Castor 1.1

Reference Manual

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1. Introduction

Castor is a pure C++ library that provides native support for the Logic paradigm (LP). Besides supporting LP, one of its key design goals is to allow easy mixing of LP with the other paradigms available in C++. Castor does not embed an interpreter or other logic programming engine to enable support for the logic paradigm. Instead it provides a few simple primitives which when put together enable LP. A discussion of the implementation techniques used in Castor to enable the Logic paradigm can found in the paper *"Blending the Logic Programming Paradigm into C++"*, available from http://www.mpprogramming.com.

This document serves only as a reference manual for Castor. For a tutorial on the Logic Paradigm and to get a better understanding on how to use Castor please refer to the paper *"Introduction to Logic Programming in C++"*, also available from http://www.mpprogramming.com.

Castor is a pure header library and does not require your applications to link with any additional static or shared libraries other than the standard C++ library. It does not require any language extensions or special preprocessing to enable LP. All facilities are part of the `castor` namespace. Including the header file *castor.h*, makes this namespace and all castor facilities available for use. The following is a trivial hello world program using Castor:

```
#include "castor.h"
using namespace castor;

int main() {
    write("Hello World")();
    return 0;
}
```

2. Common Terms

Logic reference: Variable of type `lref<T>`.

Plain old type (POT): All types other than `lref<T>`.

Effective type: Effective type of a logic reference `lref<T1>` is `T1`. Effective type of any other type `X` is `X` itself.

Effective value: If `t1` is a logic reference then its effective value is obtained by the expression `*t1`. Effective value of any other object `t2` is `t2` itself. The effective value of a logic reference is also known as the *referenced object*.

Relation: Typically refers to a function or member function having return type `relation` (or a type convertible to `relation)`. Sometimes it may also refer to objects of type `relation` (or a type convertible to `relation)`. The distinction, if needed, is usually inferred from the context in which the term is used.

3. Core Facilities

The Logic reference

Introduction

Template type `lref`, abbreviation for *logic reference*, provides a facility for passing values in/out of relations in the form of arguments. It is essentially a reference counted smart pointer designed to realize logic and functional programming techniques. It is not intended to substitute general purpose smart pointers (such as `std::auto_ptr` or `boost::shared_ptr`) which are primarily designed with the intent of simplifying memory management. The object referenced by a logic reference is called the *referenced object*.

A logic reference always refers to a copy of the value assigned to it. This copy is kept on the heap and can be accessed by dereferencing the lref. Initializing an `lref<T>` with another `lref<T>` (i.e. copy construction), causes both logic references to be *bound together*. Bound lrefs refer to the same object. Thus any change to the referenced object is observed by all lrefs bound to it. Lrefs can only be bound by initialization (i.e. copy construction) and not by assignment. A binding between lrefs cannot be broken. The referenced object is deallocated by the destructor of the last lref referencing it. An lref that is default constructed does not refer to any object unless a value is assigned to it. Lrefs that do not reference anything are said to be *undefined* or *uninitialized*. An initialized lref may be uninitialized by invoking the `reset` method. Resetting an lref will implicitly cause all lrefs bound with it to also be undefined. Resetting does not deallocate the referenced object.

Figure 1 below demonstrates the internal structure for the following logic references:

```
lret<int>  lref1 = 5;
lret<int>  lref2 = lref1;
lret<int>  lref3;
```

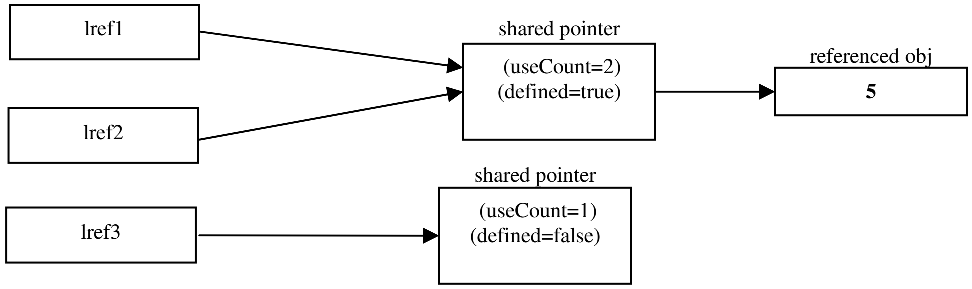


Figure 1. Internal structure of Logic References

Here `lref1` and `lref2` are bound together. They are also *defined*, as their shared pointer actually refers to an object. Since `lref3`'s shared pointer does not refer to any object, `lref3` is *undefined*.

Class Definition

```
// requires: T should support copy construction and copy assignment
template <typename T>
class lref {
public:
  typedef T result_type;
  // Construct/Copy/Destroy
  lref();
  lref(const T& value);

  template<typename T2> // requires: T provides T::T(const T2&)
  lref(const T2& value);

  lref(const lref<T>& rhs);

  ~lref();

  // Assignment
  lref& operator =(const T& newValue);

  template<typename T2>
  lref& operator=(const T2& newValue);

  lref& operator=(const lref& rhs);

  template<typename T2>
  lref& operator=(const lref<T2>& rhs);

  // Checked access
  T& operator *();
  const T& operator *();

  ..unspecified.. operator ->();
  const .. & operator ->() const ;

  // Unchecked access
  T& get();
  const T& get() const;

  // Other
  void reset();  // nothrow
  bool defined() const; // nothrow
  unsigned int use_count() const;  // nothrow
  void swap(lref<T>& other); // nothrow

}; // class lref


// Disable template instantiation of lref<T&> and lref<void>
template<> class lref<void>;

template<typename T> class lref<T&>;

// Non member swap(). Calls l.swap(r)
template<typename T>
```

```
void swap(lref<T>& l, lref<T>& r);
```

Construction, Copying and Destruction

```
lref()
```

Constructs a logic reference that does not refer to any object. An lref that does not refer to any object is said to be *undefined* or *uninitialized*. On completion, reference count is set to 1.

```
lref(const T& value)
```

Constructs a logic reference that refers to a copy of `value` on the heap. The referenced object is instantiated using the expression `new T(value)`. On completion reference count is set to 1.

```
template<typename T2> lref(const T2& value)
```

Constructs an `lref<T>` that refers to an object of type. The referenced object is instantiated using expression :

- `new T2(value)`, if `T2` is publicly derived from `T`. *OR*
- `new T(value)`, if `T` is copy constructible from `T2` (and *not* derived from `T`).

If `T2` is not derived from `T`, a converting constructor `T::T(const T2&)` must be available. On completion, reference count is set to 1. Note that this overload is invoked only when `newValue` is *not* exactly of type `T`.

```
lref(const lref<T>& rhs)
```

Constructs a logic reference that refers to the same object that is referenced by `rhs`. On completion, both lrefs will also share the same reference count which will be incremented by 1. The two logic references are now *bound together*.

```
~lref();
```

On completion, reference count is decremented by 1. If the reference count has reached 0, the referenced object (if any) will be deallocated from the heap.

Assignment semantics

From the standpoint of implementing assignment to an lref, it is possible to update the referenced object in one of the following two ways:

a. A simple assignment of `newValue` to the currently referenced object, OR
b. First deallocate the currently referenced object (if any), then allocate a new object initialized with `newValue` to replace the old object.

The first strategy is typically more efficient since it does not involve allocation and de-allocation of the referenced object. However it is not always feasible to use it. For optimization reasons, no guarantees are provided as to which of the above may actually occur. The strategy used typically depends on the types of the currently referenced object and `newValue`. For instance, the current implementation uses the following strategy to minimize calls to `new` and `delete`:

a. Use simple assignment if `lref<T>` is defined and the referenced object and `newValue` are both exactly of type `T`.

b. Otherwise, the referenced object, if any, is deallocated and replaced with a new object initialized with `newValue`. If `newValue` is of a type `T2` such that `T2` is derived from `T`, the new object is allocated using the expression `new T2(newValue)`. If `newValue` is of type `T2`, such that `T` is copy constructible from `T2` (and not derived from `T`) then the new object is allocated using the expression `new T(newValue)`.

Assignment Operators

```
lref& operator =(const T& newValue);
```

Assigns `newValue` to the logic reference. Note that this overload is invoked only when `newValue` is exactly of type `T` (and not for types derived from or copy constructible from `T`).

```
template<typename T2>
lref& operator=(const T2& newValue);
```

Assigns `newValue` to the logic reference. Note that this overload is invoked only when `T2` is publicly derived from `T`.

```
lref& operator=(const lref<T>& rhs);
```

Assigns `rhs`'s referenced object to this logic reference. This operation does *not* cause the two logic references to be bound together. Note that this overload is invoked only when the type of `rhs` is the same as this lref.

```
template<typename T2>
lref& operator=(const lref<T2>& rhs);
```

Assigns `rhs`'s referenced object to this logic reference. This operation does *not* cause the two logic references to be bound together. Note that this overload is invoked only if `T2` is *not* the same `T1` and `T2` is assignable to `T`.

Checked Access

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

Returns the referenced object. If lref is undefined, this operation throws an exception of type `InvalidDeref`.

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

Returns the referenced object. Throws `InvalidDeref` if the lref is undefined.

```
..unspecifiedType.. & operator ->();
```

This method is used to access the members of the referenced object. Exact return type is deliberately unspecified. Throws `InvalidDeref` if the lref is undefined.

```
const .. & operator ->() const ;
```

This method is used to access the members of the referenced object. Exact return type is deliberately unspecified. Throws an exception of type `InvalidDeref` if the lref is undefined.

Unchecked Access

```
T& get();
```
Returns the referenced object. If the lref is not initialized, its behavior is undefined. This method is the unchecked equivalent of `operator *`.

```
const T& get() const;
```
Returns the referenced object. If the lref is not initialized, its behavior is undefined. This method is the unchecked equivalent of `operator *`.

Other Methods

```
void reset();  // nothrow
```
This method causes the lref to be undefined. The referenced object (if any) will not be deallocated by this operation.

```
bool defined() const; // nothrow
```
Checks if the lref is currently defined.

```
unsigned int use_count() const;  // nothrow
```
Returns the total number of logic references that are bound with this lref. This value is always greater than or equal to 1.

```
void swap(lref<T>& other); // nothrow
```
Swaps the pointer to the referenced object stored in the shared pointers of the two lrefs. Use count (i.e. reference count) is not swapped.

Non member functions

```
template<typename T>
void swap(lref<T>& l, lref<T>& r);
```
Swaps the referenced objects of `l` and `r`. Semantics are same as `l.swap(r)`.

Examples:

```
// Accessing referenced object
string s="logic";
lref<string> ls1 = s, ls2 = "paradigm";
cout << *ls1 << " ";         // checked access
cout << ls2.get() << "\n";   // unchecked access

// Behavior of bound lrefs
lref<string> ls3 (ls1); // ls3 and ls1 are now bound
ls1 = "multi";
cout << *ls3;  // prints "multi"

cout << std::boolapha << ls1.defined(); // prints "true"
ls3.reset();
cout << std::boolapha << ls1.defined(); // prints "false"
ls3 = ls2; // this does not bind the two lrefs
ls2.reset();
cout << std::boolapha << ls1.defined(); // prints "true"

// Swapping lrefs
```

```
lref<int> li1 = 2;
lref<int> li2(li1); // bind
lref<int> li3;

swap(li2,li3);
cout <<  *li3 << "\n"; // prints "2"
// foll. prints: "false 2"
cout << boolalpha << li2.defined() << " " << li2.use_count() << "\n";
// foll. prints: "true 1"
cout << boolalpha << li3.defined() << " " << li3.use_count() << "\n";
```

Type relation

Introduction

The concept of a relation is to the logic paradigm what a function is to the imperative paradigm. Relations are the basic computational building blocks when programming in logic. Since C++ is based on the imperative paradigm, it is desirable to be able to describe relations as functions. Fortunately, due to the flexibility of C++, this is possible to do without extending the language. This allows relations to be given similar treatment as regular functions, facilitating the logic paradigm to blend smoothly into C++. Regular functions can be composed from other functions and relations. Similarly relations can be composed from other relations and functions[1]. The type `relation` enables this kind of integration with bare minimal syntactic overhead.

The type `relation` is typically used to specify the return type for functions and methods that represent the concept of a relation. Functions and methods with return type `relation` are themselves referred to as relations. In this manual we refer to such a function or method as a "relation" and to the type as "`relation`". (Note the difference in fonts used). The term "relation" is commonly (i.e. outside of this reference manual) used to refer to the former. The following are a few examples of relations defined using the type `relation`:

```
relation twiceOf(lref<int> x, lref<int> x2) { // non member relation
   …
}

struct Arithmetic {
    relation twiceOf(lref<int> x, lref<int> x2) { // member relation
       …
    }
};
```

From an operational semantics point of view, `relation` is used to hold function objects with return type `bool` and no arguments. A `relation` internally stores a copy of such a function object for delayed invocation. Application of the function call operator, without any arguments, on a `relation` object triggers the invocation of the stored function object. An object of type `relation` cannot be default initialized (i.e. without arguments).

[1] Composing relations from regular functions requires some care, due to the lazy evaluation semantics of relations, which is in contrast to eager evaluation semantics of regular functions.

This ensures that a `relation` is always initialized with some function object and thus it is always safe to apply the function call operator on a `relation`. A different function object can be assigned to an instance of `relation` after initialization.

Class Definition

```
class relation {
public:
    typedef bool result_type;

    // Requires : F supports method... bool F::operator()(void)
    template<class F>
    relation(F f);

    relation(const relation& rhs);

    relation& operator=(const relation& rhs);

    bool operator()(void) const;
};
```

Construction

```
    template<class F>
    relation(F f);
```

Constructs a `relation` from function object `f`. `F` is expected to support `bool F::operator()(void)`. Note, `F` must be a non-static member function type.

```
    relation(const relation& rhs);
```

Copy constructs `relation` from another. This involves storing a copy of the function object stored in `rhs`.

Other Methods

```
    relation& operator=(const relation& rhs);
```

Copies `rhs` into this `relation`.

```
    bool operator()(void) const;
```

Triggers evaluation of the internally stored function object.

Examples:

```
struct PrintHello {
    bool operator() (void) {
        cout << "Hello ";
        return true;
    }
};
struct PrintWorld {
    bool operator() (void) {
        cout << "World";
        return true;
```

```
    }
};

relation r = PrintHello();
r(); // invokes PrintHello::operator()

r = PrintHello() && PrintWorld();
r(); // invokes PrintHello::operator() then PrintWorld::operator()

relation r2; // Compiler Error! relation canot be default initialized.
```

Unification Support

Introduction

Logic paradigm uses a general purpose problem solving technique for evaluating relations to perform computation. This technique involves two fundamental operations: unification and backtracking. In a nutshell, these two operations can be described as follows:

- Backtracking determines which path of evaluation should be pursued next from a set of (possibly empty) available paths.
- Unification either produces results or tests if a desired result was produced.

This section only covers unification and the facilities provided in Castor to support unification. Backtracking is covered in the next section. The unification operation is simply an *attempt* to unify values of two items. The items could be logic references or plain old types (i.e. types other than `lref`). To unify two objects means to make their values equal. The definition of equality is governed by `operator ==`. When attempting to unify two objects, it may be the case that the two objects compare equally. In such a case unification succeeds trivially. Assignment of one object to another is considered only if one of the two objects is an uninitialized logic reference. The uninitialized logic reference is assigned the value of the other object thus making the two objects equal. In all other cases unification fails. Relation `eq` provides the fundamental support for unification. The semantics of unification relation `eq` is as follows:

- If both arguments are initialized, their values are compared for equality and the result of comparison is returned.
- If the only one argument is initialized, the uninitialized argument will be is assigned the value of initialized one in order to make them equal.
- If both arguments are uninitialized, an exception is thrown.

Castor provides a few unification relations. The choice of which relation to use primarily depends upon the nature of items being unified. The most basic unification support is provided by relation `eq`. Any two objects that can be compared and assigned to each other can be unified using `eq`. Unification of containers such a `std::list` with a sequence of values bounded by an iterator pair is supported by `eq_seq`. A more sophisticated facility for unification of sequences with values, iterator pairs or other sequences is provided by relation `sequence`. Relations `eq_f` and `eq_mf` provide support for unification of objects with values returned from functions and member functions respectively.

eq relation

```
//1. Unify logic references
template<typename L, typename R>
UnifyLR<L,R> eq(lref<L>& l, lref<R>& r)

template<typename L, typename R, typename Cmp>
UnifyLR<L,R,Cmp> eq(lref<L>& l, lref<R>& r, Cmp cmp)

//--- Treat char* as strings instead of pointer to a char ---

//2. Unify logic reference with char*. Used when T is an abstraction
for char* (like std::string)
template<typename T>
UnifyL<T,T> eq(const lref<T>& l, const char* r)

template<typename T, typename Cmp>
UnifyL<T,T,Cmp> eq(const lref<T>& l, const char* r, Cmp cmp)

template<typename T>
UnifyL<T,T> eq(const char* l, const lref<T>& r)

template<typename T, typename Cmp>
UnifyL<T,T,Cmp> eq(const char* l, const lref<T>& r, Cmp cmp)

//3. Unify two char* strings
Boolean eq(const char* l, const char* r)

template<typename Cmp>
Boolean eq(const char* l, const char* r, Cmp cmp)

//--- Remaining overloads provided for optimization ---

//4. Neither argument is a logic reference
template<typename L, typename R>
Boolean eq(const L& l, const R& r)

template<typename L, typename R, typename Cmp>
Boolean eq(const L& l, const R& r, Cmp cmp)

//5. one argument is a logic reference but the other is not
template<typename L, typename R>
UnifyL<L,R> eq(const lref<L>& l, const R& r)

template<typename L, typename R, typename Cmp>
UnifyL<L,R,Cmp> eq(const lref<L>& l, const R& r, Cmp cmp)

template<typename L, typename R>
UnifyL<R,L> eq(const L& l, const lref<R>& r)

template<typename L, typename R, typename Cmp>
UnifyL<R,L,Cmp> eq(const L& l, const lref<R>& r, Cmp cmp)
```

Declarative reading: `l` is equal to `r`.

Template Parameters:
`L,R,T` : Should satisfy the standard *CopyConstructible* [$20.1.3], *Assignable* [$23.1.4] and *EqualityComparable* [$20.1.1] requirements.

`Cmp` : A function or function object type which accepts two arguments of type T. Used to customize the comparison operation performed during unification.

Parameters:
`l` : [in/out] Item to be unified with `r`.
`r` : [in/out] Item to be unified with `l`.
`cmp` : [in] Binary predicate used to compare two objects of type `T`.

If both `l` and `r` are logic references, at least one of them must be initialized at the time of evaluation.

Exceptions:
`InvalidDeref` : If both `l` and `r` are not initialized at the time of evaluation.

Notes:
Relation `eq` will either check or make the two arguments equal. If both arguments are initialized to a value, then `eq` will compare them for equality and succeeds if the two are equal and fails (i.e. returns false) otherwise. If one of the arguments is *not* initialized, then the value of the other argument is assigned to it, thus making the two arguments equal. If both arguments are not initialized at the time of evaluation, an exception is thrown.

This operation of testing/assigning depending upon the whether or not the two arguments are initialized, is referred to as **unification**. Unification, in a sense, is the relational equivalent of `operator==` (which only performs a test for equality) and `operator=` (which only performs assignment). In short, relation `eq` unifies its arguments.

Examples:

```
// 1) with simple values and value types(i.e. not logic references)
eq(2,2)(); // compare 2 with 2 .. returns true
eq(1,2)(); // compare 1 with 2 .. returns false
int i=2;
eq(i,2)(); // compare value of i with 2 .. returns true

// 2) with initialized logic references
lref<int> li=2;
eq(i,li)(); // compare i with li .. returns true

// 3) with uninitialized logic references
lref<int> lj;  // note: lj is not initialized with a value
eq(lj,i)();    // lj is assigned value of i, thus initializing lj
cout<< *lj;    // prints "2"
```

```
    lref<int> lk; // at this point lk is not initialized but lj is
    eq(lj,lk)();  // lk is assigned value of lj, thus initializing lk

    lj.reset();   // uninitialize lj
    lj.reset();   // uninitialize lk
    eq(lj,lk)();  // throws InvalidDeref

    // 4) unifying containers
    lref<vector<int> > lvi;
    vector<int> vi = /* 1,2,3,4 */;
    eq(lvi,vi)();    // lvi is assigned a vector equivalent to vi
```

Also refer to:
`sequence, eq_seq, eq_f, eq_mf`

---

eq_f relation

```
// support for nullary functions
template<typename T, typename Func>
Eq_f_r<T, Func>
eq_f(const lref<T> l, Func f)

// remaining overloads support functions with up to 6 arguments
template<typename T, typename Func1, typename A1>
Eq_f_r1<T, Func1, A1>
eq_f(lref<T> l, Func1 f, const A1& a1_)

template<typename T, typename Func2, typename A1, typename A2>
Eq_f_r2<T, Func2, A1, A2>
eq_f(lref<T> l, Func2 f, const A1& a1_, const A2& a2_)

template<typename T, typename Func3, typename A1, typename A2
         , typename A3>
Eq_f_r3<T, Func3, A1, A2, A3>
eq_f(lref<T> l, Func3 f, const A1& a1_, const A2& a2_, const A3& a3_)

template<typename T, typename Func4, typename A1, typename A2
         , typename A3, typename A4>
Eq_f_r4<T, Func4, A1, A2, A3, A4>
eq_f(lref<T> l, Func4 f, const A1& a1_, const A2& a2_, const A3& a3_
     , const A4& a4_)

template<typename T, typename Func5, typename A1, typename A2
         , typename A3, typename A4, typename A5>
Eq_f_r5<T, Func5, A1, A2, A3, A4, A5>
eq_f(lref<T> l, Func5 f, const A1& a1_, const A2& a2_, const A3& a3_
     , const A4& a4_, const A5& a5_)

template<typename T, typename Func6, typename A1, typename A2
         , typename A3, typename A4, typename A5, typename A6>
Eq_f_r6<T, Func6, A1, A2, A3, A4, A5, A6>
eq_f(lref<T> l, Func6 f, const A1& a1_, const A2& a2_, const A3& a3_
     , const A4& a4_, const A5& a5_, const A6& a6_)
```

Declarative reading: `l` is equal to the value returned by invoking `f( a1_, .., aN_)`.

Template Parameters:
`T` : Any type which satisfies requirements of logic reference.
`FuncN` : A function pointer or function object type with arity *N*. Parameter types cannot be lref.
`An` : Type of argument passed at position *n* to the `FuncN` type. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `FuncN`.

Parameters:
`l` : [in/out] Item to be unified with result of `f`.
`f` : [in] Function pointer or function object whose result will be unified with `l`. Cannot be a member function type.
`aN_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `f`.

Notes:
Relation `eq_f` provides support for unification with values returned by evaluating functions or function objects. ILEs may also be used as arguments to parameter `f`. Parameter `l` will be compared with or assigned the result of evaluating `f`. All arguments (if any) required to evaluate `f` should be passed to `eq_f` using the `aN_` parameters. Currently `eq_f` supports a maximum of 6 arguments for `f`. The `aN_`'s effective value will be passed to `f`. Since `eq_f`, is used to perform unification with values results of traditional functions, it is assumed that `f`'s parameters are not logic references.

Examples:
```
// 1) With regular functions
int compute(int j, int k) {
    return j/k-1;
}
lref<int> li, lj, lk;
relation r = eq(lj,6) && eq(lk,2) && eq_f(li, &compute, lj, lk);
if(r())
   cout << *li;        // prints "2"

// 2) With function objects
struct Compute {
    int operator ()(int j, int k) {
        return j/k-1;
    }
};

lref<int> li, lj, lk;
relation r = eq(lj,6) && eq(lk,2) && eq_f(li, Compute(),lj,lk);
if(r())
   cout << *li;        // prints "2"

// 3) With ILE (Inline Lref Expression)
lref<int> li, lj, lk;
```

```
    relation r = eq(lj,6) && eq(lk,2) && eq_f(li, lj/lk-1 );
    if(r())
       cout << *li;        // prints "2"
```

Also refer to:

eq_mf, eq, eq_seq

---

eq_mf relation

```
// support for nullary member functions
template<typename L, typename Obj, typename MemFunT>
Eq_mf_r0<L, Obj, MemFunT>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf)

// remaining overloads support member functions with up to 6 arguments
template<typename L, typename Obj, typename MemFunT, typename A1>
Eq_mf_r1<L, Obj, MemFunT, A1>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf, const A1& a1_)

template<typename L, typename Obj, typename MemFunT, typename A1,
typename A2>
Eq_mf_r2<L, Obj, MemFunT, A1, A2>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf, const A1& a1_
      , const A2& a2_)

template<typename L, typename Obj, typename MemFunT, typename A1,
typename A2, typename A3>
Eq_mf_r3<L, Obj, MemFunT, A1, A2, A3>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf, const A1& a1_
      , const A2& a2_, const A3& a3_)

template<typename L, typename Obj, typename MemFunT, typename A1,
typename A2, typename A3, typename A4>
Eq_mf_r4<L, Obj, MemFunT, A1, A2, A3, A4>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf, const A1& a1_
      , const A2& a2_, const A3& a3_, const A4& a4_)

template<typename L, typename Obj, typename MemFunT, typename A1,
typename A2, typename A3, typename A4, typename A5>
Eq_mf_r5<L, Obj, MemFunT, A1, A2, A3, A4, A5>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf, const A1& a1_
      , const A2& a2_, const A3& a3_, const A4& a4_, const A5& a5_)

template<typename L, typename Obj, typename MemFunT, typename A1,
typename A2, typename A3, typename A4, typename A5, typename A6>
Eq_mf_r6<L, Obj, MemFunT, A1, A2, A3, A4, A5, A6>
eq_mf(lref<L> l, lref<Obj>& obj_, MemFunT mf, const A1& a1_
      , const A2& a2_, const A3& a3_, const A4& a4_, const A5& a5_
      , const A6& a6_)
```

Declarative reading: `l` is equal to the value returned by invoking member function `mf` on object `obj_` with arguments `p1..pN`.

Template Parameters:
`L` : Any type which satisfies requirements of logic reference.
`Obj` : Any type which whose member function will be invoked.
`MemFunT` : A pointer to member function of class `Obj`. Parameter types cannot be lref.
`An`: Type of parameter at position *n* for the `OP` type. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `MemFunT`.

Parameters:
`l` : [in/out] Item to be unified with result of evaluating member function `mf` on `obj_`.
`obj_` : [in] Object on which member function pointed to by `mf` will be invoked. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mf` : Member function pointer whose result will be unified with `l`.
`aN_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `mf`.

Notes:
Relation `eq_mf` provides support for unification with values returned by evaluating member functions on objects. Parameter `l` will be compared with or assigned the result of evaluating `obj_->*mf(..)`. All arguments (if any) required to evaluate `obj_->*mf(..)` should be passed to `eq_mf` using the `aN_` parameters. Since `eq_mf`, is used to perform unification with values results of traditional member functions, it is assumed that `MemFunT`'s parameters are not logic references.

Examples:
```
struct Compute {
    int j;
    Compute(int j) : j(j)
    {}
    int apply(int k) {  // unary member function to be invoked
        return j/k-1;
    }
};

lref<int> li;
lref<Compute> comp = Compute(6);
relation r = eq_mf(li, comp, &Compute::apply, 2);
if(r())
      cout << *li;        // prints "2"
```

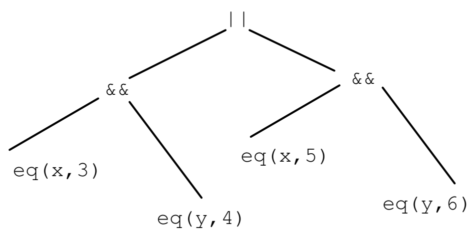
Also refer to:
`eq_f, eq, eq_seq`

Backtracking Support

Introduction

As in life, our main purpose in computation is to find *the* answer. There are often many ways to get to an answer. Some problems may have one or more answers, and other problems may have none. The search for an answer can possibly lead in several different directions, not all of which are actually productive. The search must therefore be able to step back and resume the search from an earlier point where an alternative direction was possible. This process pursuing one path of evaluation and then stepping back to try an alternative in search of a solution is referred to as backtracking.

Consider the relational expression `eq(x,3) && eq(y,4) || eq(x,5) && eq(y,6)` which basically declares "if x is 3 then y is 4, OR if x is 5 then y is 6". We can represent this using the following expression tree:



Expression tree for : `eq(x,3) && eq(y,4) || eq(x,5) && eq(y,6)`

Let us see how backtracking goes about answering the question "What is a suitable value for `x` given that `y`'s value is fixed to 6?". Goal of backtracking is to evaluate this expression tree successfully. Evaluation begins at the top of the tree and encounters the disjunction operator `||` which offers two possible choices (the left and right branches) in order to proceed. For disjunction to succeed, it is sufficient that any one branch evaluates successfully. Backtracking relies on depth first strategy and chooses the left branch. Here the conjunction operator `&&` is encountered. For the conjunction to succeed, both its branches must evaluate successfully. The left branch is evaluated first followed by the right branch. The left branch succeeds in unifying `x` with 3 (since `x` is not initialized) but the right branch fails to unify `y` with 4 (since `y` is initialized to 6). This leads to the failure of the conjunction which in turn implies failure of the entire left branch under the disjunction operator.

Now comes the time to step back and resume exploring the right branch of the disjunction. Stepping back involves reverting any side effects that occurred while pursuing the left branch under disjunction. In this case `x` went from being uninitialized to being initialized with 3. So `X` is reset to its uninitialized state. The evaluation now steps down the right branch in a fashion same as before and attempts to unify `x` with 5 and `y` with 6. This time around both operations succeed and consequently the conjunction also succeeds. This in turn implies successful evaluation of the disjunction and the entire expression tree. We now find `x` initialized with 5 which answers the question we started out to with.

As can be seen from the above example, conjunction and disjunction operators are used to build the expression tree that is traversed during backtracking. Castor provides native support for two varieties of disjunction: inclusive and exclusive. Typically, classic logic programming systems such as Prolog directly support only the inclusive variety. Operator `||`, which is used in the above example, provides support for inclusive disjunction. Support for exclusive disjunction is provided by the ex-or operator `^`. The following sections deal with each of the relational operators in further detail.

Conjunction: Operator &&

```
And_r<relation,relation> operator && (const relation& l
                                    , const relation& r)
```

Logical conjunction is a binary relation between any two relations with a meaning similar to "and" in English. Conjunction is denoted by operator `&&` in Castor. It is itself a relation which takes two other relations as arguments. In other words, it is a higher order binary relation. A simplified definition for conjunction is: a relation that succeeds when both its argument relations succeed. However, in logic, a relation may succeed zero, one or more times. The definition of conjunction needs to accommodate possibly multiple successful evaluations of its argument relations. Thus we broaden the definition of conjunction to: a relation that succeeds each time the second relation evaluates successfully for a successful evaluation of the first. Given this definition, conjunction can itself succeed zero, one or more times depending upon its argument relations. For instance consider the following simple expression:

```
range(x, 1, 3) && range(x, 2, 5)
```

Both arguments to `&&` are `range` relations. The first relation indicates that `x` is a value in the inclusive range 1 through 3. The second relation indicates that `x` is a value in the inclusive range 2 through 5. Considered in isolation, the first relation can succeed three times (producing values 1,2 and 3) and the second relation can succeed four times (producing values 2,3,4 and 5). The conjunction itself can succeed only twice, i.e. when `x` is 2 or 3. Any other value for `x` will fail either the first or the second `range` relation.

Operational semantics of `&&` can be summarized as: pursue all solutions in `r` for each solution in `l`. The following pseudo code demonstrates this.

```
//This is psuedo code!
relation tmp = rhs; //make copy of rhs
while( l() ) {
  while( r() )
    yield return true;// Not C++. 'yield' keyword borrowed from C#
  rhs = tmp; //reset rhs
}
//no more solutions left
return false;
```

In terms of the imperative paradigm, the operational semantics can be visualized as one loop nested in another as shown above. The outer loop is responsible for evaluating `l` and the inner loop for evaluating `r`. If `l` succeeds, `r` is attempted. If `r` succeeds the conjunction also succeeds and returns `true`. Further attempts to pursue more solutions from conjunction will lead to repeated evaluations of `r` until it fails. Once `r` is exhausted, `l` is evaluated once again and the whole process repeats. Finally when `l` is exhausted the conjunction has no more solutions to produce and returns `false`. Thereafter any attempts to pursue more solutions from this conjunction will fail immediately.

Note that once all solutions are exhausted in `r`, it has to be reset to its original state before pursuing the next solution in `l`. This enables `r` to resume producing a new set of solutions for each successful evaluation of `l`. Otherwise `r` will not be able to produce any new solutions. In order to be able to reset `r` to its original state, a copy of `r` is made in `tmp` prior to attempting any evaluation of `r`.

Inclusive Disjunction: Operator ||

```
// requires : L and R must be treatable as relations
template<typename L, typename R>
Or_r<L,R> operator || (const L& l, const R & r)
```

Inclusive disjunction is a binary relation between any two relations with a meaning similar to "or" in English. It is denoted by operator `||` in Castor. Inclusive disjunction is itself a relation which takes two other relations as arguments. In other words, it is a higher order binary relation. A simplified definition for inclusive disjunction is: a relation that succeeds when at least one of its argument relations succeeds. To accommodate the ability of its argument relations to evaluate successfully zero or more times, we broaden its definition to: a relation that succeeds each time there is at a successful evaluation of one of its argument relations. Given this definition, disjunction can itself succeed zero, one or more times depending upon its argument relations. For instance consider the following simple expression:

```
range(x, 1, 3) || range(x, 2, 5)
```

Both arguments to `||` are `range` relations. The first relation indicates that `x` is a value in the inclusive range 1 through 3. The second relation indicates that `x` is a value in the inclusive range 2 through 5. Considered in isolation, the first relation can succeed three times (producing values 1,2 and 3) and the second relation can succeed four times (producing values 2,3,4 and 5). The combined expression itself can succeed seven times (producing values 1,2,3,2,3,4 and 5). Relation `range(x,1,3)` produces the first three values for `x` and `range(x,2,5)` produces the remaining four values. Notice how the duplicate values are generated for `x`.

Operational semantics of operator `||` can be summarized as: pursue all solutions in `l` then pursue all solutions in `r`. The following pseudo code demonstrates this.

```
//This is psuedo code!
while( l() )
  yield return true; // Not C++. 'yield' keyword borrowed from C#
```

```
while( r() )
  yield return true;
return false; //no more solutions left
```

In terms of the imperative paradigm, the operational semantics can be visualized as two main loops, one following another as shown above. The first loop is responsible for evaluating `l` and the second for evaluating `r`. After `l`'s solutions have been exhausted by the first loop, the second loop pursues solutions in `r`. Once `r` has also been exhausted, there are no more solutions to produce and evaluation enters the third loop. Here disjunction always fails by returning `false`. Thus all future attempts to pursue more solutions from this disjunction will fail immediately.

Exclusive Disjunction: Operator ^

```
// requires : L and R must be treatable as relations
template<typename L, typename R>
ExOr_r<L,R> operator ^ (const L & l, const R & r)
```

Exclusive disjunction is a binary relation between any two relations with a meaning similar to "either or" in English. It is denoted by operator `^` in Castor. Exclusive disjunction is itself a relation which takes two other relations as arguments. In other words, it is a higher order binary relation. A simplified definition for exclusive disjunction is: a relation that succeeds when one of its argument relations succeeds. The second argument is evaluated only if the first does not succeed. To accommodate the ability of its argument relations to evaluate successfully zero or more times, we broaden its definition to: a relation that succeeds each time one of its argument relations succeeds. Disjunction can itself succeed zero, one or more times depending upon its argument relations. For instance consider the following simple expression:

```
range(x, 1, 3) ^ range(x, 7, 10)
```

Here both arguments to `^` are `range` relations. The first relation indicates that `x` is a value in the inclusive range 1 through 3. The second relation indicates that `x` is a value in the inclusive range 7 through 10. The intent here is to state that x can have a value that is either between 1 and 3 or between 7 and 10, and not in both ranges. If `x` is left undefined, only the first range relation will produce values for `x`. Due to successful evaluation of first relation, the second range relation will be ignored. However if `x`'s value is defined such that it's value in the range 7 through 10, the first relation will fail leading to the evaluation of the second range relation.

Operational semantics of operator `^` can be summarized as: for every successful evaluation of `l` make sure `r` does not succeed and vice versa. The following pseudo code demonstrates this.

```
//This is psuedo code!
bool lhsSucceded = false;
while( lhs() ) {
   lhsSucceded = true;
```

```
    yield return true; // Not C++. 'yield' keyword borrowed from C#
}
while(!lhsSucceded && rhs())
    yield return true;
return false;
```

In terms of the imperative paradigm, the operational semantics can be visualized as two main loops, one following another as shown above. The first loop is responsible for find a successful evaluation of `lhs` and the second loop for `rhs`. A boolean flag is used to ensure that `rhs` is attempted only if `lhs` never succeeded. This loop continues to succeed as long `lhs` or `rhs` succeeds.

Recursion

recurse relation

```
// support for nullary relations
template<typename Rel_0>
Recurse0_r<Rel_0>
recurse( Rel_0 r )

// remaining overloads support relations with up to 6 arguments
template<typename Rel_1, typename A1>
Recurse1_r<Rel_1,A1>
recurse(Rel_1 r, lref<A1>& a1)

template<typename Rel_2, typename A1, typename A2>
Recurse2_r<Rel_2,A1,A2>
recurse(Rel_2 r, lref<A1>& a1, lref<A2>& a2)

template<typename Rel_3, typename A1, typename A2, typename A3>
Recurse3_r<Rel_3,A1,A2,A3>
recurse(Rel_3 r, lref<A1>& a1, lref<A2>& a2, lref<A3>& a3)

template<typename Rel_4, typename A1, typename A2, typename A3
                       , typename A4>
Recurse4_r<Rel_4,A1,A2,A3,A4>
recurse(Rel_4 r, lref<A1>& a1, lref<A2>& a2, lref<A3>& a3
               , lref<A4>& a4)

template<typename Rel_5, typename A1, typename A2, typename A3
                       , typename A4, typename A5>
Recurse5_r<Rel_5,A1,A2,A3,A4,A5>
recurse(Rel_5 r, lref<A1>& a1, lref<A2>& a2, lref<A3>& a3
               , lref<A4>& a4, lref<A5>& a5)

template<typename Rel_6, typename A1, typename A2, typename A3
                       , typename A4, typename A5, typename A6>
Recurse6_r<Rel_6,A1,A2,A3,A4,A5,A6>
recurse(Rel_6 r, lref<A1>& a1, lref<A2>& a2, lref<A3>& a3
               , lref<A4>& a4, lref<A5>& a5, lref<A6>& a6)
```

Declarative reading: Same as `r(a1,..,aN)`.

Template Parameters:
`Rel_N` : A function pointer to relation that takes *N* arguments. All parameter types must be logic references.
`An` : Effective type of the N^{th} argument to being passed. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `Rel_N`.

Parameters:
`r` : Relation (with up to 6 parameters) to be recursed on. This should be the same as the relation or instance of function object within which the call to `recurse` is made.
`aN_` : [in/out] The N^{th} argument to `r`. Must be a logic reference.

Exceptions:
Same as those thrown by relation `r`.

Notes: Relation `recurse` provides the mechanism for making recursive calls inside relations. Consider the following well intentioned, but erroneous, recursive call within `ancestor` relation.

```
// ans is ancestor of descendant des
relation ancestor(lref<string> ans, lref<string> des) {
    lref<string> X;
    return parent(ans,des)
        || parent(X,des) && ancestor(ans,X);
}
```

The problem with the above definition is that the attempt below to use `ancestor` will lead to infinite recursion:

```
relation r = ancestor("Leda","Castor"); // will never return
r();       // execution will never reach here
```

The recursion in this case should only be performed when the relation is actually evaluated by executing `r()`. This problem can be resolved by using relation `recurse` to delay the recursive call in `ancestor` as follows:

```
relation ancestor(lref<string> ans, lref<string> des) {
    lref<string> X;
    return parent(ans,des)
        || parent(X,des) && recurse(&ancestor,ans,X);
}
```

Also refer to:
`recurse_mf`.

---

recurse_mf relation

```
// support for nullary member relations
template<typename Obj, typename MemRel_0>
RecurseMem0_r<Obj,MemRel_0>
```

```
recurse_mf(Obj* obj, MemRel_0 mr)

// remaining overloads support member relations with up to 6 arguments
template<typename Obj, typename MemRel_1, typename A1>
RecurseMem1_r<Obj,MemRel_1,A1>
recurse_mf(Obj* obj, MemRel_1 mr, lref<A1>& a1)

template<typename Obj, typename MemRel_2, typename A1, typename A2>
RecurseMem2_r<Obj,MemRel_2,A1,A2>
recurse_mf(Obj* obj, MemRel_2 mr, lref<A1>& a1, lref<A2>& a2)

template<typename Obj, typename MemRel_3, typename A1, typename A2,
typename A3>
RecurseMem3_r<Obj,MemRel_3,A1,A2,A3>
recurse_mf(Obj* obj, MemRel_3 mr, lref<A1>& a1, lref<A2>& a2
                   , lref<A3>& a3)

template<typename Obj, typename MemRel_4, typename A1, typename A2,
typename A3, typename A4>
RecurseMem4_r<Obj,MemRel_4,A1,A2,A3,A4>
recurse_mf(Obj* obj, MemRel_4 mr, lref<A1>& a1, lref<A2>& a2
                   , lref<A3>& a3, lref<A4>& a4)

template<typename Obj, typename MemRel_5, typename A1, typename A2,
typename A3, typename A4, typename A5>
RecurseMem5_r<Obj,MemRel_5,A1,A2,A3,A4,A5>
recurse_mf(Obj* obj, MemRel_5 mr, lref<A1>& a1, lref<A2>& a2
                   , lref<A3>& a3, lref<A4>& a4, lref<A5>& a5)

template<typename Obj, typename MemRel_6, typename A1, typename A2,
typename A3, typename A4, typename A5, typename A6>
RecurseMem6_r<Obj,MemRel_6,A1,A2,A3,A4,A5,A6>
recurse_mf(Obj* obj, MemRel_6 mr, lref<A1>& a1, lref<A2>& a2
                   , lref<A3>& a3, lref<A4>& a4, lref<A5>& a5
                   , lref<A6>& a6)
```

Declarative reading: Same as `(obj->*mr)(a1,..,aN)`.

Template Parameters:
`Obj` : Type whose member relation is to be recurse.
`MemRel_N` : Pointer to member relation in `Obj` that takes up to *N* arguments. All parameter types must be logic references.
`An` : Effective type of the N^th^ argument to being passed. If lref<`Pn`> is the type of the *N*^th^ parameter of relation `MemRel_N`, then `An` should be same as `Pn`.

Parameters:
`obj` : Object whose method member relation identified by `mr` will be recursed on. This argument should always be the `this`.
`mr` : Member relation (with up to 6 parameters) to be recursed on. This should be the same as the member relation within which the call to `recurse_mf` is made.
`aN` : [in/out] The N^th^ argument to `mr`. Must be a logic reference.

Exceptions:

Same as those thrown by `mr`.

Notes: This relation is similar to `recurse_f`, except that it used for recursing inside member relations.

Also refer to:
`recurse_f`.

Dynamic relations

Introduction

Types `Conjunctions`, `Disjunctions` and `ExDisjunctions` together provide a facility to define relations dynamically at runtime. These types are themselves relations and thus can be mixed in with any other relations either defined statically or dynamically. Any relation that can be implemented statically can also be implemented dynamically. Ability to define relations at runtime allows us to define relations based on data obtained at runtime from, for instance, a SQL query or a text file. This also naturally provides a basis for runtime metaprogramming in the Logic paradigm.

Conjunctions relation

```
class Conjunctions {
public:
    Conjunctions();

    template<typename Rel> void push_back(const Rel& r);
    template<typename Rel> void push_front(const Rel& r);

    bool operator ()(void);
};
```

Brief Description: Represents relational conjunction expression to which clauses can be added at runtime.

Methods

`Conjunctions``()`
Constructs a `Conjunctions` relation with no clauses. An empty `Conjunctions` relation will fail on evaluation.

`template<typename Rel> void` **`push_back`**`(const Rel& r)`
Adds the clause `r` at the back. `Rel` is any type that can be treated as a relation.

`template<typename Rel> void` **`push_front`**`(const Rel& r)`
Adds the clause `r` at the front. `Rel` is any type that can be treated as a relation.

`bool` **`operator()`**`(void)`
Triggers the evaluation of clauses added to `Conjunctions`. The contained relations are treated as if an `operator &&` exists between each adjacent relation.

Examples

In the following example, all three relations are semantically identical.

```
relation genderStatic(lref<string> p, lref<string> g) {
    return eq(p,"Runa") && eq(g,"female");
}

Conjunctions genderDynamic1(lref<string> p, lref<string> g) {
    Conjunctions result;
    result.push_back( eq(p,"Runa") );
    result.push_back( eq(g,"female") );
    return  result;
}

Conjunctions genderDynamic2(lref<string> p, lref<string> g) {
    Conjunctions result;
    result.push_front( eq(g,"female") );
    result.push_front( eq(p,"Runa") );
    return  result;
}
```

Also refer to

`Disjunctions`, `ExDisjunctions`.

Disjunctions relation

```
class Disjunctions {
public:
    Disjunctions();

    template <typename Rel> void push_back(const Rel& r);
    template <typename Rel> void push_front(const Rel& r);

    bool operator ()(void);
};
```

Brief Description: Represents relational inclusive disjunction expression to which clauses can be added at runtime.

Methods

`Disjunctions``()`

Constructs a `Disjunctions` relation with no clauses. An empty `Disjunctions` relation will fail on evaluation.

`template<typename Rel> void` **`push_back`**`(const Rel& r)`

Adds the clause `r` at the back. `Rel` is any type that can be treated as a relation.

`template<typename Rel> void` **`push_front`**`(const Rel& r)`

Adds the clause `r` at the front. `Rel` is any type that can be treated as a relation.

`bool` **`operator()`**`(void)`

Triggers the evaluation of clauses added to `Disjunctions`. The contained relations are treated as if an `operator ||` exists between each adjacent relation.

Examples
In the following example, all three relations are semantically identical.

```
relation genderStatic(lref<string> p, lref<string> g) {
  return   eq(p, "Roshan") && eq(g,"male")
        || eq(p, "Runa") && eq(g,"female");
}

Disjunctions genderDynamic1(lref<string> p, lref<string> g) {
  Disjunctions result;
  result.push_back( eq(p,"Roshan") && eq(g,"male") );
  result.push_back( eq(p,"Runa") && eq(g,"female") );
  return  result;
}

Disjunctions genderDynamic2(lref<string> p, lref<string> g) {
  Disjunctions result;
  result.push_front( eq(p,"Runa") && eq(g,"female") );
  result.push_front( eq(p,"Roshan") && eq(g,"male") );
  return  result;
}
```

Also refer to
`Conjunctions, ExDisjunctions.`

ExDisjunctions relation

```
class ExDisjunctions {
public:
    ExDisjunctions();

    template <typename Rel> void push_back(const Rel& r);
    template <typename Rel> void push_front(const Rel& r);

    bool operator ()(void);
};
```

Brief Description: Represents relational exclusive disjunction expression to which clauses can be added at runtime.

Methods

`ExDisjunctions``()`
Constructs an `ExDisjunctions` relation with no clauses. An empty `ExDisjunctions` relation will fail on evaluation.

`template<typename Rel>  void` **`push_back`**`(const Rel& r)`
Adds the clause `r` at the back. `Rel` is any type that can be treated as a relation.

```
template<typename Rel> void push_front(const Rel& r)
```
Adds the clause `r` at the front. `Rel` is any type that can be treated as a relation.

```
bool operator()(void)
```
Triggers the evaluation of clauses added to `ExDisjunctions`. The contained relations are treated as if an `operator ^` exists between each adjacent relation.

Examples
In the following example, all three relations are semantically identical.

```
relation genderStatic(lref<string> p, lref<string> g) {
  return  ( eq(p, "Roshan") && eq(g,"male") )
        ^ ( eq(p, "Runa") && eq(g,"female") );
}

ExDisjunctions genderDynamic1(lref<string> p, lref<string> g) {
  ExDisjunctions result;
  result.push_back( eq(p,"Roshan") && eq(g,"male") );
  result.push_back( eq(p,"Runa") && eq(g,"female") );
  return  result;
}

ExDisjunctions genderDynamic2(lref<string> p, lref<string> g) {
  ExDisjunctions result;
  result.push_front( eq(p,"Runa") && eq(g,"female") );
  result.push_front( eq(p,"Roshan") && eq(g,"male") );
  return  result;
}
```

Also refer to
`Conjunctions`, `Disjunctions`.

4. Inline Logic Reference Expressions (ILE)

ILEs are expressions composed of one or more logic references and most of the common overloadable operators. In C++, ordinarily, an expression returns the result immediately on evaluation. Evaluation of an ILE yields a function object (more precisely, an expression tree) that represents the semantics of the expression. Such function objects can be evaluated at a later point in time by applying the function call operator without arguments. The typical use of ILEs is to declaratively create simple anonymous functions for use as arguments to relations such as `eq_f`, `write_f`, `predicate` etc. Consider printing all numbers in an array that match some criteria:

```
bool lessThan5(lref<int> i) {
   return *i<5;
}

int nums[] = {8,2,9,4,0};
lref<int> i;
relation r = item(i, nums+0, nums+5) && predicate(lessThan5, i);
while(r())
   cout << *i << " ";
```

The predicate function `lessThan5` can be substituted with an ILE declared directly inline with the call to `predicate`:

```
relation r = item(i, nums+0, nums+5) && predicate(i<5);
while(r())
   cout << *i << " ";
```

Just like functions, ILEs can be classified as pure or impure. ILEs that induce side effects on any externally visible objects or logic references are impure. Typically such ILEs consist of operators such as ++. Impure ILEs, functions or member functions should not be used to create relations as they interfere with backtracking which relies on restoration of any state change. As side effects induced by ILE arguments to relations are not undone automatically during backtracking, it can lead to improper evaluation of relations.

Operator overloads for creating ILEs:

The listing below describes the overloads defined for binary operator `+` for creating ILEs. Similar overloads are also provided for the binary operators `+`, `-`, `*`, `/`, `%`, `|`, `^`, `&`, `<<`, `>>`, `==`, `!=` , `<`, `>`, `<=`, `>=`, `&&` and `||`.

```
template <typename L, typename R>
Ile<Plus_ILE<lref<L>, R> >
operator + (lref<L> & left, const R & right);

template <typename L, typename R>
Ile<Plus_ILE<L, lref<R> > >
```

```
operator + (const L & left, lref<R> & right);

template <typename L, typename R>
Ile<Plus_ILE<lref<L>, lref<R> > >
operator + (lref<L> & left, lref<R> & right);

template <typename L, typename R>
Ile<Plus_ILE<Ile<L>, R> >
operator + (const Ile<L> & left, const R & right);

template <typename L, typename R>
Ile<Plus_ILE<L, Ile<R> > >
operator + (const L & left, const Ile<R> & right);

template <typename L, typename R>
Ile<Plus_ILE<Ile<L>, Ile<R> > >
operator + (const Ile<L> & left, const Ile<R> & right);

template <typename L, typename R>
Ile<Plus_ILE<Ile<L>, lref<R> > >
operator + (const Ile<L> & left, lref<R> & right);

template <typename L, typename R>
Ile<Plus_ILE<lref<L>, Ile<R> > >
operator + (lref<L> & left, const Ile<R> & right);
```

Template type `Plus_ILE` in the above listing represents an internal type used to represent a node in the expression tree corresponding to operator `+`. It implements operator`()` evaluating the particular node it represents in the expression tree.
The listing below describes the overloads defined for the prefix unary operator `+` for creating ILEs. Overloads similar to the following are also provided for prefix unary operators `-`, `~`, `!`, `++`, and `--`.

```
template <typename T>
Ile<Prefix_Plus_ILE<lref<T> > >
operator + (lref<T> const & obj);

template <typename T>
Ile<Prefix_Plus_ILE<Ile<T> > >
operator + (Ile<T> const & expr);
```

The listing below describes the overloads defined for the postfix unary operator `++` for creating ILEs. Overloads similar to the following are also provided for postfix unary operator `--`.

```
template <typename T>
Ile<Postfix_Inc_ILE<lref<T> > >
operator ++ (lref<T> const & obj, int);

template <typename T>
Ile<Postfix_Inc_ILE<Ile<T> > >
operator ++ (Ile<T> const & expr, int);
```

Note that all overloadable operators with the exception of the following are supported for the creation of ILEs from lrefs.

- AddressOf operator `&`
- Dereference operator `*`
- Member access operator `->`
- Indexing operator `[]`
- Comma operator `,`
- All forms of assignment (=, +=, *= etc.)

Named ILEs

Since there are only a limited number of operators in C++, additional ILE operators can be introduced in the form of named functions instead. The named ILEs can be freely combined with other ILE operators in an ILE expression.

---

create

```
template<typename T>
Ile<CreateWith0<T> >
create()

template<typename T, typename A1>
Ile<CreateWith1<T,A1> >
create(const A1& a1)

template<typename T, typename A1, typename A2>
Ile<CreateWith2<T,A1,A2> >
create(const A1& a1, const A2& a2)

template<typename T, typename A1, typename A2, typename A3>
Ile<CreateWith3<T,A1,A2,A3> >
create(const A1& a1, const A2& a2, const A3& a3)

template<typename T, typename A1, typename A2, typename A3
         , typename A4>
Ile<CreateWith4<T,A1,A2,A3,A4> >
create(const A1& a1, const A2& a2, const A3& a3, const A4& a4)

template<typename T, typename A1, typename A2, typename A3
         , typename A4, typename A5>
Ile<CreateWith5<T,A1,A2,A3,A4,A5> >
create(const A1& a1, const A2& a2, const A3& a3, const A4& a4
       , const A5& a5)

template<typename T, typename A1, typename A2, typename A3
        , typename A4, typename A5, typename A6>
Ile<CreateWith6<T,A1,A2,A3,A4,A5,A6> >
create(const A1& a1, const A2& a2, const A3& a3, const A4& a4
       , const A5& a5, const A6& a6)
```

Brief Description: `create` is used to create a function object that on evaluation returns an object of type `T`. Arguments to `create` are forwarded to `T`'s constructor.

Template Parameters:

`T`: Type of object to be constructed. Depending upon the specific overload of `create` used, `T` must support a constructor with accepts arguments of types `A1` … `AN`. This type must be explicitly specified.

`A1..AN`: Types of the arguments to be passed to `T`'s constructor when creating object of type `T`. Since these types are automatically inferred by the compiler there is no need to specify them explicitly.

Parameters:

`a1..aN`: Arguments to be passed to `T`'s constructor when creating object of type `T`.

Returns:

A function object, which on evaluation returns an object of type `T`.

Notes:

`create` supports construction of objects with up to 6 arguments. It can be combined with other ILE operators or named ILEs to create more complex ILEs/function objects. For e.g. `create<complex<int> >(1,4) * 2` creates an ILE or function object that multiples the complex number (1,4) with 2.

Exceptions:

Any exception thrown by `T`'s constructor.

Examples:

```
// if i is item in arr1, and j is item in arr2,
// generate std::pair<int,int> in p such that i+j==4
int arr1[] = { 1 , 0 , 5, 3 };
int arr2[] = { 2 , 4 ,-1, 5 };
lref<pair<int,int> > p;
lref<int> i, j;
relation r = item(i, arr1+0, arr1+4) && item(j, arr2+0, arr2+4)
                && predicate(i+j==4)
                && eq_f( p, create<pair<int,int> > (i,j) );
```

Create::with **[deprecated, use create()]**

```
template<typename T>
class Create {
public:
    static Ile<CreateWith0<T> >
    with();

    template<typename A1>
    static Ile<CreateWith1<T,A1> >
    with(const A1& a1);
```

```
    template<typename A1, typename A2>
    static Ile<CreateWith2<T,A1,A2> >
    with(const A1& a1, const A2& a2);

    template<typename A1, typename A2, typename A3>
    static Ile<CreateWith3<T,A1,A2,A3> >
    with(const A1& a1, const A2& a2, const A3& a3);

    template<typename A1, typename A2, typename A3, typename A4>
    static Ile<CreateWith4<T,A1,A2,A3,A4> >
    with(const A1& a1, const A2& a2, const A3& a3, const A4& a4);

    template<typename A1, typename A2, typename A3, typename A4
             , typename A5>
    static Ile<CreateWith5<T,A1,A2,A3,A4,A5> >
    with(const A1& a1, const A2& a2, const A3& a3, const A4& a4
         , const A5& a5);

    template<typename A1, typename A2, typename A3, typename A4
             , typename A5, typename A6>
    static Ile<CreateWith6<T,A1,A2,A3,A4,A5,A6> >
    with(const A1& a1, const A2& a2, const A3& a3, const A4& a4
         , const A5& a5, const A6& a6);
};
```

Brief Description: `Create<T>::with` is used to create a function object that on evaluation returns an object of type `T`. Arguments to `with()` are forwarded to `T`'s constructor.

Template Parameters:
`T`: Type of object to be constructed. Depending upon the overload of `which` that is used, `T` must support a constructor with accepts arguments of types `A1` … `AN`.
`A1..AN`: Types of the arguments to be passed to `T`'s constructor when creating object of type `T`.

Parameters:
`a1..aN`: Arguments to be passed to `T`'s constructor when creating object of type `T`.

Returns:
A function object that on evaluation returns an object of type `T`.

Notes:
`Create::with` supports construction of objects with up to 6 arguments. It can be combined with other ILE operators or named ILEs to create more complex ILEs/function objects. For e.g. `Create<complex<int> >::with(1,4) * 2` creates an ILE or function object that multiples the complex number (1,4) with 2.

Exceptions:
Any exception thrown by `T`'s constructor

Examples:

```
// if i is item in arr1, and j is item in arr2,
// generate std::pair<int,int> in p such that i+j==4
int arr1[] = { 1 , 0 , 5, 3 };
int arr2[] = { 2 , 4 ,-1, 5 };
lref<pair<int,int> > p;
lref<int> i, j;
relation r = item(i, arr1+0, arr1+4) && item(j, arr2+0, arr2+4)
                && predicate(i+j==4)
                && eq_f( p, Create<pair<int,int> >::with(i,j) );
```

Return types for ILE operators

Since there is no way, currently, to programmatically deduce return types of arbitrary functions or operators in C++, the following assumptions are made about the return types of overloaded operators used in creating ILEs.

- All comparison operators (<, >=, ==, != etc.) and operators `&&`, `||` and `!` have return type `bool`.
- Return type of prefix operators `++` and `--` is `T&`, if `T` is the argument type.
- All other unary and binary operators are assumed to have return type same as the type of their first argument.

If operators defined on certain types do not conform to the above assumptions, it is advisable to wrap expression involving such operators and types into a regular function instead of an ILE.

5. Utils

Input/Output relations

read relation

```
template <typename T>
Read_r<T> read (lref<T> val)

Read_r<std::string> read(const char* val)
```

Declarative reading: `val` is the value read from `std::cin`.

Template Parameters:
`T` : A type that supports reading from `std::cin` using `operator <<`.

Parameters:
`val` : [in/out] The value to be read. If not initialized, it will be assigned the value that is read. If initialized, it is compared with the value read from stream.

Exceptions:
Any exception thrown by `operator >>`.

Notes:
Relation `read` provides a relational facility for reading from `std::cin`. The action of reading values from `std::cin` will not be reverted during backtracking. Relations `read_f` and `read_mf` (similar to the `write_f` and `write_mf` counterparts) are not provided since `eq_f` and `eq_mf` already provide this functionality.

Examples:
```
// 1) read words from std::cin and echo them to std::cout
lref<string> str;
relation r = read(str);
while(r())
  cout << *str << "\n";

// 2) read a word from input and check if it is "Logic"
if(read("Logic")()){
  ...
}
```

Also refer to:
`readFrom`, `write`, `writeTo`, `eq`, `eq_f`, `eq_mf`

readFrom relation

```
template <typename T>
Read_r<T> readFrom(std::istream& inputStream, lref<T> val)

Read_r<std::string> readFrom( std::istream& inputStream
                            , const char* val)
```

Declarative reading: `val` is the value read from `inputStream`.

Template Parameters:
`T :` A type that supports reading from an `inputStream` (like `std::cin`) using `operator <<`.

Parameters:
`inputStream` : The stream from which a value is to be read. Defaults to `std::cin`.
`val` : [in/out] The value to be read. If not initialized, it will be assigned the value that is read. If initialized, it is compared with the value read from stream.

Exceptions:
Any exception thrown by `operator >>`.

Notes:
This relation is similar to relation read, but the is parameterized on the input stream from which value is to be read.

Examples:
```
// 1) read from strstream and std::cin until words from both match
strstream sstrm;
sstrm << "Words in this sentence are expected";
lref<string> str;
relation r = readFrom(sstrm,str) && read(str);
while(r());

// 2) Copy all words from a strstream to cout
strstream sstrm;
sstrm << "Writing must be learnt by wrote";
lref<string> str;
relation r = readFrom(str,sstrm) && write(str) && write(" ");
while(r());
```

Also refer to:
`read`, `write`, `writeTo`, `eq`, `eq_f`, `eq_mf`

---

write relation

```
template <typename T>
Write_r<T> write(const T& obj_)

Write_r<std::string> write(const char* obj_)
```

Declarative reading: Write `obj` to `std::cout`.

Template Parameters:
`T` : Can be a logic reference, or any other POT. The effective type should support writing to `std::cout` using `operator <<`. T must support copy construction.

Parameters:
`obj_` : [in] The object to be printed. Can be a lref or POT

Exceptions:
`InvalidDeref` : If `obj_` is an uninitialized logic reference at the time of evaluation.

Any exception thrown by `operator <<`.

Notes:
Relation `write` provides a simple relational facility for writing to `std::cout`. The action of printing values will not be reverted during backtracking. `write` evaluates successfully only once.

The second overload provides special case handling for `char*` arguments by treating them as strings instead of pointer to a character. This enables usage of `write` relation in context of `char*` arguments more directly as `write("hello")` instead of `write<string>("hello")`.

Examples:
```
// 1) printing strings or other types
write("Hello world.")(); // prints "Hello world."
relation r= write("Hello ") && write("world.");
r(); // prints "Hello world."
write(2.5)(); // prints "2.5"

// 2) printing values of logic references.
lref<int> li = 4;
write(li)();  // prints "4, "
```

Also refer to:
`write_f`, `write_mf`, `writeAll`, `read`

---

writeTo relation

```
template <typename T>
Write_r<T> writeTo(std::ostream& outputStrm, T& obj_)

Write_r<std::string> writeTo(std::ostream& outputStrm, const char*
obj_)
```

Declarative reading: write `obj` to `outputStrm`.

Template Parameters:

`T` : Can be a logic reference, or any POT that supports writing to a `ostream` using `operator <<`. `T`'s effective type should support writing to `ostream` using `operator <<`. T must support copy construction.

Parameters:
`outputStrm`: The output stream to which `obj_` will be printed.
`obj_` : [in] The object to be printed.

Exceptions:
`InvalidDeref` : If `obj_` is a lref that is not initialized at the time of evaluation.

Any exception thrown by `operator <<`.

Notes:
Relation `write` provides a simple relational facility for writing to `ostream`s. The action of printing values to any `ostream` will not be reverted during backtracking. `write` evaluates successfully only once.

The second overload provides special case handling for `char*` arguments by treating them as strings instead of pointer to a character. This also enables usage of `write` relation in context of `char*` arguments more directly as `write("hello")` instead of `write<string>("hello")`.

Examples:
```
// 1) printing strings or other types
stringstream sstrm;
writeTo(sstrm, "Hello world")(); // prints "Hello world."
```

---

write_f relation

```
// support for nullary functions/function objects
template<typename Func>
WriteF_r<Func>
write_f(Func f, std::ostream& outputStrm=std::cout)

// remaining overloads provide support functions with up to 6 arguments
template<typename Func1, typename A1>
WriteF1_r<Func1, A1>
write_f(Func1 f, A1& a1_)

template<typename Func2, typename A1, typename A2>
WriteF2_r<Func2, A1, A2>
write_f(Func2 f, const A1& a1_, const A2& a2_)

template<typename Func3, typename A1, typename A2, typename A3>
WriteF3_r<Func3, A1, A2, A3>
write_f(Func3 f, const A1& a1_, const A2& a2_, const A3& a3_)
```

```
template<typename Func4, typename A1, typename A2, typename A3,
typename A4>
WriteF4_r<Func4, A1, A2, A3, A4>
write_f(Func4 f, const A1& a1_, const A2& a2_, const A3& a3_
               , const A4& a4_)

template<typename Func5, typename A1, typename A2, typename A3,
typename A4, typename A5>
WriteF5_r<Func5, A1, A2, A3, A4, A5>
write_f(Func5 f, const A1& a1_, const A2& a2_, const A3& a3_
               , const A4& a4_, const A5& a5_)

template<typename Func6, typename A1, typename A2, typename A3,
typename A4, typename A5, typename A6>
WriteF6_r<Func6, A1, A2, A3, A4, A5, A6>
write_f(Func6 f, const A1& a1_, const A2& a2_, const A3& a3_
               , const A4& a4_, const A5& a5_, const A6& a6_)
```

Declarative reading: write to `std::cin` value returned by invoking `f(a1_ .. aN_)`.

Template Parameters:
`Func`*N*: A function pointer or function object type with arity *N*. `Func`*N*'s parameters cannot be logic references.
`A`*n*: Type of argument passed at position *n* to `Func`*N*. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `Func`*N*.

Parameters:
`f` : The result of evaluating this function object or function pointer will be written to the specified stream.
`a`*N*`_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `f`.

Exceptions:
Any exception thrown by `operator <<`.

Notes:
Although arguments passed to `write_f` may be lrefs or POTs, the parameter types of `mf` cannot be lrefs.[2]

Examples:

```
    // 1) With regular functions
```

[2] Technically, this limitation keeps the interface and implementation simple by avoiding ambiguities related to deciding whether `a`*N* should be internally dereferenced when passing it to the target function/method. Ideally a lref argument would not be dereferenced if the corresponding parameter is a lref, and dereferenced otherwise. Conceptually we can rationalize this by recognizing that `write_f` (and same with `write_mf`, `writeTo_f`, `writeTo_mf`, `eq_f`, `eq_mf`, `predicate_f` and `predicate_mf`) is for consuming traditional functions in a relational fashion. Traditional functions typically do not have lref parameter types.

```
int add(int l, int r) { //No parameter type is a lref !
  return l+r;
}
lref<int> li=2, lj=3;
write_f(&add, li, lj)();

// 2) With ILEs
lref<int> li=2, lj=3;
write_f(li+lj)();
```

Also refer to:

write, write_mf, read

writeTo_f relation

```
// support for nullary functions/function objects
template<typename Func>
WriteF_r<Func>
writeTo_f(std::ostream& outputStrm,Func f)

// remaining overloads provide support functions with up to 6 arguments
template<typename Func1, typename A1>
WriteF1_r<Func1, A1>
writeTo_f(std::ostream& outputStrm, Func1 f, const A1& a1_)

template<typename Func2, typename A1, typename A2>
WriteF2_r<Func2, A1, A2>
writeTo_f(std::ostream& outputStrm, Func2 f, const A1& a1_
          , const A2& a2_)

template<typename Func3, typename A1, typename A2, typename A3>
WriteF3_r<Func3, A1, A2, A3>
writeTo_f(std::ostream& outputStrm, Func3 f, const A1& a1_
          , const A2& a2_, const A3& a3_)

template<typename Func4, typename A1, typename A2, typename A3,
typename A4>
WriteF4_r<Func4, A1, A2, A3, A4>
writeTo_f(std::ostream& outputStrm, Func4 f, const A1& a1_
          , const A2& a2_, const A3& a3_, const A4& a4_)

template<typename Func5, typename A1, typename A2, typename A3,
typename A4, typename A5>
WriteF5_r<Func5, A1, A2, A3, A4, A5>
writeTo_f(std::ostream& outputStrm, Func5 f, const A1& a1_
          , const A2& a2_, const A3& a3_, const A4& a4_, const A5& a5_)

template<typename Func6, typename A1, typename A2, typename A3,
typename A4, typename A5, typename A6>
WriteF6_r<Func6, A1, A2, A3, A4, A5, A6>
writeTo_f(std::ostream& outputStrm, Func6 f, const A1& a1_
          , const A2& a2_, const A3& a3_, const A4& a4_
          , const A5& a5_, const A6& a6_)
```

Declarative reading: write to `outputStrm` value returned by invoking `f` with arguments `a1_ .. aN_`.

Template Parameters:
`FuncN`: A function pointer/object type with arity *N*. `FuncN`'s parameters cannot be logic references.
`An`: Type of argument passed at position *n* to the `FuncN` type. Can be a lref or POT whose effective type is convertible to the corresponding parameter type in `FuncN`.

Parameters:
`f` : The result of evaluating this function object or function pointer will be written to the specified stream.
`aN_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `f`.
`outputStrm`: Stream to which value will be written.

Exceptions:
`InvalidDeref` : If any `aN_` is a lref that has not been initialized at the time of evaluation.

Any exception thrown by `operator <<`.

Notes:
Although arguments passed to `write_f` may be lrefs or POTs, the parameter types of `f` can only be POTs.

Also refer to:
`write`, `write_f`, `write_mf`, `writeTo_mf`, `read`, `readFrom`

---

write_mf relation

```
// support for nullary member functions
template<typename Obj, typename MemFunT>
WriteMF_r<Obj, MemFunT>
write_mf(lref<Obj>& obj_, MemFunT mf)

// remaining overloads support member functions with up to 6 arguments
template<typename Obj, typename MemFunT, typename A1>
WriteMF1_r<Obj, MemFunT, A1>
write_mf(lref<Obj>& obj_, MemFunT mf, const A1& a1_)

template<typename Obj, typename MemFunT, typename A1, typename A2>
WriteMF2_r<Obj, MemFunT, A1, A2>
write_mf(lref<Obj>& obj_, MemFunT mf, const A1& a1_, const A2& a2_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3>
WriteMF3_r<Obj, MemFunT, A1, A2, A3>
write_mf(lref<Obj> obj_, MemFunT mf, const A1& a1_, const A2& a2_
         , const A3& a3_)
```

```
template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3, typename A4>
WriteMF4_r<Obj, MemFunT, A1, A2, A3, A4>
write_mf(lref<Obj>& obj_, MemFunT mf, const A1& a1_, const A2& a2_
         , const A3& a3_, const A4& a4_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3, typename A4, typename A5>
WriteMF5_r<Obj, MemFunT, A1, A2, A3, A4, A5>
write_mf(lref<Obj>& obj_, MemFunT mf, const A1& a1_, const A2& a2_
         , const A3& a3_, const A4& a4_, const A5& a5_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3, typename A4, typename A5, typename A6>
WriteMF6_r<Obj, MemFunT, A1, A2, A3, A4, A5, A6>
write_mf(lref<Obj>& obj_, MemFunT mf, const A1& a1_, const A2& a2_
         , const A3& a3_, const A4& a4_, const A5& a5_, const A6& a6_)
```

Declarative reading: write to `std::cin` the value returned by invoking `(*obj_).*mf(a1_ .. aN_)`

Template Parameters:
`MemFunT`: A member function pointer/object type (with up to 6 parameters). Parameter types cannot be logic references.
`An`: Type of argument passed at position *n* to `MemFunT`. Can be a POT or lref whose effective type is same as or convertible to the corresponding parameter type in `MemFunT`.

Parameters:
`obj_` : [in] The object whose member function referred to by mf is to be evaluated. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mf` : The result of evaluating this function object/pointer will be written to the specified stream.
`aN_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `mf`.

Exceptions:
`InvalidDeref` : If `obj_` or, if any `aN_` is a lref that has not been initialized at the time of evaluation.

Any exception thrown by `operator <<`.

Notes:
Although arguments passed to `write_mf` may be lrefs or POTs, the parameter types of `mf` cannot be lrefs.

Examples:

```
// read string from std::cin and print its length
lref<string> s;
relation r = read(s) && write_mf(s,&string::size);
r();
```

Also refer to:

`write`, `write_f`, `writeTo_f`, `writeTo_mf`, `read`, `readFrom`

---

writeTo_mf relation

```
// support for nullary member functions
template<typename Obj, typename MemFunT>
WriteMF_r<Obj, MemFunT>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, MemFunT mf)

// remaining overloads support member functions with up to 6 arguments
template<typename Obj, typename MemFunT, typename A1>
WriteMF1_r<Obj, MemFunT, A1>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, MemFunT mf
           , const A1& a1_)

template<typename Obj, typename MemFunT, typename A1, typename A2>
WriteMF2_r<Obj, MemFunT, A1, A2>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, MemFunT mf
          , const A1& a1_, const A2& a2_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3>
WriteMF3_r<Obj, MemFunT, A1, A2, A3>
writeTo_mf(std::ostream& outputStrm, lref<Obj> obj_, MemFunT mf
          , const A1& a1_, const A2& a2_, const A3& a3_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3, typename A4>
WriteMF4_r<Obj, MemFunT, A1, A2, A3, A4>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, MemFunT mf
           , const A1& a1_, const A2& a2_, const A3& a3_
           , const A4& a4_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3, typename A4, typename A5>
WriteMF5_r<Obj, MemFunT, A1, A2, A3, A4, A5>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, MemFunT mf
           , const A1& a1_, const A2& a2_, const A3& a3_
           , const A4& a4_, const A5& a5_)

template<typename Obj, typename MemFunT, typename A1, typename A2,
typename A3, typename A4, typename A5, typename A6>
WriteMF6_r<Obj, MemFunT, A1, A2, A3, A4, A5, A6>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, MemFunT mf
           , const A1& a1_, const A2& a2_, const A3& a3_
           , const A4& a4_, const A5& a5_, const A6& a6_)
```

Declarative reading: write to `std::cin` the value returned by invoking `(*obj_).*mf(a1_ .. aN_)`

Template Parameters:

`MemFunT`: A member function pointer/object type (with up to 6 parameters). Parameter types cannot be logic references.
`An`: Type of argument passed at position *n* to `MemFunT`. Can be lref or POT whose effective type is same as or convertible to the corresponding parameter type in `MemFunT`.

Parameters:
`obj_` : [in] Object on which method is to be invoked. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mf` : Pointer to member function whose result will be written to the specified stream.
`aN_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `mf`.
`outputStrm`: Stream to which value will be written.

Exceptions:
`InvalidDeref` : If `obj_` or, if any `aN_` is a lref that has not been initialized at the time of evaluation.

Any exception thrown by `operator <<`.

Examples:
```
// read string from std::cin and print its length to a file
ofstream myfile("example.txt");
lref<string> s = "Castor";
writeTo_mf(myfile, s, &string::size)();
```

Also refer to:
`write`, `write_f`, `write_mf`, `writeTo_f`, `writeAll`, `writeAllTo`, `read`, `readFrom`

---

writeAll relation

```
template<typename Itr>
WriteAll_r<Itr> writeAll(Itr begin_, Itr end_
                        , const std::string& separator=" ")

template<typename Cont>
relation writeAll(lref<Cont>& cont_, const std::string& separator=" ")
```

Declarative reading: Write all values in the container `cont_` or in the range [`begin_`, `end_`) to `std::cout`.

Template Parameters:
`Itr` : A pointer, iterator, a logic reference to a pointer or a logic reference to a iterator. Dereferencing the effective value of `Itr` should yield a value that is writable to `cout` using << operator.
`Cont` : A container type. `Cont` should provide methods `begin()` and `end()` for obtaining iterators to beginning and one past the end of container. The element type should be writable to `cout` using << operator.

Parameters:
`begin_` : [in] Iterator to the beginning of a sequence to be printed to `cout`.
`end_` : [in] Iterator to one past the end of a sequence to be printed to `cout`.
`cont_` : [in] A logic reference to a container whose elements are to be printed to `cout`.
`separator` : The string to be printed between two consecutive items in the sequence. Defaults to a single space.

Exceptions:
`InvalidDeref` : If `begin_`, `end_` or `cont_` is an uninitialized logic reference at the time of evaluation.

Any exception thrown by `operator <<`.

Notes:
Relation `writeAll` provides a simple relational facility for writing a sequence of values to `std::cout`. The action of printing values will not be reverted during backtracking. `writeAll` evaluates successfully only once.

Examples:
```
// 1) print an array using pointers
string as[] = {"1","2","3","4"};
writeAll(as,as+4)();

// 2) print items in vector (using iterators) using comma as separator
vector<string> vs = ...;
writeAll(vs.begin(),vs.end(), ",");

// 3) print (comma separated) items in vector using lref<iterator>
lref<vector<string> > lvs = vector<string>(as,as+4);
lref<vector<string>::iterator> b,e;
relation r = begin(lvs,b) && end(lvs,e) && writeAll (b,e);
while(r());

// 4) printing values in a container
lref<vector<string> > lvs = vs;
writeAll(lvs)();
```

Also refer to:
`write`, `write_f`, `write_mf`, `writeTo_f`, `writeAllTo`, `writeTo_mf`, `read`, `readFrom`

---

writeAllTo relation

```
template<typename Itr>
WriteAll_r<Itr> writeAllTo(std::ostream& outputStrm, Itr begin_
                          , Itr end_, const std::string& separator=" ")

template<typename Cont>
relation writeAllTo(std::ostream& outputStrm, lref<Cont>& cont_
```

```
                        , const std::string& separator=" ")
```

Declarative reading: Write all values in the container `cont_` or in the range [`begin_`, `end_`) to `std::cout`.

Template Parameters:
`Itr` : A pointer, iterator, a logic reference to a pointer or a logic reference to an iterator. Dereferencing the effective value of `Itr` should yield a value that is writable to `outputStrm` using `<<` operator.
`Cont` : A container type. `Cont` should provide methods `begin()` and `end()` for obtaining iterators to beginning and one past the end of container. The element type should be writable to `outputStrm` using `<<` operator.

Parameters:
`outputStrm`: Stream to which values will be written.
`begin_` : [in] Iterator to the beginning of a sequence to be printed to `cout`.
`end_` : [in] Iterator to one past the end of a sequence to be printed to `cout`.
`cont_` : [in] A logic reference to a container whose elements are to be printed to `cout`.
`separator` : The string to be printed between two consecutive items in the sequence. Defaults to a single space.

Exceptions:
`InvalidDeref` : If `begin_`, `end_` or `cont_` is an uninitialized logic reference at the time of evaluation.

Any exception thrown by `operator <<`.

Notes:
Relation `writeAll` provides a simple relational facility for writing a sequence of values to `std::cout`. The action of printing values will not be reverted during backtracking. `writeAll` evaluates successfully only once.

Examples:
```
// 1) print an array to stringstream using pointers
string as[] = {"1","2","3","4"};
stringstream sstrm;
writeAllTo(sstrm,as,as+4, " ")();

// 2) print (comma separated) items in vector using lref<iterator>
stringstream sstrm;
lref<vector<string> > lvs = vector<string>(as,as+4);
lref<vector<string>::iterator> b,e;
relation r = begin(lvs,b) && end(lvs,e) && writeAllTo(sstrm,b,e);
while(r());

// 3) printing values in a container
lref<vector<string> > lvs = vs;
writeAll(lvs)();
```

Also refer to:

`write`, `write_f`, `write_mf`, `writeTo_f`, `writeAll`, `writeTo_mf`, `read`, `readFrom`

empty relation

```
template<typename Cont>
relation empty(lref<Cont> c)

template<typename Cont>
relation empty(const Cont& c)
```

Declarative reading: Container `c` is empty.

Template Parameters:
`Cont` : Must satisfy requirements of standard C++ containers [$23.1].

Parameters:
`c` : [in/out] If `c` is initialized, it will be tested for emptiness, otherwise it will be initialized with an empty container of type `Cont`.

Notes:
Evaluates successfully if container `c` is empty. If `c` is initialized, relation `empty` performs the test for emptiness by comparing `c == Cont()`. Thus default construction of type `Cont` is expected to yield an empty container. Similarly if `c` is not initialized, `c` will be assigned a default constructed instance of type `Cont`.

Also refer to:
`size`

---

eq_seq relation

```
template<typename Cont, typename Iter>
UnifySeq<Cont,Iter> eq_seq(const lref<Cont>& c, Iter begin_, Iter end_)

template<typename Cont, typename Iter, typename Cmp>
UnifySeq<Cont, Iter, Cmp> eq_seq(const lref<Cont>& c, Iter begin_, Iter
end_, Cmp cmp)
```

Declarative reading: Container `c` is equal to the sequence represented by the iterators `begin` and `end`.

Template Parameters:
`Cont` : Must satisfy requirements of standard C++ containers [$23.1].
`Iter`: A type that yields `Cont::value_type` on deferencing and supports postfix increment and decrement operators[$23.1]. In other words, any iterator or pointer type. `Iter` type is not limited the `Cont::iterator`. Thus it is possible for `Iter` to be, for example, the type `list<T>::iterator` or `T*` when `Cont` is the type `vector<T>`.

`Cmp` : A binary predicate with both parameters of type `T` such that `Cont::value_type` can be converted to `T`. Used to customize the comparison operation performed during unification.

Parameters:
`c` : [in/out] Item to be unified with `r`.
`begin_` : [in] Iterator to the beginning of the sequence to be unified with `c`.
`end_` : [in] Iterator to one past the end of the sequence to be unified with `c`.
`cmp` : [in] `cmp` : [in] Binary predicate used to compare two objects of type `Cont::value_type`. It may be a function object or pointer to function. `cmp` is used to compare an item in container `c` with the corresponding item in sequence`[begin_,end_)`for equality. `cmp` cannot be a logic reference.

Exceptions:
`InvalidDeref` : If either `begin_` or `end_` is not initialized at the time of evaluation.

Notes:
Relation `eq_seq` provides a simple and useful facility for unifying containers with a sequences represented by an iterator pairs. If iterators `begin_` and `end_` are logic references they must be initialized at the time of evaluation. If `c` is initialized, then the sequence `[ c.begin(), c.end() )` is compared for equality with the sequence `[begin_, end_)`. Comparison fails if the two sequences differ in length or if the items in the corresponding positions do not compare equally. Comparison operation can be customized by passing a binary predicate to parameter `cmp`. If `c` is not initialized, it will be initialized with a container consisting of the elements in `[begin_,end_)`.

Examples:
```
// 1) generate container with elements
const int ai[] = {1,2,3};
lref<vector<int> > vi;
if( eq_seq(vi, ai, ai+3)() )
  copy(vi->begin(), vi->end(), ostream_iterator<int>(cout, " "));

// 2) compare container with sequence
list<int> li = /* {1,2,3} */;
lref<vector<int> > vi = vector<int>(3);
(*vi)[0]=1; (*vi)[1]=2; (*vi)[2]=3;
if( eq_seq(vi, li.begin(), li.end())() )
    cout << "vi has the same elements as li";
```

Also refer to:
`sequence, eq`

---

head relation

```
template<typename Seq>
Head_r<Seq> head(lref<Seq>& seq_, lref<typename Seq::value_type> h)
```

Declarative reading: head of `seq_` is `h`.

Template Parameters:
`Seq`: Must satisfy the requirements of standard C++ sequences [$23.1.1].

Parameters:
`seq_` : [in] Sequence whose head element is of interest.
`h` : [in/out] The first element in `seq_`.

Exceptions:
`InvalidDeref` : If `seq_` is not initialized at the time of evaluation.

Notes:
The first element in `seq_` is obtained by dereferencing the `begin` iterator.

Also refer to:
`head_n, tail, tail_n, head_tail, head_n_tail, next, prev.`

---

head_n relation

```
template<typename Seq, typename HeadSeq>
relation head_n( lref<Seq>& seq_
               , lref<typename HeadSeq::size_type> n
               , lref<HeadSeq>& h )
```

Declarative reading: `h` contains first `n` items from sequence `seq_`.

Template Parameters:
`Seq` : Must satisfy requirements of standard C++ sequences [$23.1.1].
`HeadSeq` : Must satisfy requirements of standard C++ sequences [$23.1.1].

Parameters:
`seq_` : [in] Sequence whose first `n_` elements is of interest.
`n` : [in/out] Number of items in `h`. 0 <= n <= size of seq_.
`h` : [in/out] Sequence containing copies of first `n` elements from `seq_`, i.e. the head sequence.

Exceptions:
`InvalidDeref` : If `seq_` is not initialized at the time of evaluation.

Notes:
If `n` is greater than the number of elements in `seq_`, the relation fails. `h` and `seq_` may be of different types i.e. `h` can be a `list` and `seq_` may be a `vector`.

Also refer to:
`head, tail, tail_n, head_tail, head_n_tail.`

head_tail relation

```
template<typename Seq, typename TailSeq>
relation head_tail( lref<Seq>& seq_
                  , lref<typename TailSeq::value_type> h
                  , lref<TailSeq>& t )
```

Declarative reading: `h` and `t` respectively form the head and tail of `seq_`.

Template Parameters:
`Seq` : Must satisfy the requirements of standard C++ sequences [$23.1.1].
`TailSeq` : Must satisfy requirements of standard C++ sequences [$23.1.1].

Parameters:
`seq_` : [in] Sequence whose head and tail elements are of interest.
`h` : [in/out] head of `seq_`.
`t` : [in/out] tail of `seq_`.

Notes:
`h` and `t` are copies of the elements comprising the head and tail of `seq_`. `t` may be a different type than `seq_`. `head_tail` provides a convenient way to determine head and tail in a single step instead of obtaining them separately using relations `head` and `tail`.

Also refer to:
`head, head_n, tail, tail_n, head_n_tail.`

head_n_tail relation

```
template<typename Seq, typename HeadSeq>
relation head_n_tail( lref<Seq>& seq_
                    , lref<typename HeadSeq::size_type> n
                    , lref<HeadSeq>& h
                    , lref<HeadSeq>& t )
```

Declarative reading: `h` is head sequence and `t` is tail sequence of `seq_` such that size of `h` is `n`.

Template Parameters:
`Seq` : Must satisfy the requirements of standard C++ sequences [$23.1.1].
`HeadSeq` : Must satisfy requirements of standard C++ sequences [$23.1.1]. This type is the same for both head and tail.

Parameters:
`seq_` : [in] Sequence whose head and tail elements are of interest.
`n` : [in/out] size of head. 0 <= n <= size of seq_.

`h` : [in/out] head sequence from `seq_` of size `n`.
`t` : [in/out] tail of `seq_`.

Notes:
`h` and `t` are copies of the elements comprising the head and tail of `seq_`. Tail `t` comprises of the all the elements in `seq_` following the head sequence `h`.

Also refer to:
`head, head_n, tail, tail_n, head_n_tail.`

---

insert relation

```
template<typename Seq>
relation insert( lref<typename Seq::value_type> value_
               , lref<typename Seq::iterator> b_
               , lref<typename Seq::iterator> e_
               , lref<Seq>& insertedSeq )
```

Declarative reading: inserting `value_` somewhere into [`b_,e_`) yields sequence `insertedSeq`.

Template Parameters:
`Seq`: Type representing a sequence of values. `Seq` must satisfy the requirements of standard C++ sequences [$23.1.1].

Parameters:
`value_` : [in] The value to be inserted.
`b_` : [in] Iterator to the start of a sequence of values into which `value_` needs to be inserted.
`e_` : [in] Iterator to one past the end of a sequence of values into which `value_` needs to be inserted.
`insertedSeq` : [in/out] Sequence containing values from the sequence `[b_,e_)` in addition to `value_`. Contains exactly `std::distance(b_,e_)+1` elements.

Notes:
Relative order of values in `[b_,e_)` is preserved in `insertedList`.

Examples:
Number 9 can be inserted into sequence (1,2) in three ways:
(9,1,2), (1,9,2) and (1,2,9). The following code prints each of these combinations.

```
list<int> li;
li.push_back(1); li.push_back(2);
lref<list<int> > insertedSeq;
relation r = insert(9, li.begin(), li.end(), insertedSeq);
while(r()) {
    copy(insertedSeq->begin(), insertedSeq->end()
                             , ostream_iterator<int>(cout," "));
```

```
        cout << "\n";
    }
```

Also refer to:

insert_seq, merge.

---

insert_seq relation

```
template<typename Seq>
relation insert_seq(  lref<typename Seq::iterator> valuesB_
                    , lref<typename Seq::iterator> valuesE_
                    , lref<typename Seq::iterator> b_
                    , lref<typename Seq::iterator> e_
                    , lref<Seq>& insertedSeq )
```

Declarative reading: inserting the sequence of values in [valuesB_,valuesE_) somewhere into [b_,e_) yields sequence insertedSeq.

Template Parameters:

Seq: Type representing a sequence of values. Seq must satisfy the requirements of standard C++ sequences [$23.1.1].

Parameters:

value_ : [in] The value to be inserted.

b_ : [in] Iterator to the start of a sequence of values into which value_ needs to be inserted.

e_ : [in] Iterator to one past the end of a sequence of values into which value_ needs to be inserted.

insertedSeq : [in/out] Sequence containing values from the sequence [b_,e_) in addition to value_. It contains exactly std::distance(b,e)+1 elements.

Notes:

Relative order of values in [b_,e_) is preserved in insertedSeq. Exact order of values in [valuesB_,valuesE_) is preserved in insertedSeq. In other words, inserting the exact sequence [valuesB_,valuesE_) at some position into the sequence [b_,e_) yields insertedSeq.

Example:

Sequence (8,9) can be inserted into sequence (1,2) in three ways:
(8,9,1,2), (1,8,9,2) and (1,2, 8,9). The following code prints each of these combinations.

```
    list<int> li;        // sequence to insert into
    li.push_back(1);      li.push_back(2);
    list<int> values;    // sequence to insert
    values.push_back(8); values.push_back(9);
    lref<list<int> > insertedSeq;
    relation r = insert_seq(values.begin(), values.end()
                          , li.begin(), li.end(),insertedSeq);
    while(r()) {
```

```
        copy(insertedSeq->begin(), insertedSeq->end()
                                 , ostream_iterator<int>(cout," "));
        cout << "\n";
    }
```

Also refer to:
`insert, merge.`

---

merge relation

```
template<typename Seq>
relation merge(lref<Seq>& l_, lref<Seq>& r_, lref<Seq>& m)
```

Declarative reading: Merging sorted sequences `l_` and `r_` yields sorted sequence `m`.

Template Parameters:
`Cont` : Must satisfy requirements of standard C++ containers [$23.1].

Parameters:
`l_, r_` : [in] Sorted sequences to be merged.
`m` : [in/out] Merged sequence.

Exceptions:
`InvalidDeref` : If `l_` or `r_` are not initialized at the time of evaluation.

Notes:
This is the relational equivalent of `std::merge`.

Also refer to:
`insert, insert_seq.`

---

not_empty relation

```
template<typename Cont>
relation not_empty(lref<Cont> c_)

template<typename Cont>
relation not_empty(const Cont& c_)
```

Declarative reading: Container `c_` is not empty.

Template Parameters:
`Cont` : Must satisfy requirements of standard C++ containers [$23.1].

Parameters:
`c_` : [in] Container to be tested for emptiness. Must be

Notes:
Evaluates successfully if container `c_` is not empty. Unlike relation `empty`, the container argument `c_` must be initialized at the time of evaluation. Test of emptiness is performed using method `Cont::size`.

Also refer to:
`empty, size.`

---

sequence relation

```
template<typename Seq>
Sequence_r<Seq> sequence(lref<Seq>& seq)..
                        (lref<T> item)..(const ConvertibleToT& item)..
                        (lref<Seq>& items)..
                        (Iter start, Iter end)..
                        (LrefIter start, LrefIter end)
// where
// T = Seq::value_type
// LrefIter = lref<Seq::iterator>
// ConvertibleToT = any type convertible to T
```

Declarative reading: `seq` is a sequence comprising of the arguments following it.

Template Parameters:
`Seq` : Must satisfy requirements of standard C++ sequences [$23.1.1].

Parameters (Fixed):
`seq` : [in/out] The sequence to be unified with the other arguments. It must be a logic reference type. Passing regular container types directly is disabled as it leads to implicitly passing a copy of the original (which can be inefficient) and can also lead to unexpected and surprising behavior.

Parameters (Variadic):
After `seq`, the following parameter types are supported by sequence. Each of these should be separately enclosed in a pair of ( ). Any of the following variadic arguments may be optionally provided and in any order.

a) `lref<T> item` : Represents a single element in the sequence. This allows passing arguments of type `lref<T>`.

b) `ConvertibleToT& item` : Represents a single element in the sequence. This allows passing values of arbitrary types that are convertible to `T`.

c) `lref<Seq>& items` : Represents a subsequence of elements occurring in sequence. This allows passing of logic reference to a sequence of the same type as `seq`. Passing a sequence directly by value is not supported, the argument must be a `lref`.

d) `Iter start, Iter end` : A pair of iterators representing a subsequence of elements occurring in `seq`. This allows passing iterators by value. The iterator type must of type `Seq::iterator`.

e) `LrefIter start, LrefIter end` : A pair of logic references to iterators representing a subsequence of elements occurring in `seq`. This allows the use of logic references to iterators as arguments where the iterator type is `Seq::iterator`.

Note that arguments of type `lref<ConvertibleToT>` are not supported currently. Similarly when using iterator pairs, they must be iterators to a sequence of the same type. Using `vector<T>::iterator` pairs when `seq` is of type `list<T>` is not supported. All arguments other than the `seq` must be initialized at the time of evaluation.

Exceptions:
`InvalidDeref` : If any logic reference argument other than the first is an not initialized at the time of evaluation.

Notes:
`sequence` is a variadic relation. That is, its arity (number of arguments) is not predefined. The style of argument passing used in `sequence` is different compared to the traditional C style techniques used in standard variadic functions like `printf` and `scanf`. Each argument to `sequence` is surrounded by a ( ) pair. Thus the syntax for passing 4 arguments looks like `sequence(s)(7)(8)(9)` instead of `sequence(s,7,8,9)`. This method of variadic argument passing allows relation sequence to automatically preserve full type information for each argument without additional assistance on behalf of the programmer.

The first argument represents a sequence comprising of elements described by the remaining arguments. For instance if `s` is a `lref<list<int> >`, then `sequence(s)(7)(8)(9)` unifies `s` with the sequence {7,8 ,9} . Argument `s` may or may not be initialized. If `s` is **not** initialized, it will be assigned a `list<int>` containing elements 7,8 and 9 in that order. If `s` is initialized, it will be tested to see if it contains the exactly the three elements 7, 8 and 9 in order. The first argument must be logic reference to any sequence type. The remaining arguments can be classified into two kinds. The first kind is values representing individual elements in the sequence. The second kind is a sequence representing a span of elements to need to appear in the first argument. This is specified using either iterator pairs or a logic reference to sequence. For example, if `li` is a `list<int>` then `sequence(s)(li.begin(),li.end())` will unify `s` with all elements in `li`. Both kinds of arguments may appear in any order and can be logic references or regular types:

In many cases, the flexibility and brevity provided by variadic arguments in `sequence` may not be needed. In such situations, relations `eq` and `eq_seq` provide more light weight and efficient alternatives.

Examples:

```
// 1) compare sequence with {3,4,5}
lref<vector<int> > vi = /* {3, 4, 5} */;
lref<int> li = 4;
assert( sequence(vi)(3)(li)(5)() ); // vi == {3,4,5}

// 2) generate sequence {3,4,5}
lref<vector<int> > s;    // not initialized
sequence(s)(3)(4)(5)();  // s = {3,4,5}

// 3) test for empty sequence
list<int> emptyList;
assert( sequence<list<int> >(emptyList)() )

// 4) Iterator pairs : generate sequence comprised of values in vi
followed by 4
lref<vector<int> > s;
vector<int> vi = /* {1,2,3} */ ;
int four = 4;
sequence(s)( vi.begin(),vi.end() )(four)(); // s = {1,2,3,4}

// 5) Iterator pairs : generate sequence using lref<iterator>
lref<vector<int> > s; // not initialized
vector<int> vi = /* {1,2,3} */ ;
lref<vector<int>::iterator> b,e;
relation r = begin<vector<int> >(vi,b)
              && end<vector<int> > (vi,e)
              && sequence(s)(b,e); // s = {1,2,3}

// 6) Simple containers comparison
lref<vector<int> > s; // not initialized
vector<int> vi = /* {1,2,3} */ ;
lref<vector<int>::iterator> b,e;
relation r = sequence(s)(vi.begin(),vi.end()); // s = {1,2,3}
// unification with pair of iterators can be also be done with
// the more light weight but less flexible relation eq_seq:
relation r2 = eq_seq(s,vi.begin(),vi.end())
// simplest way to unify containers directly is to use eq:
relation r3 = eq(s,vi);
```

Also refer to:
`eq_seq, eq, item, getValues, size, begin, end, head, tail, head_tail, head_n, tail_n, head_n_tail.`

---

size relation

```
template<typename Cont>
Size_r<Cont> size(lref<Cont>& cont_, lref<typename Cont::size_type> sz)
```

Declarative reading: Size of container `cont_` is `sz`.

Template Parameters:

`Cont` : Must satisfy requirements of standard C++ containers [$23.1].

Parameters:
`cont_` : [in] Container whose size is to be determined.
`sz` : [in/out] Size of `cont_`.

Exceptions:
`InvalidDeref` : If `cont_` is not initialized at the time of evaluation.

Notes:
Size of `cont_` is determined by invoking its `size` member function.

Example:
```
    lref<vector<int>::size_type> sz;
    vector<int> v = vector<int> ();
    if( size(v, sz)() );
      cout << *sz;  // prints 0
```

Also refer to:
`empty, not_empty.`

---

tail relation

```
template<typename Seq, typename TailSeq>
Tail_r<Seq,TailSeq> tail( lref<Seq>& seq_, lref<TailSeq>& t )
```

Declarative reading: Tail of `seq_` is `t`.

Template Parameters:
`Seq`: Must satisfy the requirements of standard C++ sequences [$23.1.1].
`TailSeq` : Must satisfy requirements of standard C++ sequences [$23.1.1].

Parameters:
`seq_` : [in] Container whose tail is of interest.
`t` : [in/out] The tail sequence of `cont_`.

Exceptions:
`InvalidDeref` : If `seq_` is not initialized at the time of evaluation.

Notes:
The tail of a sequence comprises of all elements in sequence except for the first one (i.e. the head) .

Also refer to:
`head, head_n, tail_n, head_tail, head_n_tail, next, prev.`

tail_n relation

```
template<typename Seq, typename TailSeq>
relation tail_n( lref<Seq>& seq_
               , lref<typename TailSeq::size_type> n
               , lref<TailSeq>& t )
```

Declarative reading: `t` contains last `n` items from sequence `seq_`.

Template Parameters:
`Seq` : Must satisfy requirements of standard C++ sequences [$23.1.1].
`TailSeq` : Must satisfy requirements of standard C++ sequences [$23.1.1].

Parameters:
`seq_` : [in] Sequence whose last `n` elements are of interest.
`n` : [in/out] Number of items in `t`. 0 <= n <= size of seq_.
`t` : [in/out] Sequence containing copies of last `n` element from `seq_`.

Exceptions:
`IndexOutOfBounds`: If size of `seq_` is less than `n_`.
`InvalidDeref` : If `seq_` or `n_` is not initialized at the time of evaluation.

Notes:
`t` and `seq_` may be of different types. `t` is a copy of the elements comprising the tail of `seq_`.

Also refer to:
`head, head_n, tail, head_tail, head_n_tail.`

Iterators

begin relation

```
template<typename Cont>
Begin_r<Cont> begin(  lref<Cont>& cont_
                    , lref<typename Cont::iterator> iter)
```

Declarative reading: Iterator pointing to the start of container `cont_` is `iter`.

Template Parameters:
`Cont` : Must satisfy requirements of standard c++ containers [$23.1].

Parameters:
`cont_` : [in] Container whose begin iterator is to be determined.
`iter` : [in/out] iterator to the beginning of `cont_`.

Exceptions:
`InvalidDeref` : If `cont_` is not initialized at the time of evaluation.

dereference relation

```
relation dereference(lref<Itr> pointer_
           , lref<typename detail::Pointee<Itr>::result_type> pointee)
```

Declarative reading: Dereferencing `pointer_` yields `pointee`.

Template Parameters:
`Itr` : Either a pointer or iterator type or a logic reference to a pointer or iterator.

Parameters:
`pointer_` : [in] A pointer or iterator to be dereferenced.
`pointee` : [in/out] If `pointee` is initialized, it will be compared with the value obtained by dereferencing `pointer_` using `operator==`. If not initialized, pointee will be assigned the value obtained by dereferencing `pointer_`.

Notes:
Relation `dereference` is used for obtaining an `lref<T>` from an `lref<T*>`. This is useful when iterating over containers and streams or simply working with pointers in a relational fashion.

Examples:

```
// 1) dereferencing lref<int*> to obtain lref<int>.
int three=3;
lref<int*> lp3=&three;
lref<int> l;
relation r = dereference(lp3,l) && write(l);
r();  // prints 3
```

```
    // 2) dereferencing raw pointers.
    int two=2;
    int* pi= &two;
    lref<int> li;
    relation r = dereference(pi, li) && write(li);
    r(); // prints "2"

   // 3) dereferencing logic references to iterators.
    lref<vector<int> > lv = vector<int>();    lv->push_back(4);
    lref<vector<int>::iterator> lItr = lv->begin();
    // check if 1st element in lv 4
    relation r = begin(lv, lItr) && dereference(lItr, 4);
    if(r())
       cout << "first element is 4";
```

---

end relation

```
template<typename Cont>
End_r<Cont> end(lref<Cont>& cont_, lref<typename Cont::iterator> iter)
```

Declarative reading: Iterator pointing to one past the end of container `cont_` is `iter`.

Template Parameters:
`Cont` : Must satisfy requirements of standard c++ containers [$23.1].

Parameters:
`cont_` : [in] Container whose begin iterator is to be determined.
`iter` : [in/out] points to (one past) the end of the elements in `cont_`. End iterator of container is obtained by invoking its `end()` method.

Exceptions:
`InvalidDeref` : If `cont_` is not initialized at the time of evaluation.

---

item relation

```
template<typename Itr>
Item_r<Itr> item( lref<typename detail::Pointee<Itr>::result_type> obj
                 , Itr begin_, Itr end_ )

template<typename Cont>
relation item( lref<typename Cont::value_type> obj, lref<Cont>& cont_ )
```

Declarative reading: `obj` is an item in the sequence `[begin, end)` or the container `cont_`.

Template Parameters:
`Itr` : Can be a pointer type, an input iterator type [$24.1.1], a logic reference to a pointer, or a logic reference to an input iterator. If `Itr` is not a logic reference, it must support dereferencing with `operator *`. Similarly, if `Itr` is a logic reference type, its underlying type must support dereferencing with `operator *`.

`Cont` : Satisfies requirements of standard containers.

Parameters:
`obj`: [in/out] `obj` is an item in the sequence bounded by iterators `begin_` and `end_`.
`begin_`: [in] points to the beginning of a sequence. It must precede or be equal to `end_`.
`end_`: [in] points to (one past) the end of a sequence.
`cont_`: [in] A standard container whose items are of interest.

Exceptions:
`InvalidDeref` : If `begin_` or `end_` is not uninitialized at the time of evaluation.

Notes:
Relation `item` is typically useful for iterating over sequences in a relational fashion. However, due to the bidirectional nature of parameter `obj`, it also doubles up as a facility for testing the presence of a value in a sequence. Since `item` works with standard iterators and pointers (or logic references to pointers and iterators) it enables easier interaction with traditional C++ code that deal with containers, streams and arrays.

Example:

```
 // 1) print all values in an array
 int arr[] = {1,2,3,4};
 lref<int> val;
 lref<int*> b = arr+0, e = arr+4;
 relation r = item(obj, b, e);
 while(r())
     cout << * val << " "; // prints "1 2 3 4 "

// 2) print all items in 1st array that are also part of 2nd array
// (i.e intersection of two arrays)
 int arr1[] = {1,2,3,4};
 int arr2[] = {6,3,7,1,9};
 lref<int> i;
 relation r2 = item(i, arr1+0, arr1+4) && item(i, arr2+0, arr2+5);
 while(r2())
     cout << *i << " "; // prints "1 3 "

// 3) Intersection of two vectors
 lref<vector<int> > v1 = vector<int>(arr1+0, arr1+4);
 lref<vector<int> > v2 = vector<int>(arr2+0, arr2+5);
 lref<int> i, j;
 relation r3 = item(i, v1) && item(j, v2) && predicate(i==j);
 while(r3())
     cout << *i << " "; // prints "1 3 "
```

In the second example the first call to `item` is responsible for generating a value for `i` from `arr1` and the second call to `item` then tests if that value is part of `arr2`. The third example which works on vectors is semantically same as the second although expressed slightly differently.

next relation

```
template<typename T>
relation next(lref<T> curr_, lref<T> n)

template<typename T>
relation next(T curr_, lref<T> n)

template<typename T>
relation next(T curr_, const T& n)
```

Declarative reading: Next of `curr_` is `n`.

Template Parameters:
`T` : Must support prefix increment operator.

Parameters:
`curr_` : [in] value preceding `n`. This must be initialized at the time of evaluation.
`n` : [in/out] value following `curr_`. i.e `++curr_`.

Exceptions:
`InvalidDeref` : If `curr_` is a `lref` and is not initialized at the time of evaluation.

Notes:
Relation next is useful for incrementing both values and iterators. The second and third overloaded versions provide slightly optimized implementation for cases when one or both of the arguments is not a logic reference type. More importantly they simplify syntax for user code by not requiring explicit specification of the template parameter when arguments involve a mix of types `lref<T>` and `T`. Relation next generates only one solution.

Examples:
The following relation generates one item in `i` at a time in the sequence bounded by iterators `b_` and `e_`. By initializing argument `i` to a value, this relation could be instead used to test if a particular value is present in the sequence.

```
relation itemsIn(lref<int*> b_, lref<int*> e_, lref<int> i) {
   lref<int*> n;
   return eq(b_,e_) // stop if b_==e_
       ^ (dereference(b_,i) || next(b_,n) && recurse(&itemsIn, n, e_,
i) );
}
```

For a more generalized version of `itemsIn` refer to documentation of relation `item`.

Also refer to:
`prev, inc, dec, head, tail, item`

prev relation

```
template<typename T>
relation prev(lref<T> curr_, lref<T> p)

template<typename T>
relation prev(T curr_, lref<T> p)

template<typename T>
relation prev(T curr_, const T& p)
```

Declarative reading: Previous of `curr_` is `p`.

Template Parameters:
`T` : Must support prefix decrement operator.

Parameters:
`curr_` : [in] value succeeding `p`. This must be initialized at the time of evaluation.
`p` : [in/out] value preceding `curr_`. i.e `--curr_`.

Exceptions:
`InvalidDeref` : If `curr_` is a `lref` and is not initialized at the time of evaluation.

Notes:
Relation prev is useful for decrementing both values and bidirectional iterators. The second and third overloaded versions provide slightly optimized implementation for cases when one or both of the arguments is not a logic reference type. More importantly they simplify syntax for user code by not requiring explicit specification of the template parameter when arguments involve a mix of types `lref<T>` and `T`. Relation prev generates only one solution.

Also refer to:
`next, inc, dec, head, tail, item`

Predicates

Boolean relation

```
struct Boolean : public PureRelation<Boolean> {
    Boolean(bool value);
    // inherits :  bool operator()(void)
}
```

Brief Description: First evaluation succeeds only if return `value` is true, and all subsequent evaluations fail (i.e. return `false`).

Parameters:
`value` : The (`true`/`false`) value to be returned on first evaluation of `Boolean`.

Returns:
If `value` is `true`, returns `true` on first evaluation and `false` otherwise. All subsequent evaluations return `false`.

Exceptions:
None.

Notes: This relation is useful for creating simple predicate relations from boolean values or expressions that can be eagerly evaluated.

Example:

```
    int num;
    cin >> num;
    relation r =  ( Boolean(num<5) && write("value < 5") )
                 ^ write("value >= 5");
```

Also refer to:
`True, False.`

False relation

```
struct False : PureRelation<False> {
    // inherits :  bool operator()(void)
};
```

Brief Description: Always fails evaluation.

Returns:
Always returns `false`.

Exceptions:
None.

Also refer to:

Boolean, True.

True relation

```
struct True : PureRelation<True> {
    // inherits :  bool operator()(void)
};
```

Brief Description: First evaluation succeeds, and all subsequent evaluations fail (i.e. return false).

Returns:
First evaluation returns `true`, and all subsequent evaluations return `false`.

Exceptions:
None.

Also refer to:
Boolean, False.

---

predicate relation

```
// support for nullary functions
template<typename Pred>
Predicate0_r<Pred>
predicate(Pred pred);

// remaining overloads support member functions with up to 6 arguments
template<typename Pred, typename A1>
Predicate1_r<Pred,A1>
predicate(Pred pred, const A1& a1);

template<typename Pred, typename A1, typename A2>
Predicate2_r<Pred,A1,A2>
predicate(Pred pred, const A1& a1, const A2& a2);

template<typename Pred, typename A1, typename A2, typename A3>
Predicate3_r<Pred,A1,A2,A3>
predicate(Pred pred, const A1& a1, const A2& a2, const A3& a3);

template<typename Pred, typename A1, typename A2, typename A3
         , typename A4>
Predicate4_r<Pred,A1,A2,A3,A4>
predicate(Pred pred, const A1& a1, const A2& a2, const A3& a3
          , const A4& a4);

template<typename Pred, typename A1, typename A2, typename A3
        , typename A4 ,typename A5>
Predicate5_r<Pred,A1,A2,A3,A4,A5>
predicate(Pred pred, const A1& a1, const A2& a2, const A3& a3
          , const A4& a4, const A5& a5);
```

```
template<typename Pred, typename A1, typename A2, typename A3
         , typename A4 ,typename A5, typename A6>
Predicate6_r<Pred,A1,A2,A3,A4,A5,A6>
predicate(Pred pred, const A1& a1, const A2& a2, const A3& a3
          , const A4& a4, const A5& a5, const A6& a6);
```

Declarative reading: Same as `pred(a1,..,aN)`.

Template Parameters:
`Pred` : A function or function object that takes up to 6 arguments. Return type must be `bool` or any other type convertible to `bool`. Parameter types cannot be logic references.
`An` : Type of the Nth argument to being passed. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `Pred`.

Parameters:
`pred` : Function or function object which returns `bool` and takes up to 6 parameters.
`aN` : Argument (POT or lref) at position *N* whose effective value will be passed to `pred`.

Notes: Relation `predicate` is an adaptor relation used for treating regular functions (having up to 6 parameters) with return type `bool`, as relations. It evaluates successfully, at most once, if `pred` returns `true`. ILEs are often used as arguments to `predicate` to create simple anonymous relations directly inline, thus reducing the need to declare named predicate functions. For working with member predicate functions, use `predicate_mf`.

Examples:
Printing even numbers in an array by adapting the named predicate function `isEven`.
```
bool isEven(int num) {
    return num%2 == 0;
}

int nums[] = {4,3,9,8,15};
relation evenNums = item(n, nums+0, nums+5) && predicate(isEven,n);
while(evenNums())
   cout << *n << " ";
```

Printing even numbers with ILEs.
```
int nums[] = {4,3,9,8,15};
relation evenNums = item(n, nums+0, nums+5) && predicate(n%2==0);
while(evenNums())
   cout << *n << " ";
```

Also refer to:
`predicate_mf`.

---

predicate_mf relation

```
// support for nullary functions
```

```
template<typename Obj, typename MemPred>
MemPredicate0_r<Obj,MemPred>
predicate_mf(lref<Obj>& obj, MemPred pred)

// remaining overloads support member functions with up to 6 arguments
template<typename Obj, typename MemPred1, typename A1>
MemPredicate1_r<Obj,MemPred1,A1>
predicate_mf(lref<Obj>& obj_, MemPred1 mpred1, const A1& arg1)

template<typename Obj, typename MemPred2, typename A1, typename A2>
MemPredicate2_r<Obj,MemPred2,A1,A2>
predicate_mf(lref<Obj>& obj_, MemPred2 mpred2, const A1& arg1
             , const A2& arg2)

template<typename Obj, typename MemPred3, typename A1, typename A2,
typename A3>
MemPredicate3_r<Obj,MemPred3,A1,A2,A3>
predicate_mf(lref<Obj>& obj_, MemPred3 mpred3, const A1& arg1
             , const A2& arg2, const A3& arg3)

template<typename Obj, typename MemPred4, typename A1, typename A2,
typename A3, typename A4>
MemPredicate4_r<Obj,MemPred4,A1,A2,A3,A4>
predicate_mf(lref<Obj>& obj_, MemPred4 mpred4, const A1& arg1
             , const A2& arg2, const A3& arg3, const A4& arg4)

template<typename Obj, typename MemPred5, typename A1, typename A2,
typename A3, typename A4, typename A5>
MemPredicate5_r<Obj,MemPred5,A1,A2,A3,A4,A5>
predicate_mf(lref<Obj>& obj_, MemPred5 mpred5, const A1& arg1
             , const A2& arg2, const A3& arg3, const A4& arg4
             , const A5& arg5)

template<typename Obj, typename MemPred6, typename A1, typename A2
        , typename A3, typename A4, typename A5, typename A6>
MemPredicate6_r<Obj,MemPred6,A1,A2,A3,A4,A5,A6>
predicate_mf(lref<Obj>& obj_, MemPred6 mpred6, const A1& arg1
             , const A2& arg2, const A3& arg3, const A4& arg4
             , const A5& arg5, const A6& arg6)
```

Declarative reading: Same as `obj_.pred(a1,..,aN)`.

Template Parameters:

`Obj` : A type whose member function is to be treated as a relation.
`MemPredN` : A function pointer/object type that takes up to 6 arguments. Return type must be `bool` or any other type convertible to `bool`. Parameter types cannot be logic references.
`An` : Type of the N^th argument to being passed. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `MemPredN`.

Parameters:

obj_ : [in] Object on which member predicate function pointed to by mpred will be invoked. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of obj_.
mpred : Address of predicate member function to be treated as a relation.
argN : [in] The N[th] argument to be passed to mpred. Effective value of argN is passed to mpred.

Notes: Relation predicate_mf is an adaptor relation used for treating predicate member functions (having up to 6 parameters) as relations. It evaluates successfully, at most once, if pred returns true. For working with non-member predicate functions, use predicate_f.

Examples:
Counting empty lines in a file.

```
lref<list<string> > lines = readFromFile(..);
lref<string> line;
relation r= item(line, lines) && predicate_mf(line,&string::empty);
int count=0;
while(r())
    ++count;
cout << count << " empty lines found in file.";
```

Also refer to:
predicate_f.

Other

---

dec relation

```
template<typename T>
Dec_r<T> dec(lref<T>& value_);
```

Declarative reading: *value_* is decremented.

Template Parameters:
T : It may be a logic reference type or a regular type. If T is a logic reference type then its underlying type (i.e. T::result_type) must support prefix operator --. If T is not a logic reference type, it must support the prefix operator --.

Parameters:
value_ : [in & out] A logic reference whose value is to be decremented. value_ does not have to be initialized when dec is invoked but must be initialized at the time when dec is evaluated.

Notes: This relation evaluates successfully only once. On successful evaluation `value_` will be decremented. Any further attempt to evaluate this relation will restore the original value into `value_`.

Example:

```
lref<int> i;
relation r = dec(i); // 'i' need not be initialized at this point
i=2;       // but must be initialized before dec is evaluated
while(r())
    cout << *i << " ";  // prints 1
cout << *i << " ";  // prints 2

relation r2 = dec(3); // Compiler error. Argument must be a lref
```

Here, `r` is evaluated twice by the while loop. First evaluation attempt causes `i` to be decremented and evaluation succeeds. The second attempt at evaluation fails and the original value `2` is restored into `i`.

Also refer to:

`inc, next, prev.`

---

defined relation

```
template<typename T>
Defined_r<T> defined(const lref<T>& r_ )
```

Declarative reading: `r_` is initialized with a value.

Template Parameters:

`T`: Any type.

Parameters:

`r_` : [in] The logic reference to be tested for initialization.

Notes:

`defined` is a relational wrapper on the `lref::defined` method. Leaving `r_` uninitialized does not lead to generation of values for it. This relation merely invokes the `defined` method on `r_` when evaluated the first time. If defined returns true then evaluation succeeds, and fails otherwise. All subsequent evaluations will be unsuccessful.

Example:

```
lref<int> li=2;
//if li is initialized print its value
//otherwise print "not initialized"
relation r =  ( defined(li) && write(li) )
              ^ write("not initialized") ;
r();
```

Also refer to:

defined.

inc relation

```
template<typename T>
Inc_r<T> inc(lref<T>& value_);
```

Declarative reading: *value_* is incremented.

Template Parameters:
`T` : It may be a logic reference type or a regular type. If `T` is a logic reference type then its underlying type (i.e. `T::result_type`) must support prefix `++` operator. If `T` is not a logic reference type, it must support the prefix `++` operator.

Parameters:
`value_` : [in & out] A logic reference whose value is to be incremented. `value_` does not have to be initialized when `inc` is invoked but must be initialized at the time when `inc` is evaluated.

Notes: This relation evaluates successfully only once. On successful evaluation `value_` will be incremented. Any further attempt to evaluate this relation will restore the original value into `value_`.

Example:

```
    lref<int> i;
    relation r = inc(i); // 'i' need not be initialized at this point
    i=2;       // but must be initialized before inc is evaluated
    while(r())
        cout << *i << " ";   // prints 3
    cout << *i << " ";  // prints 2

    relation r2 = inc(3); // Compiler error. Argument must be a lref
```

Here, `inc(i)` is evaluated twice by the while loop. First evaluation attempt causes `i` to be incremented and evaluation succeeds. The second attempt restores the original value 2 into `i` and evaluation fails causing the while loop to terminate.

Also refer to:
`dec, next, prev.`

range relation

```
template<typename T>
Range_r<T> range(lref<T> val, T min_, T max_)

template<typename T>
Range_r<T> range(lref<T> val, lref<T> min_, lref<T> max_)

template<typename T>
Range_Step_r<T> range(lref<T> val, T min_, T max_, T step_)
```

```
template<typename T>
Range_Step_r<T> range(lref<T> val, lref<T> min_, lref<T> max_, lref<T>
step_)
```

Declarative reading: `val` is `>=` `min_` and `<=` `max_`.

Template Parameters:

`T` : For overloads *without* the `step_` parameter `T` must support `<`,`==` and prefix `++`.
For overloads *with* the `step_` parameter `T` must support `<`, `==` and `+=`.

Parameters:

`val`: [in/out] `val` lies within the range `(min_, max_)`.
`min_`: [in] Specifies an inclusive lower bound that is less than or equal to `max_`.
`max_`: [in] Specifies an inclusive upper bound that is greater than or equal to `min_`.
`step_`: [in] Specifies an increment to use (only) when generating values for `val_`. This is not used when checking if `val_` is in the inclusive range.

Exceptions:

`InvalidDeref` : If `min_` or `max_` is not initialized at the time of evaluation.

Notes:

If `min_` is greater than `max_` the range is considered empty and the relation will never succeed.

Examples:

```
// 1) print all values in the inclusive range (0,3)
lref<int> li;
relation r = range(li,0,3);
while(r())  // prints "0 1 2 3 "
   cout << *li << " ";

// 2) print alternate values in the inclusive range (0,10)
lref<int> li;
relation r = range(li,0,10,2);
while(r());  // prints "0 2 4 6 8 10"
   cout << *li << " ";

// 3) check if 12 is in the inclusive range (3,19)
relation r = range(12,3,19);
if(r())
   cout << "Yes.";

// 4) empty range (i.e. min_ > max_ )
relation r = range(i,10,2);
```

Also refer to:

`item, eq_seq.`

---

undefined relation

```
template<typename T>
UnDefined_r<T> undefined(lref<T>& r_)
```

Declarative reading: `r_` is not initialized with a value.

Parameters:
`r_` : [in/out] The logic reference to be tested for initialization.

Notes:
`undefined` is the logical negation of relation `defined`. Leaving `r_` uninitialized does not lead to generation of values for it. This relation merely invokes the `defined` method on `r_` when evaluated the first time. If defined returns false then evaluation succeeds, and fails otherwise. All subsequent evaluations will be unsuccessful.

Example:
```
lref<int> li =2;
//if li is initialized, print its value
//otherwise print "not initialized"
relation r =  ( undefined(li) && write("not initialized") )
              ^ write(li);
r();
```

Also refer to:
`defined`.

---

unique relation

```
template<typename T>
Unique_r<T> unique(lref<T> item_)
```

Declarative reading: `item_` has not been seen before.

Parameters:
`item_` : [in] The value to be tested for uniqueness. `item_` must be initialized at the time of evaluation.

Notes:
Duplicate results are commonly observed in logic programming. Relation `unique` is useful in filtering out duplicates from the results that are generated from other relations. An evaluation of `unique` succeeds only if it has encountered the current value of `item_` for the first time. Internally unique maintains a set of items of type `T`. Each time evaluation is triggered, it consults this set to determine if `item_` has been noticed before, if not `item_` is added to the set. Note that backtracking does not cause the relation to forget which items have been observed before. Its semantics depends on this "memory".

Exceptions:
`InvalidDeref` : If `item_` is not initialized at the time of evaluation.

Example:

```
// print items in arr[] after filtering out duplicate ocurrences
int arr[] = {0, 1, 2, 3, 3, 2};
lref<int> i;
relation r = item(i, arr+0, arr+5) && unique(i);
while(r())
  cout << *i << " ";
```

---

unique_f relation

```
template<typename FuncObj>
Unique_f_r<FuncObj> unique_f(FuncObj f)
```

Declarative reading: Value returned by `f()` has not been seen before.

Template Parameters:
`FuncObj` : A function object that does not take any parameters. It must provide a member typedef `result_type` stating the return type of its member `operator()(void)`. This must be a function object and cannot be a regular function type.

Template Parameters:
`f` : The function object whose return value has not been seen before.

Notes:
This relation is similar to relation `unique` except that its argument is a function object whose return value is used to perform the uniqueness check. ILEs are often useful as arguments to `unique_f`.

Exceptions:
Any exception thrown by `f()`.

Example:

```
// if i is an item in arr1 and j is an item in arr2
// print all pairs of i and j such that i*j is unique
int arr1[] = {0, 1, 2, 3, 3, 2};
int arr2[] = {3, 2, 1, 6, 3, 1};
lref<int> i, j;
int expected=0;
relation r = item(i, arr1+0, arr1+5) && item(j, arr2+0, arr2+5)
              && unique_f(i*j);
while(r())
    cout << *i << " " << *j << "\n";
```

6. Cuts

Introduction

The term *cut* refers to a facility used in LP for altering the default backtracking behavior. Its primary purpose is to dynamically eliminate from consideration some candidate paths of evaluation during backtracking. By default, backtracking pursues all possible paths of evaluation even if the paths do not produce any useful results. Backtracking itself has no knowledge about which paths are likely to produce results and which will not. However, the programmer may have sufficient knowledge to determine that in certain cases, pursuing alternate paths later will be simply wasteful. For instance consider the following relation which prints the result after comparing its two arguments:

```
relation greaterLessEq(lref<int> n
                     , lref<int> cmpVal) {
  return write(n) && write(" is ") &&
   (   predicate(n<cmpVal)  && write("lesser")
    || predicate(n>cmpVal)  && write("greater")
    || predicate(n==cmpVal) && write("equal")  );
}
```

It is clear by observation that if `predicate(n<cmpVal)` in the first clause succeeds, both `predicate(n>cmpVal)` and `predicate(n==cmpVal)` in the subsequent clauses will fail. Similarly if first clause fails and the second clause succeeds due to successful evaluation of `predicate(n==cmpVal)`, the third clause can be ignored by backtracking. Thus the successful evaluation of `predicate(n<cmpVal)` and `predicate(n>cmpVal)` are two important stages in the evaluation of this relations. At each of these points we can commit to the current path of evaluation and discard all alternatives. In other words, we can "cut out" the alternative paths. We can redefine the above relation using cuts by as follows:

```
relation greaterLessEq2(lref<int> n
                      , lref<int> cmpVal) {
  return write(n) && write(" is ") &&
   cutepxr(   predicate(n<cmpVal) && cut() && write("lesser")
           || predicate(n>cmpVal) && cut() && write("greater")
           || predicate(n==cmpVal) && write("equal")  );
}
```

This definition includes two important changes. First, we have specified `cut()` at each point where we are ready to commit to one path. These points are called *cut points*. Second, we have enclosed the three clauses separated by disjunction operators in a `cutexpr(...)`. The `cut()` and the `cutexpr()` are used in conjunction to specify the point at which to commit to a path and the extent of the path we are interested in committing to. By using `cut()`, we specify the points at which to commit, and by using `cutexpr()` we indicate the extent or the scope within which the cut points take effect.

In the above example, if `predicate(n<cmpVal)` succeeds, backtracking will encounter `cut()` and consequently eliminate from consideration all alternatives available just after the opening bracket of `cutexpr` and up until the `cut()`. All alternatives available before

the `cutexpr` and all alternatives after the `cut()` are left as is. So, for instance, if the first clause is rewritten as:

```
 ...  predicate(n<cmpVal) && cut() && ( write("lesser") || write("smaller") )
```

Here we have two alternative `write` clauses immediately following the `cut()`.This cut point will not influence the choices that backtracking will make when evaluating the two `write` clauses. Backtracking only commits to the path starting at `cutexpr` and ending at the cut point.

A cut point without a surrounding `cutexpr`, or a `cutexpr` without any cut points are both meaningless. By design, such mismatched occurrences will produce compilation errors. The following usage of cuts, wherein a `cutexpr` appears in the caller and a `cut()` appears in the callee, is also not allowed:

```
// Error: cannot dynamically nest cuts
relation outer(...) {
   return cutexpr( inner(..) || ... );
}

relation inner() {
   return  ... && cut() ...
}
```

Since cuts interfere with readability, their usage should be limited to cases when they have sufficiently significant effect on performance. The exclusive or operator defined over relations could be considered in many situations where cuts are applicable. Conceptually the ex-or operator is a special case of the cut facility, only more readable. In the above `greaterLessEq` example, we may simply replace all `||` operators with `^` as follows:

```
relation greaterLessEq(lref<int> n, lref<int> cmpVal) {
  return write(n) && write(" is ") &&
                           (  ( predicate(n<cmpVal)  && write("lesser") )
                            ^ ( predicate(n>cmpVal)  && write("greater") )
                            ^ ( predicate(n==cmpVal) && write("equal") ) );
}
```

Also note the use of additional brackets around each clause separated by the `^` operator. This is because operator `^` has a higher precedence than `&&`.

Support for cuts is provided in Castor via relation `cutexpr`, class `cut` and overloaded operators `&&`, `||` and `^`.

---

cutexpr relation

```
template<typename ExprWithCut>
CutExpr_r<ExprWithCut> cutexpr(const ExprWithCut& cut_expr)
```

Declarative reading: n/a.

Template Parameters:
`ExprWithCut` : A type that implements member function `bool exec(bool&)`.

Parameters:
`cut_expr` : This is a relation expression that includes at least one `cut()`.

Exceptions:
Any exception thrown by `cut_expr`.

Notes:
Relation `cutexpr` provides a scope within which a cut operates. Refer to the introductory section above on Cuts.

Also refer to:
`cut`

---

cut class

Purpose: Introduces a cut point in a cut expression.

Class Definition:
```
class cut{};
```

Notes:
The class cut is a trivial type with no user defined members. An instance of cut is used solely to mark a cut point. Refer to the introductory section above on Cuts.

7. Helper classes and functions

Coroutine class

Purpose: Optional helper base class for implementing relations as classes. Enables use of macros `rel_begin`, `rel_end`, `rel_yield`, `rel_return` in derived classes.

Class Declaration:

```
class Coroutine {
public:
  Coroutine() ;
};
```

Notes:
The task of implementing an arbitrary relation as a class can be simplified by using coroutine style implementation. Since C++ does not support coroutines natively, Castor provides four macros (`rel_begin`, `rel_end`, `rel_yield`, `rel_return`) that simulate the coroutine style programming model. Although one may use these macros outside the context of logic programming, these macros are tailored specifically for simplifying the implementation of relations.

To define a relation class as a coroutine, we derive the class from `custom_relation` and implement the function call operator `bool operator()(void)` as follows:

```
// relation to check or generate values in a specified inclusive range
template<typename T>
class Range_r : public custom_relation {
    lref<T> val, min_, max_;
public:
    Range_r(lref<T> val, lref<T> min_, lref<T> max_)
         : min_(min_), max_(max_), val(val)
    { }

    bool operator() () {
      rel_begin();
      ...
      rel_end();
    }
};
```

Note the use of macro `rel_begin` to start and macro `rel_end` to end the body of `operator()`. No statements should precede or follow these two macros in the method body. These two macros merely set up a switch statement spanning the definition of `operator()`.

We can now implement `operator()` as a coroutine:

```
bool operator() () {
  rel_begin();
  if(val.defined())
     rel_return(    ( *min_<*val && *val<*max_ )
                 || ( *min_==*val )
                 || ( *max_==*val ) );
  for(val=min_; (*val<*max_) || (*val==*max_); ++val.get())
    rel_yield(true);
  val.reset();
  rel_end();
}
```

Notice the absence of `return` statements. These have replaced with calls to macros `rel_return` and `rel_yield`. Both macros return the evaluated value of their argument back to the caller.

Macro `rel_yield` indicates a point where execution is temporarily suspended and a `true`/`false` value produced by evaluation of its argument is returned back to the caller. Next invocation of `operator()` will *resume* execution inside the method starting directly at this *yield* point. Invoking this macro essentially causes the coroutine to remember the point where execution had reached in the previous invocation. On the other hand, invoking `rel_return` indicates that no future resumption of execution is required from inside the method body, and the `true`/`false` value produced by evaluation of its argument is returned to the caller. All future invocations of `operator()` on this instance of the class will return `false` immediately.

Conceptually, `rel_yield` indicates *suspension* of execution and `rel_return` indicates *completion* of execution. Since, in logic programming, returning `false` to the caller is an indication by relations that their task is complete; `rel_yield(false)` also indicates completion. If the argument to `rel_yield` evaluates to `false`, all future invocations on `operator()` will return `false` immediately.

One important thing to keep in mind when implementing these coroutines is to avoid defining variables inside `operator()`, since their state will not persist across invocations. This is demonstrated in example 8 below, which is a more natural but incorrect way of implementing example 7.

Examples:

```
// 1) Simplest coroutine that never succeeds
struct Simple1 : public custom_relation {
  bool operator()(void) {
    rel_begin();
    rel_end();
  }
};

Simple1 r;
cout << boolalpha << r() << "\n"; // prints false
```

```
cout << boolalpha << r() << "\n"; // prints false

// 2) Coroutine that succeeds once, using rel_yield
struct Simple2 : public custom_relation {
  bool operator()(void) {
    rel_begin();
    rel_yield(true);
    rel_end();
  }
};

Simple2 r;
cout << boolalpha << r() << "\n"; // prints true
cout << boolalpha << r() << "\n"; // prints false


// 3) Succeeds once, using rel_return
struct Simple3 : public custom_relation {
  bool operator()(void) {
    rel_begin();
    rel_return(true);
    rel_end();
  }
};

Simple3 r;
cout << boolalpha << r() << "\n"; // prints true
cout << boolalpha << r() << "\n"; // prints false


// 4) Succeeds twice, using rel_yield
  bool operator()(void) {
    rel_begin();
    rel_yield(true);
    rel_yield(true);
    rel_end();
  }


// 5) Succeeds only once
  bool operator()(void) {
    rel_begin();
    rel_return(true);
    rel_return(true); // will never be executed
    rel_end();
  }


// 6) Succeeds only once
  bool operator()(void) {
    rel_begin();
    rel_yield(false);
    rel_yield(true);  // will never be executed
    rel_end();
  }

// 7) Succeeds 'n' times
```

```
class SimpleN : public custom_relation {
  int n, i;
public:
  SimpleN(int n) : n(n), i(0)
  {}

  bool operator()(void) {
    rel_begin();
    while(i++ < n)
      rel_yield(true);
    rel_end();
  }
};


// 8) Incorrect way of implementing relation SimpleN from above
class SimpleN : public custom_relation {
  int n;
public:
  SimpleN(int n) : n(n)
  {}

  bool operator()(void) {
    rel_begin();
    for(int i=0; i<n; ++i) // 'i' should not be defined here
      rel_yield(true);
    rel_end();
  }
};


// Example 9 : Relation to test/generate size of a specified string
class StrSize : public custom_relation {
    lref<string::size_type> sz;
    lref<string> str_;
public:
    // str_ is an input only parameter, sz is in/out
    StrSize(lref<string> str_, lref<string::size_type> sz)
         : sz(sz), str_(str_)
    { }

    bool operator() (void) {
      rel_begin();
      if(sz.defined())
          rel_return( *sz == str_->size() );
      sz = str_->size();
      rel_yield(true);
      sz.reset();  // revert external side effects
      rel_end();
    }
};

cout << boolalpha << StrSize("blah",4)(); // prints true

lref<string::size_type> sz;
StrSize("blah",sz)();
cout << *sz; // prints 4
```

Also refer to:
`predicate`

TestOnlyRelation class

---

effective_value function

```
template <typename T>
T& effective_value(T& obj) {
    return obj;
}

template <typename T>
const T& effective_value(const T& obj) {
    return obj;
}

template <typename T>
T& effective_value(lref<T>& obj) {
    return *obj;
}

template <typename T>
const T& effective_value(const lref<T>& obj) {
    return *obj;
}
```

Brief Description: If `t1` is a logic reference then its effective value is obtained by the expression `*t1`. Effective value of any other object `t2` is `t2` itself.

Template Parameters:
`T` : Any type.

Parameters:
`obj`: The object whose effective value is desired.

Returns:
The effective value of `obj`.

Exceptions:
`InvalidDeref` : If `obj` is an uninitialized lref.

Example:
```
    lref<int> li=2;
    int i=3;
    cout << effective_value(li); // prints 2
    cout << effective_value(i); // prints 3
```

Also refer to:
`effective_type`.

---

effective_type class (meta function)

```
template<typename T>
struct effective_type {
    typedef T result_type;
};

template<typename T>
struct effective_type<lref<T> > {
    typedef typename lref<T>::result_type result_type;
};
```

Brief Description: Effective type of a logic reference `lref<T1>` is `T1`. Effective type of any other type `T2` is `T2` itself.

Template Parameters:
`T` : Any type.

Parameters:
`obj`: The object whose effective value is desired.

Returns:
The effective value of `obj`.

Notes: Class effective_type provides a single member typedef `result_type` for determining the effective type of any given type.

Example:
```
effective_type<lref<string> >::result_type str; //str's type is string
effective_type<string>::result_type str2; //str2's type is string
```

Also refer to:
`effective_value`.

---

getValueCont function

```
template<typename ContOfT, typename ContOfLrefT>
ContOfT getValueCont(const ContOfLrefT& cont)
```

Brief Description: Produces a sequence of POT values from a sequence of logic references(or pointers or iterators). For example, it can be used to obtain a `vector<int>` from a `vector<lref<int> >`. All logic references in `cont` must be initialized.

Template Parameters:

`ContOfT` : The type of container to be returned by the function. This type must always be explicitly specified as the compiler cannot infer a type for this. Must satisfy requirements of standard C++ containers [$23.1].
`ContOfLrefT` : A container of logic references (or pointers or iterators) from which values are to be extracted by dereferencing each element. Must satisfy requirements of standard C++ containers [$23.1].

Parameters:
`cont` : A sequence of logic initialized references.

Returns:
A sequence of values obtained by dereferencing each logic reference in `cont`.

Exceptions:
`InvalidDeref` : If any logic reference in `cont` is not initialized at the time of evaluation.

Notes: Time complexity is O(n), where n is the number of elements in `seq`.

Example:
```
    list<lref<int> > lri;  // list of logic refs
    lri.push_back(1); lri.push_back(2); lri.push_back(3);
    vector<int> vi = getValues<vector<int> >(lri);
    copy(vi.begin(), vi.end()
             , ostream_iterator<int>(cout," ")); // prints 1 2 3
```

Also refer to:
`predicate`.

OneSolutionRelation class [deprecated: use custom_relation]

Purpose: Useful as a base class when imperatively implementing relations that produce at most one solution.

Class Definition:

```
template<typename Derived>
class OneSolutionRelation {
public:
    OneSolutionRelation();
    bool operator() (void);
};
```

Template Parameters:
`Derived` : Must implement methods `bool apply()` and `void revert()`.

Notes:
Implementing a relation using imperative techniques often involves placing the imperative code in a function object. To simplify some of the chore involved in the

implementation, `OneSolutionRelation` may be used as a public base class of the function object. Note, this class is only useful in implementing relations that generate at most one solution. The derived function object is required to implement two methods `apply` and `revert`. `OneSolutionRelation` implements the `bool operator()` which invokes these methods from the derived type. `apply` is invoked when the evaluation is triggered on the relation for the first time. `revert` is called when the evaluation is triggered for the second time. Thereafter neither `apply` nor `revert` will be invoked, instead `operator()` immediately returns `false` to the caller. Like any other relation it returns `true` if it succeeds or `false` otherwise. On failure, the lref arguments to the relation should be left unmodified. On success, if any of the lref arguments were modified, these changes are expected to reverted in the `revert` method. Note that `revert` will only be called if `apply` succeeded previously.

Examples:

```
//---------------------------------------------
//1)  Succeeds once, fails thereafter
struct True : OneSolutionRelation<True> {
    bool apply() {
        return true; // succeed trivially
    }
    void revert() {
       // no side effects to revert
    }
};

relation r = True();
while(r())  // condition will only succeed once
  cout << "success";

//---------------------------------------------
//2) relation to generate/test string sizes
class StringSize : public OneSolutionRelation<StringSize> {
    lref<string::size_type> sz;
    lref<string> str_;
    bool sz_changed;
public:
    // str_ is an input only parameter, sz is in/out
    StringSize(lref<string> str_, lref<string::size_type> sz)
         : sz(sz), str_(str_), sz_changed(false)
    { }

    bool apply (void) {
        if(sz.defined())
            return *sz == str_->size();
        sz = str_->size();
        sz_changed = true;
        return true;
    }

    void revert(void) {
        if(sz_changed) {
            sz.reset();
```

```
            sz_changed = false;
        }
    }
};

lref<string> str = "Hello";
lref<string::size_type> sz;
relation r = StringSize(str,sz) && write(sz);
r();
```

Also refer to:

custom_relation, predicate