Foundational Concepts for the C++0x Standard Library (Revision 5)

Authors: Douglas Gregor, Indiana University
Mat Marcus, Adobe Systems, Inc.
Thomas Witt, Zephyr Associates, Inc.
Andrew Lumsdaine, Indiana University
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Reply-to: Douglas Gregor <dgregor@osl.iu.edu>

Introduction

This document proposes basic support for concepts in the C++0x Standard Library. It describes a new header `<concepts>` that contains concepts that require compiler support (such as `SameType` and `ObjectType`) and concepts that describe common type behaviors likely to be used in many templates, including those in the Standard Library (such as `CopyConstructible` and `EqualityComparable`).

Within the proposed wording, text that has been added will be presented in blue and underlined when possible. Text that has been removed will be presented in red,~~with strike-through when possible~~.

Purely editorial comments will be written in a separate, shaded box.

Changes from N2737

— Changed the `operator*` associated function in `HasDereference` from:

```
result_type operator*(const T&);
```

to

```
result_type operator*(T&&);
```

to better match with the dereference operator in `Iterator`. See Daniel Krügler's message c++std-lib-22198 on the reflector for rationale.

— Several updates to properly cope with abstract classes, thanks to Daniel Krügler:

  — Add a restriction to [concept.transform] that prohibits users from adding concept maps for these concepts.

— Remove `TriviallyEqualityComparable` concept to be renamed and moved to atomics

— Change `ArithmeticLike` to refine from `LessThanComparable` rather than `HasLess`, `HasGreater`, `HasLessEqual`, and `HasGreatEqual`.

- Added the `HasSubscript` concept, from Daniel Krügler, to finish providing concepts for all overloadable operators.
- Based on the resolution to library issue 402 (and the follow-on issue 866), there is no longer a need for the `HasPlacementNew` concept in the Standard Library, so it has been removed.
- Made the `intmax_t`, `uintmax_t`, and `long double` constructors in the arithmetic concept `explicit`, resolving concepts issue #47.
- `MemberPointeeType` not longer refines `PointeeType`, because `void() const` is a `MemberPointeeType` but not a `PointeeType`. Also, `FunctionType` refines `MemberPointeeType` (not `PointeeType`), and both `PointeeType` and `ReferentType` are restricted to *cv-qualified* function types. Thanks to Peter Dimov for the acute observation!
- Fixed the requirements when dealing with abstract classes:
  - Abstract classes aren't `VariableTypes` (concepts issue #28) or `Returnable`.
  - `ObjectType` is not a `VariableType`, because you can't have a variable with abstract class type. However, an `ObjectType` is a `ReferentType` and a `PointeeType`.
  - `HasDestructor` does not refine `VariableType`, since abstract classes can have destructors (but aren't `VariableTypes`). Similarly for `ExplicitlyConvertible`.
- Added `ValueType` concept; see c++std-lib-22195. The concepts `Union`, `TrivialType`, `StandardLayoutType`, and `LiteralType` all refine this new concept.
- `VariableType` refines `ReferentType`.
- Added the `PolymorphicClass` concept (concepts issue #27), which refines `Class` and is further refined by `HasVirtualDestructor`.
- Moved the support concepts over to the core language wording.

Proposed Wording

Issues resolved by concepts

The following LWG are resolved by concepts. These issues should be resolved as NAD following the application of this proposal to the wording paper:

Issue 556. Is Compare a BinaryPredicate? With concepts, we've specified exactly what "convertible to bool" means for predicates, and all Compare objects are predicates (since they refine the Predicate concept). Short-circuiting is taken care of because the Predicate concept forces conversion to bool inside all constrained templates.

Issue 724. DefaultConstructible is not defined. The concepts proposal provides a `DefaultConstructible` concept.

Chapter 20 General utilities library [utilities]

2 The following clauses describe utility ~~and allocator~~ ~~requirements~~concepts, utility components, tuples, type traits templates, function objects, dynamic memory management utilities, and date/time utilities, as summarized in Table 30.

Table 30: General utilities library summary

Subclause	Header(s)
20.1 ~~Requirements~~Concepts	`<concepts>`
?? Utility components	`<utility>`
?? Tuples	`<tuple>`
?? Type traits	`<type_traits>`
?? Function objects	`<functional>`

?? Memory	`<memory>`
	`<cstdlib>`
	`<cstring>`

?? Date and time	`<ctime>`

Replace the section [utility.requirements] with the following section [utility.concepts]

20.1 Concepts [utility.concepts]

1 This subclause describes concepts that specify requirements on template arguments used throughout the C++ Standard Library. Concepts whose name is prefixed with `Has` provide detection of a specific syntax (e.g., `HasConstructor`), but do not imply the semantics of the corresponding operation. Concepts whose name has the `able` or `ible` suffix (e.g., `Constructible`) require both a specific syntax and semantics of the associated operations. These semantic concepts refine the corresponding syntax-detection concepts, for example, the `Constructible` concept refines the `HasConstructor` concept.

Header `<concepts>` synopsis

```
namespace std {
  // 20.1.1, type transformations:
  auto concept IdentityOf<typename T> see below;
  auto concept RvalueOf<typename T> see below;
  template<typename T> concept_map RvalueOf<T&> see below;

  // 20.1.2, true:
```

```
concept True<bool> { }
concept_map True<true> { }

// 20.1.3, operator concepts:
auto concept HasPlus<typename T, typename U> see below;
auto concept HasMinus<typename T, typename U> see below;
auto concept HasMultiply<typename T, typename U> see below;
auto concept HasDivide<typename T, typename U> see below;
auto concept HasModulus<typename T, typename U> see below;
auto concept HasUnaryPlus<typename T> see below;
auto concept HasNegate<typename T> see below;
auto concept HasLess<typename T, typename U> see below;
auto concept HasGreater<typename T, typename U> see below;
auto concept HasLessEqual<typename T, typename U> see below;
auto concept HasGreaterEqual<typename T, typename U> see below;
auto concept HasEqualTo<typename T, typename U> see below;
auto concept HasNotEqualTo<typename T, typename U> see below;
auto concept HasLogicalAnd<typename T, typename U> see below;
auto concept HasLogicalOr<typename T, typename U> see below;
auto concept HasLogicalNot<typename T> see below;
auto concept HasBitAnd<typename T, typename U> see below;
auto concept HasBitOr<typename T, typename U> see below;
auto concept HasBitXor<typename T, typename U> see below;
auto concept HasComplement<typename T> see below;
auto concept HasLeftShift<typename T, typename U> see below;
auto concept HasRightShift<typename T, typename U> see below;
auto concept HasDereference<typename T> see below;
auto concept HasAddressOf<typename T> see below;
auto concept HasSubscript<typename T, typename U> see below;
auto concept Callable<typename F, typename... Args> see below;
auto concept HasAssign<typename T, typename U> see below;
auto concept HasPlusAssign<typename T, typename U> see below;
auto concept HasMinusAssign<typename T, typename U> see below;
auto concept HasMultiplyAssign<typename T, typename U> see below;
auto concept HasDivideAssign<typename T, typename U> see below;
auto concept HasModulusAssign<typename T, typename U> see below;
auto concept HasBitAndAssign<typename T, typename U> see below;
auto concept HasBitOrAssign<typename T, typename U> see below;
auto concept HasBitXorAssign<typename T, typename U> see below;
auto concept HasLeftShiftAssign<typename T, typename U> see below;
auto concept HasRightShiftAssign<typename T, typename U> see below;
auto concept HasPreincrement<typename T> see below;
auto concept HasPostincrement<typename T> see below;
auto concept HasPredecrement<typename T> see below;
auto concept HasPostdecrement<typename T> see below;
auto concept HasComma<typename T, typename U> see below;

// 20.1.4, predicates:
auto concept Predicate<typename F, typename... Args> see below;
```

```
  // 20.1.5, comparisons:
  auto concept LessThanComparable<typename T> see below;
  auto concept EqualityComparable<typename T> see below;
  auto concept StrictWeakOrder<typename F, typename T> see below;
  auto concept EquivalenceRelation<typename F, typename T> see below;

  // 20.1.6, construction:
  auto concept HasConstructor<typename T, typename... Args> see below;
  auto concept Constructible<typename T, typename... Args> see below;
  auto concept DefaultConstructible<typename T> see below;
  concept TriviallyDefaultConstructible<typename T> see below;

  // 20.1.7, destruction:
  auto concept HasDestructor<typename T> see below;
  auto concept HasVirtualDestructor<typename T> see below;
  auto concept NothrowDestructible<typename T> see below;
  concept TriviallyDestructible<typename T> see below;

  // 20.1.8, copy and move:
  auto concept MoveConstructible<typename T> see below;
  auto concept CopyConstructible<typename T> see below;
  concept TriviallyCopyConstructible<typename T> see below;
  auto concept MoveAssignable<typename T> see below;
  auto concept CopyAssignable<typename T> see below;
  concept TriviallyCopyAssignable<typename T> see below;
  auto concept HasSwap<typename T, typename U> see below;
  auto concept Swappable<typename T> see below;

  // 20.1.9, memory allocation:
  auto concept FreeStoreAllocatable<typename T> see below;

  // 20.1.10, regular types:
  auto concept Semiregular<typename T> see below;
  auto concept Regular<typename T> see below;

  // 20.1.11, convertibility:
  auto concept ExplicitlyConvertible<typename T, typename U> see below;
  auto concept Convertible<typename T, typename U> see below;


  // 20.1.12, arithmetic concepts:
  concept ArithmeticLike<typename T> see below;
  concept IntegralLike<typename T> see below;
  concept SignedIntegralLike<typename T> see below;
  concept UnsignedIntegralLike<typename T> see below;
  concept FloatingPointLike<typename T> see below;
}
```

20.1.1 Type transformations [concept.transform]

1 The concepts in [concept.transform] provide simple type transformations that can be used within constrained templates.

2 A program shall not provide concept maps for any concept in [concept.transform].

```
auto concept IdentityOf<typename T> {
  typename type = T;
  requires SameType<type, T>;
}
```

3 *Note:* concept form of the `identity` type metafunction (**??**).

```
auto concept RvalueOf<typename T> {
  typename type = T&&;
  requires Convertible<T&, type> && Convertible<T&&, type>;
}
```

4 *Note:* describes the rvalue reference type for an arbitrary type `T`.

```
template<typename T> concept_map RvalueOf<T&> {
  typedef T&& type;
}
```

5 *Note:* provides the appropriate rvalue reference type for the rvalue an lvalue reference type. [*Note:*this concept map is required to circumvent reference collapsing for lvalue references. — *end note*]

20.1.2 True [concept.true]

```
concept True<bool> { }
concept_map True<true> { }
```

1 *Note:* used to express the requirement that a particular integral constant expression evaluate true.

2 *Requires:* a program shall not provide a concept map for the `True` concept.

20.1.3 Operator concepts [concept.operator]

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

1 *Note:* describes types with a binary `operator+`.

```
auto concept HasMinus<typename T, typename U> {
  typename result_type;
  result_type operator-(const T&, const U&);
}
```

2 *Note:* describes types with a binary `operator-`.

```
auto concept HasMultiply<typename T, typename U> {
  typename result_type;
  result_type operator*(const T&, const U&);
}
```

Note: describes types with a binary `operator*`.

```
auto concept HasDivide<typename T, typename U> {
  typename result_type;
  result_type operator/(const T&, const U&);
}
```

Note: describes types with an `operator/`.

```
auto concept HasModulus<typename T, typename U> {
  typename result_type;
  result_type operator%(const T&, const U&);
}
```

Note: describes types with an `operator%`.

```
auto concept HasUnaryPlus<typename T> {
  typename result_type;
  result_type operator+(const T&);
}
```

Note: describes types with a unary `operator+`.

```
auto concept HasNegate<typename T> {
  typename result_type;
  result_type operator-(const T&);
}
```

Note: describes types with a unary `operator-`.

```
auto concept HasLess<typename T, typename U> {
  bool operator<(const T& a, const U& b);
}
```

Note: describes types with an `operator<`.

```
auto concept HasGreater<typename T, typename U> {
  bool operator>(const T& a, const U& b);
}
```

Note: describes types with an `operator>`.

```
auto concept HasLessEqual<typename T, typename U> {
  bool operator<=(const T& a, const U& b);
}
```

Note: describes types with an `operator<=`.

```
auto concept HasGreaterEqual<typename T, typename U> {
  bool operator>=(const T& a, const U& b);
}
```

11 *Note:* describes types with an `operator>=`.

12 For the concepts `HasLess`, `HasGreater`, `HasLessEqual`, and `HasGreaterEqual`, the concept maps in namespace `std` for any pointer type yield a total order, even if the built-in operators `<`, `>`, `<=`, `>=` do not.

```
auto concept HasEqualTo<typename T, typename U> {
  bool operator==(const T& a, const U& b);
}
```

13 *Note:* describes types with an `operator==`.

```
auto concept HasNotEqualTo<typename T, typename U> {
  bool operator!=(const T& a, const U& b);
}
```

14 *Note:* describes types with an `operator!=`.

```
auto concept HasLogicalAnd<typename T, typename U> {
  bool operator&&(const T&, const U&);
}
```

15 *Note:* describes types with a logical conjunction operator.

```
auto concept HasLogicalOr<typename T, typename U> {
  bool operator||(const T&, const U&);
}
```

16 *Note:* describes types with a logical disjunction operator.

```
auto concept HasLogicalNot<typename T> {
  bool operator!(const T&);
}
```

17 *Note:* describes types with a logical negation operator.

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

18 *Note:* describes types with a binary `operator&`.

```
auto concept HasBitOr<typename T, typename U> {
  typename result_type;
  result_type operator|(const T&, const U&);
}
```

19 *Note:* describes types with an `operator|`.

```
auto concept HasBitXor<typename T, typename U> {
  typename result_type;
  result_type operator^(const T&, const U&);
}
```

Note: describes types with an `operator^`.

```
auto concept HasComplement<typename T> {
  typename result_type;
  result_type operator~(const T&);
}
```

Note: describes types with an `operator~`.

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

Note: describes types with an `operator<<`.

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

Note: describes types with an `operator>>`.

```
auto concept HasDereference<typename T> {
  typename result_type;
  result_type operator*(T&&);
}
```

Note: describes types with a dereferencing `operator*`.

```
auto concept HasAddressOf<typename T> {
  typename result_type;
  result_type operator&(T&);
}
```

Note: describes types with an address-of `operator&`.

```
auto concept HasSubscript<typename T, typename U> {
  typename result_type;
  result_type operator[](T&&, const U&);
}
```

Note: describes types with a subscript `operator[]`.

```
auto concept Callable<typename F, typename... Args> {
  typename result_type;
  result_type operator()(F&&, Args...);
}
```

27 *Note:* describes function object types callable given arguments of types `Args...`.

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

28 *Note:* describes types with an assignment operator.

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

29 *Note:* describes types with an `operator+ =`.

```
auto concept HasMinusAssign<typename T, typename U> {
  typename result_type;
  result_type operator-=(T&, U);
}
```

30 *Note:* describes types with an `operator- =`.

```
auto concept HasMultiplyAssign<typename T, typename U> {
  typename result_type;
  result_type operator*=(T&, U);
}
```

31 *Note:* describes types with an `operator* =`.

```
auto concept HasDivideAssign<typename T, typename U> {
  typename result_type;
  result_type operator/=(T&, U);
}
```

32 *Note:* describes types with an `operator/ =`.

```
auto concept HasModulusAssign<typename T, typename U> {
  typename result_type;
  result_type operator%=(T&, U);
}
```

33 *Note:* describes types with an `operator% =`.

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

34 *Note:* describes types with an `operator& =`.

```
auto concept HasBitOrAssign<typename T, typename U> {
  typename result_type;
```

```
  result_type operator|=(T&, U);
}
```

35 *Note:* describes types with an `operator|=`.

```
auto concept HasBitXorAssign<typename T, typename U> {
  typename result_type;
  result_type operator^=(T&, U);
}
```

36 *Note:* describes types with an `operator^=`.

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

37 *Note:* describes types with an `operator<<=`.

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

38 *Note:* describes types with an `operator>>=`.

```
auto concept HasPreincrement<typename T> {
  typename result_type;
  result_type operator++(T&);
}
```

39 *Note:* describes types with a pre-increment operator.

```
auto concept HasPostincrement<typename T> {
  typename result_type;
  result_type operator++(T&, int);
}
```

40 *Note:* describes types with a post-increment operator.

```
auto concept HasPredecrement<typename T> {
  typename result_type;
  result_type operator--(T&);
}
```

41 *Note:* describes types with a pre-decrement operator.

```
auto concept HasPostdecrement<typename T> {
  typename result_type;
  result_type operator--(T&, int);
}
```

42 *Note:* describes types with a post-decrement operator.

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

43 *Note:* describes types with a comma operator.

20.1.4 Predicates [concept.predicate]

```
auto concept Predicate<typename F, typename... Args> : Callable<F, const Args&...> {
  requires Convertible<result_type, bool>;
}
```

1 *Note:* describes function objects callable with some set of arguments, the result of which can be used in a context that requires a `bool`.

2 *Requires:* predicate function objects shall not apply any non-constant function through the predicate arguments.

20.1.5 Comparisons [concept.comparison]

```
auto concept LessThanComparable<typename T> : HasLess<T, T> {
  bool operator>(const T& a, const T& b) { return b < a; }
  bool operator<=(const T& a, const T& b) { return !(b < a); }
  bool operator>=(const T& a, const T& b) { return !(a < b); }

  axiom Consistency(T a, T b) {
    (a > b) == (b < a);
    (a <= b) == !(b < a);
    (a >= b) == !(a < b);
  }

  axiom Irreflexivity(T a) { (a < a) == false; }

  axiom Antisymmetry(T a, T b) {
    if (a < b)
      (b < a) == false;
  }

  axiom Transitivity(T a, T b, T c) {
    if (a < b && b < c)
      (a < c) == true;
  }

  axiom TransitivityOfEquivalence(T a, T b, T c) {
    if (!(a < b) && !(b < a) && !(b < c) && !(c < b))
      (!(a < c) && !(c < a)) == true;
  }
}
```

1 *Note:* describes types whose values can be ordered, where `operator<` is a strict weak ordering relation (**??**).

```
auto concept EqualityComparable<typename T> : HasEqualTo<T, T> {
  bool operator!=(const T& a, const T& b) { return !(a == b); }

  axiom Consistency(T a, T b) {
    (a == b) == !(a != b);
  }

  axiom Reflexivity(T a) { a == a; }

  axiom Symmetry(T a, T b) {
    if (a == b)
      b == a;
  }

  axiom Transitivity(T a, T b, T c) {
    if (a == b && b == c)
      a == c;
  }
}
```

2 *Note:* describes types whose values can be compared for equality with `operator==`, which is an equivalence relation.

```
auto concept StrictWeakOrder<typename F, typename T> : Predicate<F, T, T> {

  axiom Irreflexivity(F f, T a) { f(a, a) == false; }

  axiom Antisymmetry(F f, T a, T b) {
    if (f(a, b))
      f(b, a) == false;
  }

  axiom Transitivity(F f, T a, T b, T c) {
    if (f(a, b) && f(b, c))
      f(a, c) == true;
  }

  axiom TransitivityOfEquivalence(F f, T a, T b, T c) {
    if (!f(a, b) && !f(b, a) && !f(b, c) && !f(c, b))
      (!f(a, c) && !f(c, a)) == true;
  }
}
```

3 *Note:* describes a strict weak ordering relation (**??**), `F`, on a type `T`.

```
auto concept EquivalenceRelation<typename F, typename T> : Predicate<F, T, T> {
  axiom Reflexivity(F f, T a) { f(a, a) == true; }
```

```
  axiom Symmetry(F f, T a, T b) {
    if (f(a, b))
      f(b, a) == true;
  }

  axiom Transitivity(F f, T a, T b, T c) {
    if (f(a, b) && f(b, c))
      f(a, c) == true;
  }
}
```

4 *Note:* describes an equivalence relation, `F`, on a type `T`.

20.1.6 Construction [concept.construct]

```
auto concept HasConstructor<typename T, typename... Args> {
  T::T(Args...);
}
```

1 *Note:* describes types that can be constructed from a given set of arguments.

```
auto concept Constructible<typename T, typename... Args>
  : HasConstructor<T, Args...>, NothrowDestructible<T> { }
```

2 *Note:* describes types that can be constructed from a given set of arguments that also have a no-throw destructor.

```
auto concept DefaultConstructible<typename T> : Constructible<T> { }
```

3 *Note:* describes types for which an object can be constructed without initializing the object to any particular value.

```
concept TriviallyDefaultConstructible<typename T> : DefaultConstructible<T> { }
```

4 *Note:* describes types whose default constructor is trivial.

5 *Requires:* for every type `T` that is a trivial type (**??**) or a class type with a trivial default constructor (**??**), a concept map `TriviallyDefaultConstructible<T>` shall be implicitly defined in namespace `std`.

20.1.7 Destruction [concept.destruct]

```
auto concept HasDestructor<typename T> {
  T::~T();
}
```

1 *Note:* describes types that can be destroyed. These are scalar types, references, and class types with a public non-deleted destructor.

```
concept HasVirtualDestructor<typename T> : HasDestructor<T>, PolymorphicClass<T> { }
```

2 *Note:*describes types with a virtual destructor.

3 *Requires:*for every class type `T` that has a virtual destructor, a concept map `HasVirtualDestructor<T>` shall be implicitly defined in namespace `std`.

```
auto concept NothrowDestructible<typename T> : HasDestructor<T> { }
```

```
  T::~T() // inherited from HasDestructor<T>
```

4 *Requires:* no exception is propagated.

```
concept TriviallyDestructible<typename T> : NothrowDestructible<T> { }
```

5 *Note:* describes types whose destructors do not need to be executed when the object is destroyed.

6 *Requires:* for every type `T` that is a trivial type ([basic.types]), reference, or class type with a trivial destructor ([class.dtor]), a concept map `TriviallyDestructible<T>` shall be implicitly defined in namespace `std`.

20.1.8 Copy and move [concept.copymove]

```
auto concept MoveConstructible<typename T> : Constructible<T, T&&> {
  requires RvalueOf<T> && Constructible<T, RvalueOf<T>::type>;
}
```

1 *Note:* describes types that can move-construct an object from a value of the same type, possibly altering that value.

```
T::T(T&& rv); // note: inherited from HasConstructor<T, T&&>
```

2 *Postcondition:* the constructed `T` object is equivalent to the value of `rv` before the construction. [*Note:* there is no requirement on the value of `rv` after the construction. *— end note*]

```
auto concept CopyConstructible<typename T> : MoveConstructible<T>, Constructible<T, const T&> {
  axiom CopyPreservation(T x) {
    T(x) == x;
  }
}
```

3 *Note:* describes types with a public copy constructor.

```
concept TriviallyCopyConstructible<typename T> : CopyConstructible<T> { }
```

4 *Note:* describes types whose copy constructor is equivalent to `memcpy`.

5 *Requires:* for every type `T` that is a trivial type ([basic.types]), a reference, or a class type with a trivial copy constructor ([class.copy]), a concept map `TriviallyCopyConstructible<T>` shall be implicitly defined in namespace `std`.

```
auto concept MoveAssignable<typename T> : HasAssign<T, T&&> {
  requires RvalueOf<T> && HasAssign<T, RvalueOf<T>::type>;
}
```

6 *Note:* describes types with the ability to assign to an object from an rvalue, potentially altering the rvalue.

```
result_type T::operator=(T&& rv); // inherited from HasAssign<T, T&&>
```

7 *Postconditions:* the constructed `T` object is equivalent to the value of `rv` before the assignment. [*Note:* there is no requirement on the value of `rv` after the assignment. — *end note*]

```
auto concept CopyAssignable<typename T> : HasAssign<T, const T&>, MoveAssignable<T> {
  axiom CopyPreservation(T& x, T y) {
    (x = y, x) == y;
  }
}
```

8 *Note:* describes types with the ability to assign to an object.

The CopyAssignable requirements in N2461 specify that `operator=` must return a `T&`. This is too strong a requirement for most of the uses of `CopyAssignable`, so we have weakened `CopyAssignable` to not require anything of its return type. When we need a `T&`, we'll add that as an explicit requirement. See, e.g., the `IntegralLike` concept.

```
concept TriviallyCopyAssignable<typename T> : CopyAssignable<T> { }
```

9 *Note:* describes types whose copy-assignment operator is equivalent to `memcpy`.

10 *Requires:* for every type `T` that is a trivial type ([basic.types]) or a class type with a trivial copy assignment operator ([class.copy]), a concept map `TriviallyCopyAssignable<T>` shall be implicitly defined in namespace `std`.

```
auto concept HasSwap<typename T, typename U> {
  void swap(T, U);
}
```

11 *Note:* describes types that have a swap operation.

```
auto concept Swappable<typename T> : HasSwap<T&, T&> { }
```

12 *Note:* describes types for which two values of that type can be swapped.

```
void swap(T& t, T& u); // inherited from HasSwap<T, T>
```

13 *Postconditions:* `t` has the value originally held by `u`, and `u` has the value originally held by `t`.

20.1.9 Memory allocation [concept.memory]

```
auto concept FreeStoreAllocatable<typename T> {
  void* T::operator new(size_t size);
  void T::operator delete(void*);

  void* T::operator new[](size_t size) {
    return T::operator new(size);
  }

  void T::operator delete[](void* ptr) {
    T::operator delete(ptr);
  }

  void* T::operator new(size_t size, const nothrow_t&) {
```

```
    try {
      return T::operator new(size);
    } catch(...) {
      return 0;
    }
  }

  void* T::operator new[](size_t size, const nothrow_t&) {
    try {
      return T::operator new[](size);
    } catch(...) {
      return 0;
    }
  }

  void T::operator delete(void* ptr, const nothrow_t&) {
    T::operator delete(ptr);
  }

  void T::operator delete[](void* ptr, const nothrow_t&) {
    T::operator delete[](ptr);
  }
}
```

1 *Note:* describes types for which objects and arrays of objects can be allocated on or freed from the free store with `new` and `delete`.

20.1.10 Regular types [concept.regular]

```
auto concept Semiregular<typename T>
  : CopyConstructible<T>, CopyAssignable<T>, FreeStoreAllocatable<T> {
  requires SameType<CopyAssignable<T>::result_type, T&>;
}
```

1 *Note:* collects several common requirements supported by most types.

```
auto concept Regular<typename T>
  : Semiregular<T>, DefaultConstructible<T>, EqualityComparable<T> { }
```

2 *Note:* describes semi-regular types that are default constructible and have equality comparison operators.

20.1.11 Convertibility [concept.convertible]

```
auto concept ExplicitlyConvertible<typename T, typename U> {
  explicit operator U(const T&);
}
```

1 *Note:* describes types with a conversion (explicit or implicit) from `T` to `U`.

```
auto concept Convertible<typename T, typename U> : ExplicitlyConvertible<T, U> {
  operator U(const T&);
}
```

2 *Note:* describes types with an implicit conversion from `T` to `U`.

20.1.12 Arithmetic concepts [concept.arithmetic]

```
concept ArithmeticLike<typename T>
  : Regular<T>, LessThanComparable<T>, HasUnaryPlus<T>, HasNegate<T>,
    HasPlus<T, T>, HasMinus<T, T>, HasMultiply<T, T>, HasDivide<T, T>,
    HasPreincrement<T>, HasPostincrement<T>, HasPredecrement<T>, HasPostdecrement<T>,
    HasPlusAssign<T, const T&>, HasMinusAssign<T, const T&>,
    HasMultiplyAssign<T, const T&>, HasDivideAssign<T, const T&> {
  explicit T::T(intmax_t);
  explicit T::T(uintmax_t);
  explicit T::T(long double);

  requires Convertible<HasUnaryPlus<T>::result_type, T>
        && Convertible<HasNegate<T>::result_type, T>
        && Convertible<HasPlus<T, T>::result_type, T>
        && Convertible<HasMinus<T, T>::result_type, T>
        && Convertible<HasMultiply<T, T>::result_type, T>
        && Convertible<HasDivide<T, T>::result_type, T>
        && SameType<HasPreincrement<T>::result_type, T&>
        && SameType<HasPostincrement<T>::result_type, T>
        && SameType<HasPredecrement<T>::result_type, T&>
        && SameType<HasPostdecrement<T>::result_type, T>
        && SameType<HasPlusAssign<T, const T&>::result_type, T&>
        && SameType<HasMinusAssign<T, const T&>::result_type, T&>
        && SameType<HasMultiplyAssign<T, const T&>::result_type, T&>
        && SameType<HasDivideAssign<T, const T&>::result_type, T&>;
}
```

1 *Note:* describes types that provide all of the operations available on arithmetic types ([basic.fundamental]).

```
concept IntegralLike<typename T>
  : ArithmeticLike<T>,
    HasComplement<T>, HasModulus<T, T>, HasBitAnd<T, T>, HasBitXor<T, T>, HasBitOr<T, T>,
    HasLeftShift<T, T>, HasRightShift<T, T>
    HasModulusAssign<T, const T&>, HasLeftShiftAssign<T, const T&>, HasRightShiftAssign<T, const T&>
    HasBitAndAssign<T, const T&>, HasBitXorAssign<T, const T&>, HasBitOrAssign<T, const T&> {
  requires Convertible<HasComplement<T>::result_type, T>
        && Convertible<HasModulus<T, T>::result_type, T>
        && Convertible<HasBitAnd<T, T>::result_type, T>
        && Convertible<HasBitXor<T, T>::result_type, T>
        && Convertible<HasBitOr<T, T>::result_type, T>
        && Convertible<HasLeftShift<T, T>::result_type, T>
        && Convertible<HasRightShift<T, T>::result_type, T>
        && SameType<HasModulusAssign<T, const T&>::result_type, T&>
```

```
        && SameType<HasLeftShiftAssign<T, const T&>::result_type, T&>
        && SameType<HasRightShiftAssign<T, const T&>::result_type, T&>
        && SameType<HasBitAndAssign<T, const T&>::result_type, T&>
        && SameType<HasBitXorAssign<T, const T&>::result_type, T&>
        && SameType<HasBitOrAssign<T, const T&>::result_type, T&>;
}
```

2 *Note:* describes types that provide all of the operations available on integral types.

```
concept SignedIntegralLike<typename T> : IntegralLike<T> { }
```

3 *Note:* describes types that provide all of the operations available on signed integral types.

4 *Requires:* for every signed integral type `T` ([basic.fundamental]), including signed extended integral types, an empty concept map `SignedIntegralLike<T>` shall be defined in namespace `std`.

```
concept UnsignedIntegralLike<typename T> : IntegralLike<T> { }
```

5 *Note:* describes types that provide all of the operations available on unsigned integral types.

6 *Requires:* for every unsigned integral type `T` ([basic.fundamental]), including unsigned extended integral types, an empty concept map `UnsignedIntegralLike<T>` shall be defined in namespace `std`.

```
concept FloatingPointLike<typename T> : ArithmeticLike<T> { }
```

7 *Note:* describes floating-point types.

8 *Requires:* for every floating point type `T` ([basic.fundamental]), an empty concept map `FloatingPointLike<T>` shall be defined in namespace `std`.

Acknowledgments

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