

Iterators and Ranges for numerical problems

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Outline

- 1 Introduction
- 2 Iterators and ranges for dynamical systems
- 3 Iterators for GPUs
- 4 Conclusion

Introduction

Iterators

Unique way to traverse containers

Unique way to apply iterative IO

Unique way of expressing algorithms

Example – basic use

```
for( auto iter = values.begin() ;  
    iter != values.end() ;  
    ++iter )  
{  
    cout << *iter << endl;  
}
```

Example – basic use

```
for( auto iter = values.begin() ;  
    iter != values.end() ;  
    ++iter )  
{  
    cout << *iter << endl;  
}
```

C++11 - use range based for

```
for( auto v : values )  
{  
    cout << v << endl;  
}
```

Example – Container traversal

```
list< double > values;  
list< double > values2( values.size() );
```

Can be used in

```
transform( values.begin() , values.end() ,  
          values2.begin() ,  
          []( double x ) {  
              return x * 2.0; } );
```

Example – Container traversal

```
vector< double > values;  
vector< double > values2( values.size() );
```

Can be used in

```
transform( values.begin() , values.end() ,  
           values2.begin() ,  
           []( double x ) {  
               return x * 2.0; } );
```


Examples – IO

Input

```
vector< double > values;  
copy_if( istream_iterator< double >( cout ) ,  
         istream_iterator< double >() ,  
         back_inserter( values ) ,  
         []( double x ) { return x > 0.0; } );
```

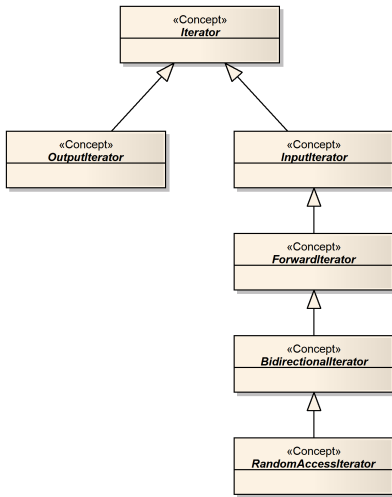
Output

```
vector< double > values;  
// fill values  
copy_if( values.begin() , values.end() ,  
         ostream_iterator< double >( std::cout , "\n" ) ,  
         []( double x ) { return x > 0.0; } );
```

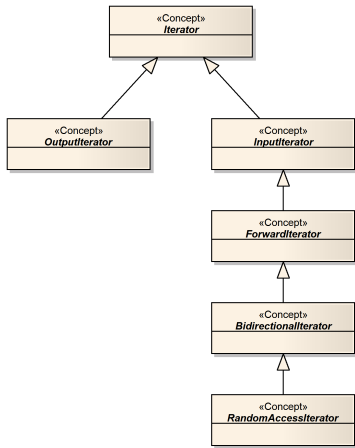
Examples – Combine algorithms

Find a nice real life example.

Iterator types – Concepts



Iterator types – Concepts

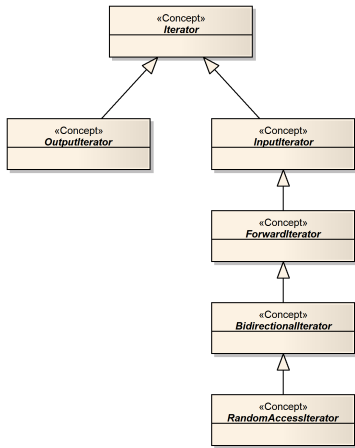


OutputIterator

```
*i = o;  
*i++ = o;  
i++;  
++i;
```

Are special, `back_inserter`,
`ostream_iterator`, ...

Iterator types – Concepts



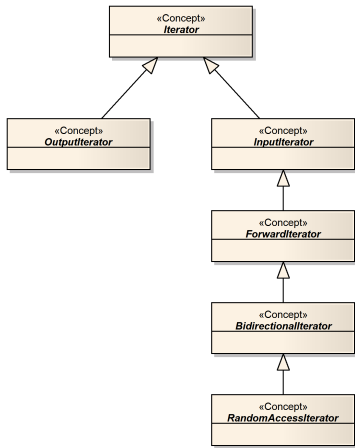
InputIterator a.k.a. Single-Pass Iterator

```
bool r = i != j;  
val x = *i;  
iterator j = ++i;  
i++;  
val x = *i++;
```

istream_iterator,
istreambuf_iterator

But, if $i == j$ then $++i != ++j$

Iterator types – Concepts

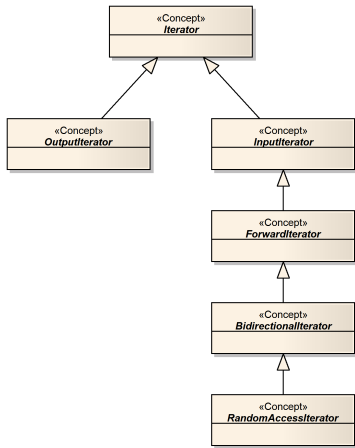


ForwardIterator

```
iterator j = i++;
```

But, if $i == j$ then $++i == ++j$

Iterator types – Concepts

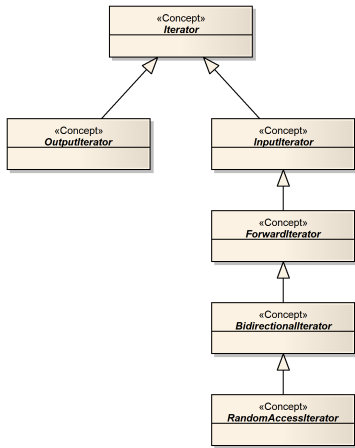


BidirectionalIterator

```
iterator j = --i;  
iterator j = i--;  
val x = *i--;
```

```
map< K , V >::iterator,  
list< T >::iterator
```

Iterator types – Concepts



RandomAccessIterator

```
i += n;  
i -= n;  
val x = i[n];  
long dist = i - j;  
bool b = i < j;
```

```
vector< T >::iterator
```


Algorithms

I all_of	F remove	is_partitioned	is_heap
I any_of	F remove_if	partition	is_heap_until
I none_of	I,O remove_copy	partition_copy	make_heap
I for_each	I,O	stable_partition	push_heap
I count	remove_copy_if	partition_point	pop_heap
I count_if	F replace	is_sorted	sort_heap
I mismatch	F replace_if	is_sorted_until	max
I equal	I,O replace_copy	sort	max_element
I find	I,O	partial_sort	min
I find_if	replace_copy_if	partial_sort_copy	min_element
I find_if_not	F swap_ranges	stable_sort	minmax
F find_end	F iter_swap	nth_element	minmax_element
I,F find_first_if	B reverse	lower_bound	lexicographical_compare
F adjacent_find	B,O reverse_copy	upper_bound	is_permutation
F search	F rotate	binary_search	next_permutation
F search_n	F,O rotate_copy	equal_range	prev_permutation
I,O copy	R random_shuffle	merge	iota
I,O copy_if	R shuffle	inplace_merge	accumulate
I,O copy_n	F unique	includes	inner_product
B,O copy_backward	I,O unique_copy	set_difference	adjacent_difference
I,O move		set_intersection	partial_sum
B,O move_backward		set_symmetric_difference	
F fill		set_union	
F fill_n			
I,O transform			
F generate			
I generate_n			

Ranges

Simplifying iterators

Generalization of iterators

First defined in Boost

Soon in the standard library?

```
vector< double > values;  
boost::for_each( values , []( double x ) { cout  
    << x << endl; } );
```

Ranges – more examples from boost

Filters

complicated algorithms

Ranges in Boost

Ranges are pairs of iterators.

Memory overhead

Filters grow exponential in size

Ranges for the native C++

Introduces new concepts:

Iterable, Container, Sentinel

The range is the main abstraction not the iterator

It holds all informations

Concepts, asymmetric algorithms, sentinels have their own type.

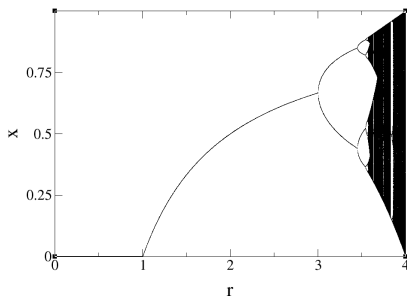
Iterators and ranges for dynamical systems

Dynamical systems – Maps

$$x_{n+1} = f(x_n)$$

Example: Logistic map

$$x_{n+1} = r x_n (1 - x_n)$$

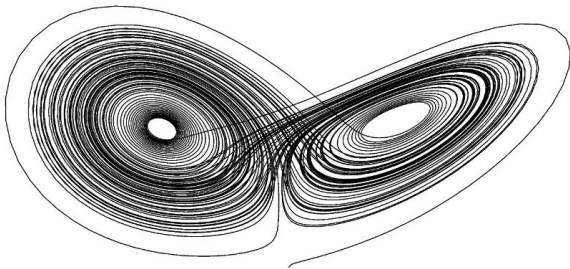


Dynamical systems – ODEs

$$\frac{dx}{dt} = f(x, t)$$

Example: Lorenz attractor

$$\dot{x} = \sigma(y - x) \quad , \quad \dot{y} = x(\rho - z) - y \quad , \quad \dot{z} = xy - \beta z$$



Numerical integration

Lagrange integration

Map range

Abstraction for $x_{n+1} = f(x_n)$

Two versions:

- 1 `map_range` - **stop predicate**
- 2 `counted_map_range` - **iterates n -times**

Map range model the SinglePassRange concept

Map range - applications

- Generalized iota
- Functional random number generators
- Ordinary differential equations
- Maps (dynamical maps)

Map range

```
template< typename T , typename F , typename C >
class map_range
{
    struct iterator { ... };

public:
    map_range( T value , F func , C condition )
        : m_value { std::move( value ) }
        , m_func { std::move( func ) }
        , m_condition( condition )
    {}

    iterator begin() const { return iterator( this ); }
    iterator end() const { return iterator( nullptr ); }

private:
    mutable T m_value;
    mutable F m_func;
    C m_condition;
};
```

Map range

```
struct iterator {
    iterator( map_range const* _r ) : r( _r ) {}

    iterator& operator++() {
        r->m_value = r->m_func( r->m_value );
        if( r->m_condition( r->m_value ) ) {
            r = nullptr;
        }
        return *this;
    }

    T& operator*() const {
        return r->m_value; }
    bool operator==( iterator const& o ) const {
        return ( r == o.r ); }
    bool operator!=( iterator const& o ) const {
        return ! ( *this == o );
    }

    map_range const* r;
};
```

Counted map range

```
template< typename T , typename F >
class counted_map_range
{
    struct iterator { ... };

public:
    counted_map_range( T value , F func , size_t
        max_iterations )
        : m_current_iteration { 0 }
        , m_max_iterations { max_iterations }
        , m_value { std::move( value ) }
        , m_func { std::move( func ) }
        {}

    iterator begin() const { return iterator( this ); }
    iterator end( void ) { return iterator( nullptr ); }

private:
    mutable size_t m_current_iteration = 0;
    const size_t m_max_iterations;
    mutable T m_value;
    mutable F m_func;
};
```

First examples

Generalized Iota:

```
size_t n = 10;
auto iota = make_counted_map_range( 1 , [] ( auto x ) {
    return x * 2; } , 10 );

std::vector< int > values;
boost::copy( iota_range , std::back_inserter( values ) );
for( auto i : values ) { cout << i << endl; }
```

Logistic map:

```
double r = 3.2;
auto l = [r] ( auto x ) { return r * x * ( 1.0 - x ); };
auto range = make_counted_map_range( 0.5 , 1 , 1000 );
for( auto x : range ) { cout << x << endl; }
```

Problems: Projection

We can not easily generate a square iota:

1, 4, 9, 16, 25, 36, ...

Iterators for GPU algorithms

High-level libraries for GPUs

- 1 Thrust
- 2 VexCL
- 3 Boost.Compute
- 4 ViennaCL
- 5 Cuda-MTL

Thrust

STL-like library for Cuda

Design is based on iterators

Iterators in Thrust

`device_vector::iterator`

`host_vector::iterator`

special iterators

Algorithms

Implementation details of Thrust iterators

Special iterators for Thrust

zip iterator

transform iterator

Special problems - and solutions

Norm

Special problems - and solutions

Bucket sort

Solving an ensemble of low-dimensional ODEs

Lorenz example and ODEs

Conclusion

Outlook

References