foo()
{
    Prime_print<10> a;
}

// output:
// unruh.cpp 30: conversion from enum to D<2> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<3> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<5> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<7> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<11> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<13> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<17> requested in Prime_print
// unruh.cpp 30: conversion from enum to D<19> requested in Prime_print
```

constexpr is_prime_recursive

2.5. Typfunktionen: längerer Datentyp, IfThenElse-Werte

Typfunktionen liefern anstelle eines Datenwertes (einer Konstanten) einen oder mehrere Datentypen *oder* sind von Datentypen abhängig:

```
template <int bits>
struct number_type
{
  typedef int type;
};
template <>
struct number_type <16>
{
  typedef short type;
};
template <>
struct number_type <8>
{
  typedef char type;
};
template <typename arg>
struct bitsize
{
  enum { value = sizeof(arg) * 8 };
};
template <typename arg>
struct bigger_type
{
  typedef typename number_type<bitsize<arg>::value * 2 >::type type;
};
```

Bedingte Werte:

```
template <bool cond , int true_part , int false_part >
struct IfThenElse ;
template <int true_part , int false_part >
struct IfThenElse <true , true_part , false_part >
{
enum { value = true_part };
};
template <int true_part , int false_part >
struct IfThenElse <false , true_part , false_part >
{
enum { value = false_part };
};
```

2.6. Template Nontype Parameter

Abschnitt 14.3.2: Template non-type arguments
Abschnitt 5.19: Constant expressions
Non-type template arguments
What are the requirements for C++ template parameters?

C++: Why can't I use float value as a template parameter?
template+floating point non type
How can I use a floating-point value as a non-type template parameter?
Why are floating point types invalid template parameter types for template functions?
c++ template parameter is ambiguous

Workaround:
Floating point arithmetic in C++ templates.

Beachte dabei auch:
ldexp() und frexp().
ieee754.h und der Zugriff auf Vorzeichen, Exponent und Mantisse:

```
#include <iostream>
#include <cmath>
#include <ieee754.h>

int main()
{
  float num = 4.0 * atan(1.0);  // PI

  ieee754_float ft;
  ft.f = num;

  std::cout << ft.ieee.negative << std::endl;
  std::cout << ft.ieee.exponent << std::endl;
  std::cout << ft.ieee.mantissa << std::endl;

  // prints:
  // 0
  // 128
  // 4788187

  ieee754_float ft2;
  ft2.ieee.negative = ft.ieee.negative;
  ft2.ieee.exponent = ft.ieee.exponent;
  ft2.ieee.mantissa = ft.ieee.mantissa;

  std::cout << ft2.f << std::endl;

  // prints:
  // 3.14159

  return 0;
}
```

2.7. Compilezeit-Fehlermeldungen in constexpr-Metafunktionen

Aus Andrzej's C++ blog:

```
constexpr int factorial( int i )
{
   return (i > 1) ? i * factorial(i - 1)
                  : 1;
}
```

oder besser:

```
constexpr int safe_factorial( int i )
{
   return (i < 0) ?                     // error condition
                    throw exception()   // error reporting
                  : factorial(i);       // real computation
}
```

Mittels einer mit selbstsprechendem Bezeichnernamen gewählten Hilfsmetafunktion:

```
constexpr int requires_nonnegative( int i )
{
  return (i < 0) ? throw exception()
                 : i;
}
```

wird die Compiler-Fehlermeldung selbsidentifizierend:

```
constexpr int safe_factorial( int i )
{
   return requires_nonnegative(i),
          factorial(i);
}
```

Eine Klasse mit Compiletime Kontruktor:

```
class Date
{
    unsigned d;
    Month m;
    unsigned y;

    public:
    constexpr Date( unsigned d, Month m, unsigned y );
    // other stuff ...
};

constexpr Date::Date( unsigned d, Month m, unsigned y )
: d( requires_goodDay(d, m, y) )
, m(m)
, y( requires_positive(y) )
{} // empty body
```

```
constexpr unsigned requires_goodDay( unsigned d, Month m, unsigned y )
{
    return (d == 0 || d > 31) ?       throw BadDayName(d)          :
           (is30day(m) && d == 31) ? throw BadDayOfMonth(d, m)     :
           (m == Feb && d >= 30) ?   throw BadDayOfMonth(d, m)     :
           (!isLeap(y) && m == Feb && d == 29) ? throw Bad29Feb(y) :
           d; // real return value
}
```

Vergleiche:
BOOST::optional
constexpr-unions
utility class to represent optional objects (Revision 2)
Parsing strings at compile-time — Part I
Parsing strings at compile-time — Part II
User-defined literals — Part I
User-defined literals — Part II
User-defined literals — Part III

2.8. C++11 Metaprogramming Examples

```
// Here are a few tricks I've used with the trunk versions of clang and libc++
// with C++11 compilation turned on. Some might be obvious, some not, but at
// least they are some kind of improvement over their C++03 counterparts.
//
// Public domain.
// ==========================================================================
// 1) Using variadic class templates recursively, like in the definitions for
// "add<T...>" here:

#include <type_traits>

// A few convenience aliases first
template <typename T, T N> using ic = std::integral_constant<T, N>;
template <int N>           using int_ = std::integral_constant<int, N>;

// Sum any number of integral constants:
template <typename... Args> struct add;
template <>
struct add<>
        : ic<int, 0> {};

template <typename A>
struct add<A>
        : ic<decltype(+A::value), A::value> {};

template <typename A, typename B, typename... More>
struct add<A, B, More...>
        : add<ic<decltype(A::value + B::value),
                        A::value + B::value>, More...> {};

// --- example ---------------------------------------------------------------

add<>::value; // 0
add<int_<1>>::value; // 1
add<int_<1>, int_<2>>::value; // 3
add<int_<1>, int_<2>, int_<3>>::value; // 6
add<int_<1>, int_<2>, int_<3>, int_<4>>::value; // 10
// etc.

// ==========================================================================
// 2a) With decltype, the "sizeof(yes_type)" trick is no longer needed for
// implementing traits. This one tests whether there is a type T::type
// defined:

using std::true_type;
using std::false_type;

namespace detail {
          template <typename T, typename Type=typename T::type>
          struct has_type_helper;

          template <typename T> true_type has_type_test(has_type_helper<T> *);
          template <typename T> false_type has_type_test(...);

}

template <typename T>
         struct has_type : decltype(detail::has_type_test<T>(nullptr)) {};

// --- example ---------------------------------------------------------------

has_type<int>::value;                           // false
has_type<std::is_integral<int>>::value;         // true, said type is "bool"
has_type<std::integral_constant<int,1>>::value; // true, said type is "int"
```

```
// ---------------------------------------------------------------------------
// 2b) This trait tests whether T is an integral constant:

namespace detail {

        template <typename T, decltype(T::value)>
                struct integral_constant_helper;

        template <typename T> true_type integral_constant_test(
                              integral_constant_helper<T,T::value> *);

        template <typename T> false_type integral_constant_test(...);
}

template <typename T>
        struct is_integral_constant
                : decltype(detail::integral_constant_test<T>(nullptr)) {};

// --- example ---------------------------------------------------------------
is_integral_constant<int>::value;                          // false
is_integral_constant<std::is_integral<int>>::value;        // true
is_integral_constant<std::integral_constant<int,1>>::value; // true

// ===========================================================================

// 3) Selection of the first matching type from a list of cases (or "pattern
// matching", if you will):

   template <typename... When> struct match;
   template <> struct match<> { static constexpr bool value = false; };
   template <typename When, typename... More> struct match<When, More...>
           : std::conditional<When::value, When, match<More...>>::type {};

// 'match' is meant to be used together with 'when', 'otherwise' and
// friends:

        template <bool Cond, typename Then=void> struct when_c;
        template <typename Then> struct when_c<true, Then> {
                typedef Then type;
                static constexpr bool value = true;
        };

        template <typename Then> struct when_c<false, Then> {
                static constexpr bool value = false;
        };

        template <bool Cond, typename Then=void>
                struct when_not_c : when_c<!Cond, Then> {};

        template <typename Cond, typename Then=void>
                struct when : when_c<Cond::value, Then> {};

        template <typename Cond, typename Then=void>
                struct when_not : when_not_c<Cond::value, Then> {};

        template <typename Then> struct otherwise {
                typedef Then type;
                static constexpr bool value = true;
        };

// --- example ---------------------------------------------------------------

struct fizz {};
struct buzz {};
struct fizzbuzz {};
```

```
template <int N>
    struct game : match<
        when_c<N % 3 == 0 && N & 5 == 0, fizzbuzz>,
        when_c<N % 3 == 0, fizz>,
        when_c<N % 5 == 0, buzz>,
        otherwise< int_c<N>>
    > {};

game<1>::type;  // int_<1>
game<2>::type;  // int_<2>
game<3>::type;  // fizz
game<4>::type;  // int_<4>
game<5>::type;  // buzz
game<6>::type;  // fizz
game<7>::type;  // int_<7>
game<8>::type;  // int_<8>
game<9>::type;  // fizz
game<10>::type; // buzz
game<11>::type; // int_<11>
game<12>::type; // fizz
game<13>::type; // int_<13>
game<14>::type; // int_<14>
game<15>::type; // fizzbuzz
game<16>::type; // int_<16>

// ============================================================================
// 4a) Variadic template template parameters. For instance,
// boost::mpl::quoteN<...> can be reimplemented with just:

   template <template <typename...> class F>
       struct quote {
           template <typename... Args> struct apply : F<Args...> {};
       };

// ----------------------------------------------------------------------------
// 4b) Here's another use for variadic template template parameters. Of course,
// the standard library offers std::tuple_size<T> for getting the number of
// elements in a tuple. But that metafunction cannot be used for any other
// tuple-like class. Suppose we defined boost::mpl::vector like:

   template <typename... T>
           struct vector {};

// By using a variadic template template, we can define a metafunction which
// works equally for both std::tuple<T...> as well as vector<T...>:

   template <typename T>
           struct size {}; // (no size defined by default)

   template <template <typename...> class C, typename... T>
           struct size<C<T...>> : ic<std::size_t, sizeof...(T)> {};

   template <typename T> struct size<T &> : size<T> {};
   template <typename T> struct size<T &&> : size<T> {};
   template <typename T> struct size<T const> : size<T> {};
   template <typename T> struct size<T volatile> : size<T> {};
   template <typename T> struct size<T const volatile> : size<T> {};

// --- example ----------------------------------------------------------------

   size<tuple<int, int> &>::value;      // 2
   size<vector<int, int, int>>::value;  // 3
   size<vector<> const &>::value;       // 0

// ============================================================================
// 5) Using nested variadic templates to get many template parameter packs to
```

```
// play with:

namespace detail {
          template <typename A> struct con;
          template <typename... T> struct con<vector<T...>> {
                   template <typename B> struct cat;
                   template <typename... U> struct cat<vector<U...>> {
                            typedef vector<T..., U...> type;
                   };
          };
}

template <typename A, typename B>
         struct concat : detail::con<A>::template cat<B> {};

// --- example ---------------------------------------------------------------

struct a; struct b; struct c; struct d; struct e;
concat<vector<a, b>, vector<c, d, e>>::type; // vector<a, b, c, d, e>

// ============================================================================
// 6) Defining function result and result type at once.

#define RETURNS(...) decltype((__VA_ARGS__)) { return (__VA_ARGS__); }

// --- example ---------------------------------------------------------------

template <typename A, typename B>
auto plus(A const & a, B const & b) -> RETURNS(a + b)

// It can't be used with recursive definitions like here, though:

struct mul_ {
       int operator()() const { return 1; }

       template <typename A>
       A operator()(A const & a) const { return a; }

       // template <typename A, typename B, typename... C>
       // auto operator()(A const & a, B const & b, C const &... c) const ->
       // RETURNS(mul_()(a * b, c...))

       // --> Error: invalid use of incomplete type mul_

       // std::declval helps, but duplicates the multiplication part:
       template <typename A, typename B, typename... C>
       auto operator()(A const & a, B const & b, C const &... c) const ->
       decltype(std::declval<mul_>()(a * b, c...)) {
            return mul_()(a * b, c...);
       }
};

constexpr mul_ mul = {}; // global function object

// --- example ---------------------------------------------------------------

mul();                // 1
mul(10);              // 10
mul(10, -20, 30.0);   // -6000.0

// ============================================================================
// 7) Counted template recursion. The function "apply_tuple(f, t)" calls the
// function (function object) "f" with the elements of the tuple "t" as
// arguments. (To simplify things a bit, I omitted the perfect forwarding
// support in this example.)
//
```

```cpp
// The count is tracked with a total number of iterations N, and the running
// index I. R is the precalculated result type.

namespace detail {
   template <typename R, std::size_t N, std::size_t I=0>
          struct apply_tuple {
                 template <typename F, typename T, typename... Args>
                 R operator()(F f, T const & t, Args const &... args) const {
                   typedef apply_tuple<R, N, I + 1> next;
                   return next()(f, t, args..., std::get<I>(t));
                 }

          };

  template <typename R, std::size_t N> struct apply_tuple<R, N, N> {
          template <typename F, typename T, typename... Args>
          R operator()(F f, T const &, Args const &... args) const {
            return f(args...);
          }
  };
}

template <typename F, typename... T>
decltype(std::declval<F>()(std::declval<T const &>()...))
apply_tuple(F f, std::tuple<T...> const & t) {
             typedef decltype(std::declval<F>()(std::declval<T const &>()...))
                     result;
             return detail::apply_tuple<result, sizeof...(T)>()(f, t);

}

// --- example -----------------------------------------------------------
int f(int a, int b) { return a + b; }
apply_tuple(f, std::make_tuple(10, 20)); // 30

auto t = std::make_tuple(10, -20, 30.0);
apply_tuple(mul, t); // -6000.0
```

(aus C++11 metaprogramming)

2.9. Fortgeschrittene Metaprogrammierung

2.9.1. Domain specific language extensions: C++11 Compile-time rational arithmetic

Bruch-Arithmetik mit Zähler/Nenner aus `intmax_t`.

```
namespace std {
// 20.10.3, class template ratio
template <intmax_t N, intmax_t D = 1> class ratio;
// 20.10.4, ratio arithmetic
template <class R1, class R2> using ratio_add = see below;
template <class R1, class R2> using ratio_subtract = see below;
template <class R1, class R2> using ratio_multiply = see below;
template <class R1, class R2> using ratio_divide = see below;
// 20.10.5, ratio comparison
template <class R1, class R2> struct ratio_equal;
template <class R1, class R2> struct ratio_not_equal;
template <class R1, class R2> struct ratio_less;
template <class R1, class R2> struct ratio_less_equal;
template <class R1, class R2> struct ratio_greater;
template <class R1, class R2> struct ratio_greater_equal;
// 20.10.6, convenience SI typedefs
typedef ratio<1, 1000000000000000000000000> yocto; // see below
typedef ratio<1, 1000000000000000000000> zepto; // see below
typedef ratio<1, 1000000000000000000> atto;
typedef ratio<1, 1000000000000000> femto;
typedef ratio<1, 1000000000000> pico;
typedef ratio<1, 1000000000> nano;
typedef ratio<1, 1000000> micro;
typedef ratio<1, 1000> milli;
typedef ratio<1, 100> centi;
typedef ratio<1, 10> deci;
typedef ratio< 10, 1> deca;
typedef ratio< 100, 1> hecto;
typedef ratio< 1000, 1> kilo;
typedef ratio< 1000000, 1> mega;
typedef ratio< 1000000000, 1> giga;
typedef ratio< 1000000000000, 1> tera;
typedef ratio< 1000000000000000, 1> peta;
typedef ratio< 1000000000000000000, 1> exa;
typedef ratio< 1000000000000000000000, 1> zetta; // see below
typedef ratio<1000000000000000000000000, 1> yotta; // see below
}
```

```
namespace std {
template <intmax_t N, intmax_t D = 1>
class ratio {
public:
typedef ratio<num, den> type;
static constexpr intmax_t num;
static constexpr intmax_t den;
};
}
```

```
static_assert(ratio_add<ratio<1,3>, ratio<1,6>>::num == 1, "1/3+1/6
    == 1/2");
static_assert(ratio_add<ratio<1,3>, ratio<1,6>>::den == 2, "1/3+1/6
    == 1/2");
static_assert(ratio_multiply<ratio<1,3>, ratio<3,2>>::num == 1, "
    1/3*3/2 == 1/2");
static_assert(ratio_multiply<ratio<1,3>, ratio<3,2>>::den == 2, "
    1/3*3/2 == 1/2");
```

2.9.2. Unrolled Loops: Durch Rekursion wegoptimierte Schleifen

Schleifen ohne Verwaltungsoverhead:
Tailrekursion statt Iteration
Ausgangspunkt (laufzeit-iterativ):

```
template <typename T>
inline T dot_product (T* a, T* b, int dim)
{
  T result = T();
  for (int i = 0; i < dim; i++)
  {
    result += a[i] * b[i];
  }
  return result;
}
```

Optimiert (Compilezeit-tailrekursive Metafunktion)

```
template <int N, typename T>
struct dotproduct_s
{
  static T result (T* a, T* b)
  {
    return (*a)*(*b) + dotproduct_s<N-1,T>::result(a+1, b+1);
  };
};
template <typename T>
struct dotproduct_s <1, T>
{
  static T result (T* a, T* b)
  {
    return (*a)*(*b);
  };
};
template <int N, typename T>
inline T dotproduct(T* a, T* b)
{
  return dotproduct_s<N, T>::result(a, b);
}
int main ()
{
int a [3] = {1, 2, 3};
int b [3] = {4, 5, 6};
std :: cout << dot_product(a, b, 3) << std :: endl ;
std :: cout << dotproduct<3>(a, b) << std :: endl ;
return 0;
}
```

Codedissassembly:

```
Listing: Mit Schleife (dot_product)
push ebp
mov ebp , esp
push edi
push esi
```

```
push ebx
mov edi , DWORD PTR [ ebp +8]
mov esi , DWORD PTR [ ebp +12]
mov ebx , DWORD PTR [ ebp +16]
mov ecx , 0
mov edx , 0
cmp ecx , ebx
jge L32
L30 :
mov eax , DWORD PTR [ edi + edx *4]
imul eax , DWORD PTR [esi +edx *4]
add ecx , eax
inc edx
cmp edx , ebx
jl L30
L32 :
mov eax , ecx
pop ebx
pop esi
pop edi
pop ebp
ret
```

```
Listing: Ohne Schleife (dotproduct_s)
push ebp
mov ebp , esp
push ebx
mov edx , DWORD PTR [ ebp +8]
mov ebx , DWORD PTR [ ebp +12]
mov eax , DWORD PTR [ edx ]
imul eax , DWORD PTR [ebx ]
mov ecx , DWORD PTR [ edx +4]
imul ecx , DWORD PTR [ebx +4]
mov edx , DWORD PTR [ edx +8]
imul edx , DWORD PTR [ebx +8]
add ecx , edx
add eax , ecx
pop ebx
pop ebp
ret
```

Acht Anweisungen statt 18 Anweisungen.
(aus: http://www.cs.hs-rm.de/ linn/fachsem0809/cppmeta/pdf/otte_cppmeta.pdf Metaprogrammierung Seite 45ff.)

Endrekursion
Tailrekursion

A generic loop unroller based on template meta-programming
C++11 anonyme Funktion

2.9.3. Expression templates

C++ Expression templates:
Expression templates are a category of C++ template meta programming which delays evaluation of subexpressions until the full expression is known, so that optimizations (especially the elimination of temporaries) can be applied. (lazy evaluation)
Zum Beispiel:
statt `x = a + b + c` der Aufruf von `Expression<Expression<Array,plus,Array>,plus,Array>` mit

```
struct plus {
  static int apply(int a, int b) {
    return (a + b); }
};

template < typename L, typename OpTag, typename R >
struct Expression {
  Expression(L const& l, R const& r) : l(l), r(r) {}
    int operator[](unsigned index) const {
      return OpTag::apply(l[index],r[index]);
    }
    L const& l;
    R const& r;
};

template< typename L, typename R >
Expression<L,plus,R> operator+(L const& l, R const& r) {
  return Expression<L,plus,R>(l,r);
}
...
// verzoegerte Ausdrucksauswertung (lazy evaluation)
// --- sofort wird nur der Parsbaum aufgebaut ---
// bis zur Aktivierung von operator=
template<typename Expr> {
Array& Array::operator=(Expr const& x) {
  for(unsigned i = 0; i < this->size(); ++i) {
    (*this)[i] = x[i];
  return (*this);
}
```

(aus: http://pqkeylength.com/lehre/SS05/seminar/C++/Hoffmann_Meta.pdf Metaprogrammierung)

Matrixdimension	Zeit (nicht opt.)[s]	Zeit (opt.)[s]
100x100	1.776	1.059
200x200	7.204	4.237
300x300	17.091	9.796
400x400	30.305	18.087
500x500	46.842	28.154
600x600	85.316	54.125
700x700	114.167	73.604

Dr.Dobbs: Expression Templates
A. Langer: Expression Templates
Blitz++

Lazy evaluation
Expression templates and C++11

2.10. Vor- und Nachteile der Metaprogrammierung

Vor- und Nachteile der Template-Metaprogrammierung:

- **Längere Übersetzungszeit und kürzere Ausführungszeit:** Da der gesamte Template-Quelltext während der Übersetzung verarbeitet, ausgewertet und eingesetzt wird, dauert die Übersetzung insgesamt länger, während der ausführbare Code dadurch an Effizienz gewinnen kann. Obwohl dieser Zusatzaufwand im Allgemeinen sehr gering ausfällt, kann er auf große Projekte oder Projekte, in denen intensiv Templates eingesetzt werden, großen Einfluss auf die Dauer der Übersetzung besitzen.
- **Kürzerer Quelltext:** Templatemetaprogrammierung erlaubt es dem Programmierer, sich auf die Architektur des Programms zu konzentrieren und dem Compiler die Erzeugung von jeglichen Implementierungen, die vom aufrufenden Quelltext benötigt werden, zu überlassen. Daher kann Templatemetaprogrammierung zu kürzerem Quelltext und erhöhter Wartbarkeit führen.
- **Schlechtere Lesbarkeit:** Verglichen mit konventioneller C++-Programmierung wirken Syntax und Schreibweisen der Templatemetaprogrammierung ungewohnt. Fortgeschrittene oder sogar die meiste nicht-triviale Templatemetaprogrammierung kann daher schwer zu verstehen sein. Dadurch können Metaprogramme von Programmierern, die in Templatemetaprogrammierung unerfahren sind, schwer zu pflegen sein. Letzteres hängt allerdings auch davon ab, wie die Templatemetaprogrammierung im speziellen Fall umgesetzt wurde.
- **Geringere Portierbarkeit:** Die Portierbarkeit von Quelltext, der von Template-Metaprogrammierung starken Gebrauch macht, kann auf Grund von Unterschieden zwischen den verschiedenen Compilern eingeschränkt sein.
- **Ungewohnter Programmierstil:** Durch die rein-funktionale Struktur der Templates wären zwar theoretisch Optimierungen wie etwa in Haskell (Glasgow Haskell Compiler) möglich, praktisch werden solche Vorteile jedoch von keinem Compiler ausgenutzt und statt dessen verursacht diese Struktur in erster Linie (insbesondere für Programmierer, die strukturierte Programmierung aus C++ gewohnt sind) schwer verständlichen Code.
- **Schlechte Fehlermeldungen und schlechte Debuggbarkeit**

2.11. Die BOOST Metaprogramming Library MPL

Will man selbst Metafunktionsbibliotheken schreiben sollte man die MPL nutzen:
MPL

2.12. Metaprogramme für die Manipulation von Typen in C++

Metafunktionen für Container (Sequenzen, Listen, ...) von Typen:

```
template<class List1, class List2>
struct TypeListAppend
{
    typedef TypeList<typename List1::Head, typename TypeListAppend<
       typename List1::Tail, List2 >::Result> Result;
};
template<class List2>
struct TypeListAppend<NullType, List2>
{
    typedef List2 Result;
};
// Auf die Implementierung von TypeListBeforePivot und TypeListAfterPivot
   soll hier verzichtet werden
template<class List, template<typename A, typename B> class Comparator>
struct TypeListSort
{
    typedef typename TypeListAppend<
                        typename TypeListSort<
                            typename TypeListBeforePivot<
                                typename List::Tail,
                                typename List::Head,
                                Comparator>::Result,
                            Comparator>::Result,
                        TypeList<
                            typename List::Head,
                            typename TypeListSort<
                                typename TypeListAfterPivot<
                                    typename List::Tail,
                                    typename List::Head,
                                    Comparator>::Result,
                                Comparator>::Result
                            >
                        >::Result Result;
};
```

Funktionale Programmierung
Lisp
Scheme
Scala

2.13. Spracherweiterung (DSL) Maßeinheiten

2.13.1. Eine Softwarekatastrophe und ihr Einfluß auf neue Programmiersprachen

Anlaß: 1999 verpasste die NASA-Sonde Mars Climate Orbiter den Landeanflug auf den Mars, weil die Programmierer das falsche Maßsystem verwendeten - Pfund x Sekunde statt Newton x Sekunde. Die NASA verlor dadurch die Sonde.

Einheiten können durch geeignete Klassen (`Euro, Franken, Pfund,` ... statt `double`) mit (automatisch durchgefürten) Typkonversionen ähnlich wie in

```
class Euro
{
private:
  double Wert;
public:
  Euro() : Wert(0.0) {};
  Euro(double w) : Wert(w) {};
  Euro(const Euro &e) : Wert(e.Wert) {};
  Euro(DM dw);
  double ZeigeWert() const { return Wert; };
  friend Euro operator+(Euro a, Euro b);
  friend Euro operator-(Euro a, Euro b);
  friend Euro operator*(Euro a, double d);
  friend Euro operator/(Euro a, double d);
  friend bool operator<(Euro a, Euro b);
  friend ostream&  operator<<(ostream& os, const Euro& e);
};
Euro::Euro(DM dw)
{
  Wert = dw.ZeigeWert() / 1.95583;
}
```

realisiert werden.

Flexibler ist es jedoch, wenn die Programmiersprache Maßeinheiten unterstützt:

- Units und Dimensions in Fortress:

$$kineticEnergy(m : \mathbb{R}\ \underline{\mathrm{kg}}, v : \mathbb{R}\ \underline{\mathrm{m/s}}) : \mathbb{R}\ \underline{\mathrm{kg\ m^2/s^2}} = (m\ v^2)/2$$

encoded as `kg_`
and rendered in
roman font

`m_`	*is rendered as*	m	`s_`	*is rendered as*	s
`km_`	*is rendered as*	km	`kg_`	*is rendered as*	kg
`V_`	*is rendered as*	V	`kW_`	*is rendered as*	kW
`_v`	*is rendered as*	**v**	`_foo13`	*is rendered as*	$\mathbf{foo}_{13}$

$$v : \mathbb{R}\ \mathrm{m/s} = (3\,\mathrm{meters} + 4\,\mathrm{meters})/5\,\mathrm{seconds}$$

Corre

$$v : \mathbb{R}\ \mathrm{m/s} = (\underline{3\,\mathrm{meters} + 4\,\mathrm{seconds}})/5\,\mathrm{seconds}$$

static error

$$v : \mathbb{R}\ \mathrm{m/s} = (\underline{3\,\mathrm{meters} + 4\,\mathrm{meters})/5}$$

static error

$$kineticEnergy(3.14\,\mathrm{kg}, \underline{32\,\mathrm{f/s}\ \mathtt{in}\ \mathrm{m/s}})$$

unit conversion

- Units und Dimensions in der Programmiersprache F#

```
let gravityOnEarth = 9.81<m/s^2>   // Beschleunigung
```

```
let heightOfDrop   = 3.5<m>        // Laenge
let speedOfImpact  = sqrt(2.0 * gravityOnEart * heightOfDrop)
```

C++11 bleibt leider bei den SI-Skalierfaktoren

```
// 20.10.6, convenience SI typedefs
typedef ratio<1, 1000000000000000000000000> yocto; // see below
typedef ratio<1, 1000000000000000000000> zepto; // see below
typedef ratio<1, 1000000000000000000> atto;
typedef ratio<1, 1000000000000000> femto;
typedef ratio<1, 1000000000000> pico;
typedef ratio<1, 1000000000> nano;
typedef ratio<1, 1000000> micro;
typedef ratio<1, 1000> milli;
typedef ratio<1, 100> centi;
typedef ratio<1, 10> deci;
typedef ratio< 10, 1> deca;
typedef ratio< 100, 1> hecto;
typedef ratio< 1000, 1> kilo;
typedef ratio< 1000000, 1> mega;
typedef ratio< 1000000000, 1> giga;
typedef ratio< 1000000000000, 1> tera;
typedef ratio< 1000000000000000, 1> peta;
typedef ratio< 1000000000000000000, 1> exa;
typedef ratio< 1000000000000000000000, 1> zetta; // see below
typedef ratio<1000000000000000000000000, 1> yotta; // see below
```

stehen, was die Unterstützung von Maßeinheiten angeht.

Kann uns da Metaprogrammierung helfen?

2.13.2. DSLs

In software development and domain engineering, a domain-specific language (DSL) is a programming language or specification language dedicated to a particular problem domain, a particular problem representation technique, and/or a particular solution technique. The concept isn't new—special-purpose programming languages and all kinds of modeling/specification languages have always existed, but the term has become more popular due to the rise of domain-specific modeling.

Scala DSLs
DSLs
C++ template metaprogramming for DSLs

2.13.3. Ausflug in die Domain des technische-wissenschaftlichen Rechnens: Units and Measure in F#

Introducing Units:

```
[<Measure>] type kg
[<Measure>] type m
[<Measure>] type s

let gravityOnEarth = 9.81<m/s^2>
let heightOfMyOfficeWindow = 3.5<m>

let speedOfImpact = sqrt(2.0 * gravityOnEarth * heightOfMyOfficeWindow)
...
```

`speedOfImpact` hat die Einheit `<m/s>`.
Der Fehler

```
let speedOfImpact = sqrt(2.0 * gravityOnEarth + heightOfMyOfficeWindow)
...
```

führt zur Compiler-Fehlermeldung
`The unit measure 'm' does not match the unit measure 'm/s^2'.`

Unit Conversions:

```
...
let heightOfMyOfficeWindow = 11.5<ft>
let FeedPerMetre = 3.28084<ft/m>
...
let heightOfMyOfficeWindowInMetres = heightOfMyOfficeWindow /
   FeedPerMetre
...
type float = float<1>
...
```

Generic Units
Parameterized Types

2.13.4. SI-Einheitssystem

Internationales Einheitensystem

2.13.5. Boost.Units

Automatische Einheiten-Dimensionsrechnung in C++

```
#include <complex>
#include <iostream>

#include <boost/typeof/std/complex.hpp>

#include <boost/units/systems/si/energy.hpp>
#include <boost/units/systems/si/force.hpp>
#include <boost/units/systems/si/length.hpp>
#include <boost/units/systems/si/electric_potential.hpp>
#include <boost/units/systems/si/current.hpp>
#include <boost/units/systems/si/resistance.hpp>
#include <boost/units/systems/si/io.hpp>

using namespace boost::units;
using namespace boost::units::si;

quantity<energy>
work(const quantity<force>& F, const quantity<length>& dx)
{
    return F * dx; // Defines the relation: work = force * distance.
}

int main()
{
    /// Test calculation of work.
    quantity<force>     F(2.0 * newton); // Define a quantity of force.
    quantity<length>    dx(2.0 * meter); // and a distance,
    quantity<energy>    E(work(F,dx));  // and calculate the work done.

    std::cout << "F  = " << F << std::endl
              << "dx = " << dx << std::endl
              << "E  = " << E << std::endl
              << std::endl;

    /// Test and check complex quantities.
    typedef std::complex<double> complex_type; // double real and
        imaginary parts.

    // Define some complex electrical quantities.
```

```
    quantity<electric_potential, complex_type> v = complex_type(12.5,
       0.0) * volts;
    quantity<current, complex_type>            i = complex_type(3.0,
       4.0) * amperes;
    quantity<resistance, complex_type>         z = complex_type(1.5,
       -2.0) * ohms;

    std::cout << "V   = " << v << std::endl
              << "I   = " << i << std::endl
              << "Z   = " << z << std::endl
              // Calculate from Ohm's law voltage = current *
                 resistance.
              << "I * Z = " << i * z << std::endl
              // Check defined V is equal to calculated.
              << "I * Z == V? " << std::boolalpha << (i * z == v) <<
                 std::endl
              << std::endl;
    return 0;
}
```

produziert folgende Ausgabe:

```
F  = 2 N
dx = 2 m
E  = 4 J

V   = (12.5,0) V
I   = (3,4) A
Z   = (1.5,-2) Ohm
I*Z = (12.5,0) V
I*Z == V? true
```

Boost.Units benutzt Metafunktionen, um quantity<.>-Werte mit automatischer Dimensionsanalyse zu ermöglichen:

```
quantity<length> L = 2.0*meters;                     // quantity of
   length
quantity<time>   E = 14.5*seconds;                   // quantity of
   time
// mit:
// template<class Unit,class Y = double> class quantity;
//
```

Conversions

```
Pool von vordefinierten Konstanten
alphabetische Liste der Grundeinheiten

Meßungenauigkeiten und Fehlerfortpflanzung:
```

```
quantity<length,measurement<double> >
    u(measurement<double>(1.0,0.0)*meters),
    w(measurement<double>(4.52,0.02)*meters),
    x(measurement<double>(2.0,0.2)*meters),
    y(measurement<double>(3.0,0.6)*meters);
```

```
mit den Ergebniswerten (Fehlerbalken):

x+y-w          = 0.48(+/-0.632772) m
w*x            = 9.04(+/-0.904885) m^2
x/y            = 0.666667(+/-0.149071) dimensionless

...

w*y^2/(u*x)^2 = 10.17(+/-3.52328) m^-1
w/(u*x)^(1/2) = 3.19612(+/-0.160431) dimensionless

Dabei wurde die folgende Benutzererweiterung verwendet:
```

```
// Boost.Units - A C++ library for zero-overhead dimensional
   analysis and
// unit/quantity manipulation and conversion
//
// Copyright (C) 2003-2008 Matthias Christian Schabel
// Copyright (C) 2008 Steven Watanabe
//
// Distributed under the Boost Software License, Version 1.0. (
   See
// accompanying file LICENSE_1_0.txt or copy at
// http://www.boost.org/LICENSE_1_0.txt)

#ifndef BOOST_UNITS_MEASUREMENT_HPP
#define BOOST_UNITS_MEASUREMENT_HPP

#include <cmath>
#include <cstdlib>
#include <iomanip>
#include <iostream>

#include <boost/io/ios_state.hpp>
#include <boost/units/static_rational.hpp>

namespace boost {
```

```
namespace units {

namespace sqr_namespace /**/ {

template<class Y>
Y sqr(Y val)
{ return val*val; }

} // namespace

using sqr_namespace::sqr;

template<class Y>
class measurement
{
    public:
        typedef measurement<Y>                    this_type;
        typedef Y                                 value_type;

        measurement(const value_type& val = value_type(),
                    const value_type& err = value_type()) :
            value_(val),
            uncertainty_(std::abs(err))
        { }

        measurement(const this_type& source) :
            value_(source.value_),
            uncertainty_(source.uncertainty_)
        { }

        //~measurement() { }

        this_type& operator=(const this_type& source)
        {
            if (this == &source) return *this;

            value_ = source.value_;
            uncertainty_ = source.uncertainty_;

            return *this;
        }

        operator value_type() const    { return value_; }

        value_type value() const       { return value_; }
        value_type uncertainty() const { return uncertainty_; }
```

```
        value_type lower_bound() const { return value_-
           uncertainty_; }
        value_type upper_bound() const { return value_+
           uncertainty_; }

        this_type& operator+=(const value_type& val)
        {
            value_ += val;
            return *this;
        }

        this_type& operator-=(const value_type& val)
        {
            value_ -= val;
            return *this;
        }

        this_type& operator*=(const value_type& val)
        {
            value_ *= val;
            uncertainty_ *= val;
            return *this;
        }

        this_type& operator/=(const value_type& val)
        {
            value_ /= val;
            uncertainty_ /= val;
            return *this;
        }

        this_type& operator+=(const this_type& /*source*/);
        this_type& operator-=(const this_type& /*source*/);
        this_type& operator*=(const this_type& /*source*/);
        this_type& operator/=(const this_type& /*source*/);

    private:
        value_type          value_,
                            uncertainty_;
};

}

}

#if BOOST_UNITS_HAS_BOOST_TYPEOF
```

```
BOOST_TYPEOF_REGISTER_TEMPLATE(boost::units::measurement, 1)

#endif

namespace boost {

namespace units {

template<class Y>
inline
measurement<Y>&
measurement<Y>::operator+=(const this_type& source)
{
    uncertainty_ = std::sqrt(sqr(uncertainty_)+sqr(source.
       uncertainty_));
    value_ += source.value_;

    return *this;
}

template<class Y>
inline
measurement<Y>&
measurement<Y>::operator-=(const this_type& source)
{
    uncertainty_ = std::sqrt(sqr(uncertainty_)+sqr(source.
       uncertainty_));
    value_ -= source.value_;

    return *this;
}

template<class Y>
inline
measurement<Y>&
measurement<Y>::operator*=(const this_type& source)
{
    uncertainty_ = (value_*source.value_)*
              std::sqrt(sqr(uncertainty_/value_)+
                        sqr(source.uncertainty_/source.value_));
    value_ *= source.value_;

    return *this;
}
```

```
template<class Y>
inline
measurement<Y>&
measurement<Y>::operator/=(const this_type& source)
{
    uncertainty_ = (value_/source.value_)*
              std::sqrt(sqr(uncertainty_/value_)+
                        sqr(source.uncertainty_/source.value_));
    value_ /= source.value_;

    return *this;
}

// value_type op measurement
template<class Y>
inline
measurement<Y>
operator+(Y lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs,Y(0))+=rhs);
}

template<class Y>
inline
measurement<Y>
operator-(Y lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs,Y(0))-=rhs);
}

template<class Y>
inline
measurement<Y>
operator*(Y lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs,Y(0))*=rhs);
}

template<class Y>
inline
measurement<Y>
operator/(Y lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs,Y(0))/=rhs);
}
```

```
// measurement op value_type
template<class Y>
inline
measurement<Y>
operator+(const measurement<Y>& lhs,Y rhs)
{
    return (measurement<Y>(lhs)+=measurement<Y>(rhs,Y(0)));
}

template<class Y>
inline
measurement<Y>
operator-(const measurement<Y>& lhs,Y rhs)
{
    return (measurement<Y>(lhs)-=measurement<Y>(rhs,Y(0)));
}

template<class Y>
inline
measurement<Y>
operator*(const measurement<Y>& lhs,Y rhs)
{
    return (measurement<Y>(lhs)*=measurement<Y>(rhs,Y(0)));
}

template<class Y>
inline
measurement<Y>
operator/(const measurement<Y>& lhs,Y rhs)
{
    return (measurement<Y>(lhs)/=measurement<Y>(rhs,Y(0)));
}

// measurement op measurement
template<class Y>
inline
measurement<Y>
operator+(const measurement<Y>& lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs)+=rhs);
}

template<class Y>
inline
measurement<Y>
operator-(const measurement<Y>& lhs,const measurement<Y>& rhs)
```

```
{
    return (measurement<Y>(lhs)-=rhs);
}

template<class Y>
inline
measurement<Y>
operator*(const measurement<Y>& lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs)*=rhs);
}

template<class Y>
inline
measurement<Y>
operator/(const measurement<Y>& lhs,const measurement<Y>& rhs)
{
    return (measurement<Y>(lhs)/=rhs);
}

/// specialize power typeof helper
template<class Y,long N,long D>
struct power_typeof_helper<measurement<Y>,static_rational<N,D> >
{
    typedef measurement<
        typename power_typeof_helper<Y,static_rational<N,D> >::
           type
    > type;

    static type value(const measurement<Y>& x)
    {
        const static_rational<N,D>  rat;

        const Y m = Y(rat.numerator())/Y(rat.denominator()),
                newval = std::pow(x.value(),m),
                err = newval*std::sqrt(std::pow(m*x.uncertainty
                   ()/x.value(),2));

        return type(newval,err);
    }
};

/// specialize root typeof helper
template<class Y,long N,long D>
struct root_typeof_helper<measurement<Y>,static_rational<N,D> >
{
```

```
    typedef measurement<
        typename root_typeof_helper<Y,static_rational<N,D> >::
           type
    > type;

    static type value(const measurement<Y>& x)
    {
        const static_rational<N,D>  rat;

        const Y m = Y(rat.denominator())/Y(rat.numerator()),
                newval = std::pow(x.value(),m),
                err = newval*std::sqrt(std::pow(m*x.uncertainty
                   ()/x.value(),2));

        return type(newval,err);
    }
};

// stream output
template<class Y>
inline
std::ostream& operator<<(std::ostream& os,const measurement<Y>&
   val)
{
    boost::io::ios_precision_saver precision_saver(os);
    boost::io::ios_flags_saver flags_saver(os);

    os << val.value() << "(+/-" << val.uncertainty() << ")";

    return os;
}

} // namespace units

} // namespace boost

#endif // BOOST_UNITS_MEASUREMENT_HPP
```

2.13.6. Erweiterung des C++-Typsystems um Units

... mit Hilfe der Boost MPL-Library (Implementierungsidee der Boost.Units-Bibliothek):

Dimensions:

```
// die sieben Grundeinheiten:
typedef int dimension[7]; // m  l  t  ...
dimension const mass      = {1, 0, 0, 0, 0, 0, 0};
dimension const length    = {0, 1, 0, 0, 0, 0, 0};
dimension const time      = {0, 0, 1, 0, 0, 0, 0};
...
// und die abgeleiteten Einheiten:
dimension const force  = {1, 1, -2, 0, 0, 0, 0};
...
```

Diese Dimensionen sind jedoch alle vom gleichen C++-Typ, führen also nicht zu den gewünschten Fehlermeldungen bei Dimensionsrechnungsabweichungen. Mit Hilfe des Datentyps vector_c der MPL ändert sich das:

```
#include <boost/mpl/vector_c.hpp>

typedef mpl::vector_c<int,1,0,0,0,0,0,0> mass;
typedef mpl::vector_c<int,0,1,0,0,0,0,0> length; // or position
typedef mpl::vector_c<int,0,0,1,0,0,0,0> time;
typedef mpl::vector_c<int,0,0,0,1,0,0,0> charge;
typedef mpl::vector_c<int,0,0,0,0,1,0,0> temperature;
typedef mpl::vector_c<int,0,0,0,0,0,1,0> intensity;    // in cd
typedef mpl::vector_c<int,0,0,0,0,0,0,1> angle;        // oder mol
// abgeleitete Einheiten:
typedef mpl::vector_c<int,0,1,-1,0,0,0,0> velocity;     // l/t
typedef mpl::vector_c<int,0,1,-2,0,0,0,0> acceleration; // l/(t2)
typedef mpl::vector_c<int,1,1,-1,0,0,0,0> momentum;     // ml/t
typedef mpl::vector_c<int,1,1,-2,0,0,0,0> force;        // ml/(t2)
...
typedef mpl::vector_c<int,0,0,0,0,0,0,0> scalar;
...
```

Quantities:

```
template <class T, class Dimensions>
struct quantity
{
    explicit quantity(T x)
        : m_value(x)
    {}

    T value() const { return m_value; }
 private:
    T m_value;
};
...
quantity<float,length> l( 1.0f );
quantity<float,mass>   m( 2.0f );
...
m = l;      // compile-time type error
```

Quantity-Arithmetik (value und dimension):

add/subtract:

```
template <class T, class D>
quantity<T,D>
operator+(quantity<T,D> x, quantity<T,D> y)
{
  return quantity<T,D>(x.value() + y.value());
}

template <class T, class D>
quantity<T,D>
operator-(quantity<T,D> x, quantity<T,D> y)
{
  return quantity<T,D>(x.value() - y.value());
}

// ...

quantity<float,length> len1( 1.0f );
quantity<float,length> len2( 2.0f );

len1 = len1 + len2;    // OK
len1 = len2 + quantity<float,mass>( 3.7f ); // error
```

multiplicate:

```
template <class T, class D1, class D2>
quantity<
    T
  , typename mpl::transform<D1,D2,plus_f>::type   // new dimensions
>
operator*(quantity<T,D1> x, quantity<T,D2> y)
{
    typedef typename mpl::transform<D1,D2,plus_f>::type dim;
    return quantity<T,dim>( x.value() * y.value() );
}
// mit MPL-Hilfe:
template <class OtherDimensions>
quantity(quantity<T,OtherDimensions> const& rhs)
  : m_value(rhs.value())
{
    BOOST_STATIC_ASSERT((
        mpl::equal<Dimensions,OtherDimensions>::type::value
    ));
}
```

divide:

```
template <class T, class D1, class D2>
quantity<
    T
  , typename mpl::transform<D1,D2,mpl::minus<_1,_2> >::type
>
operator/(quantity<T,D1> x, quantity<T,D2> y)
{
   typedef typename
      mpl::transform<D1,D2,mpl::minus<_1,_2> >::type dim;

   return quantity<T,dim>( x.value() / y.value() );
}
```

MPL-Metafunktionsklasse:
The most basic way to formulate a compile-time function so that it can be treated as polymorphic metadata; that is, as a type. A metafunction class is a class with a nested metafunction called apply.

Gewöhnungsbedürftige Syntax der Metaprogrammierung: MPL-ManualSeite 99

```
typedef vector<int,char,long,short,char,short,double,long> types;
typedef count<types, short>::type n;
BOOST_MPL_ASSERT_RELATION( n::value, ==, 2 );
```

(Werte des Metaprogramms werden durch `typedef`s an „Typnamen-Aliases” gebunden, ...)

2.13.7. Nachteile von DSLs

- meist Nischensprachen, häufig fehlende Sprachstandards, fehlende freie Implementierungen, ...
- hoher Aufwand für das Erlernen der nur in wenigen Fällen benutzbaren DSL
- Risiko, dass der Anwender zusätzlich viel Entwicklung in der Hostsprache (hier C++) statt der DSL selbst erledigen muß.
- Risiko des Bindens an den Anbieter einer Nischensprache
- Risiko des zukünftigen Vermeidens der Entwicklung von Problemlösungen in etablierten allgemeinen Hochsprachen
- hoher Aufwand der Spezifikation, Entwicklung und Wartung der DSL
- Schwierigkeit, die langfristig benötigten Eigenschaften der DSL richtig abzuschätzen
- Risiko der schleichenden Entwicklung der DSL zu einer allgemeinen Programmiersprache
- Schwierigkeit der Findung des der DSL angemessenen Abstraktionsniveaus
- Hoher Anspruch an die Kompetenz der Entwickler des DSLs

Nachteile DSLs

2.14. User-Defined Literals to Handling Scientific Quantities, Number Representation and String Manipulation

Mikhail Semenov: Quantities

2.15. Literaturhinweise zum Metaprogrammieren

C++ Template Metaprogramming: Concepts, Tools, and Techniques from Boost and Beyond

3. Template template-Parameter, Policy-basiertes Klassendesign

3.1. Templates als Template-Parameter

Die Template-Klassen `vector, deque, list, ...` als Container.

dequeue
vector
...

Template Template-Parameter erlauben die gemeinsame Programmierung von Programmkonstrukten für alle altuellen Parametervarianten eines gemeinsamen formalen generischen Template-Templateparameters:

```
template <template <typename, typename> class Container, typename Type>
class Example
{
  Container<Type, std::allocator <Type> > baz;
};

// Beispiel der Verwendung:
//
// statt xxxxxx<std::deque<int>, int> ...

Example <std::deque, int> exampleDeque;
Example <std::vector, int> exampleVector;
...
```

(Beispiel eines Objektgenertors, einer ObjektFactory.)

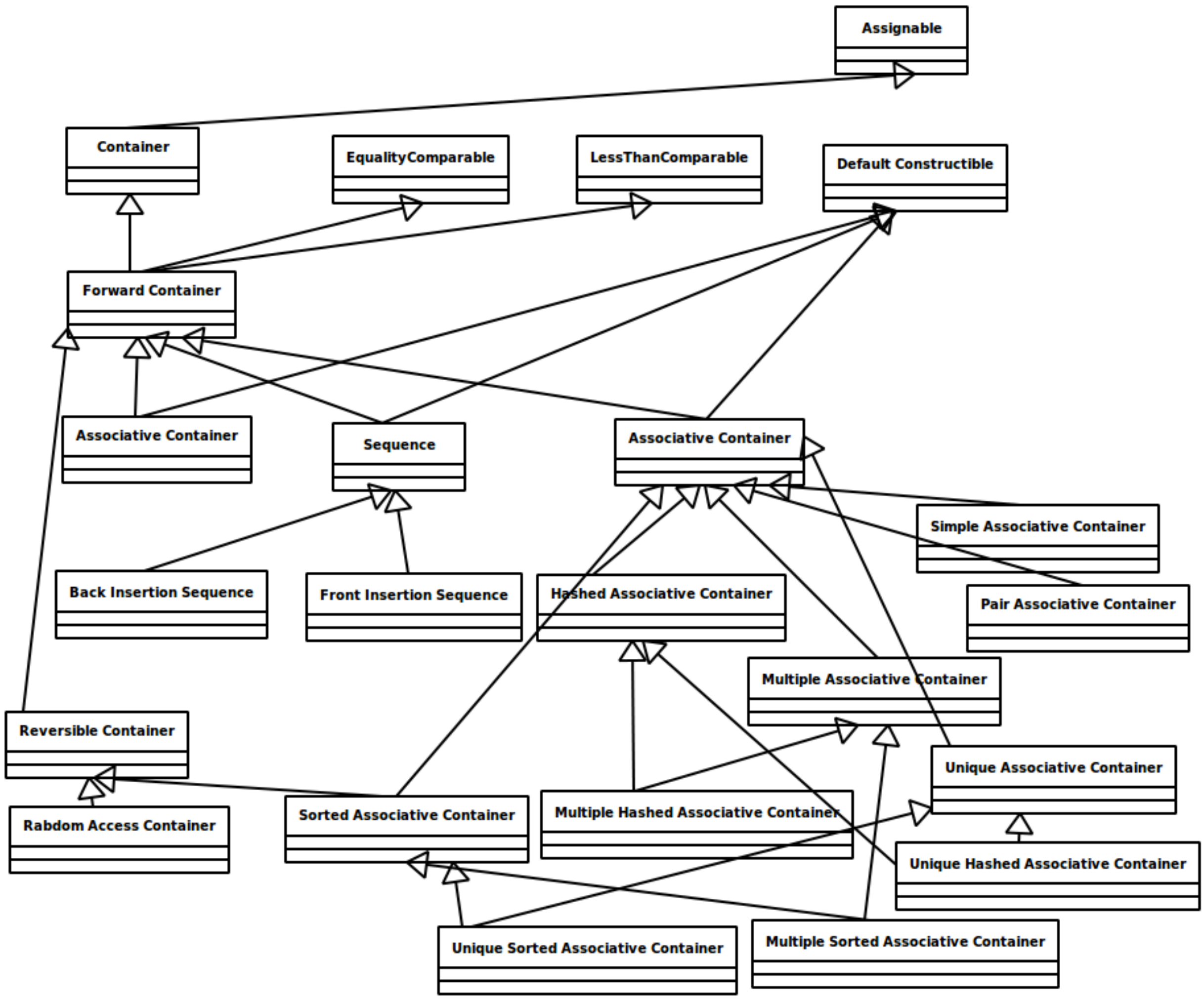
3.2. Policies (Strategien, Entscheidungen, Implementierungsvarianten)

Policies bei der Template-Metaprogrammierung:
„Policies sind Klassen-Templates, die dazu dienen, Verhalten auszulagern.“

Ein Beispiel:

```
struct MultiThreadingPolicy {
  typedef /*...*/ Mutex;
  struct Lock {
    Lock(Mutex& mtx) : mtx_(mtx) {lock(mtx_);}
    ~Mutex() {unlock(mtx_);}
    Mutex& mtx_;
  };
};
struct SingleThreadingPolicy {
  class Mutex {};
  struct Lock {
    Lock(Mutex&) {}
    ~Mutex() {}
  };
};
//
// Ein Algorithmus koennte jetzt so aussehen:
//
template< class ThreadingPolicy >
void f(typename ThreadingPolicy::Mutex& mtx)
{
  // ...
  if( needToTouchThreadSensibleData() ) {
    typename ThreadingPolicy::Lock lock(mtx); // lock mutex
    // thread-safe section
  }
  // ...
}
```

STL-Container:



Policies (Implementierungsvarianten/-verhaltensweisen) der STL-Container:

```
assoziativ/nichtassoziativ
sortiert/unsortiert
hashed/ohne hash
unique/multiple
```

Andere Policies:

```
threadsave
errorhandling (exception, errno, ...)
allocator (threadsave, singleclient, malloc-based, ...)
...
```

Policy based Design:

Implementiert wird durch eine zur Compilezeit durchgeführte Template-Instantiierung der gewünschten Policy-Ausprägungen der Template-Kindklasse aller Policies:

```
template < typename output_policy , typename language_policy >
class HelloWorld : public output_policy , public language_policy
{
    using output_policy::Print;
    using language_policy::Message;

public:
    //behaviour method
    void Run()
    {
        //two policy methods
        Print( Message() );
    }
};

#include <iostream>

class HelloWorld_OutputPolicy_WriteToCout
{
 protected:
    template< typename message_type >
    void Print( message_type message )
    {
        std::cout << message << std::endl;
    }
};

#include <string>

class HelloWorld_LanguagePolicy_English
{
 protected:
    std::string Message()
    {
        return "Hello, World!";
    }
};

class HelloWorld_LanguagePolicy_German
{
 protected:
    std::string Message()
    {
        return "Hallo Welt!";
    }
};
```

```cpp
int main()
{
    /* example 1 */
    typedef HelloWorld<HelloWorld_OutputPolicy_WriteToCout,
        HelloWorld_LanguagePolicy_English> my_hello_world_type;

    my_hello_world_type hello_world;
    hello_world.Run(); // Prints "Hello, World!"

   /* example 2
    * does the same but uses another policy, the language has changed
    */
    typedef HelloWorld< HelloWorld_OutputPolicy_WriteToCout,
        HelloWorld_LanguagePolicy_German > my_other_hello_world_type;

    my_other_hello_world_type hello_world2;
    hello_world2.Run(); // Prints "Hallo Welt!"
}
```

Seite 8: ThreadingPolicy
CreationPolicy
Generic Pool Design: CreationPolicy, ExpirationPolicy
Boost numeric conversions: OverflowhHandler, Float2IntRounder, RawConverter, UserRangeChecker
Policies and the STL: AllocationPolicy, CharTPolicy

3.3. Beispiel: polare oder karthesische Koordinaten/long double, double oder float

Um als (programmierender) Anwender die gewünschte Implementierungsstrategie

> polare oder karthesische Koordinaten/long double, double oder float für die Vektorkomponenten

ad hoc auswählen zu können ist Policy-basiertes Design das Mittel der Wahl:

```
// ...
        //statt typedef Vektor2D<long double, Cartesian> cartVek;
        using cartVek = Vektor2D<long double, Cartesian>;
        cartVek v1(3.0l, 4.0l);
        //v1.set_x(3.0l);
        //v1.set_y(0.0l);
        std::cout << v1.get_x() << std::endl;
        std::cout << v1.get_y() << std::endl;
        std::cout << v1.get_r() << std::endl;
        std::cout << v1.get_phi() << std::endl;
        std::cout << std::endl;

        using polarVek = Vektor2D<long double, Polar>;
        polarVek v2(1.0l, M_PI/2.0);
        std::cout << v2.get_x() << std::endl;
        std::cout << v2.get_y() << std::endl;
        std::cout << v2.get_r() << std::endl;
        std::cout << v2.get_phi() << std::endl;
// ...
```

mit

```
#include <iostream>
#include <cmath>
#include <type_traits>

// ...
/* Policy Cartesian ***********************************************/
template<typename FloatingPointLike>
class Cartesian{
        static_assert(std::is_floating_point<FloatingPointLike>::value,
                      "no floating point type");
public:
         Cartesian(const FloatingPointLike&& my_x,
                   const FloatingPointLike&& my_y): v1(my_x), v2(
                      my_y) {}

    FloatingPointLike get_x() const {
                return v1;
        }
        FloatingPointLike get_y()const{
                return v2;
        }
        FloatingPointLike get_r()const{
```

```
                        return std::sqrt(std::pow(get_x(), 2)+std::pow(
                            get_y(),2));
                }
        FloatingPointLike get_phi()const{
                        return std::atan2(get_y(), get_x());
                        }
        void set_x(FloatingPointLike my_x){
                v1 = my_x;
        }
        void set_y(FloatingPointLike my_y){
                v2 = my_y;
        }
protected:
        FloatingPointLike v1; // x
        FloatingPointLike v2; // y
};


/* Policy Polar **************************************************/
template<typename FloatingPointLike>
class Polar{
        static_assert(std::is_floating_point<FloatingPointLike>::value,
                                "no floating point type");
public:
           Polar(const FloatingPointLike&& my_r,
                     const FloatingPointLike&& my_phi): v1(my_r), v2(
                        my_phi) {}

           FloatingPointLike get_x()const{
                        return get_r()*cos(get_phi());
                }
                FloatingPointLike get_y()const{
                        return get_r()*std::sin(get_phi());
                }
                FloatingPointLike get_r()const{
                                return v1;
                        }
                FloatingPointLike get_phi()const{
                                return v2;
                        }
                void set_r(FloatingPointLike my_r){
                        v1 = my_r;
                }
                void set_phi(FloatingPointLike my_phi){
                        v2 = my_phi;
                }
protected:
        FloatingPointLike v1; // r
        FloatingPointLike v2; // phi
};
```

```
/* class Vektor2D *********************************************/
template <typename FloatingPointLike = long double,
          template <typename> class CoordinateType = Cartesian>
class Vektor2D: public CoordinateType<FloatingPointLike>
{
public:
  static_assert(std::is_floating_point<FloatingPointLike>::value,
                                "no floating point type");

  using typename CoordinateType<FloatingPointLike>::CoordinateType;
  using typename CoordinateType<FloatingPointLike>::get_x;
  using typename CoordinateType<FloatingPointLike>::get_y;
  using typename CoordinateType<FloatingPointLike>::get_r;
  using typename CoordinateType<FloatingPointLike>::get_phi;

  //using CoordinateType<FloatingPointLike>::v1;
  //using CoordinateType<FloatingPointLike>::v2;
};

/****************************************************************/
```

Damit die Definition der Vektor2D benutzenden Algorithmen unabhängig von der gerade ad hog gewählten Variantenwahl wird, sollte `Cartesian` und `Polar` dieselben Methoden mit denselben Namen benutzen!
Ergänzen Sie also oben die jeweils noch fehlenden Methoden.

Variable templates: pi

C++11 uniform initialization
uniform erase_if
non-member std::size, N4280

3.4. Entwurfsmuster Strategie

Policies als Compile-Time-Variante des Strategie-Designmusters
C++ Design Pattern: What is a Design Pattern?
Einführung in Design Patterns: 4.4 Das Strategy Pattern
Strategy pattern
The Strategy design motif
Implementing the Strategy Pattern

Design patterns
Entwurfsmuster Iterator
Entwurfsmuster Observer

Wikibook Entwurfsmuster

3.5. Policies als Template Template-Parameter

(aus: http://ess.cs.tu-dortmund.de/Teaching/SS2013/SuS/Downloads/06.2-PL-mit-Templates.pdf#page=15:)
Konfigurierbare `CreationPolicy` mit den Ausprägungen

```
template <typename T>
class NewCreator {
public:
   static T *create() {
      return new T;
   }
};
// ...
   Widget *w = NewCreator<Widget>::create();
```

und

```
template <typename T>
class MallocCreator {
public:
   static T *create() {
      void *buf = malloc(sizeof(T));
      if (!buf) return 0; // oder Exception werfen
      return new(buf) T; // placement new
   }
};
...
   Widget *w = MallocCreator<Widget>::create();
```

Diese (und eventuell andere ausfaktorisierte Policies werden benutzt zum Beispiel in der Host-Klasse:

```
template <typename CreationPolicy>
class WidgetManager {
public:
   void newWidget() {
      Widget *w = CreationPolicy::create();
      // ...
   }
   // ...
};
// ...
typedef WidgetManager<NewCreator<Widget> > WM1;
// ...
typedef WidgetManager<MallocCreator<Widget> > WM2;
// ...
```

Ärgerlich, aber durch Nutzung von Template Template-Parameter vermeidbar, ist die Notwendigkeit, als aktuellen template-Parameter immer `Widget` angeben zu müssen.

Hier also die entgültige Lösung:

```
template <template <typename> class CreationPolicy>
class WidgetManager {
public:
    void newWidget() {
        Widget *w = CreationPolicy<Widget>::create();
        // ...
    }
    // ...
};
// jetzt kompakter und einfacher:
typedef WidgetManager<NewCreator> WM1;
// ...
typedef WidgetManager<MallocCreator> WM2;
// ...
```

Die Benutzung von Template Template-Paramertern macht den Code einfacher zu lesen, weniger fehleranfällig und flexibler.
C++17: Allow typename in a template template parameter

3.6. Orthogonale Policy-Dimensionen

A Case for Orthogonality in Design
Orthogonality

Policies sollten minimale orthogonale Implementierungsvarianten sein.

3.7. Policies (Fortsetzung)

(aus WordIQ.com:)
Policy-based design is a programming technique, which one could call the compile-time equivalent of the Strateqy pattern. ...
The technique is used to create a flexible set of types, providing the same interface, but employing different implementation behind. Therfore this technique has a lot of similarity to the Strategy pattern. However while Strategy allows the type to "change its ways" runtime, policy-based design fixes the implementation during compilation. In fact, it creates a new type for each different implementation. While their interface (functions present, their names etc.) will be the same, they will be different type – as opposed to Strategy, where the same type behaves differently.
The main idea is to use commonality-variablility analysis to divide the type into fixed implementation and interface (the policy based class) and the different policies. The main class, the policy based class takes template arguments (types, templates of types etc.) and delegates parts of the work to the policies.
...

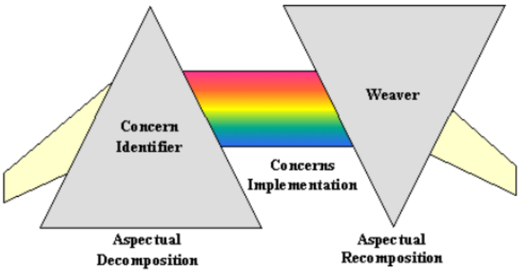
3.8. Loki

Loki (C++): example designs of common design patterns and idioms
Loki Pattern visitor

3.9. A Policy-Based flex_string Implementation

A Policy-Based basic_string Implementation

4. Aspektorientiertes Programmiern in komplexen Unternehmensanwendungen



Policy-basiertes Design = Template-gesteuerte statische Wahl einer Implementierungsvariante durch den entwickelden Bibliotheksbenutzer.

Enterprise Software

Aspect-Oriented Programming (AOP) = Ergänzung einer Programmiersprache um neue Sprachmittel (aspekt, advice) zur lokalisierten übersichtlichen, wartbaren und insbesondere erweiterbaren Codierung von Querschnittsanforderungen (= Cross-Cutting Concerns (CCC))

AOP:
Aspect-Oriented Programming (AOP) complements Object-Oriented Programming (OOP) by providing another way of thinking about program structure. The key unit of modularity in OOP is the class, whereas in AOP the unit of modularity is the aspect. Aspects enable the modularization of concerns such as transaction management that cut across multiple types and objects.

AOP als Ergänzung des OOP
Code Scattering der Wirkungsstellen einzelner Belange/Anforderungen
Seite 21: Aspectual Decomposition, Aspectual Recomposition
I want my AOP!:

- Aspectual decomposition: Decompose the requirements to identify crosscutting and common concerns. You separate module-level concerns from crosscutting system-level concerns. For example, in the aforementioned credit card module example, you would identify three concerns: core credit card processing, logging, and authentication.
- Concern implementation: Implement each concern separately. For the credit card processing example, you'd implement the core credit card processing unit, logging unit, and authentication unit.

- Aspectual recomposition: In this step, an aspect integrator specifies recomposition rules by creating modularization units – aspects. The recomposition process, also known as weaving or integrating, uses this information to compose the final system. For the credit card processing example, you'd specify, in a language provided by the AOP implementation, that each operation's start and completion be logged. You would also specify that each operation must clear authentication before it proceeds with the business logic.

Weitere Beispiele von Aspekten:

- logging
- object counting
- locking
- errorhandling
- creational OO design patterns
  - Singleton
  - ...
- structural design patterns
  - Proxy
  - ...
- behavioral design patterns
  - Strategy
  - ...
- Class/Component Scale Aspects
- Application Scale Aspect
- Enterprise Scale Aspect
- Director Design Pattern
- ...

(aus: AspectJ Cookbook: Aspect Oriented Solutions to Real-World Problems)

Scattering und Tangling Code

Needed an AOP language with:

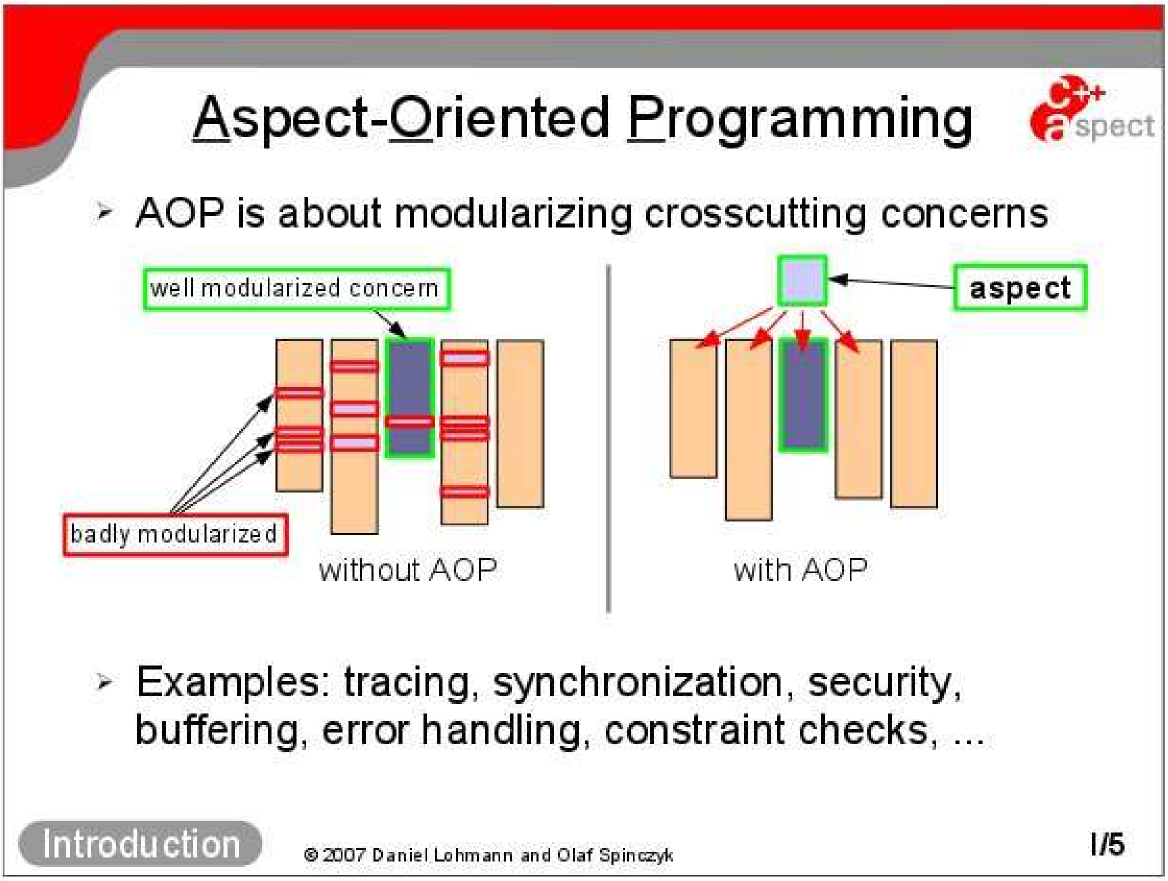
- implementation of concerns: Mapping an individual requirement into code so that a compiler can translate it into executable code. Since implementation of concerns takes the form of specifying procedures, you can to use traditional languages like C, C++, or Java with AOP.

```
.NET Framework languages (C# / VB.NET)[10]
ActionScript[11]
Ada[12]
AutoHotkey[13]
C / C++[14]
COBOL[15]
The Cocoa Objective-C frameworks[16]
ColdFusion[17]
Common Lisp[18]
Delphi[19][20][21]
```

```
Delphi Prism[22]
e (IEEE 1647)
Emacs Lisp[23]
Groovy
Haskell[24]
Java[25]
    AspectJ
JavaScript[26]
Logtalk[27]
Lua[28]
Matlab[29]
make[30]
ML[31]
PHP[32]
Racket[33]
Perl[34]
Prolog[35]
Python[36]
Ruby[37][38][39]
Squeak Smalltalk[40][41]
UML 2.0[42]
XML[43]
```

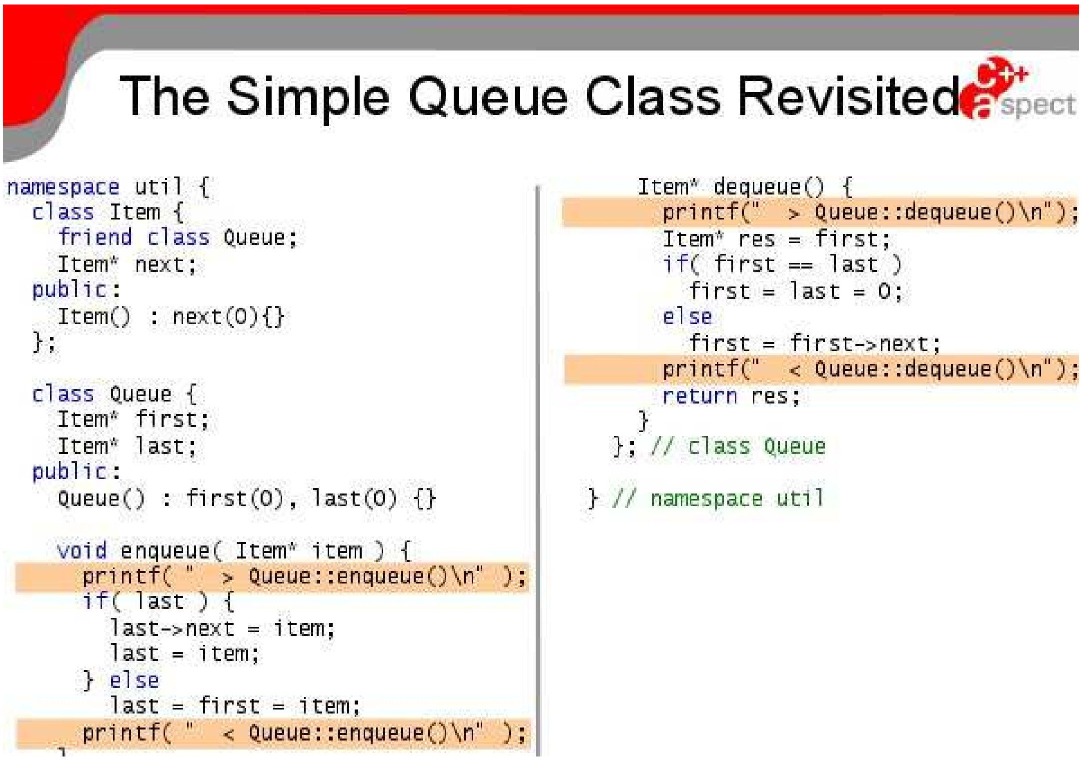
(aus: AOP Implementations)

- Weaving rules specification: How to compose independently implemented concerns to form the final system. For this purpose, an implementation needs to use or create a language for specifying rules for composing different implementation pieces to form the final system. The language for specifying weaving rules could be an extension of the implementation language, or something entirely different.
- Recompile the whole enterprise application.

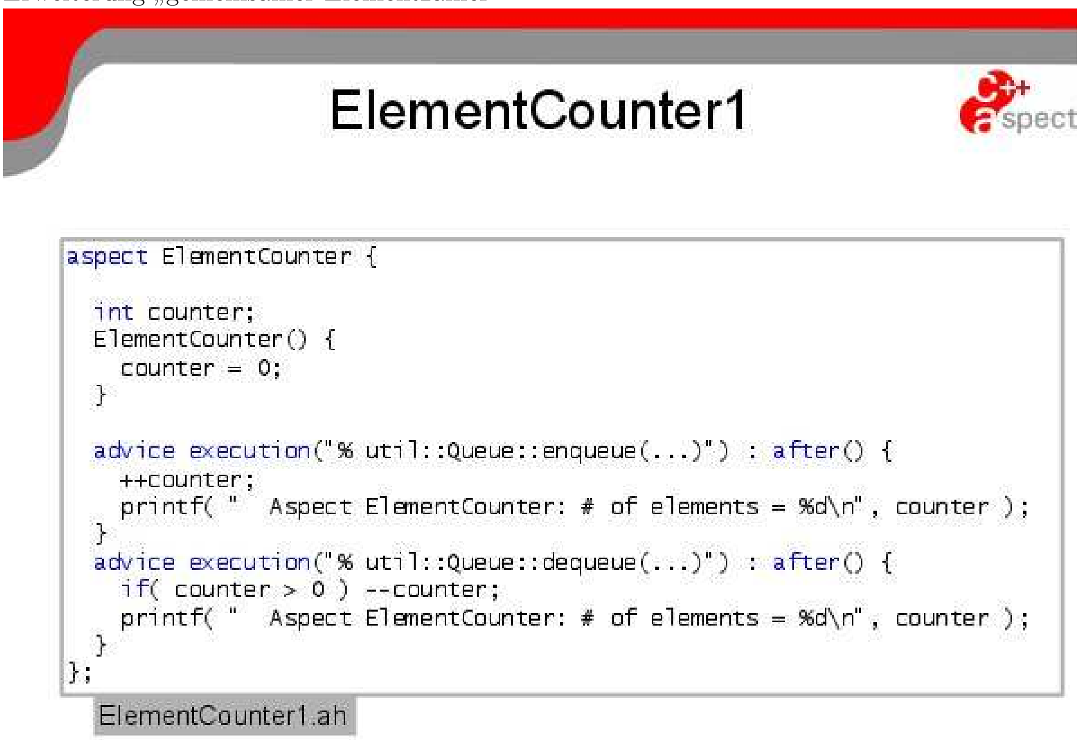


AOP vocabulary: aspect, join point, pointcut, advice

Ausgangspunkt: Geschäftslogik



Erweiterung „gemeinsamer Elementzähler“



modifizierte Erweiterung „Elementzähler für jede Warteschlange getrennt“

ElementCounter2

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                   && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

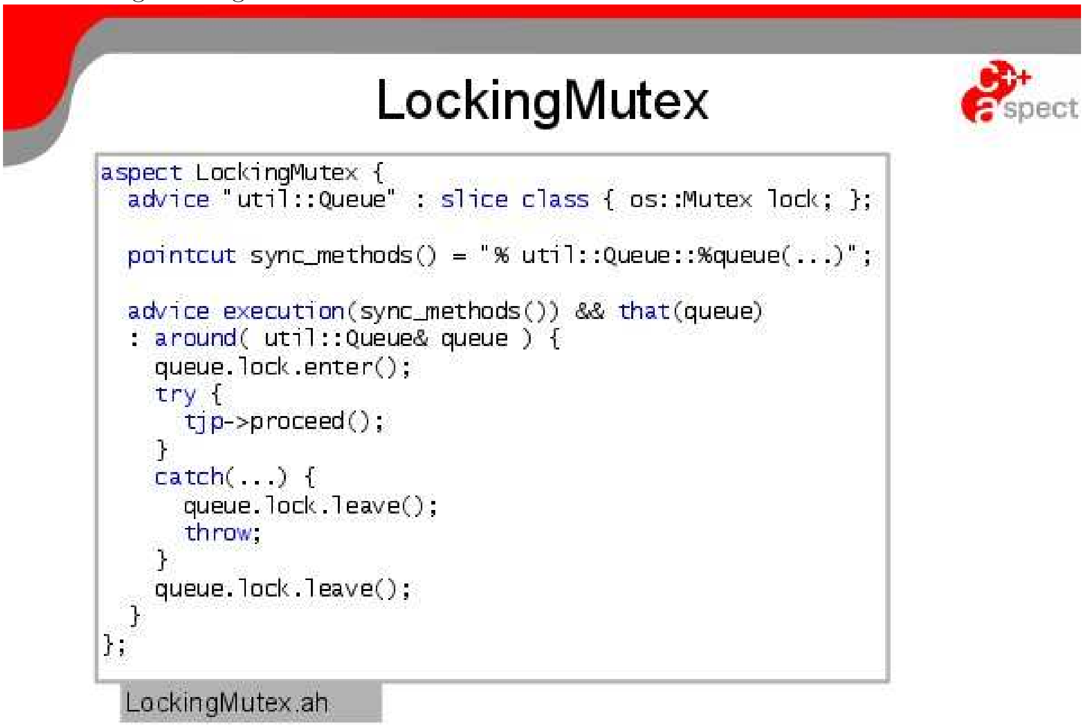
Erweiterung Errorhandling

ErrorException

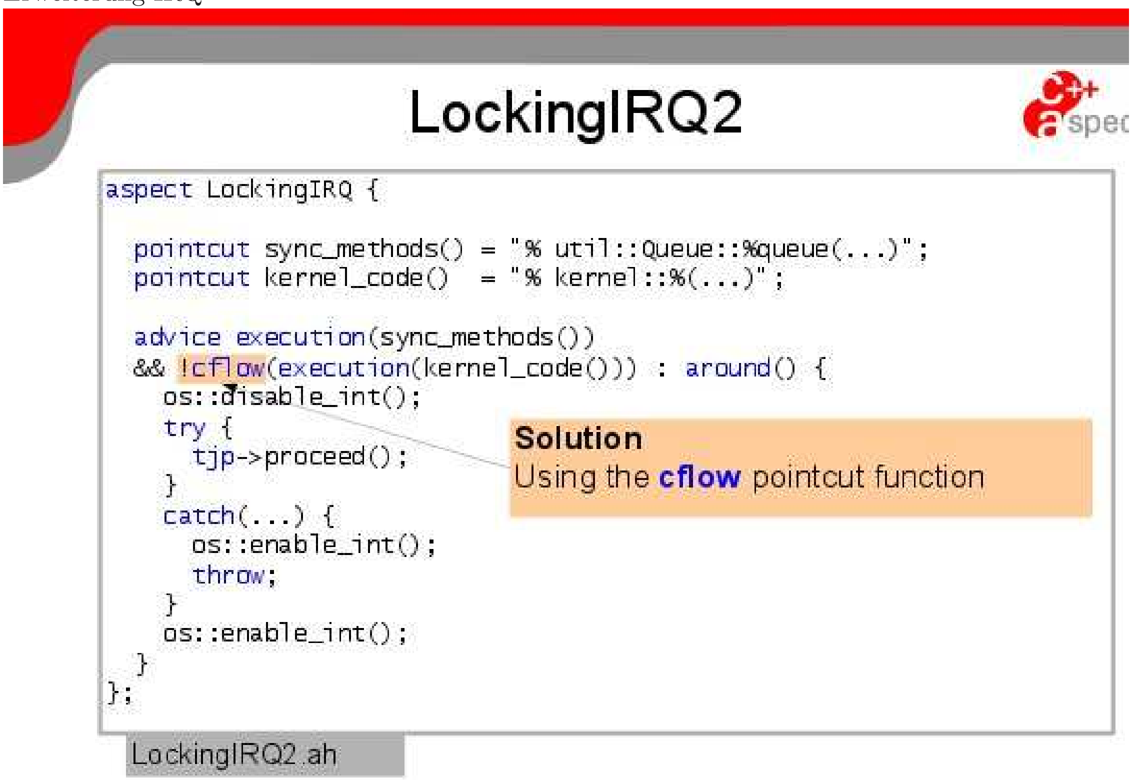
```
namespace util {
  struct QueueInvalidItemError {};
  struct QueueEmptyError {};
}

aspect ErrorException {

  advice execution("% util::Queue::enqueue(...)") && args(item)
      : before(util::Item* item) {
    if( item == 0 )
      throw util::QueueInvalidItemError();
  }
  advice execution("% util::Queue::dequeue(...)") && result(item)
      : after(util::Item* item) {
    if( item == 0 )
      throw util::QueueEmptyError();
  }
};
```

ErrorException.ah

Erweiterung Locking



Erweiterung IRQ



Spezifikation der Cutpoints durch „Name Matching“.

siehe: 3 Name Matching, Seite 16f.
.Net Introduction to AOP:

Advice types

Now that we have defined *what* is advised and *where* we can add the minor detail of *when* it is applied, because we have different kinds of advices. The example above uses a so called *around* advice. That is, the advice is wrapped around the joinpoint. It controls the moment when the joinpoint is executed explicitly by calling Proceed(). Other examples of advice types are:

before and *after* advices, which are executed before or after the execution of the joinpoint respectively. Those advices can't explicitly define when the joinpoint is executed.
throwing advices, which are only executed if the execution of the joinpoint raised an exception
returning advices, which are only executed if the execution of the joinpoint did *not* raise an exception

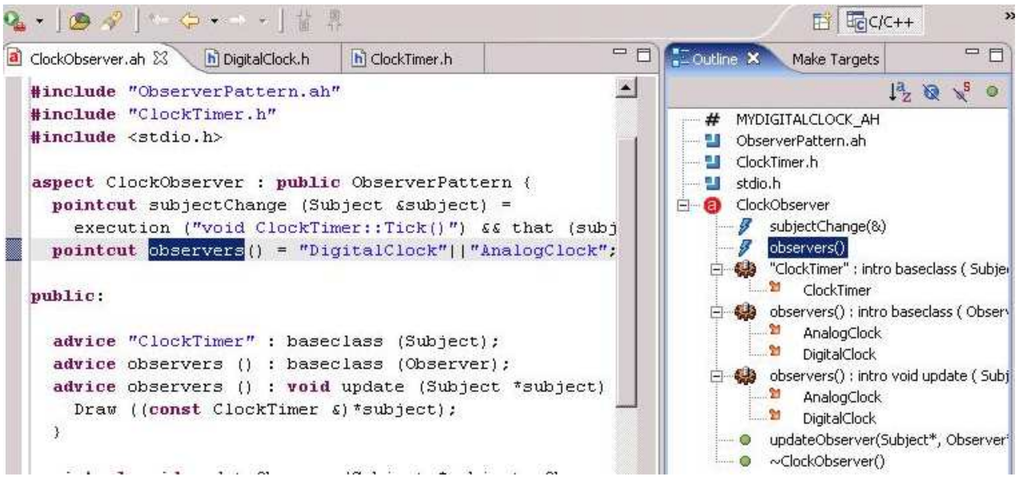
Finally, here's a fine-tuned version of our pseudo code example:

```
pointcut ServiceMethods : call( Service.* )

around(context) : ServiceMethods {
  try {
    context.Proceed();
  } catch(Exception e) {
    if(ExceptionHandler.ShouldRethrow(e)) {
      throw;
    }
  }
}
```

By the way, I didn't come up with this notation all by myself. It resembles the syntax used with AspectJ, which is more or less the most prominent (Java) AOP framework available. It has grown quite mature and if you're interested in AOP I highly recommend to have a look at it. Yes - even it uses Java :-)

AspectC++ Home
AspectC++ ... and your code gets untangled (AspectC++ Literatur)

Eclipse AspectC/C++ Development Tools:



(aus: Screenshots)

Nachteile:
Schlechte Unterstützung beim Debuggen, Profilen, ...
(mögliche) Codeexplosion beim Aspekt-Einweben
Setzt AOP-Begriffe und -Ideologien als Bekannt voraus (dann allerdings leicht erlernbar))
Erfordert Pattern-Matching-Erfahrungen (Filterdefinition)
Erfordert Recompilation der in der Regel riesigen Unternehmensapplikationen
Probleme der Abhängigkeit von der Reihenfolge des Einwebens(?)
evtl. schlecht lesbarer neu entstehender Code
Sind wirklich alle relevanten Codestellen mit Advices geändert worden? (fehlende direkte Sprachkonstruckte von C++, z.B. Annotationen mit Aspekt-Bezug, ...)

Vorteile:
Schnell und einfach aufzusetzen
selektiv einsetzbar
keine Modifikation der Originalquellen nötig
leicht entfernbar
gute Performance

AOP-Implemetierung

http://en.wikipedia.org/wiki/Aspect-oriented_programming#Implementation

Code Injection
Bytecode Instrumentation
Dynamic Bytecode Instrumentation

The Design and Implementation of AspectC++
AspectC++ Qick Reference (page 8f.)
Advances in AOP with AspectC++

Entwicklungsstand:
(siehe Entwicklungsstand der aspektorientierten Programmierung)

- noch in den Kinderschuhen (erfaßt unter anderem nur selbst Compiliertes, nicht jedoch lediglich Benutztes, ...)
- Realisierung des AOP noch unausgereift (Patchlisten, ...)
- Bis zu akzeptabler Reife dürfte es noch einige Jahre und einige Programmiersprachengenerationen dauern
- hohe Abstraktion und völlig andere ungewohnte Herangehensweise stellt hohe Anforderungen an den (zukünftigen) Entwickler

Spring (Framework mit integriertem AspectJ)
Framework

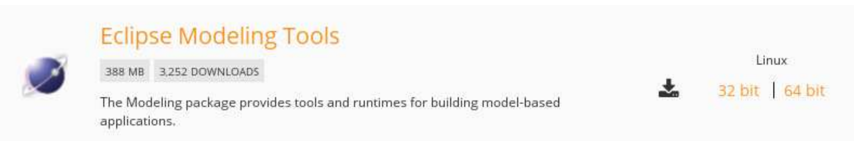
A. Quelloffenes Eclipse mit CDT/UML2.5/OCL2.4-Tools zur C++ Programmentwicklung

Hilfsmittel (Tools) zur „state of the art"-Entwicklung von C++-Anwendungen:
Verfügbar (vorinstalliert) auf allen Ausbildungsclustern (CIP/IT/PI: I101, ...) der Fachgruppe Mathematik/Informatik der BUW als `eclipse-papyruso1`.

```
Eclipse-Modelling (inkl. Java) mit
   CDT (C/C++ Development Environment inklusive Eclipse standalone Debugger),
   UML (Papyrus mit Papyrus-Designer (CPP- und Java-Codeerzeugung),
   OCL-Tools (Object Constraint Language),
   CDT-Linux Tools (für Gcov, Gprof, Perf, Valgrind, ...),
   PyDev (Python),
   D Development Tools (mit gesondert installiertem dmd, dub),
   Scala,
   Kotlin,
   OcaIDE (Ocaml),
   ...,
   CUTE (C++ Unit-Tests),
   cppcheclipse (mit gesondert installierte cppcheck)
```

Hinweis zur Installation auf dem eigenen Linux-Notebook:

Eclipse Downloads (Download Packages):



Installiere *Eclipse Modeling Tools*, (zur Zeit die Version Oxygen 1 durch Download der Datei `eclipse-modeling-oxygen-1-linux-gtk-x86_64.tar.gz` von `http://www.eclipse.org/downloads/`, installiere sie mittels:

```
/Downloads> gunzip eclipse-modeling-oxygen-1-linux-gtk-x86_64.tar.gz
buhl@rhea3:~/Downloads> ls -al ec*
-rw-r--r-- 1 buhl users 495882240 22. Aug 09:05 eclipse-modeling-oxygen-1-
    linux-gtk-x86_64.tar
```

wechsle ins Zielverzeichnis für selbstinstallierte Software (etwa `$HOME/sw`) und entpacke `eclipse` dorthin:

```
~/sw> tar xf ~/Downloads/eclipse-modeling-oxygen-1-linux-gtk-x86_64.tar
~/sw> ls -al
drwxr-xr-x  9 buhl users  4096 19. Feb 09:36 eclipse
~/sw> mv eclipse eclipse-modeling-oxygen-1-linux-gtk-x86_64
~/sw> cd ~/bin
```

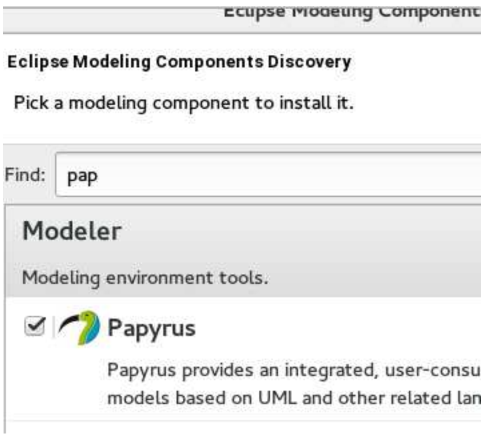
Erzeuge in `S$HOME/bin` ein Startskript $HOME/bin/eclipse-papyruso1 mit dem Inhalt:

```
#!/bin/sh
#
$HOME/sw/eclipse-modeling-oxygen-1-linux-gtk-x86_64/eclipse $*
```

und gib ihm Ausführbarkeitsrechte:

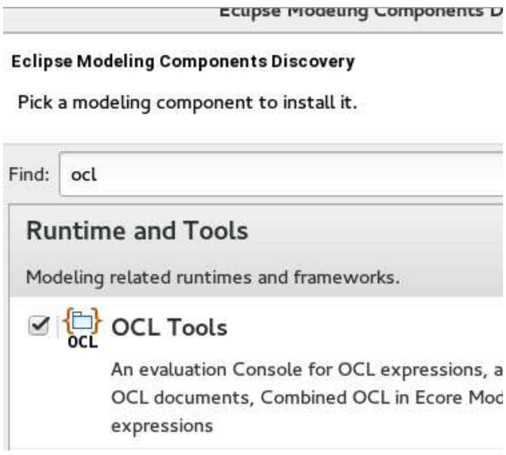
```
~/bin> chmod 755 $HOME/bin/eclipse-papyruso1
```

Ergänze dann unter `Help, Install Modelling Components` das UML-Tool `Papyrus` (für die Erstellung von UML-Modellen):



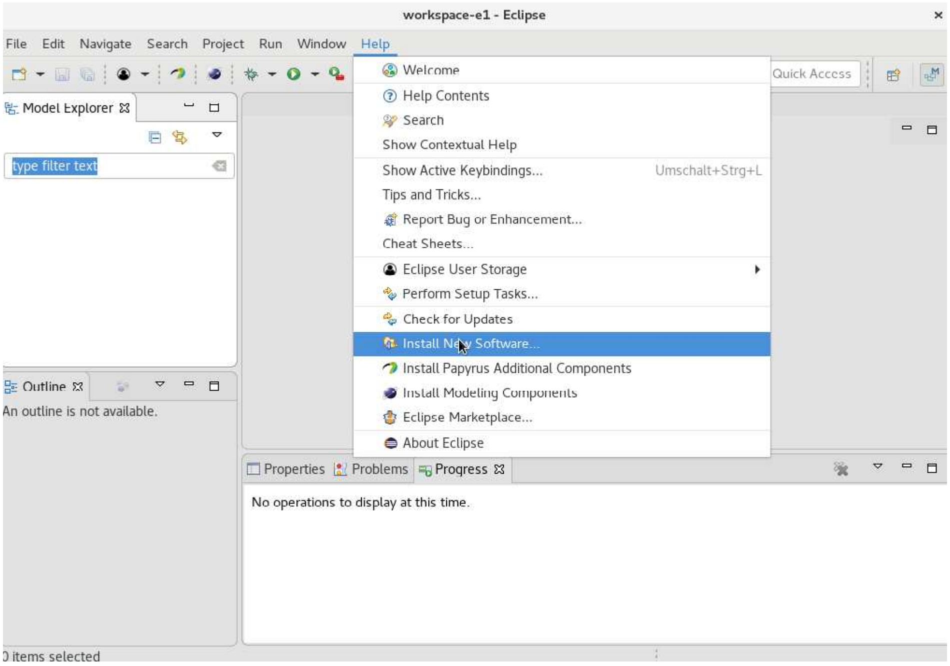
⋮

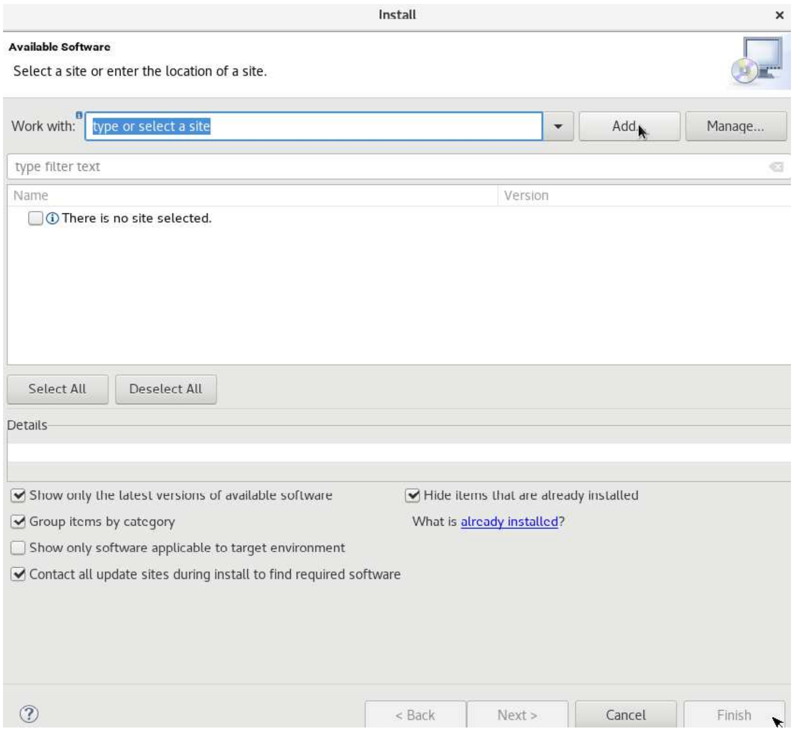
ergänze dann die `OCL Tools` zur Erstellung von formalen Constraints (Codeverträge an die UML-Komponenten):

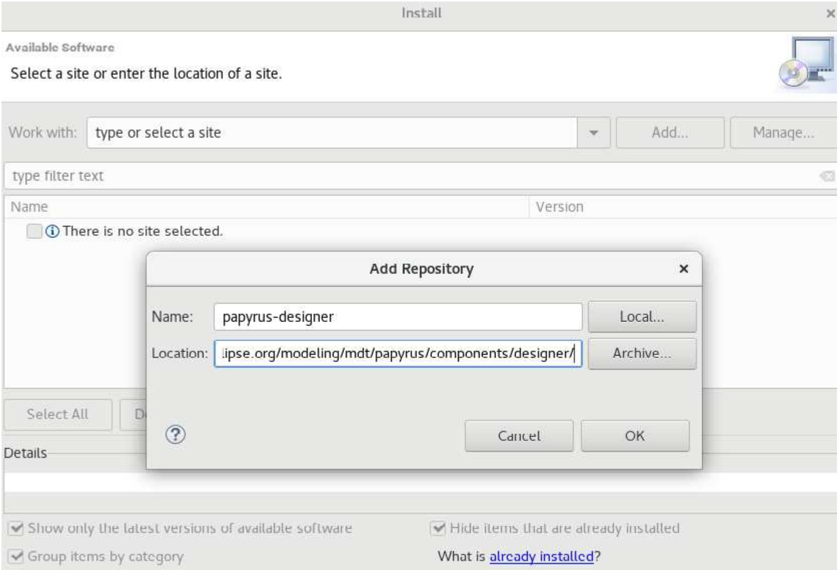


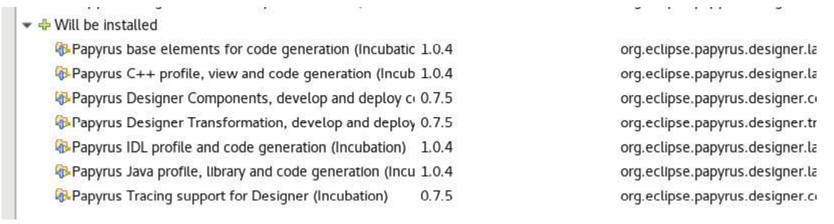
aktualisiere Papyrus unter `Help, Check for updates`, falls nötig, ergänze unter `Help, Install New Software, Add` den C/C++-Designer (zur Codeerzeugung unter CDT und JAVA):

```
papyrus-designer
http://download.eclipse.org/modeling/mdt/papyrus/components/designer/
```



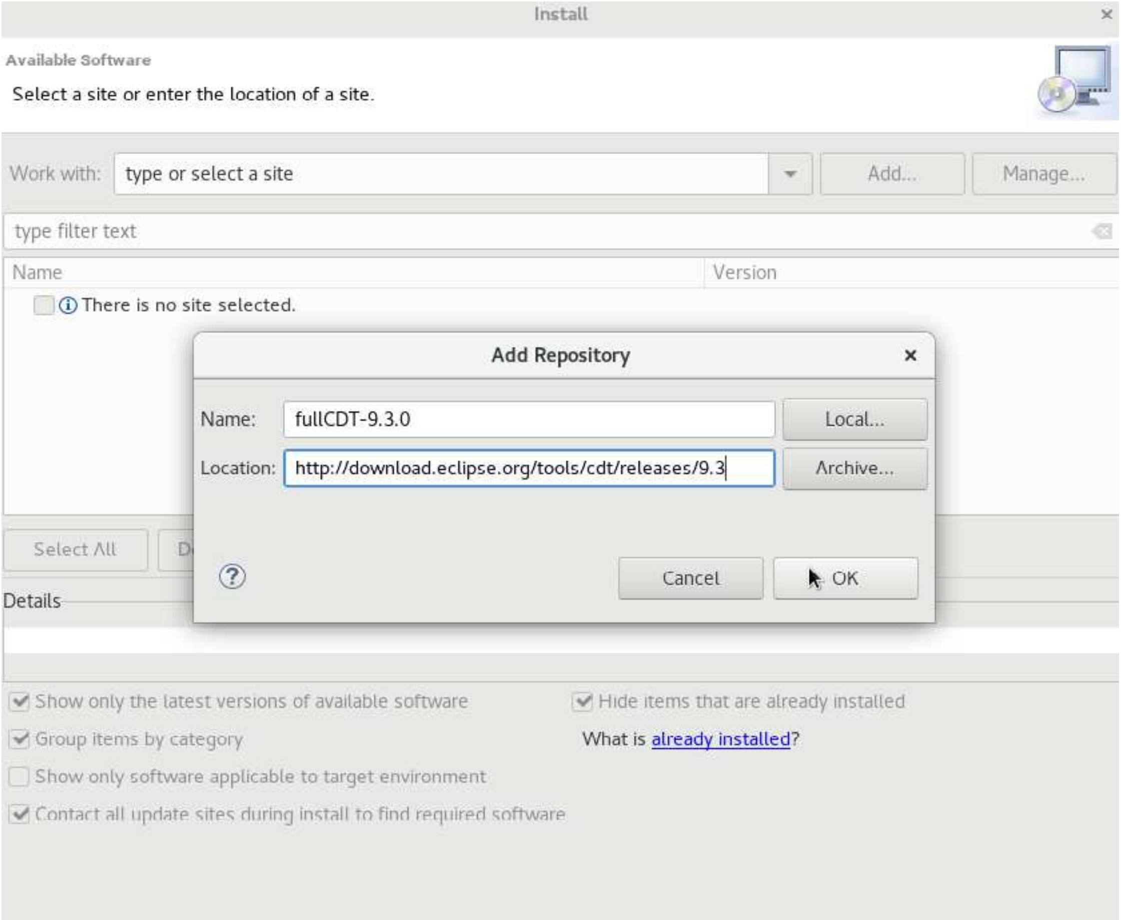






ergänze unter `Help, Install New Software, Add`

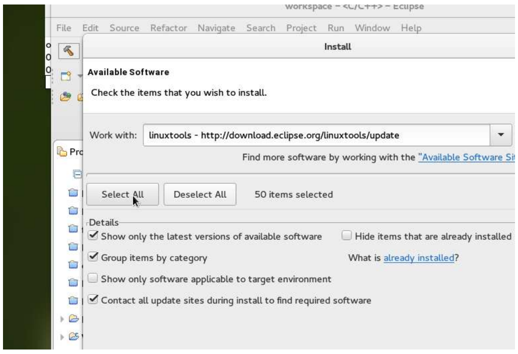
```
full CDT 9.3.0
http://download.eclipse.org/tools/cdt/releases/9.3
```



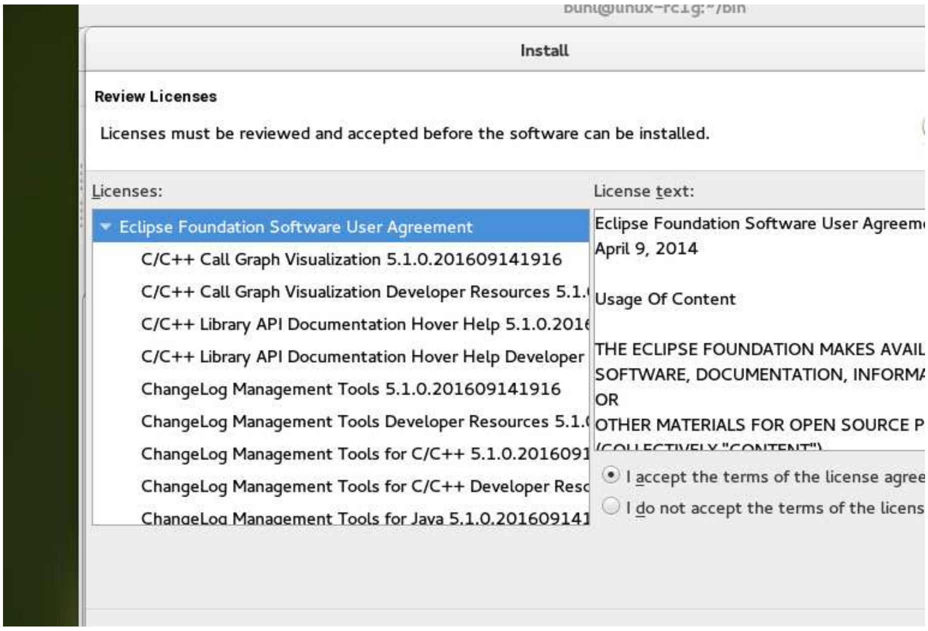
und wähle mittels `Select All` das volle CDT-Plugin aus
und installiere es,

ergänze unter `Help, Install New Software, Add`

```
linuxtools
http://download.eclipse.org/linuxtools/update
```



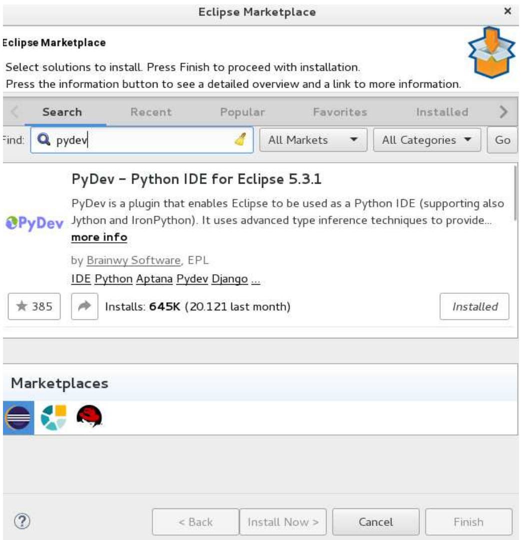
das Linuxtools-Repositorium und wähle `Select All` an:



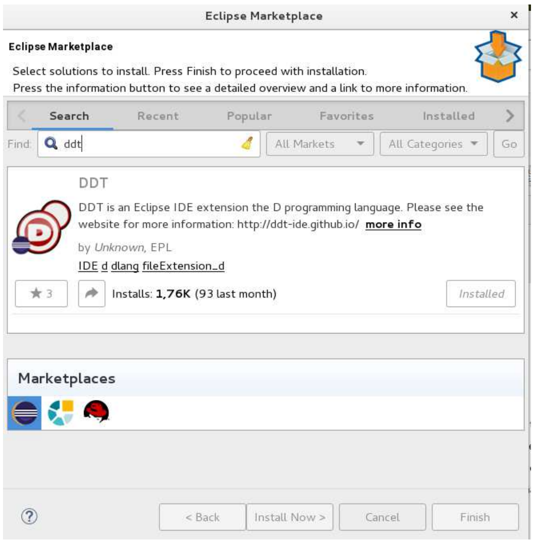
Die Linuxtools bieten Eclipse-Integration qualitätssteigernder Tools für die C++-Entwicklung:

- Callgraph
- ChangeLog
- GProf
- Gcov (oder lcov)
- Libhover
- Man Page
- LTTng
- OProfile
- Perf
- Systemtap
- Valgrind

Bei Bedarf kann man unter `Help, Eclipse Marketplace` schließlich noch die `Python-`Entwicklungsumgebung

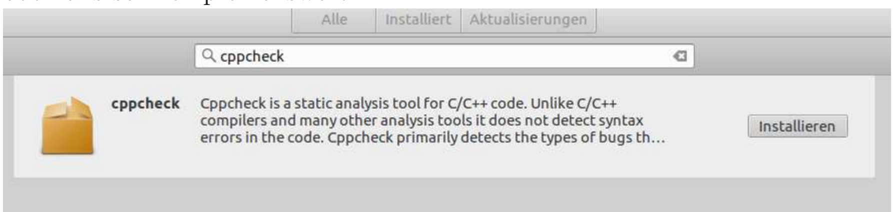


und `D-Unterstützung` (sofern auf Ihrer Maschine `dmd` und `dub` installiert sind)



und ... hinzuinstallieren.
(Vorinstalliert auf den Ausbildungsclustern der Fachgruppe als `eclipse-papyruso` sind zum Beispiel zusätzlich: `Scala, Kotlin, OcaIDE (für Ocaml)` sowie `Cute`.)

`cppcheclipse` (`Eclipse-Marketplace` Plugin für cppcheck) ist nach Installation von cppcheck ebenfalls sehr empfehlenswert:



Getting started with CDT development
CDT Documentation, Tutorials, ...
Eclipse CDT (C/C++ Development Tooling)
Eclipse für C/C++-Programmierer, dritte Auflage

Hinweis zu verfügbaren Softwareentwicklungssystemen:
GNU g++ für Linux
gcc7 vor den Toren
Compiler: GCC 7.1 kennt die Sprachfeatures von C++17
GCC, the GNU Compiler Collection
C++17: Standardbibliotheksänderungen

Cygwin für Windows, Cygwin
mingw-64
Windows 10 Linux-Subsystem
C++17 Features In Visual Studio 2017 Version 15.3 Preview

Microsoft Imagine (früher MSDNAA): VisualStudio 201x für Windows

B. Ausblick

Concepts-Lite — experimental branch of the GCC C++ compiler
Concepts Lite — Constraining Template Arguments with Predicates, Presentation
Concepts Lite — Constraining Template Arguments with Predicates, Paper
A Concept Design for the STL