# 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

## 3.1 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;
```

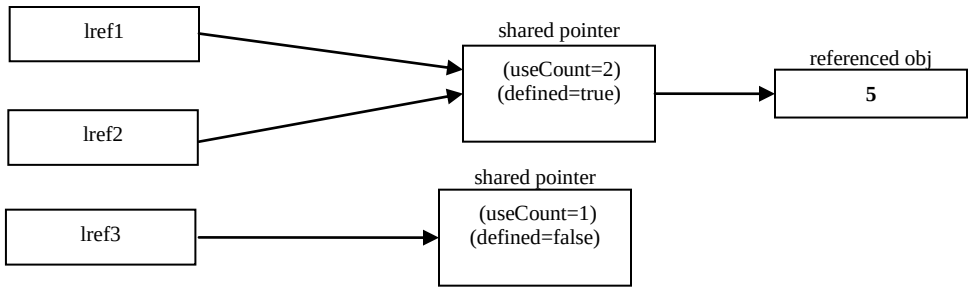



**Figure 1. Internal structure of Logic References**

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*.

As noted above, whenever a value is assigned to a logic reference it maintains of copy the assigned value. The lifetime of this object is then managed by the logic reference. There can be situations when we may want to have an lref pointing to a particular object (and not its copy). This enables us grab objects that emanate from anywhere in the system and treat them relationally using an lref. Sometimes operating on a copy may not be practical, too expensive or even plain wrong.

Starting with Castor 1.1, pointers to objects can also be used to initialize an lref.. When using pointers we must specify whether the lref should manage the lifetime of the object referenced by the pointer. For example:

```
//lifetime of "Roshan" will be managed
lref<string> s(new string("Roshan"), true);

//lifetime of name will not be managed
string name="Naik";
lref<string> s2(&name, false);
```

Assignment with pointers is performed using method `set_ptr`:

```
string str="Castor";
s.set_ptr(&str, false); // deallocates "Roshan". Will not manage
lifetime of str
```

### 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);

private:
  template<typename T2>
  lref(const lref<T2>& rhs);

public:
  lref(T* ptr, bool manage);

  ~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);

  template<typename T2>
  void set_ptr(T2* ptr, bool manage);

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

  ..unspecified.. operator ->();
  const ..unspecified.. & 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
  bool bound(const lref& rhs) const; // no throw
}; // 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)`. Lifetime of this referenced object will be managed by the lref. On completion reference count is set to 1.

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

Constructs an `lref<T>`. The referenced object is instantiated using the 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. Note that this overload is invoked only when `newValue` is *not* exactly of type `T`. Lifetime of the referenced object will be managed by the lref. On completion, reference count is set to 1.

```
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*.

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

This is a private constructor. It disables construction of `lref<T>` from `lref<T2>`.

```
lref(T* ptr, bool manage)
```

Constructs a logic reference that refers to the same object as `*ptr`. The lifetime of the object referenced by `ptr` will be managed if `manage` is `true`. On completion reference count is set to 1.

```
~lref();
```

On completion, reference count is decremented by 1. If the reference count has reached 0, and the referenced object (if any) is being managed, the referenced object will be deleted.

***Assignment semantics***

From the standpoint of implementing assignment to an lref, it is possible to update the referenced object with the new object in one of 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**

```
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. If `rhs` is not initialized, this lref will also be reset. 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. If `rhs` is not initialized, this lref will also be reset. Note that this overload is invoked only if `T2` is *not* the same `T1` and `T2` is assignable to `T`.

```
template<typename T2>
void set_ptr(T2* ptr, bool manage)
```
Causes the lref to refer to the object pointed to by `ptr`. Unlike other forms of assignment, this operation does *not* make a copy of the object pointed to be `ptr`. If prior to this method, the lref references an object whose lifetime is managed, that object will be deleted. The lifetime of the new object referenced by `ptr` will be managed if `manage` is `true`. Note that `T2` should either be same as `T`, or `T2*` should be 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.

```
bool bound(const lref& rhs)
```
Checks if the lref and `rhs` refer to the same object in memory.

### 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";
```

## 3.2 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. Due to the flexibility of C++, this is possible 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
       …
    }
};
```

[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.

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). 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.
```

## 3.3 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

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

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_)

.. additional overloads supporting upto 6 arguments to f


// overloads for function pointers
template<typename T, typename R>
Eq_f_r<T,R(*)(void)>
eq_f(lref<T> l, R(* f)(void))

template<typename T, typename R, typename P1, typename A1>
Eq_f_r1<T,R(*)(P1),A1>
eq_f(lref<T> l, R(* f)(P1), const A1& a1_)

template<typename T, typename R, typename P1, typename P2, typename A1
```

```
        , typename A2>
Eq_f_r2<T,R(*)(P1,P2),A1,A2>
eq_f(lref<T> l, R(* f)(P1,P2), const A1& a1_, const A2& a2_)

.. additional overloads supporting upto 6 arguments to f
```

**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.
`Func`*N* : A function object type with arity *N*.
`R`: Return type of the function pointer.
`P`*n*: Type of the N[th] parameter of function pointer. Can be an lref or POT. `A`*N* should be either same as or convertible to the corresponding `P`*n*.
`A`*n* : Type of argument passed at position *n* to the `Func`*N* type. Can be a POT or lref whose effective type is convertible to the corresponding parameter type in `Func`*N*.

**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.
`a`*N*`_` : [in] Argument (POT or lref) at position *N* whose effective value will be passed to `f`.

**Exceptions:**
`InvalidDeref` : If any argument `aN` is an lref and is not initialized at the time of evaluation.
Any exception thrown by `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 `a`*N*`_` parameters. Effective value of every `a`*N*`_` will be passed to `f`.

**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

```
// Overloads for non-const member functions
template<typename L, typename R, typename Obj>
Eq_mf_r0<L,Obj,R(Obj::*)(void)>
eq_mf(lref<L> l, lref<Obj>& obj_, R(Obj::*mf)(void) )

template<typename L, typename R, typename P1, typename Obj
        , typename A1>
Eq_mf_r1<L,Obj,R(Obj::*)(P1),A1>
eq_mf(lref<L> l, lref<Obj>& obj_, R(Obj::* mf)(P1), const A1& a1_)

template<typename L, typename R, typename P1, typename P2
        , typename Obj, typename A1, typename A2>
Eq_mf_r2<L,Obj,R(Obj::*)(P1,P2),A1,A2>
eq_mf(lref<L> l, lref<Obj>& obj_, R(Obj::* mf)(P1,P2), const A1& a1_
      , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf

// Overloads for const member functions
template<typename L, typename R, typename Obj>
Eq_mf_r0<L,Obj,R(Obj::*)(void) const>
eq_mf(lref<L> l, lref<Obj>& obj_, R(Obj::*mf)(void) const)

template<typename L, typename R, typename P1, typename Obj
        , typename A1>
Eq_mf_r1<L,Obj,R(Obj::*)(P1) const,A1>
eq_mf(lref<L> l, lref<Obj>& obj_, R(Obj::* mf)(P1) const
      , const A1& a1_)

template<typename L, typename R, typename P1, typename P2
        , typename Obj, typename A1, typename A2>
Eq_mf_r2<L,Obj,R(Obj::*)(P1,P2) const,A1,A2>
```

```
eq_mf(lref<L> l, lref<Obj>& obj_, R(Obj::* mf)(P1,P2) const
      , const A1& a1_, const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf
```

**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` : A type whose member function is to be invoked.
`R` : Return type of the member function.
`Pn`: Type of the n$^{th}$ parameter of member function.
`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 `Pn`.

**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 is to 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(..)`.Note that any side effects induced by `mf` will not be undone during backtracking. Hence `eq_mf` should be used with care, ensuring that it does not interfere with the correct evaluation of other relations by modifying `obj_` or other objects that are shared with other relations. `eq_mf` always succeeds at most once.

**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`, `eval_f`, `eval_mf`

---

**eq_mem relation**

```
template<typename L, typename Obj, typename MemberT>
Eq_mem_r<L, Obj, MemberT>
eq_mem(lref<L> l, lref<Obj>& obj_, MemberT Obj::* mem)
```

**Declarative reading**: `l` is equal to member variable `Obj::mem`.

**Template Parameters:**
`L` : Any type which satisfies requirements of logic reference.
`Obj` : Any type which whose member variable is to be accessed.
`MemberT` : Type of the data member to be accessed.

**Parameters:**
`l` : [in/out] Item to be unified with result of evaluating member function `mf` on `obj_`.
`obj_` : [in] The object whose data member is to be accessed. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mem` : Pointer to a member variable which is to be unified with `l`.

**Notes:**
Relation `eq_mem` provides support for unification with member variables. Parameter `l` will be compared with or assigned the result of evaluating `(*obj_).*mem`.

**Examples:**

```
// Get a first item in a pair of strings representing a person's name
lref<pair<string,string> > p = pair<string,string>("Roshan","Naik");
lref<string> firstName;
eq_mem(firstName, p, &pair<string,string>::first)();
cout << *firstName;       // prints "Roshan"


// Compute total salary of all employees
struct employee {
    string name;
    int salary;

    bool operator == (const employee& rhs) const {
        return name==rhs.name && salary==rhs.salary;
    }
};

list<employee> employees = ...;
lref<int> salary;
lref<employee> e;
relation salaries = item(e, employees.begin(), employees.end())
                  && eq_mem(salary, e, &employee::salary);
```

```
int total=0;
while(salaries())
  total+=*salary;
cout << total;
```

**Also refer to:**

eq, eq_f, eq_mf, eq_seq

---

**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";
```

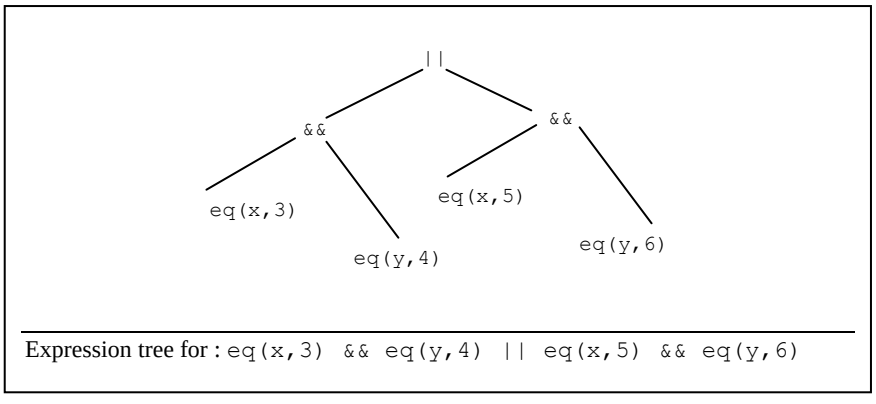
**Also refer to:**
`sequence, eq`

## *3.4 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 is not valid 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.

## 3.5 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 below attempt to use `ancestor` will lead to infinite recursion:

```
relation r = ancestor("Leda","Castor"); // will never return!
r();       // execution will not 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`.

## *3.6 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 be avoided or used with extreme care when defining relations as it may interfere with backtracking which relies on restoration of any state change. Side effects induced by impure ILE arguments to relations are not reverted automatically during backtracking. This can lead to improper evaluation of relations.

## *4.1 Closure Semantics*

The closure of an ILE is the collection of all objects (lrefs and regular variables) referenced in the ILE. All objects referenced in an ILE are stored *by value* in the function object representing the ILE. In other words, by default, the closure of an ILE has lvalue semantics. However, since copy construction of an lref creates a coreference, all lrefs in the closure effectively exhibit lvalue semantics. Therefore we can say that all lrefs in the closure exhibit lvalue semantics and all other objects exhibit rvalue semantics.

## 4.2 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>, Value_ILE<R> > >
operator + (lref<L>& left, const R& right);

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

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

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

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

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

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

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

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

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

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.)

## 4.3 Named ILEs

Since there are only a limited number of operators in C++, additional ILE operations can be introduced in the form of named functions. The named ILEs can be freely combined with other ILE operators in an ILE expression. Below is a description of each named ILEs provided by Castor.

---

**at**

```
template<typename Obj, typename Index>
Ile<At<Obj,Index> >
at (lref<Obj>& obj, Index i)
```

**Brief Description**: Used to perform indexed access into `obj` using `operator []`.

**Template Parameters:**
`Obj` : Any type which supports `operator []`. Must also define member typedef `value_type` indicating the result of `Obj::operator[](Index)`.
`Index` : The type of the index argument used when invoking `Obj::operator[]`. Can be a lref or a POT.

**Parameters:**
`obj` : The object on which to invoke the `operator []`.
`index`: The index into `obj`.

**Returns:**
A reference to `(*obj_)[*index]` if `index` is an lref or else and returns `(*obj_)[i]`.

**Notes**:
Use this named ILE where the indexing operator is required.

**Exceptions:**
`InvalidDeref` : If `obj` or `index` is not initialized at the time of evaluation.

**Examples**:

```
lref<vector<int> > lv = vector<int>();
lv->push_back(10);
lv->push_back(20);
lv->push_back(30);

lref<int> i=0;
cout << "v[0] = " << at(lv,i)() << ", v[2] = " << at(lv,2);

cout << boolalpha
     << (at(lv,i)+at(lv,1)!=at(lv,2))() ); // v[0]+v[1]==v[2]
```

---

**call**

```
// For nullary through sestiary(6-ary) functions
template<typename FuncT>
Ile<Call_0<...> >
call(const FuncT& f)

template<typename FuncT, typename A1>
Ile<Call_1<...> >
call(const FuncT& f, const A1& a1)

template<typename FuncT, typename A1, typename A2>
Ile<Call_2<...> >
call(const FuncT& f, const A1& a1, const A2& a2)
```

```
.. additional overloads supporting upto 6 arguments to f


// For nullary through sestiary(6-ary) function objects
template<typename Ret>
Ile<Call_0<...> >
call(Ret(* f)(void))

template<typename Ret, typename P1, typename A1>
Ile<Call_1<...> >
call(Ret(* f)(P1), const A1& a1)

template<typename Ret, typename P1, typename P2
                     , typename A1, typename A2>
Ile<Call_2<...> >
call(Ret(* f)(P1,P2), const A1& a1, const A2& a2)

.. additional overloads supporting upto 6 arguments to f
```

**Brief Description**: `call` is used to create an ILE function object that on evaluation invokes the function or function object `f`.

**Template Parameters:**
`FuncT`: Type of the function object to be invoked. `FuncT` should be copy constructible.
`Ret`: Return type function to be invoked.
`A1..An`: Types of the arguments to be passed to the function or function object. Can be a lref or a POT.
`P1..Pn` : Parameters types of the function. Any `An` should be either same as or convertible to the corresponding `Pn`. Can be a lref or a POT.

**Parameters:**
`f`: The function or function object to invoked. Note that if `f` is a function object, the actual invocation will occur on a copy of `f`.
`a1..aN`: Arguments to be passed to `f`. Arguments can be lrefs or POTs. Lref arguments (if any) will be automatically dereferenced during invocation of `f`.

**Returns:**
A function object, which on evaluation returns the value produced by invoking `f`.

**Notes**:
`call` supports invocation of functions and function objects with up to 6 arguments. The function object returned by `call` contains a *copy* of all its arguments (including `f`) to `call`. Arguments are always passed to `f` *by- value*. This is the case regardless of whether the arguments to `call` or the `f`'s parameter types are regular C++ references or logic references.

**Exceptions:**
Any exception thrown by invocation of `f`.
Any exception thrown during copy construction of some `AN`, OR, during the conversion of `AN` to `PN` (if `AN` is not same as `PN`).
Any exception thrown by copy construction of `f` if `f` is a function object.

**Examples**:

```
int squareroot(int i) {
    return ...;
}

int arr[] = {4,9,16,25,36};

// Basic standalone usage - calling squareroot()
lref<int> sr,i;
relation r = item(i,arr,arr+5) && eq_f(sr, call(squareroot,i) );
while(r())
    cout << *sr << " ";

// Compound expressions - computing square of the square root
lref<int> j,s;
relation r2 = item(j,arr,arr+5)
               && eq_f(s, call(squareroot,j)*call(squareroot,j) );
while(r2())
    cout << *s << " ";
```

---

**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)

.. additional overloads supporting upto 6 arguments
```

**Brief Description**: `create` returns a function object that on evaluation instantiates and 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);

    .. additional overloads supporting upto 6 arguments to f
};
```

**Brief Description**: `Create<T>::with` is used to create an ILE 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 that 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) );
```

---

**get**

```
template<typename Obj, typename MemberT>
Ile<Get<Obj,MemberT> >
get(const lref<Obj>& obj_, MemberT Obj::* mem)
```

**Brief Description**: `get` is used to create an ILE function object that on evaluation returns a reference to a data member of `obj_`.

**Template Parameters:**
`Obj` : Any type which satisfies requirements of logic reference.

`MemberT` : The actual type of the data member to be accessed in class `Obj`. The type of the pointer to data member is `MemberT Obj:: *`

**Parameters:**
`obj_` : The object whose data member is to be accessed. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mem` : Pointer to a data member of `obj_`.

**Returns:**
A reference to `(*obj_).*mem`

**Notes**:
It can be combined with other ILE operators or named ILEs to create more complex ILEs/function objects as shown in the example below.

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

**Examples**:

```
struct Name {
    string firstName, lastName;
    Name(string firstName, string lastName)
          : firstName(firstName), lastName(lastName)
    { }
    bool operator==(const Name& rhs) {
        return firstName==rhs.firstName && lastName==rhs.lastName;
    }
};

// print all first names from a list<Name>
lref<Name> n;
lref<list<Name> > names = ...;
relation printFname = item(n, names)
               && write_f( get(n, &Name::firstName) + string(" ") );
while(printFname());
```

---

**mcall**

```
// For nullary through sestiary(6-ary) member functions
template<typename R, typename Obj>
Ile<MCall_r0<Obj,R(Obj::*)(void),R> >
mcall(lref<Obj>& obj_, R(Obj::*mf)(void) )

template<typename R, typename P1, typename Obj, typename A1>
Ile<MCall_r1<Obj,R(Obj::*)(P1),R,A1> >
mcall(lref<Obj>& obj_, R(Obj::* mf)(P1), const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
```

```
        , typename A1, typename A2>
Ile<MCall_r2<Obj,R(Obj::*)(P1,P2),R,A1,A2> >
mcall(lref<Obj>& obj_, R(Obj::* mf)(P1,P2), const A1& a1_
      , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf


// For nullary through sestiary(6-ary) const member functions
template<typename R, typename Obj>
Ile<MCall_r0<Obj,R(Obj::*)(void) const,R> >
mcall(lref<Obj>& obj_, R(Obj::*mf)(void) const)

template<typename R, typename P1, typename Obj, typename A1>
Ile<MCall_r1<Obj,R(Obj::*)(P1) const,R,A1> >
mcall(lref<Obj>& obj_, R(Obj::* mf)(P1) const, const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
        , typename A1, typename A2>
Ile<MCall_r2<Obj,R(Obj::*)(P1,P2) const,R,A1,A2> >
mcall(lref<Obj>& obj_, R(Obj::* mf)(P1,P2) const, const A1& a1_
      , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf
```

**Brief Description**: `mcall` is used to create an ILE function object that on evaluation invokes the member function `mf` on `obj_`.

**Template Parameters:**
`R`: Return type of member function to be invoked.
`P1..Pn` : Parameters types of the member function. Can be a lref or a POT.
Any `An` should be either same as or convertible to the corresponding `Pn`.
`A1..An` : Types of the arguments to be passed to the member function. Can be a lref or a POT.

**Parameters:**
`mf`: Pointer to a member function.
`a1..aN` : Arguments to be passed to `mf`. Arguments can be lrefs or POTs. Lref arguments (if any) will be automatically dereferenced during invocation of `f`.

**Returns:**
A function object, which on evaluation returns the value produced by invoking `mf`.

**Notes**:
`mcall` supports invocation of member functions with up to 6 arguments. The function object returned by `mcall` contains a copy of all its arguments. Arguments are always passed to `mf` *by- value*. This is the case regardless of whether the arguments to `mcall` or the `mf`'s parameter types are regular C++ references or logic references.

**Exceptions:**
Any exception thrown by invocation of `mf`.
Any exception thrown during copy construction of some `AN`, OR, during the conversion of `AN` to `PN` (if `AN` is not same as `PN`).

**Examples**:

```
// print non empty strings
vector<string> values = ... ;
lref<string> s;
relation r = item(s,values.begin(),values.end())
                  && predicate( mcall(s,&string::length)>0 );
while(r())
      cout << *s << "\n";
```

---

**ref**

```
template<typename T>
Ile<Ref<T> > ref(T& obj)
```

**Brief Description**: `ref` is used to create an ILE function object that on evaluation returns a reference to `obj`.

**Template Parameters:**
`T`: Any type.

**Parameters:**
`obj`: The object to which a reference is to be taken.

**Returns:**
Reference to `obj`.

**Exceptions:**
None.

**Notes**:
ILE `ref` is useful when the original object should be used in the ILE expression (and not a copy, for e.g. `std::cout`). It also enables us to use objects that do not allow copy construction in an ILE. Users must ensure that `obj` continues to exist at the time when the ILE undergoes evaluation; otherwise it results in undefined behavior.

**Examples**:

```
//create an ILE that prints to cout values of x
int a[] = {1,2,3};
lref<int> x;
relation r = item(x,a,a+3) && eval( ref(cout)<< x << string(" ") );
```

```
while(r());
```

## 4.4 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 logical 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 and they need to be use in an ILE expression, wrap the sub expression involving such operators into a regular function and invoke it via `call`.

# 5 Higher-Order relations

---

**zip relation**

```
template<typename L, typename R>
Zip_r<L,R> zip(const L& l, const R& r)
```

**Declarative reading**: Succeed until both relations `l` and `r` succeed.

**Template Parameters:**
`L, R:` Any type that can be treated as a `relation`.

**Parameters:**
`l`: The first relation to be evaluated.
`r`: The second relation to be evaluated.

**Exceptions:**
Any exception thrown by `l` or `r`.

**Notes**:
Relation `zip` provides a facility for interleaved evaluation of relations `l` and `r`. Each evaluation `zip` will evaluate relations `l` and `r` once, in that order. Relation `r` will be evaluated only if `l` succeeds. If both `l` and `r` succeed then `zip` succeeds else `zip` will fail.

**Examples**:

```
// print parallel sum of two arrays
lref<int> i, j, sum;
int ai[] = { 1,2,3,4 }, aj[] = { 1,2,3,4,5,6,7,8 };
relation r = zip( item(i,ai,ai+4), item(j,aj,aj+5) ) && eq_f(sum,i+j);
while( r() )
   cout << *sum << " "; // prints: 2,4,6,8
```

# 6 Utils

## 6.1 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**

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

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_)

.. additional overloads supporting upto 6 arguments to f

// overloads for function pointers
template<typename R>
WriteF_r<R(*)(void)>
write_f(R(* f)(void))
```

```
template<typename R, typename P1, typename A1>
WriteF1_r<R(*)(P1),A1>
write_f(R(* f)(P1), const A1& a1_)

template<typename R, typename P1, typename P2, typename A1
        , typename A2>
WriteF2_r<R(*)(P1,P2),A1,A2>
write_f(R(* f)(P1,P2), const A1& a1_, const A2& a2_)


.. additional overloads supporting upto 6 arguments to f
```

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

**Template Parameters:**
`FuncN`: A function pointer or function object type with arity *N*. `FuncN`'s parameters cannot be logic references.
`R`: Return type of the function pointer.
`Pn`: Type of the N$^{th}$ parameter of function pointer. Can be an lref or POT. `AN` should be either same as or convertible to the corresponding `Pn`.
`An`: Type of argument passed at position *n* to `FuncN`. Can be a POT or lref 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`.

**Exceptions:**
Any exception thrown by `operator <<` when applied to `std::cout`.

**Notes:**
Although arguments passed to `write_f` may be lrefs or POTs.

**Examples:**
```
    // 1) With regular functions
    int add(int l, int r) {
      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**

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

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_)

.. additional overloads supporting upto 6 arguments to f

// overloads for function pointers
template<typename R>
WriteF_r<R(*)(void)>
writeTo_f(std::ostream& outputStrm, R(* f)(void))

template<typename R, typename P1, typename A1>
WriteF1_r<R(*)(P1),A1>
writeTo_f(std::ostream& outputStrm, R(* f)(P1), const A1& a1_)

template<typename R, typename P1, typename P2, typename A1
         , typename A2>
WriteF2_r<R(*)(P1,P2),A1,A2>
writeTo_f(std::ostream& outputStrm, R(* f)(P1,P2), const A1& a1_
          , const A2& a2_)

.. additional overloads supporting upto 6 arguments to f
```

**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.
`R`: Return type of the function pointer.
`Pn`: Type of the N$^{th}$ parameter of function pointer. Can be an lref or POT. `AN` should be either same as or convertible to the corresponding `Pn`.
`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:**
This relation is similar to `write_f` but allows explicit specification of the stream to which data is to be written.

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

---

**write_mf relation**

```
// Overloads for non-const member functions
template<typename R, typename Obj>
WriteMF_r<Obj,R(Obj::*)(void)>
write_mf(lref<Obj>& obj_, R(Obj::*mf)(void) )

template<typename R, typename P1, typename Obj, typename A1>
WriteMF1_r<Obj,R(Obj::*)(P1),A1>
write_mf(lref<Obj>& obj_, R(Obj::* mf)(P1), const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
        , typename A1, typename A2>
WriteMF2_r<Obj,R(Obj::*)(P1,P2),A1,A2>
write_mf(lref<Obj>& obj_, R(Obj::* mf)(P1,P2), const A1& a1_
        , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf

// Overloads for const member functions
template<typename R, typename Obj>
WriteMF_r<Obj,R(Obj::*)(void) const>
write_mf(lref<Obj>& obj_, R(Obj::*mf)(void) const)

template<typename R, typename P1, typename Obj, typename A1>
WriteMF1_r<Obj,R(Obj::*)(P1) const,A1>
write_mf(lref<Obj>& obj_, R(Obj::* mf)(P1) const, const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
        , typename A1, typename A2>
WriteMF2_r<Obj,R(Obj::*)(P1,P2) const,A1,A2>
write_mf(lref<Obj>& obj_, R(Obj::* mf)(P1,P2) const, const A1& a1_
        , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf
```

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

**Template Parameters:**
`Obj` : A type whose member function is to be invoked.
`R` : Return type of the member function.
`Pn`: Type of the n$^{th}$ parameter of member function.
`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 `Pn`.

**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 member function 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 <<`.

**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**

```
// Overloads for non-const member functions
template<typename R, typename Obj>
WriteMF_r<Obj,R(Obj::*)(void)>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_
          , R(Obj::*mf)(void) )

template<typename R, typename P1, typename Obj, typename A1>
WriteMF1_r<Obj,R(Obj::*)(P1),A1>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, R(Obj::* mf)(P1)
          , const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
        , typename A1, typename A2>
WriteMF2_r<Obj,R(Obj::*)(P1,P2),A1,A2>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_
          , R(Obj::* mf)(P1,P2), const A1& a1_, const A2& a2_)
```

```
// Overloads for const member functions
template<typename R, typename Obj>
WriteMF_r<Obj,R(Obj::*)(void) const>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_, R(Obj::*mf)(void)
const)

template<typename R, typename P1, typename Obj, typename A1>
WriteMF1_r<Obj,R(Obj::*)(P1) const,A1>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_
          , R(Obj::* mf)(P1) const, const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
        , typename A1, typename A2>
WriteMF2_r<Obj,R(Obj::*)(P1,P2) const,A1,A2>
writeTo_mf(std::ostream& outputStrm, lref<Obj>& obj_
          , R(Obj::* mf)(P1,P2) const, const A1& a1_, const A2& a2_)
```

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

**Template Parameters:**

`Obj` : A type whose member function is to be invoked.

`R` : Return type of the member function.

`Pn`: Type of the n$^{th}$ parameter of member function.

`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 `Pn`.

**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 <<`.

**Notes:**

This relation is similar to `write_mf` but allows explicit specification of the stream to which data is to be written.

**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`

---

**write_mem relation**

```
template<typename Obj, typename MemberT>
WriteMem_r<Obj, MemberT>
write_mem(lref<Obj>& obj_, MemberT Obj::* mem)
```

**Declarative reading**: Write to `std::cout` the value of `(*obj_).*mem`

**Template Parameters:**

`Obj` : Any type which whose member variable is to be accessed.
`MemberT` : Type of the data member to be accessed.

**Parameters:**

`obj_` : [in] The object whose member variable is to be accessed. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mem` : Pointer to a member variable of `obj_` whose value is to be written out to the `std::cout`.

**Exceptions:**

`InvalidDeref` : If `obj_` has not been initialized at the time of evaluation.

Also any exception thrown by `operator <<`.

**Examples:**

```
typedef pair<string,string> fullname;
lref<fullname> me = fullname("Roshan","Naik");
write_mem(me, &fullname::first)();
```

**Also refer to:**

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

---

**writeTo_mem relation**

```
template<typename Obj, typename MemberT>
WriteMem_r<Obj, MemberT>
writeTo_mem(std::ostream& outputStrm, lref<Obj>& obj_
            , MemberT Obj::* mem)
```

**Declarative reading**: Write to `outputStrm` the value of `(*obj_).*mem`

**Template Parameters:**
`Obj` : Any type which whose member variable is to be accessed.
`MemberT` : A Type of the data member to be accessed.

**Parameters:**
`obj_` : [in] The object whose member variable is to be accessed. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mem` : Pointer to a member variable of `obj_` whose value is to be written to `outputStrm`.
`outputStrm`: Stream to which the value will be written.

**Exceptions:**
`InvalidDeref` : If `obj_` has not been initialized at the time of evaluation.

Also any exception thrown by `operator <<`.

**Examples:**

```
typedef pair<string,string> name;
lref<name> me = name("Roshan","Naik");
stringstream sstrm;
writeTo_mem(sstrm, me, &name::first)();
```

**Also refer to:**
`write`, `write_f`, `writeTo_f`, `writeTo_mf`, `writeTo_mem`, `read`, `readFrom`

---

**writeAll relation**

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

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

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

**Template Parameters:**
`Itr` : A pointer OR an iterators OR 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 `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.
`terminateWith` : The string to be printed after all items in the sequence have been printed.

**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)(); // prints: "1, 2, 3, 4\n"

// 2) print items in vector (using iterators) using space as separator
writeAll(as.begin(),as.end(), " ")(); // prints: "1 2 3 4\n"

// 3) print 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=" "
                          , const std::string& terminateWith="\n")
)
```

```
template<typename Cont>
relation writeAllTo(std::ostream& outputStrm, lref<Cont>& cont_
                    , const std::string& separator=" "
                    , const std::string& terminateWith="\n")
```

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

**Template Parameters:**
`Itr` : A pointer, an 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.
`terminateWith` : The string to be printed after all items in the sequence have been printed.

**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 an ouput stream. 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`

## 6.2 Sequences and Containers

---

**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`

---

**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** **[Deprecated. Use size_of()]**

```
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.

**Also refer to:**
`size_of, 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`.

## 6.3 Aggregates

---

**average TLR**

```
template<class T>
Average_tlr<..> average(lref<T>& i)

template<class T, class Adder>
Average_tlr<..> average(lref<T>& i, Adder adder)

template<class T, class Adder, class Divider>
Average_tlr<..>
average(lref<T>& i, Adder adder, Divider divider)
```

**Declarative reading**: Average `i`.

**Template Parameters:**
`T`: Requires `operator +(T,T)` and `operator/(T,size_t)` to be defined for this type unless functions objects to perform addition and division are provided explicitly.
`Adder`: is a binary function pointer/object which returns a `T` and takes two args of type `T`.
`Divider`: is a binary function pointer/object which returns a `T` and argument types `(T, size_t)`.

**Parameters:**
`i`: [in & out] *in:* The items to be averaged. *out:* The average.
`adder`: Function pointer/object used to add the values in container.
`divider`: Function pointer/object used to divide the sum of the values with the size of the container.

**Exceptions:**
`InvalidArg` : If `i` is initialized at the time of first evaluation.

**Notes:**
Argument `i` is used both as input and output simultaneously. Once all the values have been read from `i`, the result will be produced in `i`. Thus TLR `average` can only be used to generate a result.

**Examples:**

```
    // average of nums[]
    int nums[] = { 1, 2, 3, 4, 5 };
    relation r = item(i,nums,nums+5) >>= average(i);
    r();
    cout << *i;  // prints 3
```

---

**average_of relation**

```
template<class Cont>
AvgOf_r<..>
```

```
average_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& a)

template<class Cont, class Adder>
AvgOf_r<..>
average_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& a
           , Adder adder)

template<class Cont, class Adder, class Div>
AvgOf_r<..>
average_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& a
           , Adder adder, Div divider)
```

**Declarative reading**: Average value in `cont_` is `a`.

**Template Parameters:**
`Cont`: Must satisfy requirements of standard C++ containers [$23.1].
`Adder`: is a binary function pointer/object which returns a `T` and takes two args of type `T`.
`Divider`: is a binary function pointer/object which returns a `T` and argument types `(T, size_t)`.

**Parameters:**
`cont_` : [in] Container whose average is to be determined.
`a`: [in/out] The average.

**Notes:**
This relation may be used in generate mode (leaving `a` uninitialized) or in test mode (by initializing `a`).

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

---

**count TLR**

```
template<class T>
Count_tlr<..> count(const lref<T>& n)
```

**Declarative reading**: `n` is number of times the relation to the left of `>>=` succeeded.

**Template Parameters:**
`T`: an integral type that supports prefix increment.

**Parameters:**
`n` : [out] The number of times the relation to the left of `>>=` succeeded. `n` should not be initialized as it is a purely an out parameter.

**Exceptions:**
`InvalidArg`: If `n` is pre-initialized at the time of first evaluation.

Any exception thrown by applying the prefix `operator ++` on `T`.

**Notes**:
`count` succeeds only once.

**Examples**:

```
// count even numbers in the array
int ai[] = { 10,2,11,4,6,15,7,3,9,8 };
lref<int> j, n;
relation r = item(j,ai,ai+10) && predicate(j%2==0)  >>= count(n);
if(r())
    cout << *n << " ";
```

---

**max TLR**

```
template<class T>
Max_tlr<..> max(const lref<T>& n)

template<class T, class Cmp>
Max_tlr<..> max(const lref<T>& n, Cmp cmp)
```

**Declarative reading**: Max `n`.

**Template Parameters:**
`T`: is *LessThanComparable* [$20.1.2].
`Cmp`: is a binary function pointer/object which returns a `bool` and accepts arguments `(T, T)`.

**Parameters:**
`n`: [in & out] *in:* The items whose max is to be computed. *out:* The max value.
`cmp`: Function pointer/object used to compare values.

**Exceptions:**
`InvalidArg` : If `n` is pre-initialized at the time of first evaluation.

**Notes:**
Argument `n` is used both as input and output simultaneously. Once all the values have been read from `n`, the result will be produced in `n`. Thus TLR `max` can only be used to generate a result.

**Examples:**

```
int nums[] = { 1, 2, 3, 4, 5 };
relation r = item(i,nums,nums+5) >>= max(i);
r();
cout << *i;  // prints 5
```

### max_of relation

```
template<class Cont>
MaxOf_r<..>
max_of(lref<Cont>& cont, const lref<typename Cont::value_type>& m)

template<class Cont, class Cmp>
MaxOf_r<..>
max_of(lref<Cont>& cont, const lref<typename Cont::value_type>& m
       , Cmp cmp)
```

**Declarative reading**: Max value in container is `m`.

**Template Parameters:**
`Cont`: Must satisfy requirements of standard C++ containers [$23.1].
`Cont::value_type` should satisfy *EqualityComparable*[$20.1.1] and *LessThanComparable*[$20.1.2]
`Cmp`: A binary function pointer/object which returns `bool` and accepts arguments `(Cont::value_type, Cont::value_type)`.

**Parameters:**
`cont_` : [in] Container whose max value is to be determined.
`m`: [in/out] The max value.

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

**Notes:**
This relation may be used in generate mode (leaving `m` uninitialized) or in test mode (by initializing `m`).

### min TLR

```
template<class T>
Min_tlr<..> min(const lref<T>& n)

template<class T, class Cmp>
Min_tlr<..> min(const lref<T>& n, Cmp cmp)
```

**Declarative reading**: Min `n`.

**Template Parameters:**
`T`: is *LessThanComparable* [$20.1.2].
`Cmp`: is a binary function pointer/object which returns a `bool` and accepts arguments `(T, T)`.

**Parameters:**
`n`: [in & out] *in:* The items whose min is to be computed. *out:* The min value.

`cmp`: Function pointer/object used to compare values.

**Exceptions:**
`InvalidArg` : If `n` is pre-initialized at the time of first evaluation.

**Notes:**
Argument `n` is used both as input and output simultaneously. Once all the values have been read from `n`, the result will be produced in `n`. Thus TLR `min` can only be used to generate a result.

**Examples:**

```
int nums[] = { 1, 2, 3, 4, 5 };
relation r = item(i,nums,nums+5) >>= min(i);
r();
cout << *i;  // prints 1
```

---

**min_of relation**

```
template<class Cont>
MinOf_r<..>
min_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& m)

template<class Cont, class Cmp>
MinOf_r<..>
min_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& m
       , Cmp cmp)
```

**Declarative reading**: Min value in container is `m`.

**Template Parameters:**
`Cont`: Must satisfy requirements of standard C++ containers [$23.1] and `Cont::value_type` should satisfy *EqualityComparable*[$20.1.1] and *LessThanComparable*[$20.1.2].
`Cmp`: A binary function pointer/object which returns `bool` and accepts arguments `(Cont::value_type, Cont::value_type)`.

**Parameters:**
`cont_` : [in] Container whose min value is to be determined.
`m`: [in/out] The min value.

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

**Notes:**
This relation may be used in generate mode (by leaving `m` uninitialized) or in test mode (by initializing `m`).

### reduce TLR

```
template<class T, class BinFunc>
Reduce_tlr<..> reduce(lref<T>& i, BinFunc acc)
```

**Declarative reading**: Reduce `i` using accumulator `acc`.

**Template Parameters:**
`T`: type of the values to be reduced.
`BinFunc`: is a binary function pointer/object which returns `T` and accepts arguments `(T, T)`.

**Parameters:**
`i`: [in & out] *in:* The items to be reduced. *out:* The reduced value.
`acc`: Accumulator used for reducing.

**Exceptions:**
`InvalidArg` : If `n` is pre-initialized at the time of first evaluation.

**Notes:**
This TLR is functionally similar to `std::accumulate`, but a seed value is not required as it will not succeed if the input sequence is empty. Argument `i` is used both as input and output simultaneously. Once all the values have been read from `i`, the result will be produced in `i`. Thus TLR `reduce` can only be used to generate a result.

**Examples:**

```
range(j,1,10) >>= reduce(j, std::multiplies<int>()); // factorial of 10
```

---

### reduce_of relation

```
template<class Cont, class BinFunc>
ReduceOf_r<..>
reduce_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& r
          , BinFunc acc)
```

**Declarative reading**: Reducing values in container using accumulator `acc` yields `r`.

**Template Parameters:**
`Cont`: Must satisfy requirements of standard C++ containers [$23.1]
`BinFunc`: A binary function pointer/object which returns `Cont::value_type` and accepts arguments `(Cont::value_type, Cont::value_type)`.

**Parameters:**
`cont_` : [in] Container whose values are to be reduced.
`r`: [in/out] The reduced value.

**Exceptions:**

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

**Notes:**
This relation is functionally similar to `std::accumulate`, but a seed value is not required as it will not succeed if `cont_` is empty. This relation may be used in generate mode (by leaving `r` uninitialized) or in test mode (by initializing `r`).

---

**sum TLR**

```
template<class T>
Reduce_tlr<..> sum(lref<T>& i)
```

**Declarative reading**: Sum of `i`.

**Template Parameters:**
`T`: Type of the values to be summed. `operator +` should be for type `T` with return type `T`.

**Parameters:**
`i`: [in & out] *in:* The items to be summed. *out:* The sum.

**Exceptions:**
`InvalidArg` : If `i` is pre-initialized at the time of first evaluation.

**Notes:**
This TLR invokes `reduce` using accumulator `std::plus<T>()`.

**Examples:**

```
int nums[] = { 1, 2, 3, 4, 5 };
relation r = item(i,nums,nums+5) >>= sum(i);
r();
cout << *i;  // prints 15
```

---

**sum_of relation**

```
template<class Cont>
ReduceOf_r<..>
sum_of(lref<Cont>& cont_, const lref<typename Cont::value_type>& s)
```

**Declarative reading**: Sum of values in container `s`.

**Template Parameters:**
`Cont`: Must satisfy requirements of standard C++ containers [$23.1].
`Cont::value_type` must support `operator +`.

**Parameters:**
`cont_` : [in] Container whose values are to be summed.

`s`: [in/out] The sum.

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

**Notes:**
This relation invokes `reduce_of` using accumulator `std::plus<Cont::value_type>()`.

---

**size_of relation**

```
template<typename Cont>
Size_r<..> size_of(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 a `cont_` is determined by invoking its `size` method.

**Example**:

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

**Also refer to:**
`size_of, empty, not_empty.`

## 6.4 Iteration

---

**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` : A pointer, an iterators, a logic reference to a pointer or a logic reference to an 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>
Itemcont_r<Cont> 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**:
When `obj` is initialized, `item` will succeed once for each occurrence of `obj` in the sequence.
Relation `item` is typically useful for iterating over sequences in a relational fashion. 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 "
```

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`.

**Also refer to:**
`ritem`

---

**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`

---

**ritem relation**

```
template<typename Cont>
ItemRCont_r<Cont> ritem(  lref<typename Cont::value_type> obj
                        , lref<Cont>& cont_)
```

**Declarative reading**: `obj` is an item in the container `cont_`.

**Template Parameters:**
`Cont` : Satisfies requirements of standard reversible containers.

**Parameters:**
`obj`: [in/out] `obj` is an item in the sequence bounded by iterators `begin_` and `end_`.
`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**:
When `obj` is not initialized, `ritem` will generate all values in the container in reverse order using the iterators provided by the container's `rbegin()` and `rend()` methods.

When `obj` is initialized, `ritem` will succeed once for each occurrence of `obj` in the sequence.

**Example:**

```
// 1) print all values in a vector in reverse
int arr[] = {1,2,3,4};
lref<vector<int> > v = vector<int>(arr, arr+4);
lref<int> i;
relation r = ritem(i, v);
while(r())
    cout << *i << " "; // prints "4 3 2 1 "
```

**Also refer to:**
`item`

## 6.5 Predicates

---

**Boolean relation**

```
class Boolean : public Coroutine  {
    explicit Boolean(bool value);
    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 {
    bool operator ()(void) { return false; }
};
```

**Brief Description**: Always fails.

**Returns:**
Always returns `false`.

**Exceptions:**
None.

**Also refer to:**
`Boolean, True.`

---

**True relation**

```
class True : public Coroutine {
      True();   // succeed once
      explicit True(unsigned long n); // succeed once 'n' times
      bool operator ()(void);
};
```

**Brief Description**: Succeed n times.

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

**Exceptions:**
None.

**Also refer to:**
`Boolean, False.`

---

**predicate relation**

```
// overloads for function objects
template<typename Pred>
Predicate0_r<Pred>
predicate(Pred pred)

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_)

.. additional overloads supporting upto 6 arguments to f

// overloads for function pointers
template<typename R>
Predicate0_r<R(*)(void)>
predicate(R(* pred)(void))

template<typename R, typename P1, typename A1>
Predicate1_r<R(*)(P1),A1>
predicate(R(* pred)(P1), const A1& a1_)

template<typename R, typename P1, typename P2, typename A1
         , typename A2>
Predicate2_r<R(*)(P1,P2),A1,A2>
```

```
predicate(R(* pred)(P1,P2), const A1& a1_, const A2& a2_)

.. additional overloads supporting upto 6 arguments to f
```

**Declarative reading**: `pred(a1,..,aN)` is true.

**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`.
`R`: Return type of the function pointer. Must be `bool` or a type convertible to `bool`.
`Pn` : Type of n$^{th}$ parameter of function pointer. Can be a POT or lref.
`An` : Type of the n$^{th}$ argument to being passed to the function or function object. 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` : [in] 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 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 predicate member functions, use `predicate_mf`.

**Examples:**
Searching for even numbers in an array by adapting the 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 << " ";
```

Searching for 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 non-const member functions (with upto 6 arguments)
template<typename R, typename Obj>
MemPredicate0_r<Obj,R(Obj::*)(void)>
predicate_mf(lref<Obj>& obj_, R(Obj::* mempred)(void) )

template<typename R, typename P1, typename Obj, typename A1>
MemPredicate1_r<Obj,R(Obj::*)(P1),A1>
predicate_mf(lref<Obj>& obj_, R(Obj::* mempred)(P1), const A1& arg1)

template<typename R, typename P1, typename P2, typename Obj
         , typename A1, typename A2>
MemPredicate2_r<Obj,R(Obj::*)(P1,P2),A1,A2>
predicate_mf(lref<Obj>& obj_, R(Obj::* mempred)(P1,P2), const A1& arg1
             , const A2& arg2)

.. additional overloads supporting upto 6 arguments to mf


// Support for const member functions (with upto 6 arguments)
template<typename R, typename Obj>
MemPredicate0_r<Obj,R(Obj::*)(void) const>
predicate_mf(lref<Obj>& obj_, R(Obj::* mempred)(void) const)

template<typename R, typename P1, typename Obj, typename A1>
MemPredicate1_r<Obj,R(Obj::*)(P1) const,A1>
predicate_mf(lref<Obj>& obj_, R(Obj::* mempred)(P1) const
             , const A1& arg1)

template<typename R, typename P1, typename P2, typename Obj
         , typename A1, typename A2>
MemPredicate2_r<Obj,R(Obj::*)(P1,P2) const,A1,A2>
predicate_mf(lref<Obj>& obj_, R(Obj::* mempred)(P1,P2) const
             , const A1& arg1, const A2& arg2)

.. additional overloads supporting upto 6 arguments to mf
```

**Declarative reading**: `obj_.pred(a1,..,aN)` is true.

**Template Parameters:**

`Obj` : A type whose member function is to be treated as a relation.

`R`: Return type of the member function pointer. Must be `bool` or a type convertible to `bool`.

`P`*n* : Type of n$^{th}$ parameter of member function. Can be a POT or lref.

`A`*n* : Type of the n$^{th}$ argument to being passed. Can be a POT or lref whose effective type is convertible to the corresponding `P`*n*.

**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_`.

`mempred` : Address of predicate member function to be treated as a relation.

`argN` : [in] The N[th] argument to be passed to `mempred`. 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`. The overloads are designed to eliminate the need for a `static_cast` on `mempred` even in the face of overload ambiguities. Refer to examples in `eval_mf` for more details on this.

**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, predicate_mem, eq_mf.`

---

**predicate_mem relation**

```
template<typename Obj, typename MemberT>
Predicate_mem_r<Obj, MemberT>
predicate_mem(lref<Obj>& obj_, MemberT Obj::* mem)
```

**Declarative reading**: `(*obj_).*mem` is `true`.

**Template Parameters:**
`Obj` : Any type which whose member variable is to be accessed.
`MemberT` : Type of the data member to be accessed. This is should be either `bool` or a type convertible to `bool`.

**Parameters:**
`obj_` : [in] The object whose data member is to be accessed. This argument must be a logic reference. This restriction ensures methods are invoked on the actual argument and not on a copy of `obj_`.
`mem` : Pointer to a member variable.

**Notes:**
Relation `predicate_mem` is used for checking the value of a boolean member variable. The relation succceds if the member variable's value is `true` (or convertible to `true`). This relation succeeds at most once.

## 6.6 Collection

---

**permute relation**

```
template<typename Seq>
Permute_r<Seq>
permute(lref<Seq>& seq_i, const lref<Seq>& p_seq)

template<typename Seq, typename Pred>
PermutePred_r<Seq,Pred>
permute(lref<Seq>& seq_i, const lref<Seq>& p_seq, Pred cmp)
```

**Declarative reading**: `p_seq` is a permutation of the input sequence `seq_i`.

**Template Parameters:**
`Seq` : Must satisfy requirements of standard C++ sequences [$23.1.1].
`Pred` : A function or function object. Return type must be `bool` or convertible to `bool`.

**Parameters:**
`seq_i` : [in] The sequence for which permutations need to be generated (or tested).
`p_seq` : [out] This sequence is a permutation of `seq_i`.

**Notes:** If `p_seq` is not initialized, all permutations of `seq_i` will be generated in `p_seq`. If `p_seq` is initialized, the relation succeeds if `p_seq` and `seq_i` are of the same and each element in `seq_i` also exists in `p_seq`. The input sequence is not modified by this relation.

**Example:**

```
//1) Test for permutation
lref<string> s = "hello", ps="olleh";
if( permute(s,ps)() )
  cout << *ps << " is a permutation of " << *s;

//2) Generate all permutations
lref<string> s = "hello", ps;
relation p = permute(s,ps);
while( p() )
  cout << *ps << "\n";
```

**Also refer to:**
`shuffle`.

---

**shuffle relation**

```
template<typename Cont, typename InItr>
Shuffle_r<Cont,InItr>
shuffle (const InItr& begin_i, const InItr& end_i
```

```
          , const lref<Cont>& shuf)

template<typename Seq>
relation shuffle(lref<Seq>& seq_i, const lref<Seq>& shuf)
```

**Declarative reading**: `shuf` is a random shuffle of the input sequence `seq_i`.

**Template Parameters:**
`Seq` : Must satisfy requirements of standard C++ sequences [$23.1.1].
`Cont` : Must satisfy requirements of standard C++ containers [$23.1].
`InItr` : A pointer, an input iterator , a logic reference to a pointer or a logic reference to an input iterator.

**Parameters:**
`seq_i` : [in] The sequence to be shuffled.
`begin_i, end_i` : [in] Iterators to the sequence to be shuffled.
`shuf` : [in, out] Shuffled `seq_i`.

**Notes:** If `shuf` is not initialized, all permutations of `seq_i` will be generated in `shuf`. If `shuf` is initialized, the relation succeeds if `shuf` and `seq_i` are of the same and each element in `seq_i` also exists in `shuf`. Unless the input sequence us empty, `shuffle` indefinitely produces randomized versions of the input sequence and the generated sequences can be repetitions. If input sequence is empty, the relation will fail on first evaluation. The input sequence is not modified by this relation.

**Also refer to:**
`permute`.

## *6.7 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`.

## 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`.

## eval relation

```
// overloads for function objects
template<typename Func, typename A1>
Eval_r1<Func,A1>
eval(Func f, const A1& a1_)

template<typename Func, typename A1, typename A2>
Eval_r2<Func,A1,A2>
eval(Func f, const A1& a1_, const A2& a2_)

.. additional overloads supporting upto 6 arguments to f

// overloads for function pointers
template<typename R>
Eval_r0<R(*)(void)>
eval(R(* f)(void))

template<typename R, typename P1, typename A1>
Eval_r1<R(*)(P1),A1>
eval(R(* f)(P1), const A1& a1_)
```

```
template<typename R, typename P1, typename P2, typename A1
         , typename A2>
Eval_r2<R(*)(P1,P2), A1,A2>
eval(R(* f)(P1,P2), const A1& a1_, const A2& a2_)

.. additional overloads supporting upto 6 arguments to f
```

**Declarative reading**: Evaluate the function or function object `f`.

**Template Parameters:**
`Func` : A function object type that takes up to 6 arguments. `Func` must define a member typedef `result_type` indicating its result type.
`R`: Return type of the function pointer.
`Pn`: Type of the N[th] parameter of function pointer. Can be an lref or POT. `AN` should be either same as or convertible to the corresponding `Pn`.
`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 `Func`.

**Parameters:**
`f` : A function pointer or function object that is to be invoked when the relation is evaluated.
`aN_` : [in] The N[th] argument to be passed to `f`. Effective value of `aN` is passed to `f`. It can be an lref or POT.

**Exceptions:**
`InvalidDeref` : If any argument `aN` is an lref and is not initialized at the time of evaluation.
Any exception thrown by `f`.

**Notes:** This relation can be used to execute imperative tasks, defined as a regular function of function object, during the evaluation of relations. Functions and function objects with up to 6 arguments are supported. Note that any side effects induced by `f` will not be undone during backtracking. Hence `eval` should be used with care, ensuring that it does not interfere with the correct evaluation of other relations by modifying objects that are shared with other relations. `eval` always succeeds once. Note that the value returned (if any) by `f` is not accessible. Consider using `eq_f` if access to return value is required.

**Example:**

```
//1) Print array items using eval
void print(int x) {
    cout << x << " ";
}
lref<int> x;
int a[] = {1, 2,3};
relation r = item(x,a,a+3) && eval(print,x);
while(r());
```

```
//2) Using an ILE instead of print()
relation r2 = item(x,a,a+3) && eval(ref(cout)<<x);
while(r());
```

The signature of `eval_f` is designed to eliminate the need for a `static_cast` on the `f` argument in user code, even in the presence of overload ambiguities. For example consider using `eval_f` on the following type with a function having two overloads differing in arity (i.e. number of parameters).

```
int add(int i, int j) {
   return i+j;
}

int add(int i, int j, int k) {
   return i+j+k;
}
// messy static_cast works but not needed
eval_f(static_cast<int(*)(int,int,int)>(add), 1, 2, 3)();

// equivalent simpler syntax
eval_f(add, 1, 2, 3)();
```

This more direct syntax works when the overloads differ in arity. When the overloads have the same arity and differ in the parameter types we can still avoid a `static_cast` by specifying only the return type and parameter types of the member function as follows.

```
int add(int i, int j) {
   return i+j;
}

double add(double i, double j) {
   return i+j;
}

// messy static_cast works but not needed
eval_f(static_cast<int(*)(int,int)>(add), 1, 2)();

// equivalent simpler syntax
eval_f<int,int,int>(add, 1, 2)();
```

**Also refer to:**

`eval_mf, predicate, predicate_mf, eq_f, eq_mf.`

---

**eval_mf relation**

```
// Overloads for non-const member functions
template<typename R, typename Obj>
Eval_mf_r0<Obj,R(Obj::*)(void)>
eval_mf(lref<Obj>& obj_, R(Obj::*mf)(void) )

template<typename R, typename P1, typename Obj, typename A1>
```

```
Eval_mf_r1<Obj,R(Obj::*)(P1),A1>
eval_mf(lref<Obj>& obj_, R(Obj::* mf)(P1), const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
         , typename A1, typename A2>
Eval_mf_r2<Obj,R(Obj::*)(P1,P2),A1,A2>
eval_mf(lref<Obj>& obj_, R(Obj::* mf)(P1,P2), const A1& a1_
        , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf


// Overloads for const member functions
template<typename R, typename Obj>
Eval_mf_r0<Obj,R(Obj::*)(void) const>
eval_mf(lref<Obj>& obj_, R(Obj::*mf)(void) const)

template<typename R, typename P1, typename Obj, typename A1>
Eval_mf_r1<Obj,R(Obj::*)(P1) const,A1>
eval_mf(lref<Obj>& obj_, R(Obj::* mf)(P1) const, const A1& a1_)

template<typename R, typename P1, typename P2, typename Obj
        , typename A1, typename A2>
Eval_mf_r2<Obj,R(Obj::*)(P1,P2) const,A1,A2>
eval_mf(lref<Obj>& obj_, R(Obj::* mf)(P1,P2) const, const A1& a1_
        , const A2& a2_)

.. additional overloads supporting upto 6 arguments to mf
```

**Declarative reading**: Evaluate member function `mf` on object `obj_`.

**Template Parameters:**
`Obj` : A type whose member function is to be invoked.
`R` : Return type of the member function.
`Pn` : Type of the n$^{th}$ parameter of member function.
`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 `Pn`.

**Parameters:**
`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` : Pointer to a member function that is to be invoked when this relation is evaluated.
`aN_` : [in] The N$^{th}$ argument to be passed to `mf`. Effective value of `aN` is passed to `mf`. Thus it can be an lref or POT.

**Exceptions:**
`InvalidDeref` : If any argument `aN` is a lref and is not initialized at the time of evaluation.
Any exception thrown by `mf`.

**Notes:** This relation can be used to execute imperative tasks defined in member functions during the evaluation of relations. Member functions with up to 6 arguments are supported. Note that any side effects induced by `mf` will not be undone during backtracking. Hence `eval_mf` should be used with care, ensuring that it does not interfere with the correct evaluation of other relations by modifying objects that are shared with other relations. `eval_mf` always succeeds once. Note that the value returned (if any) by `mf` is not accessible. Consider using `eq_mf` if access to return value is required.

**Examples:**
The signature of `eval_mf` is designed to eliminate the need for a `static_cast`[2] on the `mf` argument in user code, even in the presence of overload ambiguities. For example consider using `eval_mf` on the following type with a member function having two overloads differing in arity (i.e. number of parameters).

```
struct calculator {
    int add(int i, int j) {
      return i+j;
    }

    int add(int i, int j, int k) {
      return i+j+k;
    }
};

lref<calculator> lc = calculator();
eval_mf(lc
       , static_cast<int(calculator::*)(int,int,int)>(&calculator::add)
       , 1, 2, 3)();  // messy static_cast works but not needed

eval_mf(lc, &calculator::add, 1, 2, 3)(); // equivalent simpler syntax
```

This more direct syntax works when the overloads differ in arity. When the overloads have the same arity and differ in the parameter types we can still avoid a `static_cast` by specifying only the return type and parameter types of the member function as follows.

```
struct calculator {
    int add(int i, int j) {
      return i+j;
    }

    double add(double i, double j) {
      return i+j;
    }
};

lref<calculator> lc = calculator();
eval_mf(lc
```

[2] Microsoft Visual C++ 2008 compiler needs explicit resolution when there exists a const and a non-const overload for the member function. CodeGear C++ Builder 2007 compiler does not support this ability when multiple overloads having the same arity exist for a member function. In this case *all* template arguments must be specified in addition to explicitly resolving the particular member function overload.

```
        , static_cast<int(calculator::*)(int,int)>(&calculator::add)
        , 1, 2)();  // messy static_cast works but not needed

eval_mf<int,int,int>(lc, &calculator::add, 1, 2)();// simpler syntax
```

Relation `eval_mf` also safe to use with virtual and pure virtual functions.

```
struct Shape {
    virtual void draw()=0;
    virtual ~Shape(){}
};

struct Circle : public Shape  {
    virtual void draw() { cout << "Circle"; }
};

lref<Shape> lc = Circle();
eval_mf(lc, &Shape::draw)();// calls Circle::draw()
```

**Also refer to:**

`eval_f, predicate, predicate_mf, eq_f, eq_mf.`

---

**pause relation**

```
template<typename T>
Pause_r<T> pause(lref<T>& msg)

template<typename T>
Pause_r<T> pause(const T& msg)

template<typename T>
Pause_r<const T*> pause(T* msg)
```

**Declarative reading**: Print `msg` to `std::cout` and wait for key press to continue.

**Template Parameters:**

`T` : Type of object to be printed. Should support the expression `cout<<msg` where `msg` is of type `T`.

**Parameters:**

`msg`: [in] The object to be printed.

**Exceptions:**

`InvalidDeref` : If `msg` is an lref and not initialized at the time of evaluation.

**Notes:**

On evaluation, the relation prints the object to `cout` and then performs a `cin.ignore()`,waiting for user to press the ENTER key. This relation is useful for debugging purposes when one wishes to manually step through an execution.

**Examples:**

```
    // print each number in range and wait for keypress each time
    lref<int> li;
    relation r = range(li,0,3) && pause(li);
    while(r());
```

**Also refer to:**
`pause_f`.

---

**pause_f relation**

```
template<typename Func>
PauseF_r<..> pause_f(Func f)
```

**Declarative reading**: Print result of `f()` to `std::cout` and waits for key press to continue.

**Template Parameters:**
`Func` : Function pointer or function object type taking no arguments. Should support the expression `cout<<f()` where `f` is of type `Func`.

**Parameters:**
`f`: The function object or a pointer to function whose return value will be printed to `std::cout`.

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

**Notes:**
On evaluation, the relation prints the result of `f()` to `cout` and then performs a `cin.ignore()`, waiting for user to press the ENTER key. This relation is useful for debugging purposes when one wishes to manually step through an execution.

**Examples:**
```
// print each name on a new line and wait for keypress each time
    lref<string> s;
    lref<vector<string> > names = ...;
    relation r = item(s, names) && pause_f(s + "\n");
    while(r());
```

**Also refer to:**
`pause`.

---

**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_)

//with step
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 `val` is not initialized, relation `range` generates all values in the inclusive range [`min`,`max`]. If `val` is initialized, range will succeed if val in the inclusive range [`min`,`max`]. 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, item_dec, eq_seq.`

---

**range_dec relation**

```
template<typename T>
RangeDec_r<T> range_dec(lref<T> val, lref<T> max_, lref<T> min_)

template<typename T>
RangeDec_r<T> range_dec(lref<T> val, T max_, T min_)

//with step
template<typename T>
RangeDec_Step_r<T> range_dec(lref<T> val, lref<T> max_, lref<T> min_
                           , lref<T> step_)

template<typename T>
RangeDec_Step_r<T> range_dec(lref<T> val, T max_, T min_, T step_)
```

**Declarative reading**: `val` is in the decreasing (inclusive) range `[min_, 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 a decrement value 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:**
This relation is similar to range, but generates the values in reverse order.
Note that the order of `max_` and `min_` arguments here is opposite as that of relation `range`.

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

    // 2) print in reverse, alternate values in the range [0,10]
```

```
lref<int> li;
relation r = range_dec(li,10,0,2);
while(r());  // prints "10 8 6 4 2 0"
   cout << *li << " ";

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

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

**Also refer to:**

`item, range.`

---

**repeat relation**

```
template<typename T>
Repeat_r<T>
repeat(lref<T>& val_i, unsigned int count_i, lref<T>& r)

template<typename T>
Repeat_r<T> repeat(T val_i, unsigned int count_i, lref<T>& r)
```

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

**Template Parameters:**

`T` : Any type that satisfies the requirements of lref.

**Parameters:**

`val_i` : [in] The value to be repeated.
`count_i` : [in] The number of times to repeat.
`r` : [out] Value of `val_i` will be repeated in `r`.

**Notes:**

`repeat` succeeds `count_i` times, each time producing the original value of `val_i` in `r`. Assignment of

Note that the value of `val_i` is assigned to `r` only once on first evaluation of `repeat`. Thus any changes to the value of `val_i` in between evaluations of `repeat` will not reflect in `r`. Also `r` is not reassigned the original value of `val_i` on each evaluation. If `r` is found to be already initialized on first evaluation, this value will be memorized prior to being overwritten and on final evaluation of `repeat` this value will be restored into `r`.

**Example:**

```
// repeat '1' three times in j
lref<int> j;
int times=3;
relation r = repeat(1,times,j);
```

```
while( r() )
      cout << s << " ";
```

---

**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.

**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";
```

---

**unique_mf relation**

```
template<typename R, typename Obj>
UniqueMf_r<R,R(Obj::*)(void), Obj>
unique_mf( lref<Obj>& obj_, R(Obj::*mf)(void) )


template<typename R, typename Obj>
UniqueMf_r<R,R(Obj::*)(void) const, Obj>
unique_mf( lref<Obj>& obj_, R(Obj::*mf)(void) const)
```

**Declarative reading**: Value returned by `((*obj_).*mf)()` has not been seen before.

**Template Parameters:**
`R` : Return type of member function.
`Obj` : Type of the object on which the member function is to be invoked.

**Parameters:**
`obj_` : Lref to an object on which member function is to be invoked.
`mf` : Pointer to a member function on the object.

**Notes:**
This relation is similar to relation `unique_f` except that its argument is a member function whose return value is used to perform the uniqueness check.

**Exceptions:**
`InvalidDeref` : If `obj_` is not initialized at the time of evaluation.
Any exception thrown by `mf()`.

**Example:**

```
// Filter based on string's length
string words[] = {"mary", "had", "a", "little", "lamb"};
lref<string> w;
relation r = item(w,words,words+5) && unique_mf(w,&string::length);
while(r())
    cout << *w << " ";  // 'lamb' will not be printed
```

---

**unique_mem relation**

```
template<typename Obj, typename MemberT>
UniqueMem_r<Obj, MemberT>
unique_mem(lref<Obj>& obj_, MemberT Obj::* mem)
```

**Declarative reading**: `(*obj_).*mem` has not been seen before.

**Template Parameters:**
`MemberT` : Type of data member.
`Obj` : Type of the object whose the data member is to be accessed.

**Parameters:**
`obj_` : Lref to an object whose data member is to be accessed.
`mem` : Pointer to a data member on the `obj_`.

**Notes:**
This relation is similar to relation `unique_mf` except that its argument is a data member whose value is used to perform the uniqueness check.

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

**Example:**

```
struct person {
   string firstName, lastName;
   person (string firstName, string lastName)
              : firstName(firstName), lastName(lastName)
   { }

   bool operator==(const person& rhs) const {
      return (firstName==rhs.firstName) && (lastName==rhs.lastName);
   }
};
```

```
// Print unique last names
person people[] = { person("Roshan","Naik"), person("Runa","Naik")
                  , person("Harry","Potter") };
lref<person> p;
relation r = item(p,people,people+3)&& unique_mem(p,&person::lastName);
while(r())
   cout << p->lastName << " ";
```

# 7 Take Left Relations (TLRs)

## *7.1 Introduction*

Some operations that deal with a sequence of input values do not require full visibility of the input sequence in order to start producing results. For example, to transform an input sequence of numbers into a sequence of squares, as each number in the input sequence is encountered the corresponding value in the output sequence can be generated. Other operations such as sorting or reversing a sequence require a fuller view of the input sequence before being able to produce any result(s). *Take Left relations* or *TLR*s are designed to simply the specification and usage of relations that require a fuller view of the input data.

As seen in section 3.2, under the covers, ordinary relations are just function objects that take no arguments and return a `bool`. TLRs on the other hand, are function objects that require a `relation` as argument and return a `bool`. Type `relation_tlr` provides the same type erasure services for TLRs as `relation` does for regular relations.

Consider the following TLR that reverses the input sequence:

```
template<typename T>
relation_tlr reverse(lref<T>& val);
```

And the following usage that reverses the input sequence generated by `range`.

```
relation rng = range(i,1,5);
relation_tlr rev = reverse(i);

while(rev(rng))
   cout << *i << " "; // prints: 5 4 3 2 1
```

TLR `reverse` internally performs the following steps:

- On first evaluation in the while loop:
  - Evaluates `rng` repeatedly till it fails.
  - Each value generated by `rng` in `i` is internally stored in a vector.
  - Makes `i` point to the last element in this vector and succeeds. Or fails if vector is empty.
- On subsequent evaluations:
  - Makes `i` point to the element prior to element that it currently points to and succeeds. Or fails if there are no more elements.

The argument `i` to `reverse` at the time of invocation, serves two purposes simultaneously. First, it makes the input sequence available to `reverse`. Second, it also serves as an out parameter in which the results are generated by `reverse`.

The above usage of reverse TLR can be simplified using operator >>= as follows:

```
lref<int> i;
relation rev = range(i,1,5) >>= reverse(i);
while(rev())
   cout << *i << " "; // prints: 5 4 3 2 1
```

Operator >>= simplifies the task of passing a relation as an argument to the TLR. It also converts the expression involving a TLR into an ordinary relation which can then be further composed with other relations or TLRs:

```
relation rev = range(i,1,5) >>= reverse(i) >>= reverse(i);
while(rev())
   cout << *i << " "; // prints: 1 2 3 4 5
```

Since relations such as `reverse` take the relation to the left of >>= as an argument during evaluation, they are referred to as a "Take Left Relations"[3] or TLRs.

TLR related facilities in Castor are described in the sections below.

## 7.2 Core Support

This section covers the type `relation_ltr` and `operator >>=` which form the core facilities that provide support for using TLRs.

---

**relation_tlr class**

**Purpose:** Any function object that returns `bool` and takes a `relation` as argument can be assigned to this type.

**Class Declaration:**

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

    // Concept : F supports method... bool F::operator()(relation&)
    template<class F>
    relation_tlr(F f);

    relation_tlr(const relation_tlr& rhs);

    relation_tlr& operator=(const relation_tlr& rhs);

    bool operator()(relation & r);
};
```

**Notes:** Operator >>= minimizes the need to explicitly use this type.

[3] For lack of a better name.

### >>= operator (TakeLeft operator)

```
TakeLeft_r operator >>= (const relation& lhs, const relation_tlr& rhs)
```

**Purpose:** Simplifies syntax when using TLRs.

**Example:**

```
int ai[] = { 10,2,1,4,6,5,7,3,9,8 };
lref<int> j;
relation r = item(j,ai,ai+10) >>= order(j);
while(r())
    cout << *j << " "; // prints: 1 2 3 4 5 6 7 8 9 10
```

**Notes:** Operator >>= minimizes the need to explicitly use this type.

## 7.3 TLRs

This section covers the TLRs defined in Castor. All TLRs defined in Castor can be used in generate mode only.

### group_by TLR

```
template<class Item, class Sel, class K, class V>
GroupBy<..>
group_by(lref<Item>& i_, Sel keySelector, lref<group<K,V> >& g)

template<class Item, class Sel, class K, class V, class KCmp>
GroupBy<..>
group_by(lref<Item>& i_, Sel keySelector, lref<group<K,V> >& g
         , KCmp keyCmp)

// cascaded .then()
template<class SelN>
GroupBy<..>::then(SelN keySelectorN)

template<class SelN, class KCmpN>
GroupBy<..>::then(SelN keySelectorN, KCmpN keyCmpN)

// cascaded .item_order() - only once at the very end
template<class ICmp>
GroupBy<..>::item_order(ICmp itemCmp)


// -- supporting type --

template<class Key, class Value>
struct group {
```

```
        typedef Key key_type;
        typedef Value value_type;
        typedef ... iterator; // random access iterator
        typedef ... size_type;
        Key key;

        size_type size() const;     // size of this group
        bool empty() const;      // size()==0 ?
        bool operator==(const group& rhs) const;

        // iteration support
        iterator begin() const;
        iterator end() const};
};
```

**Declarative reading**: `i` is grouped using `keySelector` into `g`.

**Template Parameters:**

`Item`: Type of the object to be grouped.

`Sel`: Unary function pointer or function object that takes argument of type `Item` and returns type `K`.

`K`: Key type for top level grouping. This is same as the return type of `Sel`.

`V`: For single level grouping, this is same as `Item`. For nested grouping, it is the type of the inner group.

`KCmp`: Function pointer or function object that takes two arguments of type `K` and returns `bool`.

`SelN`: Type of key selector at level *N* of the grouping. `SelN` is a function pointer or function object that which takes argument of type `Item` and has a return type is convertible to the key type at grouping level *N*.

`KCmpN`: Type of key comparator at level *N*. `KCmpN` is a function pointer or function object that takes two arguments of type `KN` and returns `bool`, where `KN` is the return type of the corresponding `SelN`.

`ICmp`: Function pointer or function object that takes two arguments of type `Item` and returns `bool`.

**Parameters:**

`i` : [in] The items to be grouped. Input sequence is first read from this argument. Next, the groups are generated as output in argument `g`. `i` should not already be initialized when `group_by` is evaluated first.

`keySelector`: Function object or function pointer to extract the key for each element.
`keyCmp` : Function object or function pointer to compare keys.

`g`: [out] A group of items having a common key of type `K`. Its type dictates the number of levels in the grouping and the type of the key at each level. See Notes section below for details.

`keySelector`***N***: Function object or function pointer to extract the key for each element at grouping level *N*.

`keyCmp`***N*** : Comparator for ordering keys at grouping level *N*.

`itemCmp`: Comparator for ordering the objects (of type `Item`) in the inner most group.

**Exceptions:**
`InvalidArg` : If `i` or `g` is pre-initialized at the time of first evaluation.
Any exception thrown by the `keySelector`.
Any exception thrown by the comparator used for type `Item`.

**Notes**:
`group_by` allows grouping of objects based on specified criteria. There is no limit on the number of levels of nested grouping. Every successful evaluation of `group_by` yields one top level group along with all its subgroups. When the input sequence is empty or there are no more groups to be generated, the relation fails.

Argument `g`'s type provides all the necessary type information for describing the nature of the grouping. This information explicitly includes the type of the value being grouped and the key at each level. It also implicitly includes the number of levels of grouping. For instance if `g` is of type `group<int,string>`, it indicates a single level grouping of `string` objects where the key is of type `int`. Similarly if `g` is of type `group<int, group<char, group<bool,string> > >`, it indicates a three level nested grouping of `string` objects where the keys are of type `int`, `char` and `bool` at grouping levels 1,2 and 3 respectively.

The key selector and an optional key comparator for each level are provided via *cascaded* invocations of **`.then()`** as shown in the examples below.The number of cascaded `.then(..)` invocations following a `group_by(..)` invocation should be exactly 1 less than the total grouping levels. This is enforced at compile time. Thus for single level grouping there will not be any `.then()` invocations. A four level grouping would have three cascaded `.then()` invocations of the following nature: `group_by(..).then( .. ).then( .. ).then( .. )`. Also the return types of the selectors should be compatible with (i.e. convertible to) the corresponding key type as specified in `g`'s type.

The key selectors are used to split the objects into groups and subgroups. The key comparators are used to order the keys at each level. By default, the keys are generated in ascending order using `std::less<>` as the comparator.

The grouped objects are located in the inner most group level. By default, these objects will not be in any order. This ordering can be overridden by providing a custom comparator using a cascaded invocation of `.item_order()` at the end, after all the `.then()` invocations, if any, have been specified. For example, in the case of a single level grouping this would be of the nature: `group_by(..).item_order(..)` , and for a three level grouping: `group_by(..).then(..).then(..).item_order(..)`. `std::less<Item>` and `std::greater<Item>` can be used to obtain ascending and descending order

**Examples**:

```
char firstChar(const string& s) { return s[0]; }
```

```
size_t str_len(const string& s) { return s.size(); }

lref<vector<string> > nums =..; /* {"One","Two","Three","Four"
                                   , "Five","Six","Fifty"}; */

//1) Single level grouping: Group strings by first character
lref<string> n;
lref<group<char,string> > g; // type of each group

relation r = item(n,nums) >>= group_by(n, &firstChar, g);
while(r()) {  // iterate over each group
    cout << "\n" << g->key<< ": ";
    lref<string> s;
    relation r2= item(s,g);
    while(r2()) {  // enumerate values in this group
        cout << *s << " ";
    }
}
// Console Output
F: Four Five Fifty
O: One
S: Six
T: Two Three



//2) Two level grouping: First by firstChar() and then by str_len()
//   Also ensure strings are in ascending order
lref<string> n;
lref<group<char,group<size_t,string> > > g;

relation r = item(n,nums)  >>= group_by(n, firstChar, g)
                               .then(str_len)
                               .item_order(std::less<string>());
while(r()) {  // iterate over outer groups
   cout << g->key;
   lref<group<size_t,string> > g2; // inner group
   relation subgroups = item(g2,g);
   while(subgroups()) {
        cout << "\n   " << g2->key << " : ";
        writeAll(g2)(); // print all items in subgroup
   }
}

// Console Output:
F
   4 : Five, Four

   5 : Fifty
O
   3 : One
S
   3 : Six
T
   3 : Two

   5 : Three
```

**Also refer to:**
`order`, `order_mem`, `order_mf`

---

**order TLR**

```
template<typename T>
Order_tlr<..> order(lref<T>& obj);

template<typename T, typename Pred>
Order_tlr<..>  order(lref<T>& obj, Pred cmp);
```

**Declarative reading**: `obj` is in sorted order.

**Template Parameters:**
`T`: Type of the objects to be sorted. `T` must support comparison using operator `<` unless a custom predicate is specified.

`Pred`: Type of predicate used to compare two objects of type `T`. `Pred` should accept two arguments of type `T` and return `bool`. Could be a function pointer or function object.

**Parameters:**
`obj` : [in & out] *in:* Values to be ordered. *out:* Ordered values.
`obj` should not already be initialized when `order` is evaluated first (see examples).
`cmp` : Comparator used to order the values.

**Exceptions:**
`InvalidArg` : If `obj` is pre-initialized at the time of first evaluation.
Any exception thrown by the comparator used for type `T`.

**Notes**:
This relation is used for producing a sequence of values in sorted order. Unless a comparator is explicitly provided, default order is ascending and uses `std::less<T>` to compare values. Order of sorting can be reversed by specifying `std::greater<int>` as the comparator.

**Examples**:

```
// 1) sort ascending
int ai[] = { 10,2,1,4,6,5,7,3,9,8 };
lref<int> j;
relation r = item(j,ai,ai+10) >>= order(j);
while(r())
    cout << *j << " ";

// 2) sort descending : using a custom comparator
```

```
item(j,ai,ai+10) >>= order(j, std::greater<int>());

// 3) Unsupported usage
j=3;  // do not pre-initialize!
relation r2 = item(j,ai,ai+10) >>= order(j, std::greater<int>());
r(); // will throw
```

**Also refer to:**

`order_mf`, `order_mem`, `group_by`

---

**order_mem TLR**

```
template<typename T, typename MemberT>
OrderMem_tlr<..>
order_mem(lref<T>& obj, MemberT T::* mem);

template<typename T, typename MemberT, typename Pred>
OrderMem_tlr<..>
order_mem(lref<T>& obj, MemberT T::* mem, Pred cmp);
```

**Declarative reading**: `obj` is ordered by data member `obj->mem`.

**Template Parameters:**

`T` : Type of the objects to be sorted.

`MemberT` : Type of the data member used for sorting. Must support comparison using operator `<` unless a custom predicate is specified.

`Pred`: Type of predicate used to compare two objects of type `MemberT`. Should accept two arguments of type `MemberT` and return `bool`. Could be a function pointer or function object.

**Parameters:**

`obj` : [in & out] Must be an lref. Input sequence is first read from this argument. Next the ordered values are generated as output in this argument. `obj` should not already be initialized when `order_mem` is evaluated first.

`mem` : Pointer to data member of `T`.

`cmp` : Comparator used to order the `obj`.

**Exceptions:**

`InvalidArg`: If `obj` is pre-initialized at the time of first evaluation.

Any exception thrown by the comparator used for type `T`.

**Examples**:

```
struct Name {
    string firstName;
    string lastName;
    Name(const char* first, const char* last) :  firstName(first)
                                                , lastName(last)
```

```
    { }
    bool operator(const Name& rhs) {
        return  firstName==rhs.firstName
              && lastName==rhs.lastName;
    }
};

// sort by last name
vector<Name> names = .... ;
lref<Name> n;
relation r = item(n,names.begin(),names.end())
                      >>= order_mem(n, &Name::lastName);
while(r())
    cout << n->firstName << " " << n->lastName << "\n";
```

**Also refer to:**
`order`, `order_mem`, `group_by`

---

**order_mf TLR**

```
template<class T, class R>
OrderMf_tlr<...>
order_mf(lref<T>& obj, R(T::* mf)(void))

template<class T, class R, class Pred>
OrderMf_tlr<..>
order_mf(lref<T>& obj, R(T::* mf)(void), Pred cmp)
```

**Declarative reading**: `obj` is ordered by result of `obj->mf()`.

**Template Parameters:**
`T`: Type of the objects to be sorted.
`R`: Return type of member function of `T`. R must be *LessThanComparable* [$20.1.2] unless a comparator is provided.
`Pred`: Predicate function pointer/object that accepts arguments `(R,R)` and returns `bool`.

**Parameters:**
`obj` : [in & out] *in:* Values to be ordered. *out:* Ordered values.
`obj` should not already be pre-initialized when `order_mf` is evaluated first.
`mf` : A nullary member function whose return values is used to order the objects.
`cmp` : A comparator for the value returned by `obj->mf()`.

**Exceptions:**
`InvalidArg`: If `obj` is pre-initialized at the time of first evaluation.
Any exception thrown by the comparator used for type `T`.

**Notes**:
This relation is useful for ordering types that provide accessor methods to read values of data members.

**Examples**:

```
// sort by string length
vector<string> names ;
lref<string> n;
relation r = item(n,names.begin(),names.end())
                    >>= order_mf(n, &string::length);
while(r())
    cout << *n << " ";
```

**Also refer to:**
`order`, `order_mf`, `group_by`

---

**reverse TLR**

```
template<typename T>
Reverse_tlr<..> reverse(lref<T>& obj)
```

**Declarative reading**: Produce `obj's` in reverse order.

**Template Parameters**:
`T`: Type of the objects to be reverse.

**Parameters:**
`obj` : [in & out] *in:* Values. *out:* Values in reverse order. `obj` should not already be pre-initialized when `reverse` is evaluated first.

**Exceptions:**
`InvalidArg`: If `obj` is pre-initialized at the time of first evaluation.

**Notes**:
This relation is useful to reverse an input sequence.

**Examples**:

```
// reverse the range
lref<int> n;
relation r = range(n,1,5) >>= reverse(n);
while(r())
    cout << *n << " "; // prints 5 4 3 2 1
```

**Also refer to:**
`ritem`

---

**reduce TLR**

```
template<typename T, typename BinFunc>
Reduce_tlr<..> reduce(lref<T>& i, BinFunc acc)
```

**Declarative reading**: Reduce the input sequence of `i` using accumulator `acc`.

**Template Parameters**:
`T:` Type of the objects to be reduced into a value.
`BinFunc:` A function object or a pointer to a function that takes two arguments of type `T` and returns type `T`.

**Parameters:**
*`i`*: [in & out] *in:* Values. *out:* A value obtained by reducing the input sequence values. `i` should not already be pre-initialized when `reduce` is evaluated first.
*`acc`*: This is the accumulator function used to reduce the sequence of input values.

**Exceptions:**
`InvalidArg`: If `i` is pre-initialized at the time of first evaluation.
Any exception thrown by `acc`.

**Notes**:
This relation succeeds only once.

**Examples**:

```
// 5 factorial
lref<int> n;
relation r = range(n,1,5) >>= reduce(n, std::multiplies<int>());
if(r())
   cout << *n;
```

**Also refer to:**
`sum`

---

**sum TLR**

```
template<typename T>
Reduce_tlr<..> sum(lref<T>& i)
```

**Declarative reading**: Add up the input sequence of `i`.

**Template Parameters**:
`T:` Type of the objects to be reduced into a value.
`BinFunc:` A function object or a pointer to a function that takes two arguments of type `T` and returns type `T`.

**Parameters:**
*`i`*: [in & out] *in:* Values. *out:* Sum of input values. `i` should not already be pre-initialized when `sum` is evaluated first.

**Exceptions:**
`InvalidArg`: If `i` is pre-initialized at the time of first evaluation.

Any exception thrown by `acc`.

**Notes**:
This is just a special case of the more generic `reduce` TLR where the accumulator defaults to `std::plus<T>`. This relation succeeds only once.

**Examples**:

```
// Sum of all elements in a vector
lref<vector<int> > nums = ...;
lref<int> n;
(item(n,num) >>= sum(n))();
cout << *n;
```

# 8 Coroutine Support

This section covers Castor's coroutine support which is useful for defining relations imperatively. Coroutines are implemented as classes which derive (public or protected) from class `Coroutine`. One of the member functions in this class can then be enabled to provide coroutine style execution by using the `co_begin`, `co_end`, `co_yield` and `co_return` macros. Usage of class `Coroutine` and the related macros is described below.

---

**Coroutine class**

**Purpose:** Optional helper base class for implementing relations as classes. Enables use of macros `co_begin`, `co_end`, `co_yield`, `co_return` in derived classes.

**Class Declaration:**

```
class Coroutine {
protected:
  int co_entry_pt;
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 (`co_begin`, `co_end`, `co_yield`, `co_return`) that simulate the coroutine style programming model.

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

```
// relation to check or generate values in a specified range
class Myrelation_r : public custom_relation {
    lref<int> p1, p2;
public:
    Myrelation_r(lref<int> p1, lref<int> p2) : p1(p1), p2(p2)
    { }

    bool operator() () {
      co_begin();
      ... // definition of coroutine goes here
      co_end();
    }
};
```

Note the use of macro `co_begin` to start and macro `co_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()`. Also avoid defining local variables inside `operator()`, since their state will not persist across invocations of `operator()`. This is demonstrated in example 8 below, which is a more natural but incorrect way of implementing example 7.

Avoid defining variables locally within `operator()` as values of such variables will not be retained across coroutine invocations. Consider promoting such variables to data members in order to retain their values across invocations.

**Examples:**

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

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

// 2) Coroutine that succeeds once, using co_yield
struct Simple2 : public custom_relation {
  bool operator()(void) {
    co_begin();
    co_yield(true);
    co_end();
  }
};

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


// 3) Succeeds once, using co_return
struct Simple3 : public custom_relation {
  bool operator()(void) {
    co_begin();
    co_return(true);
    co_end();
  }
};

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


// 4) Succeeds twice, using co_yield
  bool operator()(void) {
```

```
    co_begin();
    co_yield(true);
    co_yield(true);
    co_end();
  }


// 5) Succeeds only once
  bool operator()(void) {
    co_begin();
    co_return(true);
    co_return(true); // will never be executed
    co_end();
  }


// 6) Succeeds only once
  bool operator()(void) {
    co_begin();
    co_yield(false);
    co_yield(true);  // will never be executed
    co_end();
  }

// 7) Compiler Error !

   co_yield(true); co_yield(true); // can't use two macros on same line



// 8) Succeeds 'n' times
class SimpleN : public custom_relation {
  int n, i;
public:
  SimpleN(int n) : n(n), i(0)
  {}

  bool operator()(void) {
    co_begin();
    while(i++ < n)
      co_yield(true);
    co_end();
  }
};


// 9) Incorrect way of implementing relation SimpleN from above
class SimpleN : public custom_relation {
  int n;
public:
  SimpleN(int n) : n(n)
  {}

  bool operator()(void) {
    co_begin();
    for(int i=0; i<n; ++i) // 'i' should not be defined here
      co_yield(true);
```

```
    co_end();
  }
};


// 10) 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) {
      co_begin();
      if(sz.defined())
          co_return( *sz == str_->size() );
      sz = str_->size();
      co_yield(true);
      sz.reset();  // revert external side effects
      co_end();
    }
};

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

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

**Also refer to:**
`predicate, co_begin, co_end, co_yield, co_return`

---

**co_begin macro**

```
#define co_begin()  ...
```

**Brief Description**: Used at the beginning of the method body of a coroutine. T This macro can only be used in non-static member functions and requires the enclosing class to derive (public/protected) from class `Coroutine`.

**Also refer to:**
`Coroutine, co_end, co_yield, co_return`

---

**co_end macro**

```
#define co_end()  ...
```

**Brief Description**: Used at the end of the method body of a coroutine. The macro also implicitly returns `false` to the caller. This macro can only be used in non-static member functions and requires the enclosing class to derive (public/protected) from class `Coroutine`.

**Also refer to:**
`Coroutine, co_begin, co_yield, co_return`

---

**co_return macro**

```
#define co_return(booleanExpr)  ...
```

**Brief Description**: Used by coroutines to return a value to caller. This macro indicates completion of the lifetime of the coroutine. All future attempts to execute the coroutine instance will return `false`. This macro can only be used in non-static member functions and requires the enclosing class to derive (public/protected) from class `Coroutine`.

**Parameters:**
`booleanExpr`: Any expression that evaluates to `true` or `false`. This value will be return back to the caller of the coroutine.

**Also refer to:**
`Coroutine, co_begin, co_end, co_yield`

---

**co_yield macro**

```
#define co_yield(booleanExpr)  ...
```

**Brief Description**: Used by coroutines to return a value to caller. When the argument to `co_yield` evaluates to `true`, this macro indicates a temporary suspension of execution of the coroutine and it returns true back to the caller. Next time the coroutine is invoked, it resumes execution directly from the last `co_yield`, skipping all statements preceding the `co_yield`. However if the argument to `co_yield` evaluates to `false`, it indicates the completion of the lifetime of the coroutine similar to `co_return`. All future attempts to execute the coroutine instance will return `false`. This macro can only be used in non-static member functions and requires the enclosing class to derive (public/protected) from class `Coroutine`.

**Parameters:**
`booleanExpr`: Any expression that evaluates to `true` or `false`. This value will be return back to the caller of the coroutine.

**Also refer to:**
`Coroutine, co_begin, co_end, co_return`

# 9 Helper classes, functions and macros

---

**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 Coroutine]**

**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

# 10 Cuts

## *10.1 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 - nesting limited to lexical scope
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.