A very brief intrudction to

The Standard Template Library

Standard Template Library

- A collection of common data structures and algorithms
- Compile-time polymorphism (templates)

```
std::vector<int>
std::list<double>
std::hash_map<std::string, std::pair<int, int>>
```

- Efficient implementations

```
std::sort(...);    //O(n log n)
```

- Correct implementations!

```
std::binary_search(...);
```

Raises the level of abstraction

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```
void PanelBar::RepositionExpandedPanels(Panel* fixed_panel) {
  CHECK(fixed_panel);

  // First, find the index of the fixed panel.
  int fixed_index = GetPanelIndex(expanded_panels_, *fixed_panel);
  CHECK_LT(fixed_index, expanded_panels_.size());

  // Next, check if the panel has moved to the other side of another panel.
  const int center_x = fixed_panel->cur_panel_center();
  for (size_t i = 0; i < expanded_panels_.size(); ++i) {
    Panel* panel = expanded_panels_[i].get();
    if (center_x <= panel->cur_panel_center() ||
        i == expanded_panels_.size() - 1) {
      if (panel != fixed_panel) {
        // If it has, then we reorder the panels.
        ref_ptr<Panel> ref = expanded_panels_[fixed_index];
        expanded_panels_.erase(expanded_panels_.begin() + fixed_index);
        if (i < expanded_panels_.size()) {
          expanded_panels_.insert(expanded_panels_.begin() + i, ref);
        } else {
          expanded_panels_.push_back(ref);
        }
      }
    break;
    }
  }
```

Actual code!

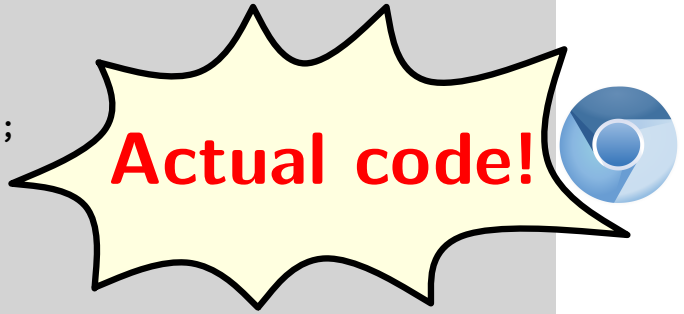
Raises the level of abstraction


```
// Find the total width of the panels to the left of the fixed panel.
  int total_width = 0;
  fixed_index = -1;
  for (int i = 0; i < static_cast<int>(expanded_panels_.size()); ++i) {
    Panel* panel = expanded_panels_[i].get();
    if (panel == fixed_panel) {
      fixed_index = i;
      break;
    }
    total_width += panel->panel_width();
  }

  CHECK_NE(fixed_index, -1);
  int new_fixed_index = fixed_index;

  // Move panels over to the right of the fixed panel until all of the ones
  // on the left will fit.
  int avail_width = max(fixed_panel->cur_panel_left() - kBarPadding, 0);
  while (total_width > avail_width) {
    new_fixed_index--;
    CHECK_GE(new_fixed_index, 0);
    total_width -= expanded_panels_[new_fixed_index]->panel_width();
  }

  // Reorder the fixed panel if its index changed.
  if (new_fixed_index != fixed_index) {
    Panels::iterator it = expanded_panels_.begin() + fixed_index;
    ref_ptr<Panel> ref = *it;
```



⋮

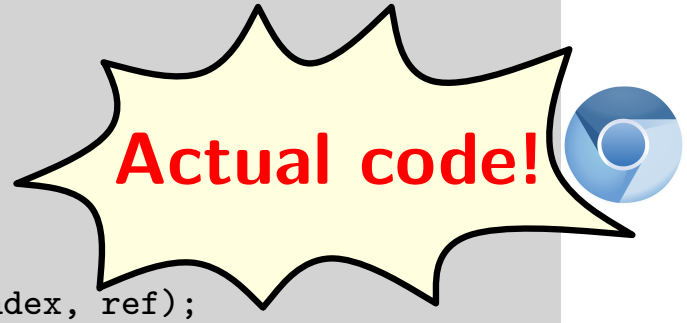
Raises the level of abstraction


```
  expanded_panels_.erase(it);
  expanded_panels_.insert(expanded_panels_.begin() + new_fixed_index, ref);
  fixed_index = new_fixed_index;
}

// Now find the width of the panels to the right, and move them to the
// left as needed.
total_width = 0;
for (Panels::iterator it = expanded_panels_.begin() + fixed_index + 1;
       it != expanded_panels_.end(); ++it) {
  total_width += (*it)->panel_width();
}
avail_width = max(wm_->width() - (fixed_panel->cur_right() + kBarPadding), 0);

while (total_width > avail_width) {
  new_fixed_index++;
  CHECK_LT(new_fixed_index, expanded_panels_.size());
  total_width -= expanded_panels_[new_fixed_index]->panel_width();
}

// Do the reordering again.
if (new_fixed_index != fixed_index) {
  Panels::iterator it = expanded_panels_.begin() + fixed_index;
  ref_ptr<Panel> ref = *it;
  expanded_panels_.erase(it);
  expanded_panels_.insert(expanded_panels_.begin() + new_fixed_index, ref);
  fixed_index = new_fixed_index;
}
```



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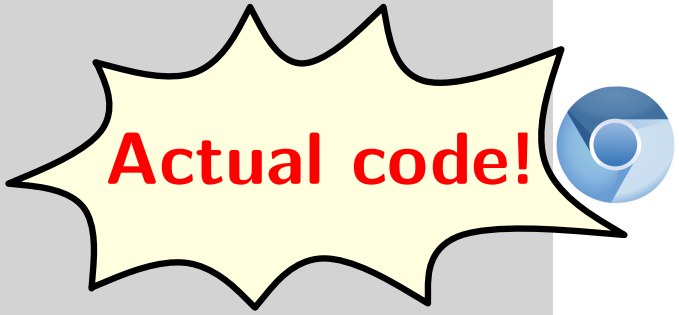
Raises the level of abstraction

4/4

```
// Finally, push panels to the left and the right so they don't overlap.
 int boundary = expanded_panels_[fixed_index]->cur_panel_left() - kBarPadding;
 for (Panels::reverse_iterator it =
      // Start at the panel to the left of 'new_fixed_index'.
      expanded_panels_.rbegin() + (expanded_panels_.size() - new_fixed_index);
      it != expanded_panels_.rend(); ++it) {
   Panel* panel = it->get();
   if (panel->cur_right() > boundary) {
     panel->Move(boundary, kAnimMs);
   } else if (panel->cur_panel_left() < 0) {
     panel->Move(min(boundary, panel->panel_width() + kBarPadding), kAnimMs);
   }
   boundary = panel->cur_panel_left() - kBarPadding;
 }
 boundary = expanded_panels_[fixed_index]->cur_right() + kBarPadding;

 for (Panels::iterator it = expanded_panels_.begin() + new_fixed_index + 1;
      it != expanded_panels_.end(); ++it) {
   Panel* panel = it->get();
   if (panel->cur_panel_left() < boundary) {
     panel->Move(boundary + panel->panel_width(), kAnimMs);
   } else if (panel->cur_right() > wm_->width()) {
     panel->Move(max(boundary + panel->panel_width(),
                 wm_->width() - kBarPadding),
                 kAnimMs);
   }
   boundary = panel->cur_right() + kBarPadding;
 }
}
```



Raises the level of abstraction

Using STL:

```
void PanelBar::RepositionExpandedPanels(Panel* fixed_panel) {
  CHECK(fixed_panel);

  // First, find the index of the fixed panel.
  int fixed_index = GetPanelIndex(expanded_panels_, *fixed_panel);
  CHECK_LT(fixed_index, expanded_panels_.size());

  // Next, check if the panel has moved to the left side of another panel.
  auto f = begin(expanded_panels_) + fixed_index;
  auto p = lower_bound(begin(expanded_panels_), f, center_x,
    [](const ref_ptr<Panel>& e, int x){ return e->cur_panel_center() < x; });

  // If it has, then we reorder the panels.
  rotate(p, f, f + 1);
}
```

Credit: Sean Parent

Collections & Iterators

Pairs

- `std::pair<T,U>` represents a pair of objects of types T and U, respectively.

```
std::pair<int, char> p(5, 'a');
std::cout << p.first << "\n"; //5
std::cout << p.second << "\n"; //a
```

- `std::make_pair(x,y)` creates a pair from its arguments `x` and `y`.

```
std::pair<int, char> p = std::make_pair(5, 'a');
```

- See also `std::tuple<T, U, V ...>`

Arrays

- A collection of **fixed** length
- Contains elements of the same type

```
std::array<int, 3> A; //Uninitialized contents
std::array<int, 3> B = {}; //Default initialized
std::array<int, 3> C = {1,2,3}; //Initialized
```

- Essentially a wrapper for C arrays.

```
C[0] = 4; //C now contains 4,2,3
```

- Better value semantics

```
std::array<int, 3> D;
D = C; //D's elements are now a copy of C's elements
```

- Supports additional operations, e.g., `size()` or at()

Vectors

- A collection of **variable** length

```
std::vector<int> A; //Empty vector
std::vector<int> B(10); //10 default initialized ints
std::vector<int> C(10, 42); //10 ints initialized to 42
std::vector<int> D {1, 2, 3};
```

- Random access:

```
D[0] = 4; // D now contains: 4, 2, 3
```

- Insert an element at the end

```
D.push_back(10); // D now contains: 4, 2, 3, 10
```

- Delete the last element

```
D.pop_back();
```

Vectors

- A collection of **variable** length

```
std::vector<int> A; //Empty vector
std::vector<int> B(10); //10 default initialized ints
std::vector<int> C(10, 42); //10 ints initialized to 42
std::vector<int> D {1, 2, 3};
```

- Random access: $O(1)$

```
D[0] = 4; // D now contains: 4, 2, 3
```

- Insert an element at the end $O(1)$ amortized

```
D.push_back(10); // D now contains: 4, 2, 3, 10
```

- Delete the last element $O(1)$

```
D.pop_back();
```

Vectors

- Insert an element at position i:

```
int i=2;
std::vector<int> D {1, 2, 3, 4, 5};
D.insert(D.begin()+i, 10);
// D now contains: 1, 2, 10, 3, 4, 5
```

- Delete the element at position i:

```
int i=2;
std::vector<int> D {1, 2, 3, 4, 5};
D.erase(D.begin()+i);
// D now contains: 1, 2, 4, 5
```

Vectors

- Insert an element at position i:
  $O(1)$ amortized $+ O(\#\text{elements} - i)$

```
int i=2;
std::vector<int> D {1, 2, 3, 4, 5};
D.insert(D.begin()+i, 10);
// D now contains: 1, 2, 10, 3, 4, 5
```

- Delete the element at position i: $O(\#\text{elements} - i)$

```
int i=2;
std::vector<int> D {1, 2, 3, 4, 5};
D.erase(D.begin()+i);
// D now contains: 1, 2, 4, 5
```

Deque

- A vector-like collection that supports fast insertions and deletions from both ends

```
std::deque<int> D {1, 2, 3};
```

- Access to elements

```
std::cout << D[1] << "\n"; //Prints 2
```

- Insert an element at the beginning/end

```
D.push_front(10); //10, 1, 2, 3
D.push_back(20); //10, 1, 2, 3, 20
```

- Delete an element from the beginning/end

```
D.pop_front(); //2,3
D.pop_back(); //2
```

(See also `std::queue` and `std::stack`)

Deque

- A vector-like collection that supports fast insertions and deletions from both ends

```
std::deque<int> D {1, 2, 3};
```

- Access to elements $O(1)$

```
std::cout << D[1] << "\n"; //Prints 2
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- Insert an element at the beginning/end $O(1)$ amortized

```
D.push_front(10); //10, 1, 2, 3
D.push_back(20); //10, 1, 2, 3, 20
```

- Delete an element from the beginning/end $O(1)$ amortized

```
D.pop_front(); //2,3
D.pop_back(); //2
```

(See also `std::queue` and `std::stack`)

Iterators

- Iterators provide access to elements in a collection
- An iterator object points to an element of a collection
- Iterators can be dereferenced (* operator) to access the pointed element
- Iterators can be advanced with the ++ operator.
- Some iterators can moved backwards with the -- operator.
- Some iterators support random access via addition or the [] operator.

Iterators

- Collections have a `begin()` method that returns an iterator to their first element.
- ... and an `end()` method that returns an iterator pointing *one past* the last element.
- Use `std::begin()` and `std::end()` to get iterators for C arrays.

```
std::vector<int> V {1,2,3,4,5};
for(std::vector<int>::iterator it=V.begin(); it<V.end(); it++)
    std::cout << *it << "␣";
std::cout << "\n";
```

```
int V[] = {1,2,3,4,5};
auto it = std::begin(V);
std::cout << *(it+2) << "\n";
```

Lists

- A collection of **variable** length. Implemented as a doubly-linked list.

```
std::list<int> A; //Empty list
std::list<int> B(10); //10 default initialized ints
std::list<int> C(10, 42); //10 ints initialized to 42
std::list<int> D {1, 2, 3};
```

- No random access
- Insert an element at the beginning/end

```
D.push_front(10); //10, 1, 2, 3
D.push_back(20); //10, 1, 2, 3, 20
```

- Delete an element from the beginning/end

```
D.pop_front(); //2,3
D.pop_back(); //2
```

Lists

- A collection of **variable** length. Implemented as a doubly-linked list.

```
std::list<int> A; //Empty list
std::list<int> B(10); //10 default initialized ints
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std::list<int> D {1, 2, 3};
```

- No random access
- Insert an element at the beginning/end $O(1)$

```
D.push_front(10); //10, 1, 2, 3
D.push_back(20); //10, 1, 2, 3, 20
```

- Delete an element from the beginning/end $O(1)$

```
D.pop_front(); //2,3
D.pop_back(); //2
```

Lists

- Get an iterator to position i

```
int i=2;
std::list<int> L {1, 2, 3, 4, 5};
std::list<int>::it = L.begin();
std::advance(it, i); //*it = 3
```

- Insert an the element at a given position:

```
L.insert(it, 10); // L now contains: 1, 2, 10, 3, 4, 5
```

- Delete the element at a given position:

```
L.erase(it);
```

Lists

- Get an iterator to position i $O(1+i)$

```
int i=2;
std::list<int> L {1, 2, 3, 4, 5};
std::list<int>::it = L.begin();
std::advance(it, i); //*it = 3
```

- Insert an the element at a given position: $O(1)$

```
L.insert(it, 10); // L now contains: 1, 2, 10, 3, 4, 5
```

- Delete the element at a given position: $O(1)$

```
L.erase(it);
```

Sets

- A collection that mantains a *sorted* set of unique keys

```
std::set<int> S {1, 2, 5};
```

- Insertion

```
S.insert(10); //S now represents {1,2,5,10}
S.insert(10); //S represents the same set
```

- Lookup

```
S.find(5); //Returns an iterator to element 5
S.find(20); //No such element. Returns S.end()
```

- Deletion

```
S.erase(5);
```

Sets

- A collection that mantains a *sorted* set of unique keys

```
std::set<int> S {1, 2, 5};
```

- Insertion $O(\log n)$

```
S.insert(10); //S now represents {1,2,5,10}
S.insert(10); //S represents the same set
```

- Lookup $O(\log n)$

```
S.find(5); //Returns an iterator to element 5
S.find(20); //No such element. Returns S.end()
```

- Deletion $O(\log n)$

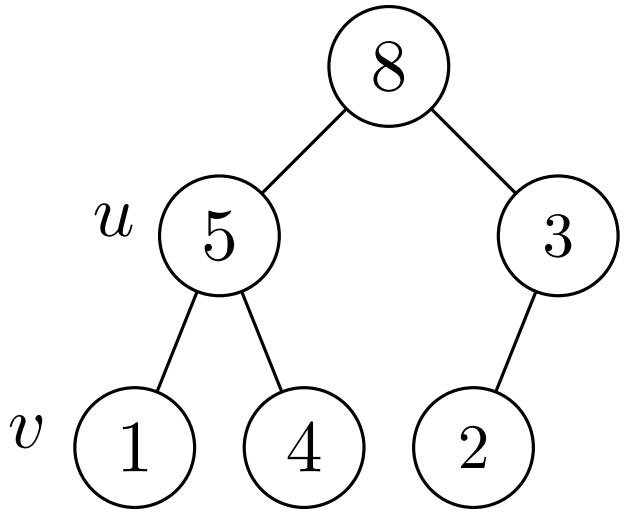
```
S.erase(5);
```

(See also `std::unordered_set`, `std::multiset`, and `std::unordered_multiset`)

Algorithms

(max-)Heaps

- Binary tree with keys attached to vertices
- Nearly complete
  (Complete except possibly for the last level. All leaves on the left.)
- Heap property: if u is v's parent $\Rightarrow$ key$(u) \geq$ key(v)



0	1	2	3	4	5
8	5	3	1	4	2

left$(u) = 2u + 1$

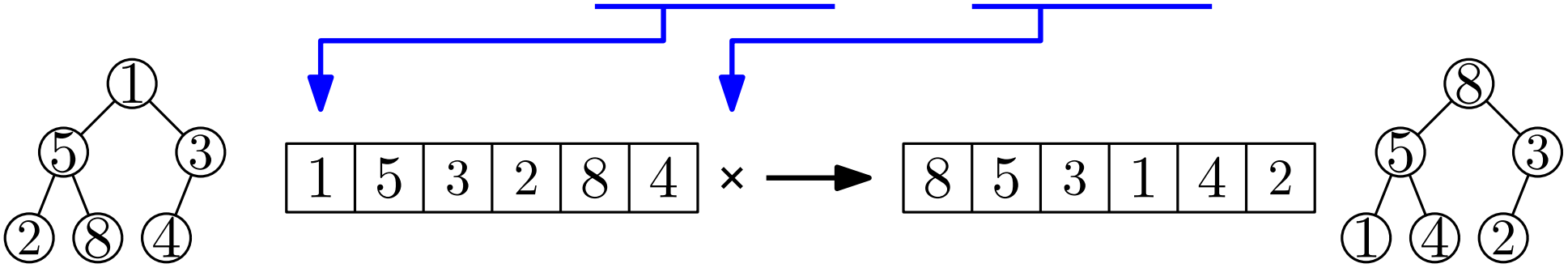
right$(u) = 2u + 2$

parent$(u) = \lfloor \frac{u-1}{2} \rfloor$

(max-)Heaps

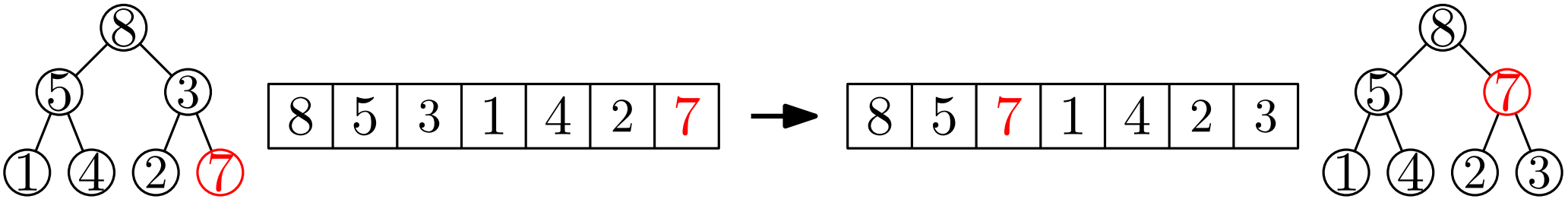
- Building a Heap $O(n)$

```
std::make_heap(vec.begin(), vec.end());
```



- Insering a new key $O(\log n)$

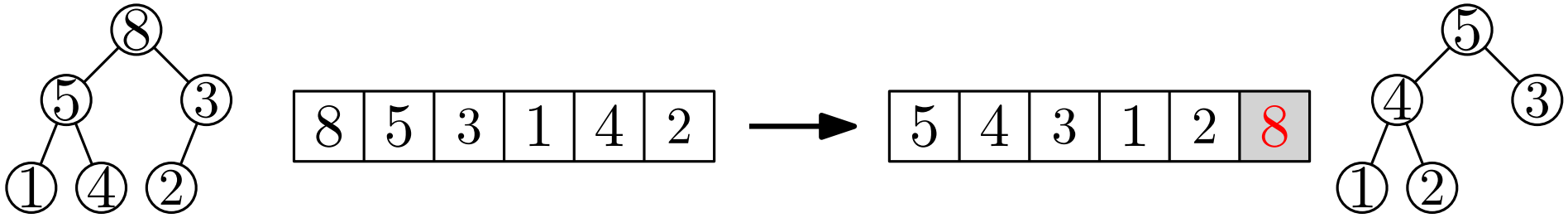
```
std::push_heap(vec.begin(), vec.end());
```



(max-)Heaps

- Extracting the maximum key $O(\log n)$

```
std::pop_heap(vec.begin(), vec.end());
```



(max-)Heaps

- Extracting the maximum key $O(\log n)$

```
std::pop_heap(vec.begin(), vec.end());
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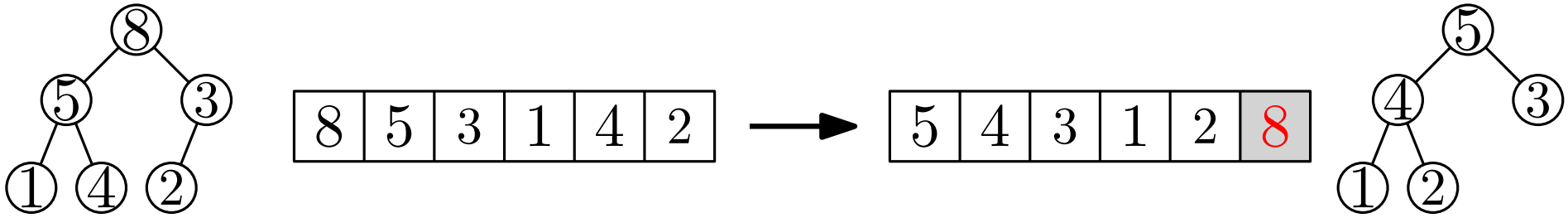


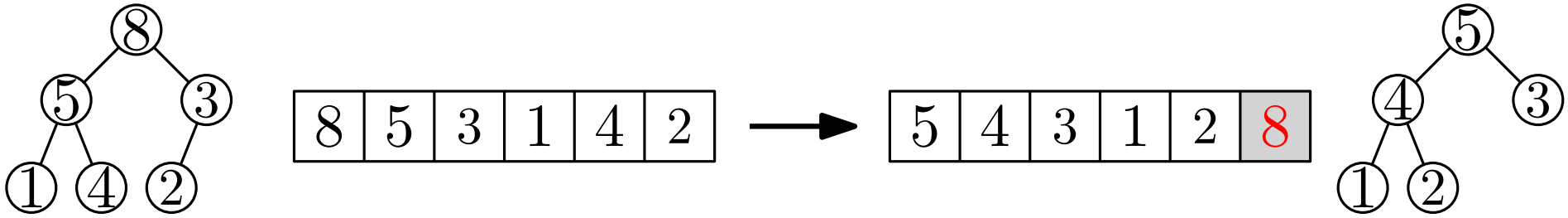
Example: Heapsort

```
std::vector<int> vec { 4, 1, 6, 2, 5, 3 };

std::make_heap(vec.begin(), vec.end());
for(int i=vec.size(); i>1; i--)
    std::pop_heap(vec.begin(),vec.begin()+i);
```

(max-)Heaps

- Extracting the maximum key $O(\log n)$

```
std::pop_heap(vec.begin(), vec.end());
```



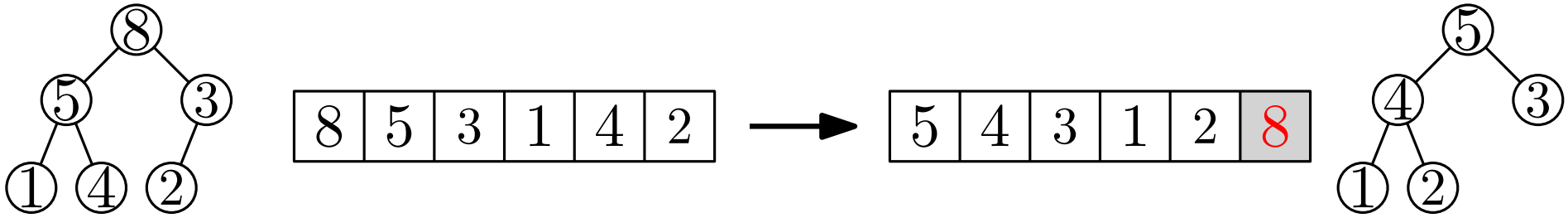
Example: Heapsort

```
std::vector<int> vec { 4, 1, 6, 2, 5, 3 };

std::make_heap(vec.begin(), vec.end());
std::sort_heap(vec.begin(), vec.end());
```

(max-)Heaps

- Extracting the maximum key $O(\log n)$

```
std::pop_heap(vec.begin(), vec.end());
```



Example: Heapsort

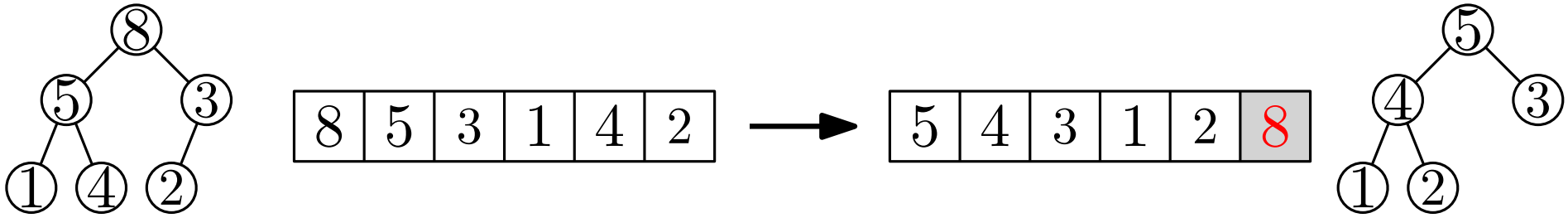
```
std::vector<int> vec { 4, 1, 6, 2, 5, 3 };

std::make_heap(vec.begin(), vec.end());
std::sort_heap(vec.begin(), vec.end());
```

Min-Heaps?

(max-)Heaps

- Extracting the maximum key $O(\log n)$

```
std::pop_heap(vec.begin(), vec.end());
```



Example: Heapsort

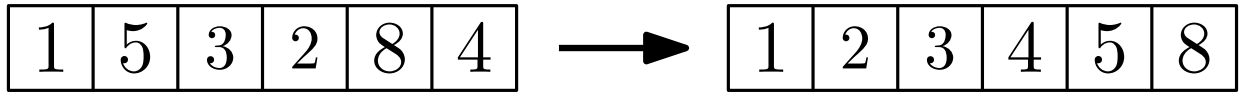
```
std::vector<int> vec { 4, 1, 6, 2, 5, 3 };

std::make_heap(vec.begin(), vec.end());
std::sort_heap(vec.begin(), vec.end());
```

Min-Heaps? See `std::priority_queue` for a wrapper.

Sorting

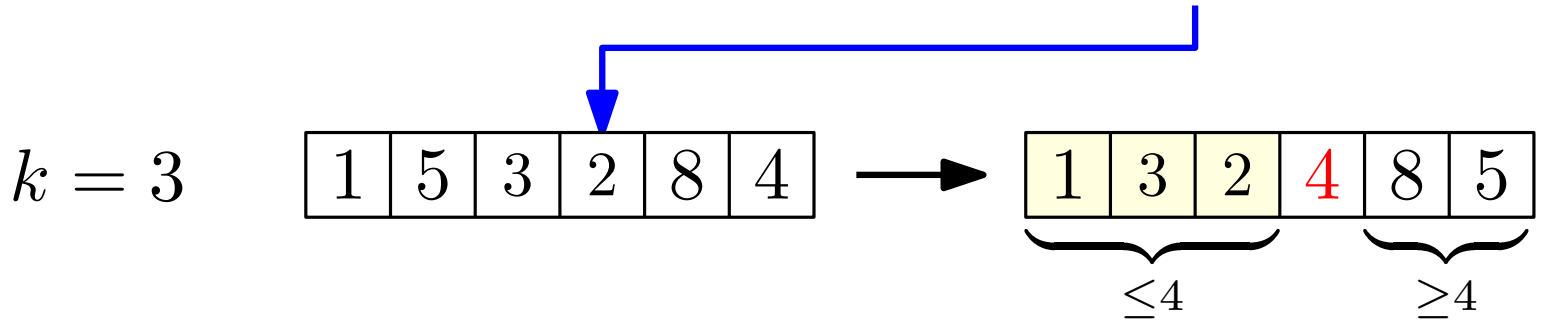
- The whole container $O(n \log n)$ comparisons

```
std::sort(vec.begin(), vec.end());
```



- k-th smallest element $O(n)$ comparisons

```
std::nth_element(vec.begin(), vec.begin()+k, vec.end());
```



Linear Search

- Minimum/Maximum of a collection $O(n)$ comparisons

```
std::min_element(vec.begin(), vec.end());
```

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std::max_element(vec.begin(), vec.end());
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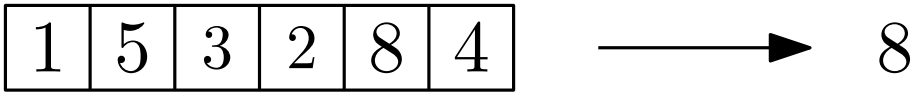

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std::minmax_element(vec.begin(), vec.end());
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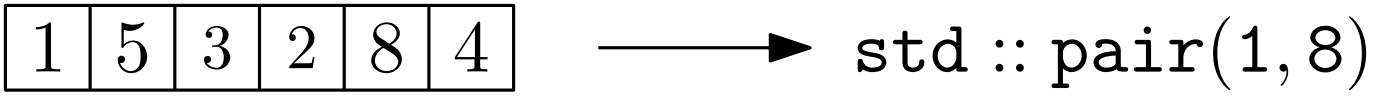

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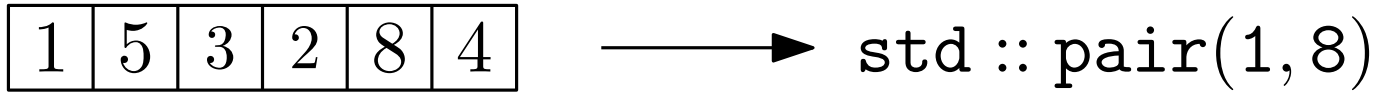
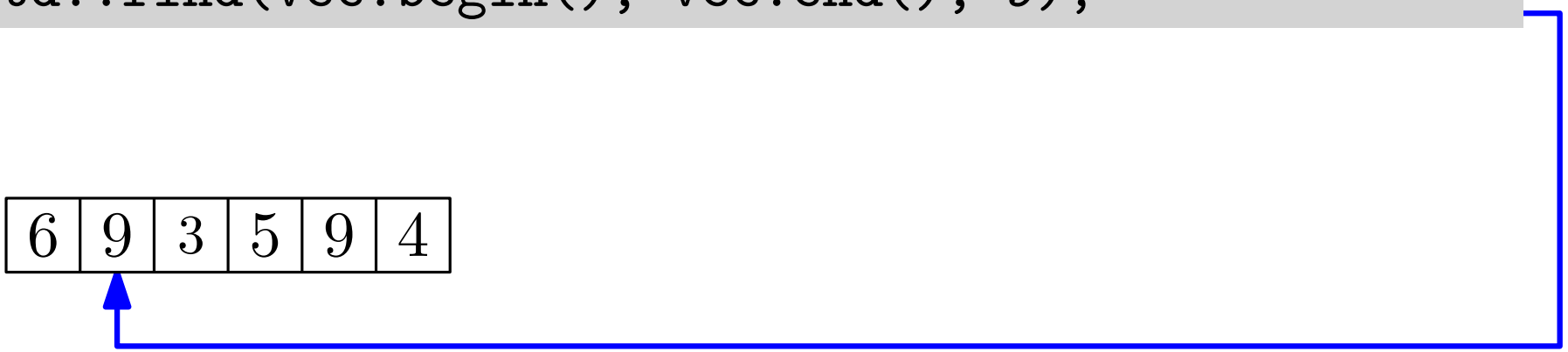


- Searching for an element

```
std::find(vec.begin(), vec.end(), 9);
```



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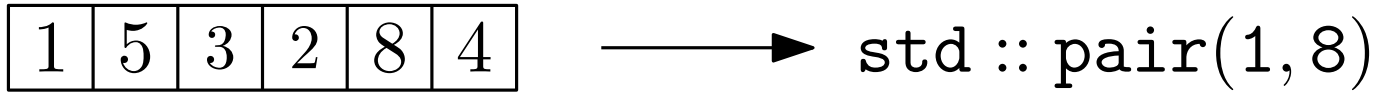
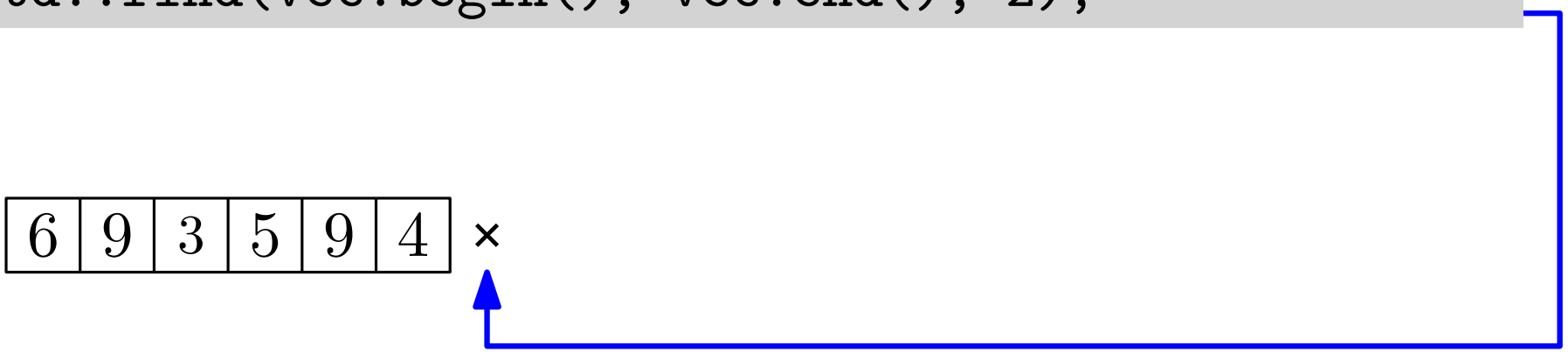
std::minmax_element(vec.begin(), vec.end());
```



- Searching for an element

```
std::find(vec.begin(), vec.end(), 2);
```



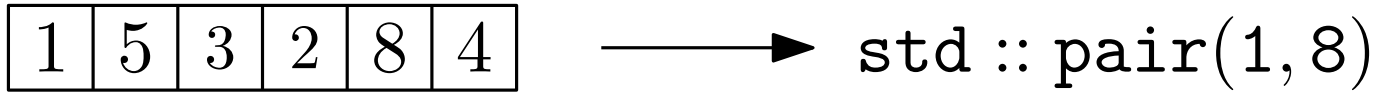
Linear Search

- Minimum/Maximum of a collection $O(n)$ comparisons

```
std::min_element(vec.begin(), vec.end());
```

```
std::max_element(vec.begin(), vec.end());
```

```
std::minmax_element(vec.begin(), vec.end());
```



- Searching for an element

```
std::find(vec.begin(), vec.end(), 2);
```

```
std::find_if(vec.begin(), vec.end(), [](int x) { return x%3; });
```

Binary Search

- Is 6 in the (sorted) collection? $O(\log n)$ comparisons

```
bool std::binary_search(vec.begin(), vec.end(), 6);
```

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```
std::lower_bound(vec.begin(), vec.end(), 3);
```

Binary Search

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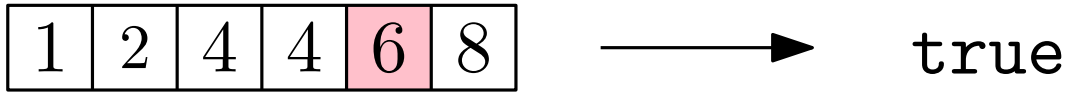


- First index i s.t. $v[i] \geq 3$ (Where should 3 be inserted?)

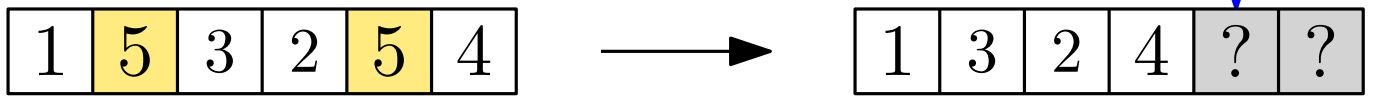
```
std::lower_bound(vec.begin(), vec.end(), 3);
```

- First index i s.t. $v[i] > 4$

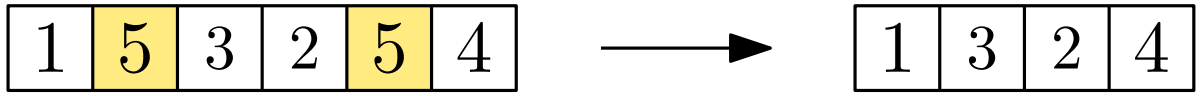
```
std::upper_bound(vec.begin(), vec.end(), 4);
```

Deleting and replacing elements

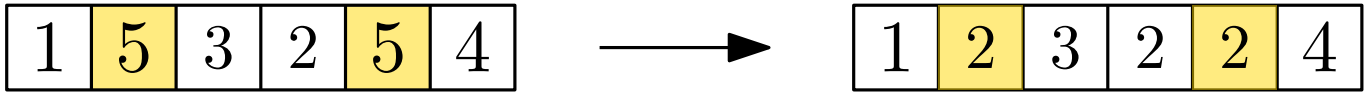
```
std::remove(vec.begin(), vec.end(), 5);
```




```
vec.erase(std::remove(vec.begin(), vec.end(), 5), vec.end());
```




```
std::replace(vec.begin(), vec.end(), 5, 2);
```



See also `std::remove_if` and `std::replace_if`.

(Partial) Sums

- Accumulate

$O(n)$ sums

```
std::accumulate(vec.begin(), vec.end());
```

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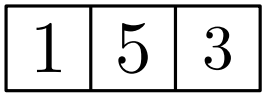

$\longrightarrow \quad \sum_{i=0}^{2} \texttt{vec[i]} = 1 + 5 + 3 = 9$

$\oplus$

```
std::accumulate(vec.begin(), vec.end(), init, binary_op);
```

Note: `binary_op` needs to be commutative and associative.

Returns: $\texttt{init} \oplus \left(\bigoplus_{i=0}^{n-1} \texttt{vec[i]} \right)$

(Partial) Sums

- Accumulate

```
std::accumulate(vec.begin(), vec.end(), 2, std::multiplies<int>);
```

$\oplus$

```
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Returns: $\texttt{init} \oplus \left(\bigoplus_{i=0}^{n-1} \texttt{vec[i]} \right)$

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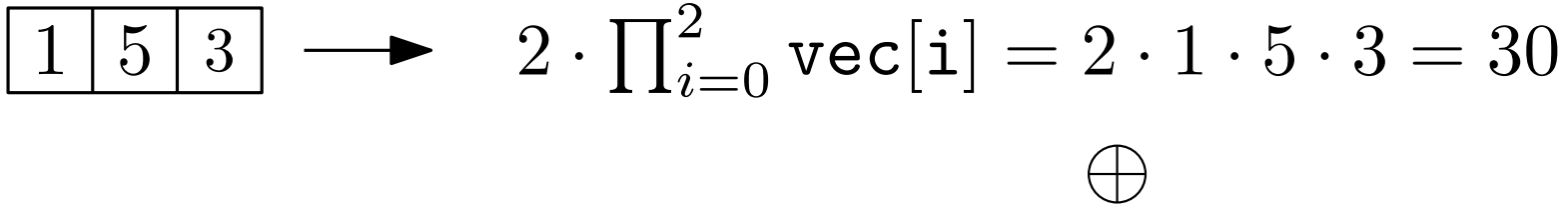


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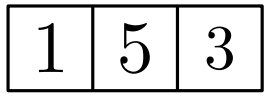


$$\longrightarrow \quad 2 \cdot \prod_{i=0}^{2} \texttt{vec[i]} = 2 \cdot 1 \cdot 5 \cdot 3 = 30$$

$$\bigoplus$$

```
std::accumulate(vec.begin(), vec.end(), init, binary_op);
```

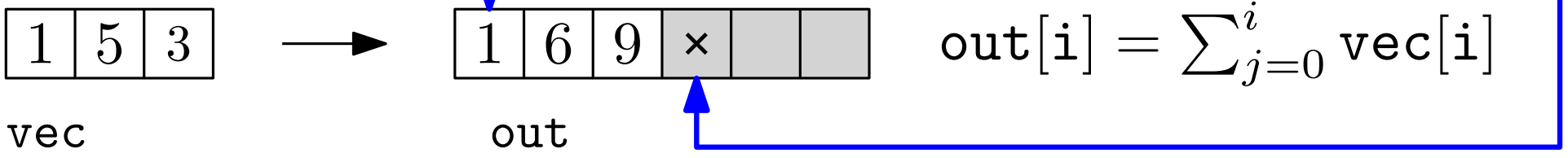
Note: `binary_op` needs to be commutative and associative.

Returns: $\texttt{init} \oplus \left(\bigoplus_{i=0}^{n-1} \texttt{vec[i]} \right)$

- Partial sums

$O(n)$ sums

```
std::partial_sum(vec.begin(), vec.end(), out.begin());
```



. . . and much more.

See: `https://www.boost.org/sgi/stl/`