



Concept proposal comparison

N1899 = 05-0159

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Papers

- N1510 etc: *outline of design space*.
Bjarne and Gaby, 2003
- N1849: *Indiana proposal*.
Doug et al, August 2005.
- N1782 and N1886: *Texas proposal*.
Bjarne and Gaby, 2005.



Common approach



Goals

- Better error detection
 - Separate error checking
 - Simpler and earlier instantiation errors
- Express documentation in code
- Concept-based overloading



Basic scheme

- Declare *concept*: requirement on type or types
- *Model assertion*: declare that a type, or family of types, satisfies a concept
- *Constrained template*: arguments must satisfy a concept



Declaring a concept

- Parameters: types it's constraining
 - List of operations the parameters must provide
 - Associated types, and constraints on them.
 - Refinement
- Rejected approaches:
 - base class
 - exact signature



Model assertions

- Assert that a type (or family) models a concept
- Assertion failure is an error
- Can be used for syntax rewriting
- Concept author gets to say whether it's mandatory or optional



Constrained templates

- where clause
 - Assert that argument(s) used for instantiation model(s) a concept
 - Multiple assertions allowed
 - Syntactic sugar: omit where for one-argument concepts
- Type check at definition time
- Concept matching at instantiation time



Separate type checking

- We check types in at least three places
- Soundness:

“If a constrained template definition concept checks and if its uses both concept check and type check then its instantiations for those uses also type check.”



Overloading on concepts

- Attempt concept matching on all overloads
- No matches \Rightarrow error
- One match \Rightarrow choose it
- Multiple matches
 - One best match \Rightarrow choose it
 - Otherwise error



Sample code



Defining a concept: TAMU

```
concept Input_iterator<Trivial_iterator Iter>
  where Equality_comparable<Iter>
    && Assignable<Iter>
    && Arrow<Iter> {
  Integer difference_type;
  Var<Iter> p;
  const Iter::value_type& v = *p;
  const Iter::value_type& v2 = *p++;
};
```



Defining a concept: IU

```
template <typename X>
concept InputIterator : IteratorAssociatedTypes<X>.
    CopyConstructible<X>,
    Assignable<X>,
    EqualityComparable<X> {
    where SignedIntegral<difference_type>;
    where Convertible<reference, value_type>;
    where Arrowable<pointer, value_type>;

    typename postincrement_result = X;
    where Dereferenceable<postincrement_result, value_type>;

    pointer operator->(X);
    X& operator++(X&);
    postincrement_result operator++(X&, int);
    reference operator*(const X&);
};
```



Defining a template: TAMU

```
template <Forward_iterator Iter, typename T>  
    where Assignable<Iter::value_type, T>  
void fill(Iter first, Iter last, const T& t) {  
    ...  
}
```



Defining a template: IU

```
template <Forward_iterator Iter, typename T>
    where { Assignable<value_type, T> }
void fill(Iter first, Iter last, const T& t) {
    ...
}
```



Model assertion: TAMU

```
concept MyConcept<typename T> {  
    ...  
};
```

```
// optional  
static_assert template <typename T> !MyConcept<T>;  
...
```

```
static_assert MyConcept<MyType>;
```




Model assertion: IU

```
template <typename T>  
/* struct */ concept MyConcept {  
    ...  
};
```

...

```
template<> concept MyConcept<MyType>;
```

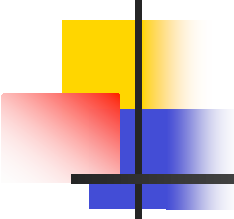


Differences



Summary

- Use patterns (valid expressions) vs pseudosignatures (abstract signatures)
- Implicit checking vs nominal conformance
- Concept composition: disjunction and negation?
- Builtin same-type requirement
- Model assertions for as-yet-undeclared types
- Default definitions in concepts
- Syntactic differences
 - Refinement: special support, or just where clause and conjunction?
 - Associated types in concepts vs concept parameters



Usage patterns vs pseudosignatures

- Believed to have equivalent expressive power
 - Can map a valid expression to pseudosignatures by introducing auxiliary associated types
 - Is there an algorithm for mapping the other way?
- Is this purely a syntactic difference?



Usage patterns vs pseudosignatures

Usage pattern warts	Pseudosignature warts
Can't express \rightarrow	Exactly how pseudo is it?
Special-case syntax for variables	Less traditional for generic programming
No clean syntactic hook for extra stuff	Hard to express $a*b+c$
Less precise	Invites overspecification



Syntax remapping (both proposals)

```
template <typename T>
concept X {
    typename type;
    T foo(const T&);
};
```

...

```
template<> concept X<MyType> {
    typedef MyType::type type;
    T foo(const T& t) { return t.Foo(); }
};
```



Default definitions in concept (IU only)

```
template <typename T>
concept Comparable {
    bool operator<(const T&, const T&);
    bool operator>(const T& x, const T& y) {
        return y < x;
    }
};
```

```
// A type that models Comparable only needs to
// provide <.
```



Implicit checking vs nominal conformance

- Both proposals provide both forms
- Author of concept chooses which form is used
- Defaults differ
 - TAMU: use negative assertion to request nominal conformance
 - IU: use struct concept to request implicit checking



Why nominal conformance might just be workable

```
template<typename OldIter>  
where {Convertible<typename std::iterator_traits<OldIter>::category*,  
                std::random_access_iterator_tag*> }  
model RandomAccessIterator<OldIter> {};
```

- Very broad model declaration
- Applies even to types we haven't seen yet



Why implicit checking might just be workable

Use negative assertions to distinguish between concepts that differ only in semantics

```
concept InputIterator<typename Iter> { ... };  
concept ForwardIterator<InputIter Iter> { };
```

```
static_assert  
template <ValueType T>  
    !ForwardIterator<std::istream_iterator<T> >;
```



Combining where clauses

- IU: conjunction only
- TAMU: conjunction, disjunction, negation
 - Negation: probably not necessary except to choose nominal conformance
 - Disjunction: harder call



Disjunction

- **Argument for:**

```
template<C1 T> void helper(T x);  
template<C2 T> void helper(T x);
```

```
template<C0 T> void foo(T x) where C1<T> || C2<T> {  
    ...  
    helper(x);  
}
```

- **Argument against:**

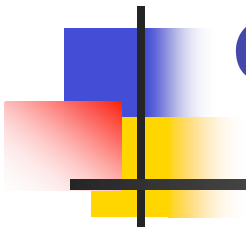
- **Aesthetic:** should factor out into a base concept
- **Essentially splits template into duplicates**
- **Unclear what to do in case of multiple matches**



Philosophy: reification of concepts and models

- IU: model is “the realization of a concept.”
- TAMU: assert “explicit checking of conformance of a type with respect to a concept.” Model not mentioned as a noun.
- *Is a model a thing? A concept?*

Technical challenges and open issues





Soundness and name lookup

- Soundness: type-check a constrained template at definition time, not instantiation time
- \Rightarrow All name lookup at definition time
- Tension with areas where we might want later lookup



Name lookup in templates

- Today's templates: two-phase name lookup
- Constrained templates
 - Dependent name found in concept: use it
 - Dependent name not mentioned in concept: what do we do?



The helper function problem

```
template <ForwardIterator FI>
bool binary_search(FI first, FI last) {
    ...
    advance(first, n);
}
```

- We want the random access version of advance when appropriate
- What type lookup rules will ensure that, and also ensure soundness?



The ambiguity problem

```
template <class T> where TrivialIterator<T> void foo(T& x) { ... }
```

```
template <class T> where InputIterator<T> void foo(T& x) { ... }
```

```
template <class T> where OutputIterator<T> void foo(T& x) { ... }
```

```
template <class T> where TrivialIterator<T> void bar(T& x) { foo(x); }
```

- `bar` seems to pass concept check, but fails if we call it with a forward iterator.
- How can we modify type checking rules so that `bar` won't concept check?



The specialization problem

```
template<typename T> where { CopyConstructible<T> }  
void foo(T x)  
{  
    std::vector<T> vec(1, x);  
    T& f = vec.front();  
}
```

- Foo appears to pass concept check, but might fail type check at instantiation time
- Possible solution (TAMU): forbid specialization that changes template's conformance to requirements



Can we prove a soundness theorem?

- IU: yes for System F^G , no for C++ as it stands now
- TAMU: yes, but
 - Proof isn't yet complete
 - May require restrictions on specialization



Other open questions

- Implications for expression templates
- Is concept-safe template metaprogramming possible?



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