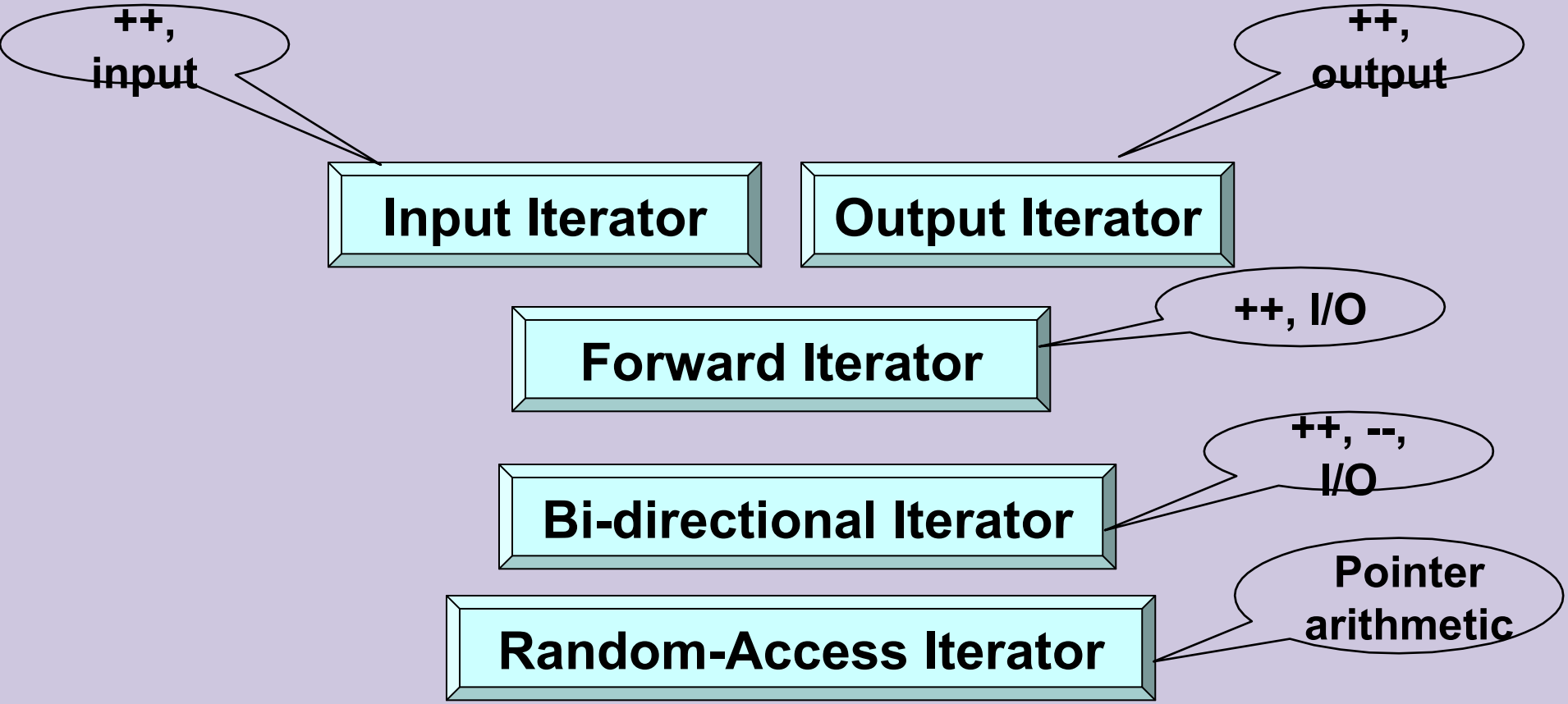
The Standard C++ Library – Iterators

Version 1: Dr. Ofir Pele
Version 2: Dr. Erel Segal-Halevi

Why Iterators?

- Instead of writing e.g. "find" for vector, "find" for unordered_set, "find" for array, etc. -
- - we write only **one** find that accepts two iterators (begin and end): http://www.cplusplus.com/reference/algorithm/find/
- The same "find" would work for *any* container that defines the iterators correctly, and even for non-containers such as "range", "chain".

Iterator types



Iterator Types

	Output	Input	Forward	Bi-directional	Random
Read		`x = *i`	`x = *i`	`x = *i`	`x = *i`
Write	`*i = x`		`*i = x`	`*i = x`	`*i = x`
Iteration	`++`	`++`	`++`	`++, --`	`++, --, +, -, +=, -=`
Comparison		`==, !=`	`==, !=`	`==, !=`	`==, !=, <, >, <=, >=`

- Output: write only and can write only once
- Input: read many times each item
- Forward supports both read and write
- Bi-directional support also decrement
- Random supports random access

(just like C pointer)

Iterators & Containers

Input/output/forward iterators:

- iostreams (folder 3)

Bidirectional iterators:

- list, map, set

Random access iterators:

- vector

Iterators & Containers

```
class NameOfContainer {
   …
   typedef … iterator; // iterator type
   iterator begin();      // first element
   iterator end();        // element after last
```

```
NameOfContainer<...> c

…

NameOfContainer<...>::iterator it;

for( it= c.begin(); it!=c.end(); ++it)

      // do something that changes *it
```

Iterators & Containers: c++11

```
class NameOfContainer {
   …
   typedef … iterator; // iterator type
   iterator begin();      // first element
   iterator end();        // element after last
```

```
NameOfContainer<...> c

…


for(auto it= c.begin(); it!=c.end(); ++it)
      // do something that changes *it
```

Iterators & Containers: c++11

```
class NameOfContainer {
   …
   typedef … iterator; // iterator type
   iterator begin();      // first element
   iterator end();        // element after last
```

```
NameOfContainer<...> c

…


for(auto& val : c)
      // do something that changes val
```

const_iterators & Containers

```
class NameOfContainer {
   …
typedef … const_iterator; // iterator type
const_iterator begin() const;      // first element
const_iterator end() const;        // element after last
```

```
NameOfContainer<...> c

…

NameOfContainer<...>::const_iterator it;

for( it= c.begin(); it!=c.end(); ++it)

      // do something that does not change *it
```

const_iterators & Containers: c++11

```
class NameOfContainer {
   …
typedef … const_iterator; // iterator type
const_iterator cbegin() const;      // first element
const_iterator cend() const;        // element after last
```

```
NameOfContainer<...> c

…


for(auto it= c.cbegin(); it!=c.cend(); ++it)
      // do something that does not change *it
```

const_iterators & Containers: c++11

```
class NameOfContainer {
   …
typedef … const_iterator; // iterator type
const_iterator cbegin() const;      // first element
const_iterator cend() const;        // element after last
```

```
NameOfContainer<...> c

…


for(const auto& val : c)
      // do something that does not change val
```

const_iterators & Containers

```
...
const_iterator cbegin() const;
const_iterator cend() const;
const_iterator begin() const;
const_iterator end() const;
```

```
...

iterator begin();
iterator end();
```

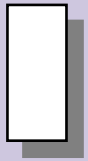
Note that the begin() and end() methods that return regular iterator are not **const** methods. i.e: if we get a container by const (const ref, ...) we can't use these methods. We have to use the methods that return **const_iterator**

[end of first week]

IntBufferSwap example revisited

- See folder 4.
- Focus on iterator and const_iterator.

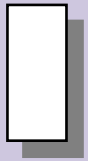
Iterators & Sequence Containers



```
SeqContainerName<...> c;
SeqContainerName<...>::iterator i,j;
```

- `c.insert(i,x)` – inserts `x` before `i`
- `c.insert(i,first,last)`
  – inserts elements in `[first,last)` before `i`
- `c.erase(i)` – erases the element that `i` points to
- `c.erase(i,j)`
  – erase elements in range `[i,j)`

Iterators & Sequence Containers c++11



```
SeqContainerName<...> c;
SeqContainerName<...>::iterator i,j;
```

- `c.emplace(i,p1,...,pn)`:

Constructs and inserts before `i` an object with a constructor that gets `p1,...,pn` parameters

Iterators & other Containers

- insert and erase has the same ideas, except they keep the invariants of the specific container.
- For example, a Sorted Associative Container will remain sorted after insertions and erases.

Iterators & other Containers

- So what does `c.insert(pos,x)` does, when c is a Unique Sorted Associative Container ?

- Inserts x into the set, using **pos** as a **hint** to where it will be inserted.

Iterators & other Containers: c++11

- So what does `c.emplace_hint(pos,x)` does, when c is a Unique Sorted Associative Container?

- Constructs and Inserts x into the set, using **pos** as a **hint** to where it will be inserted.

Iterator validity

- When working with iterators, we have to remember that their validity can change

What is wrong with this code?

```
Container<...> c;
...
for(auto i= c.begin(); i!=c.end(); ++i )
    if( f( *i ) ) { // some test
      c.erase(i);
    }
```

Iterator validity

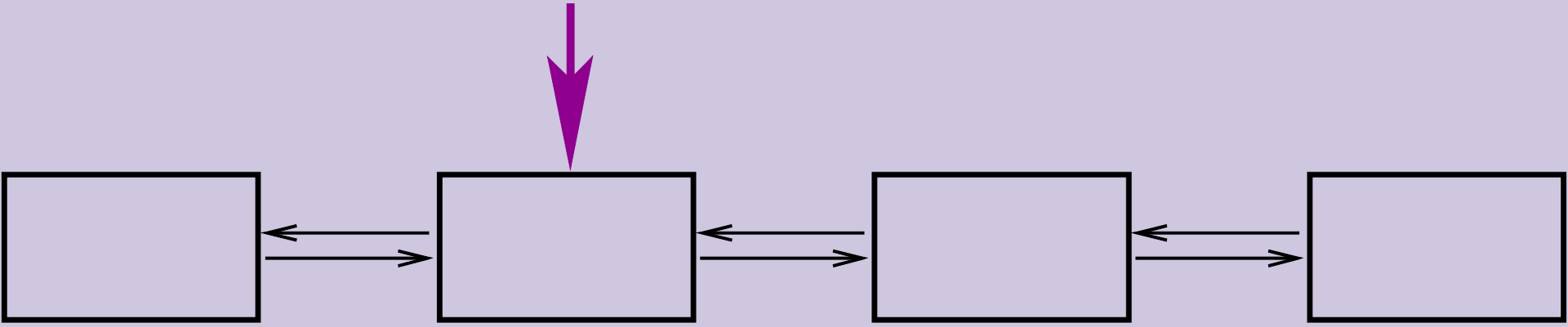
Two cases:

- list, set, map
  - `i` is not a legal iterator

Iterator validity

Two cases:

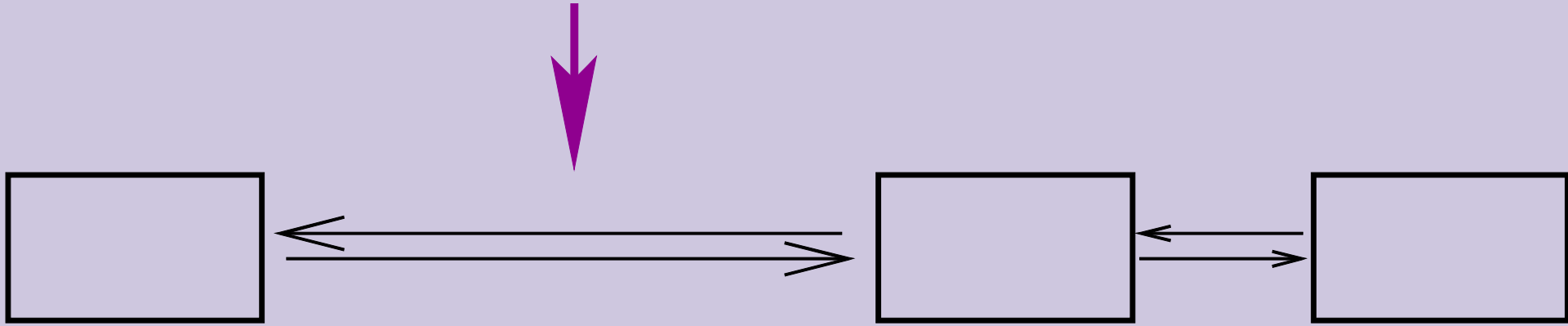
- **list**, set, map
  - `i` is not a legal iterator



Iterator validity

Two cases:

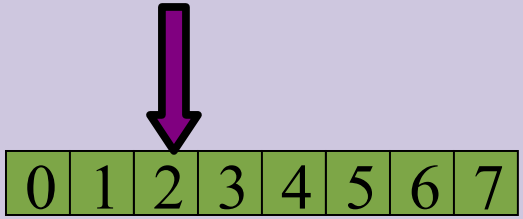
- **list**, set, map
  - `i` is not a legal iterator



Iterator validity

Two cases:

- list, set, map
  - `i` is not a legal iterator
- **vector**
  - `i` points to the element after



Iterator validity

Two cases:

- list, set, map
  - `i` is not a legal iterator
- **vector**
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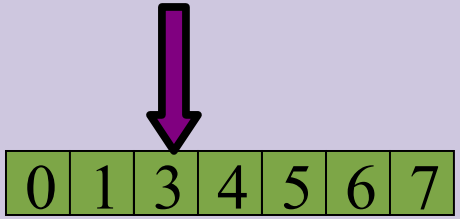

Iterator validity

Two cases:

- list, set, map
  - `i` is not a legal iterator
- **vector**
  - `i` points to the element after

In either case,

this is not what we want…

Erasing during iteration (folder 5)

```
Container<...> c;
...
for(auto i= c.begin(); i!=c.end();/*no ++i*/ )
  if( f( *i ) ) { // some test
    i = c.erase(i);
  } else {
    ++i;
  }
```

Iterators & Map

Suppose we work with:

```
map<string,int> dictionary;
map<string,int>::iterator it;
…
it = dictionary.begin();
```

What is the type of `*it` ?

Iterators & Map

Every STL container type Container defines

`Container::value_type`

Type of elements stored in container

- This is the type returned by an iterator

```
Container::value_type operator*();
```

Iterators & Map

- Ok, so what type of elements does a map return?

- `map<KeyType,ValueType>` keeps pairs
  - `KeyType key` – "key" of entry
  - `ValueType value` – "value" of entry

Pairs

```
template< typename T1, typename T2>
struct pair {
  typedef T1 first_type;
  typedef T2 second_type;

  T1 first;
  T2 second;

  pair( const T1& x, const T2& y )
     : first(x), second(y)
  {}
};
```

Map value_type

```
template< typename Key, typename T,
          typename Cmp = less<Key> >
class map {
public:
  typedef pair<const Key, T> value_type;

  typedef Key key_type;
  typedef T mapped_type;
  typedef Cmp key_compare;
};
```

Using map iterator

```
map<string,int> dict;
…

for( auto i = dict.cbegin();
     i != dict.cend();
     ++i )
{
   cout << i->first << " "
        << i->second << "\n";
}
```

Using map iterator

```
  map<string,int> dict;
  …

  for( const auto& val : dict) {
     cout << val.first << " "
          << val.second << "\n";
}
```

Iterators and Assoc. Containers (folder 6)

Additional set of operations:

- **`iterator C::find(key_type const& key)`**

Return iterator to first element with **`key`**.

Return **`end()`** if not found

- **`iterator C::lower_bound(key_type const& key)`**

Return iterator to first element greater or equal to **`key`**

- **`iterator C::upper_bound(key_type const& key)`**

Return iterator to first element greater than **`key`**