Iterators and Ranges for numerical problems

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Outline

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; } );
```

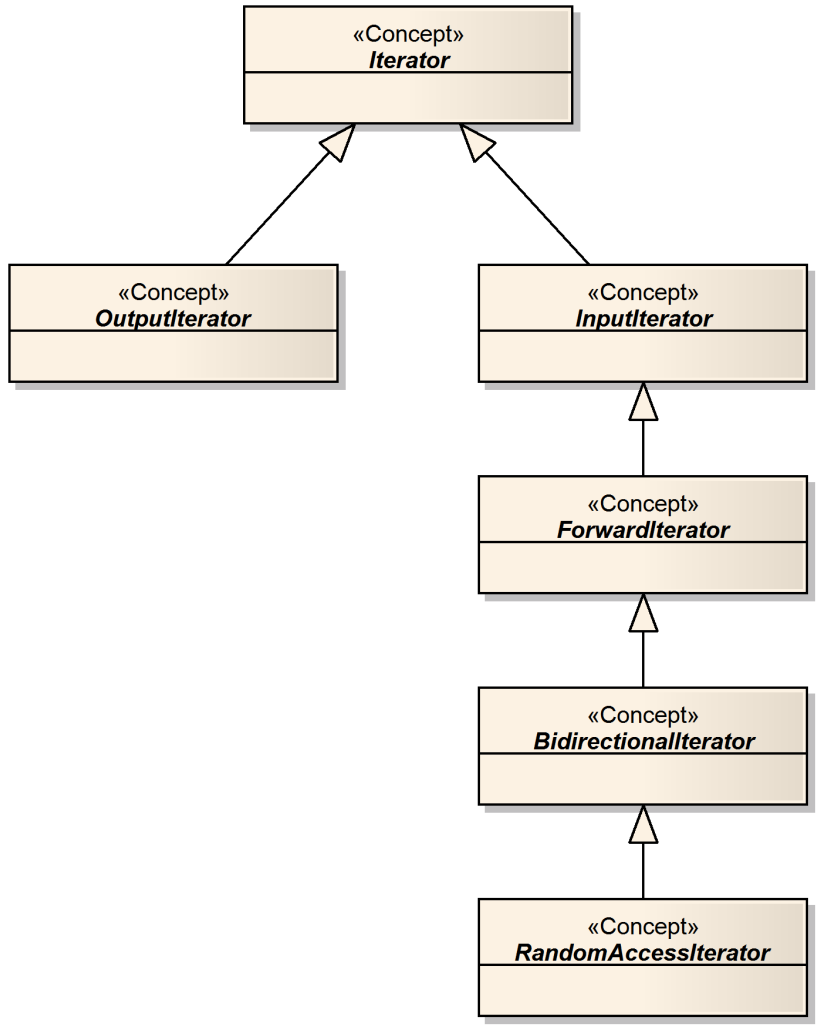
Output

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

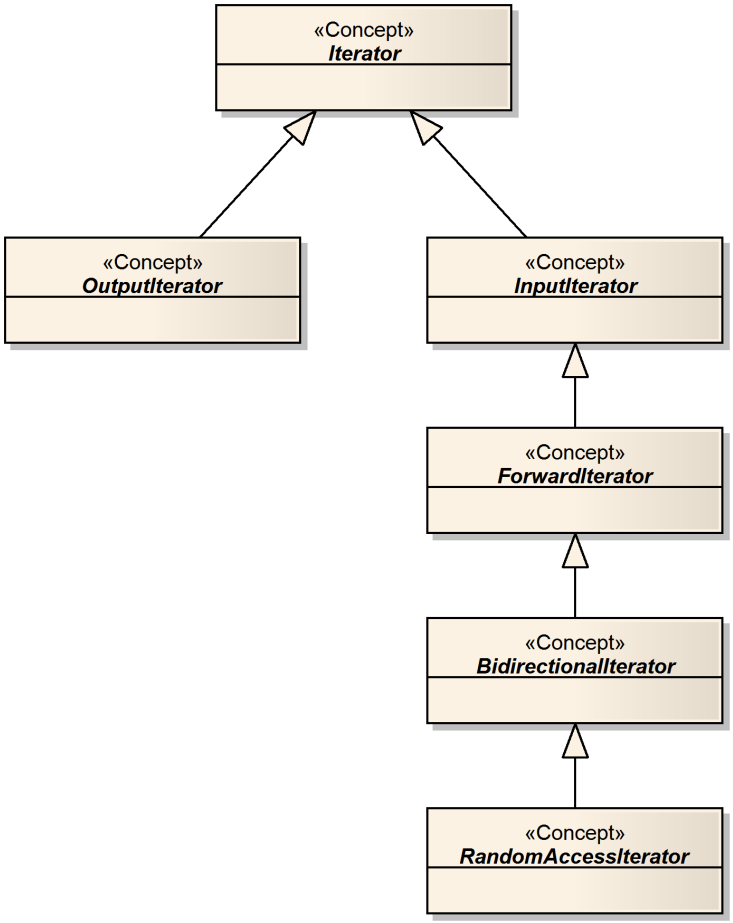
Examples – Combine algorithms

Find a nice real life example.

Iterator types – Concepts



Iterator types – Concepts

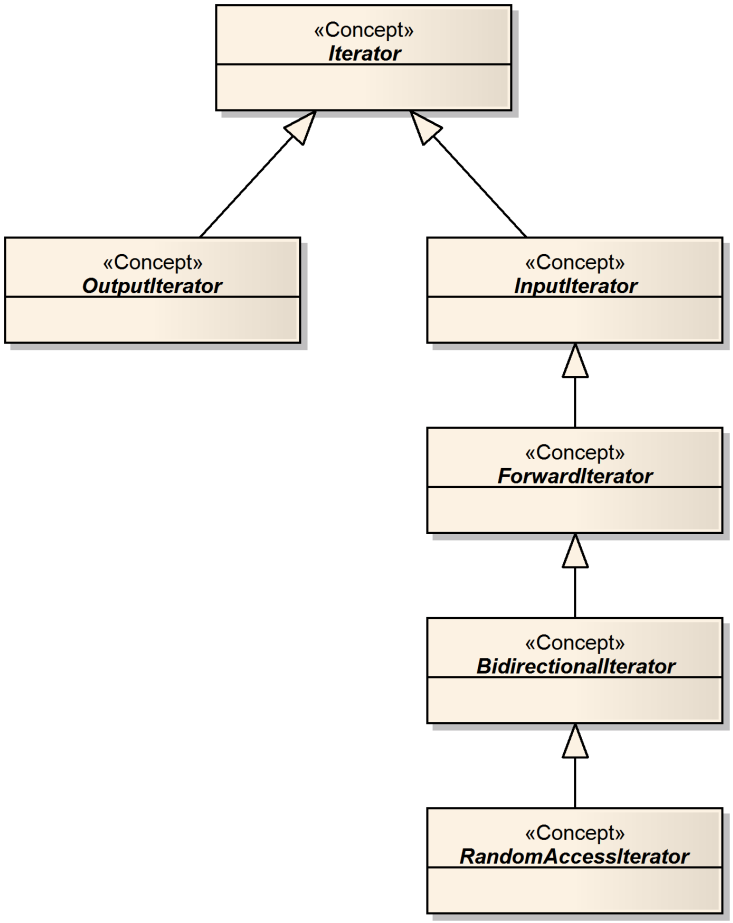


OutputIterator

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

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

Iterator types – Concepts



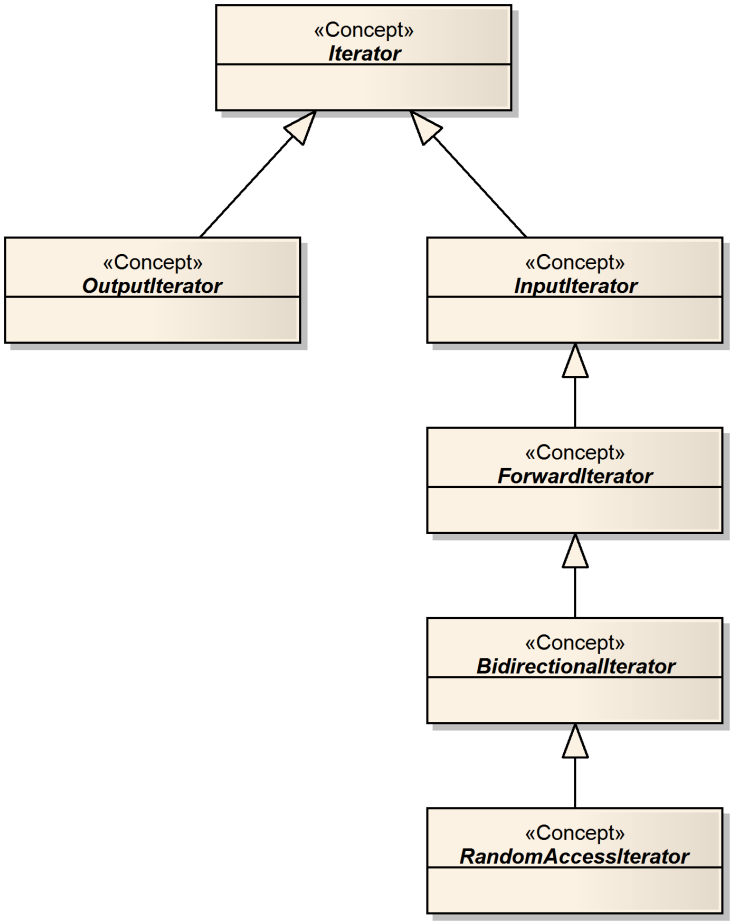
InputIterator a.k.a. Single-Pass Iterator

```
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

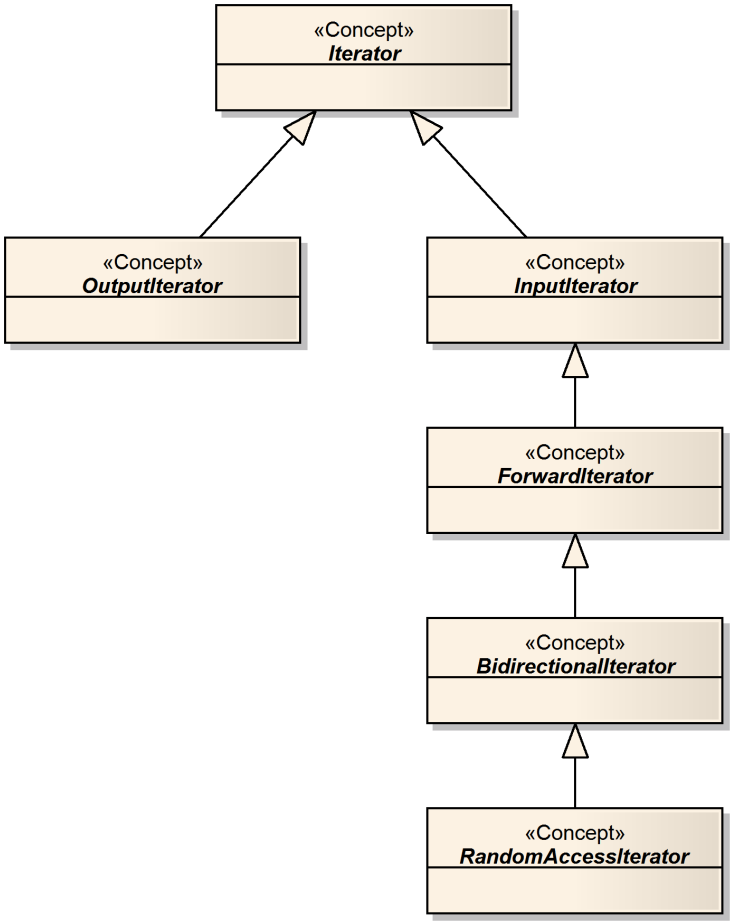


ForwardIterator

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

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

Iterator types – Concepts

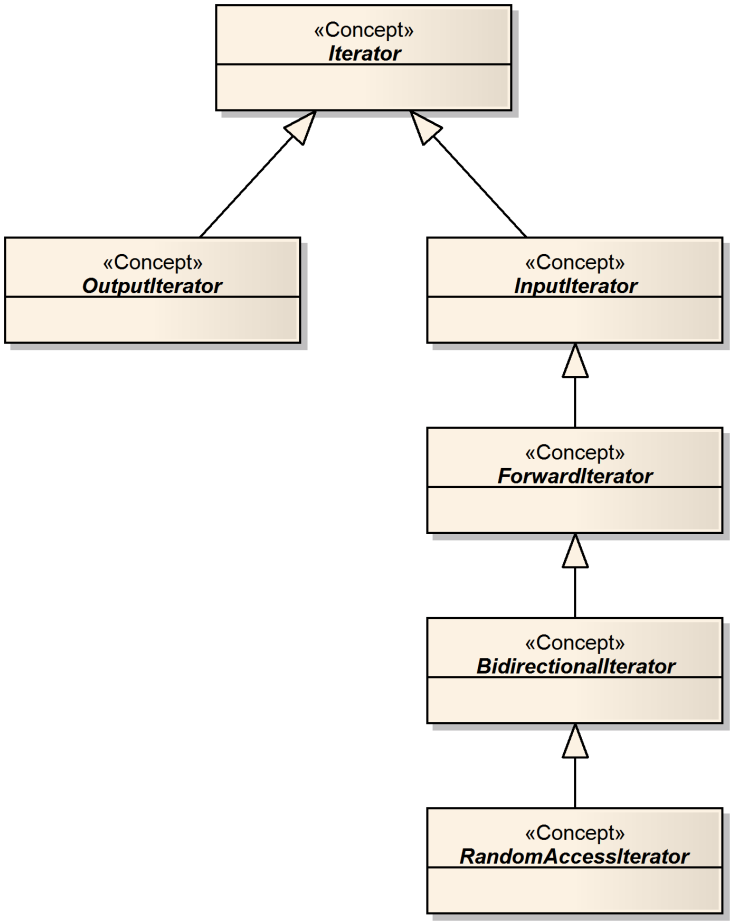


BidirectionalIterator

```
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
I any_of
I none_of
I for_each
I count
I count_if
I mismatch
I equal
I find
I find_if
I find_if_not
F find_end
I,F find_first_if
F adjacent_find
F search
F search_n

I,O copy
I,O copy_if
I,O copy_n
B,O copy_backward
I,O move
B,O move_backward
F fill
F fill_n
I,O transform
F generate
I generate_n

F remove
F remove_if
I,O remove_copy
I,O remove_copy_if
F replace
F replace_if
I,O replace_copy
I,O replace_copy_if
F swap_ranges
F iter_swap
B reverse
B,O reverse_copy
F rotate
F,O rotate_copy
R random_shuffle
R shuffle
F unique
I,O unique_copy

is_partitioned
partition
partition_copy
stable_partition
partition_point
is_sorted
is_sorted_until
sort
partial_sort
partial_sort_copy
stable_sort
nth_element

lower_bound
upper_bound
binary_search
equal_range
merge
inplace_merge
includes
set_difference
set_intersection
set_symmetric_difference
set_unition

is_heap
is_heap_until
make_heap
push_heap
pop_heap
sort_heap

max
max_element
min
min_element
minmax
minmax_element
lexicographical_compare
is_permutation
next_permutation
prev_permutation

iota
accumulate
inner_product
adjacent_difference
partial_sum

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++

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

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

picture of logistic map

Dynamical systems – Maps

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

Iota:

```
std::iota( first , last , 1 );
```

$$x_{n+1} = x_n + 1 \qquad (1, 2, 3, 4, \dots)$$

Generalized iota:

$$x_{n+1} = x_n + 2 \qquad (1, 3, 5, 7, \dots)$$

$$x_{n+1} = 2x_n \qquad (1, 2, 4, 8, \dots)$$

$$x_{n+1} = x_n^2 \qquad (1, 1, 1, 1, \dots)$$

Dynamical systems – ODEs

$$\frac{\mathrm{d}x}{\mathrm{d}t} = f(x, t)$$

picture of lorenz system?

Numerical integration

Lagrange integration

Map iterator

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

1. x could be intrinsic state of the iterator, or the iterator iterates x.
2. Stop criterium, which is the end iterator

Map iterator - applications

Generalized iota
Functional random number generators

Map iterator

Implementation
Naive implementation

Map range

Better implementation

Map iterators and ranges for the new standard

Sentinels

Iterators for GPUs 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