C++1z: Concepts-Lite

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slides: http://wiki.hsr.ch/PeterSommerlad/

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Credo:

- **Work Areas**
  - Refactoring Tools (C++, Scala, ...) for Eclipse
  - Decremental Development (make SW 10% its size!)
  - C++ (ISO C++ committee member)
- **Pattern Books (co-author)**
  - Pattern-oriented Software Architecture Vol. 1
  - Security Patterns
- **Background**
  - Diplom-Informatiker / MSc CS (Univ. Frankfurt/M)
  - Siemens Corporate Research - Munich
  - itopia corporate information technology, Zurich
  - Professor for Software Engineering, HSR Rapperswil, Director Institute for Software

- **People create Software**
  - communication
  - feedback
  - courage
- **Experience through Practice**
  - programming is a trade
  - Patterns encapsulate practical experience
- **Pragmatic Programming**
  - test-driven development
  - automated development
  - Simplicity: fight complexity

What is a concept?

- The STL defined many "concepts" for template parameters since the 1990s, e.g.,
  - ForwardIterator
  - SequenceContainer
  - UnaryFunction
- The language standard defines concepts as type categories:
  - integer types, arithmetic types, ...

Template Argument's Concepts

```
template <typename T>
T const& min(T const& a, T const& b){
   return (a < b)? a : b ;
}
```

what is the concept of type T in min()?

- Requirements on a template's typename parameter are given implicitly by its usage.
- Such implicit requirements are called the "concept" of the template parameter
  - fulfillment is only checked when template is used, i.e., min() is called with a type

Concept for min()'s T

defines the concept of type T in min()?

```
template <typename T>
T const& min(T const& a, T const& b){
  return (a < b)? a : b ;
}
```

- operator<(T const&, T const&) must be defined
  - or operator<(T,T)
  - and it must return a value convertible to bool
  - void operator<(T, T) would be impossible

What is the concept for max()'s T?

```cpp
template <typename T>
T max(T a, T b){
   return a < b ? b : a;
}
```

- operator<(T const&, T const&) must be defined
  - or operator<(T,T)
  - and it must return a value convertible to bool
- What else?

Concept LessThanComparable

```
template <typename LTC>
concept bool LessThanComparable() {
   return requires(LTC a, LTC b) {
      { a < b } -> bool;
   };
}
```

```
template <typename T>
requires LessThanComparable<T>()
T const &max(T const &a, T const &b)
{
   return (a < b)?b:a;
}
```

```
template <typename T>
T max(T a, T b){
   return a < b ? b : a;
}
```

```
template <LessThanComparable T>
T const &min(T const &a, T const &b)
{
   return (a<b)?a:b;
}
```

What does a concept provide?

- A concept for a type denotes the allowed operations on values of that type or usages of that type in specific contexts
  - Those are rules in the standard to be enforced by compilers and the library
  - If not followed, often "undefined behavior"
- However, C++ language support for concepts of the library is only available through clumsy workarounds with traits, i.e.,
  - `iterator_traits<iteratortype>::iterator_category`

Why do we want concepts?

- In contrast to regular function parameters that have a type
  - `void foo(int i)`
- template typename parameters are unconstrained
  - `template <typename T> void foo(T)`
- calling foo with the wrong type argument can result in compile errors, depending on foo's implementation

Benefits of unconstrained templates

- Better reuse
  - can use templates in unforeseen ways
- fostered by partial instantiation
  - only what is actually used is instantiated
- enabling "conditional compilation" through SFINAE
  - e.g., `std::enable_if<cond,type>` return types or parameter types for function overloads to select implementations in a generic way

Drawbacks of unconstrained templates

- potentially late and unintelligible error messages
  - not where the mistake is made by the user, but deeply nested in a library
- `enable_if` is hard to teach and apply
  - and might get overused
    - for functions overloading might be better
- Debugging compilation problems of template programs that make use of SFINAE and partial specialization is tricky (minimal mistake can lead to enormous error message)
- Many more...

Dreams of template library authors

- Specify that a template argument must follow some rules explicitly
  - not implicitly by its usage in the template
- Early error messages when misapplied
  - not in deeply nested template instantiations
- Have a type system for template (template) parameters
  - constrain usages, guide template users

Why concepts are hard?

fine ⟷ coarse

- Getting the granularity right is problematic:
  - too coarse: templates become less reusable
    - too stringent on individual template argument, i.e., when only partial functionality of a class is actually needed
  - too fine: concept explosion leads to chaos
    - combining the right concepts and knowing them is hard (-> let to abandonment of concepts for C++0x)

New approach: concepts-lite

- Stage introduction of concepts into C++:

1. **introduce syntax to establish syntactic constraints on template arguments (concepts-lite)**
2. **adapt or rewrite standard library to gain experience**
3. **establish "full-fledged" concepts with semantic constraints and template definition checking as language feature and adapt library**

How will it look like?

- Provide implicit constraints on template typename or template parameters through using a concept name instead of "typename"

- ```
  template<Integral INT> void foo(INT i)
  ```

- ```
  template<SameType ...Args>
  auto make_vector_from_values(Args... values)
  ```

- ```
  template<Sortable CONTAINER>
  void sort(CONTAINER &c)
  ```
  ```

Details unfolded

- Specifying a `concept`
- Defining concepts using constraints
- Constraining code through requirements

- Deeper details: ordering of requirements, overloading viability, specialization order, member requirements

Specifying a concept

```
template <typename ADD, typename ADD2=ADD>
 concept bool Addable(){
        return requires(ADD a, ADD2 b){
                a+b;
        };
}
```

introduces parameters

syntactic requirement

- A concept looks like a constexpr bool function
  - constexpr function syntax was first proposed, currently concept is a separate thing
  - still some discussion on syntax is going on
- requires(){}; -> specifies constraints
  - all elements in list must be fulfilled

Specifying a requirement

```
template < typename ADD, typename ADD2=ADD>
requires Addable<ADD, ADD2>()
ADD add(ADD a, ADD2 b)
{
        return a+b;
}
```

current syntax requires () here to refer to concept

- requires clauses specify requirements on template parameters
- works for function templates, template classes
- member functions of template classes
  - special syntax before body

requirement for member of template

```
template <typename T>
struct Vec : std::vector<T> {
using std::vector<T>::vector;
T sum() const requires Addable<T>() {
        T res{};
        for(auto x:*this){ res = res + x ; }
        return res;
}
};
```

current syntax requires () here to refer to concept

- member functions of template classes
  - special syntax just before body
  - after a trailing return type (->T)

Shorthand for requires clause

```
template <typename ADD>
concept bool Addable1(){
   return requires(ADD a, ADD b){
     a+b;
   };
}
template <Addable1 ADD>
ADD add1(ADD a, ADD b)
{
       return a+b;
}
```

shorthand instead of typename

shorthand instead of type

```
auto twice(Addable a)
{
       return a+a;
}
```

- You can use a concept's name instead of typename when defining templates
- For functions/lambdas you can even use it as pseudo parameter type (not implemented yet)

requires clause: Allowed checks

- concept checks ("call concept function")
- requires expressions
- "atomic propositions"
  - any other constant expression -> bool
  - e.g. from type_traits
  - constexpr function calls
- conjunction && and disjunction ||

requires clause: combined concepts

- clause is a constant expression evaluating to bool, but only some operators are allowed:
- Conjunction: && - both satisfied
  - no overloaded operator&&()
- Disjunction: || - at least one satisfied
  - no overloaded operator||()
- NO logical negation allowed
  - would make ordering impossible

Overloading with concepts

Substitution-Failure Is Not An Error

- Like with SFINAE you can select overloads with concept requirements
  - a viable function without satisfied concept is not chosen
- Unlike SFINAE constrained templates are ordered by how "specialized" a constraint is
  - "more specialized" match is chosen

Example overload selection

```
#include <iostream>

template <typename T>
bool concept is_red() {
   return requires (T a) {
   a.red();
};
}
template <typename T>
bool concept is_green() {
   return requires (T a) {
   ++a;
};
}

template <typename T>
requires is_green<T>()
auto doit(T t){
std::cout << "doit with green\n";
return ++t;
}
```

```
template <typename T>
auto doit(T t) {
std::cout << "doit without green
\n";
return t;
}
template <typename T>
requires is_red<T>()
auto doit(T t) {
std::cout << "doit with red\n";
return t;
}
struct Green{void operator++(){}};
struct Red{void red() const {}};
struct Blue{};
int main(){
   doit(5); // green
   doit(Red{}); // red
   doit(Green{}); // green
   doit(Blue{}); // without green
}
```

Template Specialization: concepts

```
template<typename T> class S { };
template<Integer T> class S<T> { }; // #1 -> A
template<Unsigned_integer T> class S<T> { }; // #2->B-> more special
// compiler internal rewrite to determine ordering:
template<Integer T> void f(S<T>); // A
template<Unsigned_integer T> void f(S<T>); // B more specialized
```

- class template specializations are ordered towards "more specialized"
  - but only if constraints are satisfied
  - non-satisfied constraint hides specialization, like with SFINAE
- Logic determined through ordering of pseudo-function template definitions using constraints

requires expressions: what?

- requires expression can provide a list of syntactical requirements or nested requires expressions.
  - simple: expression requiring syntax:
    - a++;
  - compound: { expression } -> result_type
    - { *it } -> Value_type<ITER> const &
  - type: type existence guarantee
    - typename Value_type<ITER>;
  - nested: requires(params) { ... }

A complicated example

```
#include <iterator>
#include <algorithm>
template <typename ITER>
using Value_type=typename
std::iterator_traits<ITER>::value_type;
template <typename ITER>
using IterCategory=typename
std::iterator_traits<ITER>::iterator_category;

template <typename ITER>
concept bool Iterator() {
return requires(ITER it, ITER end){
    IterCategory<ITER>();
    { *it++ } -> Value_type<ITER>;
    { it != end } -> bool;
};
}
template <typename OITER>
concept bool OutputIterator() {
return requires(OITER out){
    {IterCategory<OITER>()}->std::output_iterator_tag;
    *out = Value_type<OITER>();
    ++out;
};
}
template <Iterator ITER>
concept bool ForwardIterator() {
return requires(ITER it, ITER end){
    { std::iterator_traits<ITER>::iterator_category() }
      -> std::forward_iterator_tag;
};
}
```

```
template <ForwardIterator ITER>
requires OutputIterator<ITER>()
concept bool WritableRandomAccessIterator()
{
return requires(ITER it) {
    { it[0] } -> Value_type<ITER>;
};
}

template <WritableRandomAccessIterator ITER>
void mysort(ITER b, ITER e) {
    std::sort(b,e);
}
```

```
#include "iterator.h"
#include <vector>
#include <list>

int main(){
    std::vector<int>
      v{3,1,4,1,5,9,2,6};
    mysort(v.begin(),v.end());
    std::list<int> l{3,1,4,1,5,9,2,6};
//  mysort(l.begin(),l.end()); // fails
}
```

More experiments...

- What do you want to know?

Microsoft's roadmap (2013)

Conformance roadmap: The road to C++14 *wave*

VC++ 2013 Preview today	**VC++ 2013 RTM** later this year	**Post-RTM CTP** What we're currently implementing, roughly in order… *some subset* in CTP		**Planned** What's next for full conformance	
Explicit conversion operators	Non-static data member initializers	__func__ Extended sizeof	Thread-safe function local static init	Unrestricted unions	Attributes
Raw string literals	= default	Implicit move generation	User-defined literals	Universal character names in literals	thread_local
Function template default arguments	= delete	Ref-qualifiers: & and && for *this	noexcept	Expression SFINAE	C++11 preprocessor (incl. C++98 & C11)
Delegating constructors	"using" aliases C++14 libs: type aliases	C++14 generalized lambda capture	alignof alignas	Inheriting constructors	C++98 two-phase lookup
Uniform init & initializer_lists	C99 variable decls C99 _Bool	C++14 auto function return type deduction	constexpr (except ctors / literal types)	constexpr (literal types)	C++14 generalized constexpr
Variadic templates	C99 compound literals	C++14 generic lambdas	C++14 decltype(auto)	Inline namespaces	C++14 dyn. arrays C++14 var templates
C++14 libs: cbegin/ greater<>/make_unique	C99 designated initializers	**C++TS? async/await**	C++14 libs: std:: user-defined literals	char16_t, char32_t	**C++TS concepts lite**

- Tough job: oldest compiler code base!

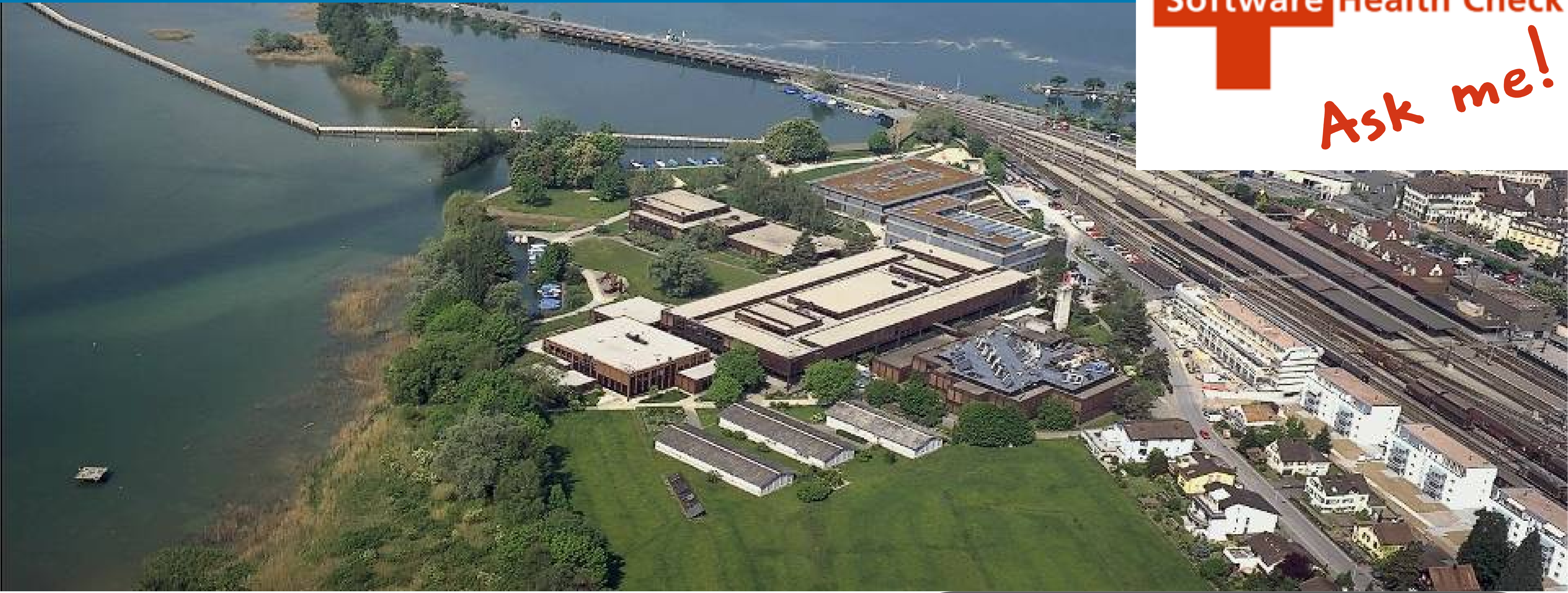
Round up

- Concepts will come for C++ (only ‘?’ when?)
  - even though there are "bike-shed" discussions on syntax
- Early implementation not yet complete
  - stay tuned -> http://concepts.axiomatics.org/
- "Conceptifying" the standard library will come as a second step and may result in a new STL with ranges etc.

Questions ?

Software Health Check

Ask me!



- http://cevelop.com (soon!)
- http://cute-test.com http://mockator.com
- http://linticator.com http://includator.com
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Have Fun with C++
Try TDD, Mockator
and Refactoring!