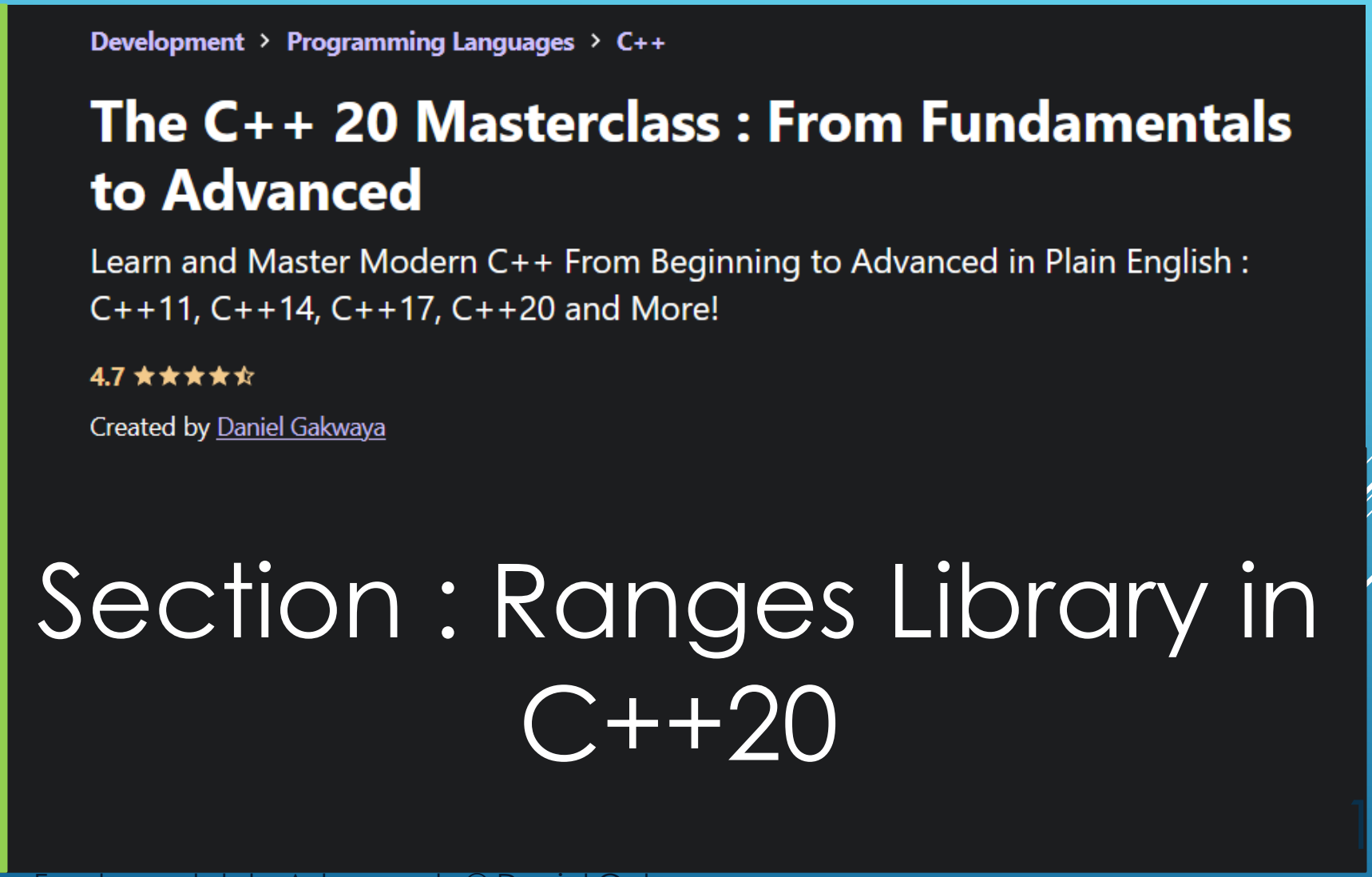
Slides



Section : Ranges Library in C++20

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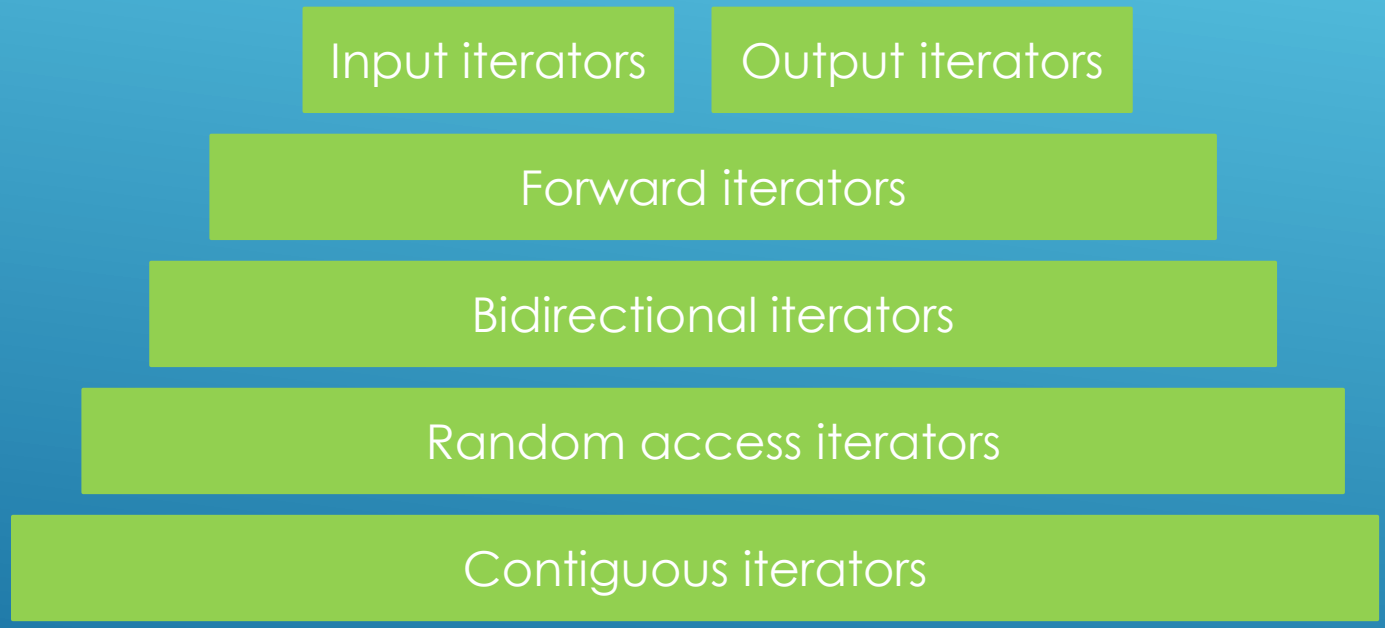
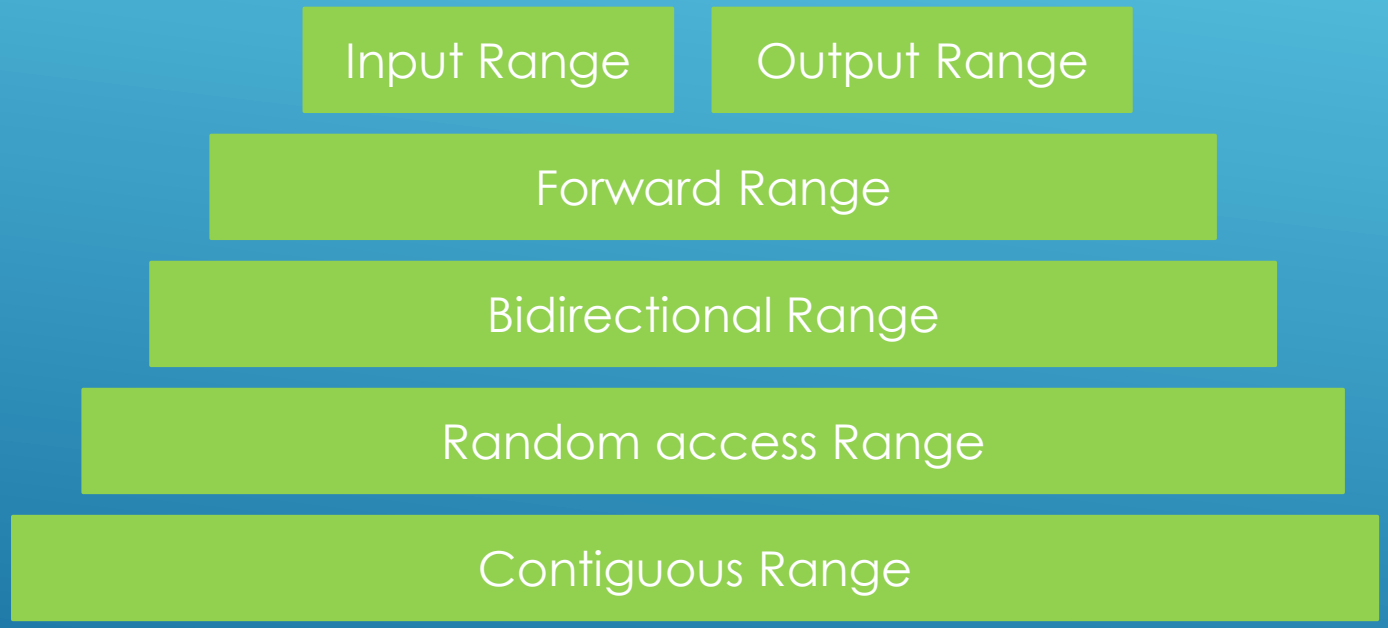
Ranges Library in C++20

- Range algorithms
- Projections
- Views and view adaptors
- Function composition
- Range factories


Input iterators
Output iterators
Forward iterators
Bidirectional iterators
Random access iterators
Contiguous iterators


Input Range
Output Range
Forward Range
Bidirectional Range
Random access Range
Contiguous Range

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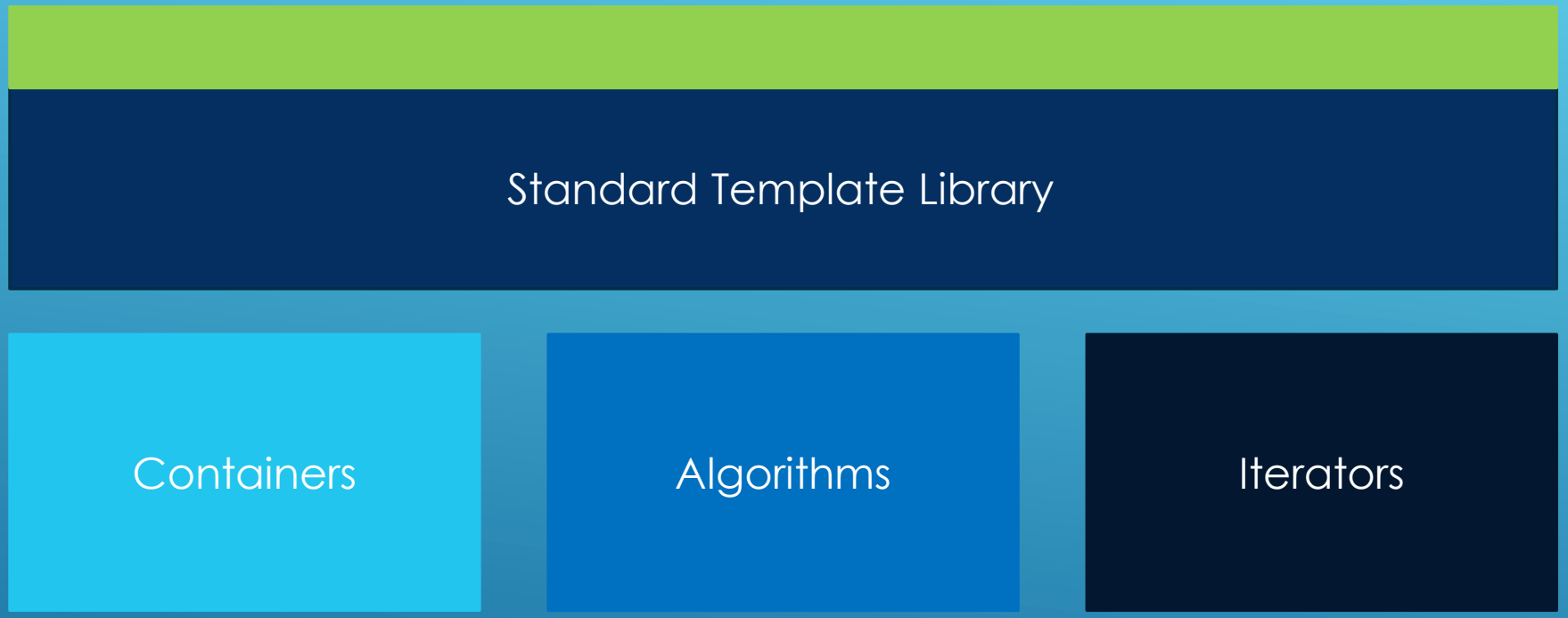
Range Algorithms


Standard Template Library
Containers
Algorithms
Iterators


Legacy algorithms
Work on iterator pairs
Range algorithms
Work on containers directly

std::all_of [Iterator pair]

```
//std::vector<int> collection{2,6,8,40,64,70};
//std::set<int> collection{2,6,8,40,64,70};
int collection[] {2,6,8,40,64,70};

//std::all_of , lambda function predicate
if (std::all_of(std::begin(collection), std::end(collection), [](int i){ return i % 2 == 0; })) {
    std::cout << "(std::all_of) :  All numbers in collection are even" << std::endl;
}else{
    std::cout << "(std::all_of) : Not all numbers in collection are even" << std::endl;
}
```

std::ranges::all_of

```
std::vector<int> numbers {11,2,6,4,8,3,17,9};
print_collection(numbers);

//std::ranges::all_of()
std::cout << std::endl;
std::cout << "std::ranges::all_of() : " << std::endl;

auto odd = [](int n){
    return n%2 !=0;
};

auto result = std::ranges::all_of(numbers,odd);

if(result){
    std::cout << "All elements in numbers are odd" << std::endl;
}else{
    std::cout << "Not all elements in numbers are odd" << std::endl;
}
```

std::ranges::for_each

```
//For each
std::cout << std::endl;
std::cout << "std::ranges::for_each() : " << std::endl;
print_collection(numbers);
std::ranges::for_each(numbers,[](int& n){n*=2;});
print_collection(numbers);
```

std::ranges::sort

```
//Sort
std::cout << std::endl;
std::cout << "std::ranges::sort() : " << std::endl;
print_collection(numbers);
std::ranges::sort(numbers);
print_collection(numbers);
```

std::ranges::find

```
//Find
std::cout << std::endl;
std::cout << "std::ranges::find() : " << std::endl;
auto odd_n_position = std::ranges::find_if(numbers,odd);

if (odd_n_position != std::end(numbers)) {
    std::cout << "numbers contains at least one odd number : " << *odd_n_position  << std::endl;
} else {
    std::cout << "numbers does not contain any odd number" << std::endl;
}
```

Copy into output stream on the fly

```
//Important, copying into outputstream on the fly
std::cout << std::endl;
std::cout << "numbers : " ;
std::ranges::copy(numbers,std::ostream_iterator<int>(std::cout, " "));
```

More

https://en.cppreference.com/w/cpp/algorithm

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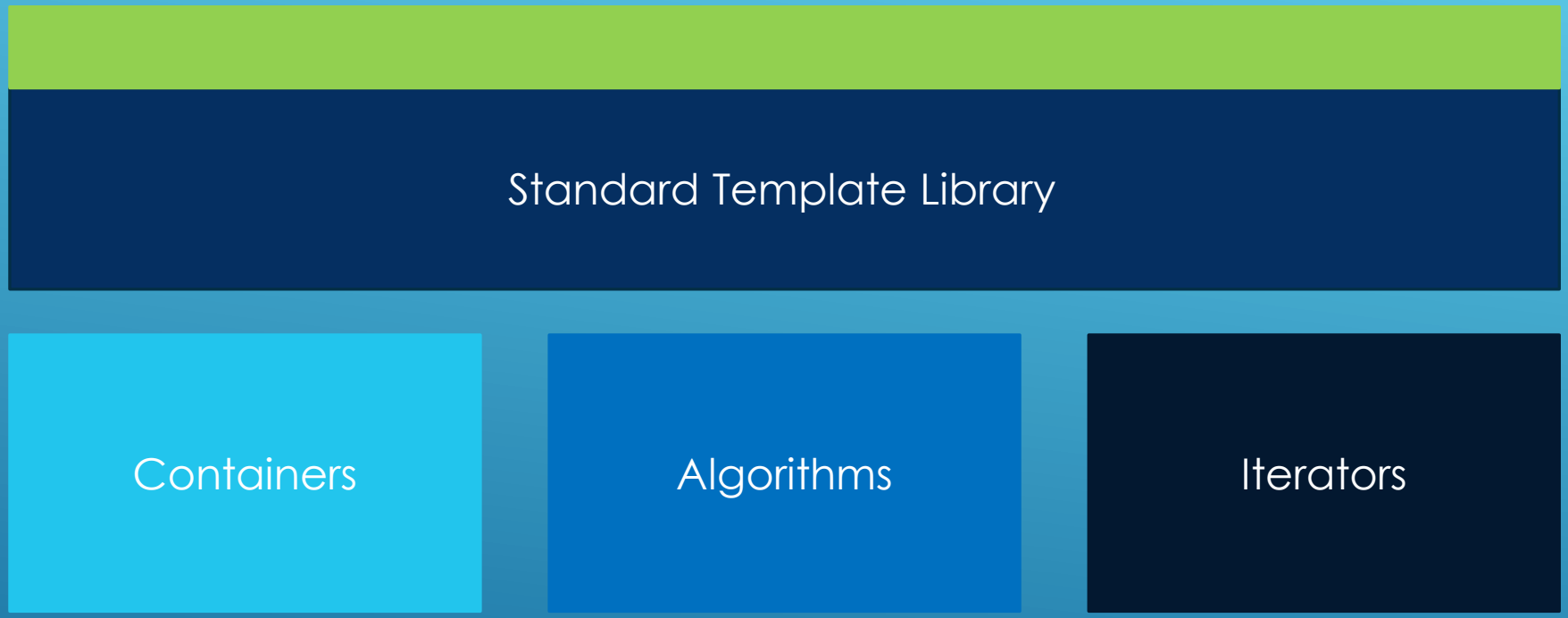
Constrained Iterator Pair Algorithms


Standard Template Library
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Work on containers directly

std::all_of [Iterator pair]

```
//std::vector<int> collection{2,6,8,40,64,70};
//std::set<int> collection{2,6,8,40,64,70};
int collection[] {2,6,8,40,64,70};

//std::all_of , lambda function predicate
if (std::all_of(std::begin(collection), std::end(collection), [](int i){ return i % 2 == 0; })) {
    std::cout << "(std::all_of) :  All numbers in collection are even" << std::endl;
}else{
    std::cout << "(std::all_of) : Not all numbers in collection are even" << std::endl;
}
```

std::ranges::all_of

```
std::vector<int> numbers {11,2,6,4,8,3,17,9};
print_collection(numbers);

//std::ranges::all_of()
std::cout << std::endl;
std::cout << "std::ranges::all_of() : " << std::endl;

auto odd = [](int n){
    return n%2 !=0;
};

auto result = std::ranges::all_of(numbers,odd);

if(result){
    std::cout << "All elements in numbers are odd" << std::endl;
}else{
    std::cout << "Not all elements in numbers are odd" << std::endl;
}
```

std::ranges::for_each

```
//For each
std::cout << std::endl;
std::cout << "std::ranges::for_each() : " << std::endl;
print_collection(numbers);
std::ranges::for_each(numbers,[](int& n){n*=2;});
print_collection(numbers);
```

std::ranges::sort

```
//Sort
std::cout << std::endl;
std::cout << "std::ranges::sort() : " << std::endl;
print_collection(numbers);
std::ranges::sort(numbers);
print_collection(numbers);
```

std::ranges::find

```
//Find
std::cout << std::endl;
std::cout << "std::ranges::find() : " << std::endl;
auto odd_n_position = std::ranges::find_if(numbers,odd);

if (odd_n_position != std::end(numbers)) {
    std::cout << "numbers contains at least one odd number : " << *odd_n_position  << std::endl;
} else {
    std::cout << "numbers does not contain any odd number" << std::endl;
}
```

Copy into output stream on the fly

```
//Important, copying into outputstream on the fly
std::cout << std::endl;
std::cout << "numbers : " ;
std::ranges::copy(numbers,std::ostream_iterator<int>(std::cout, " "));
```

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Constrained Iterator Pair Algorithms

```cpp
//Ranges, iterator pair
auto result = std::ranges::all_of(numbers.begin(),numbers.end(),odd);

if(result){
    std::cout << "All elements in numbers are odd" << std::endl;
}else{
    std::cout << "Not all elements in numbers are odd" << std::endl;
}
```

```cpp
//For each
std::cout << std::endl;
std::cout << "std::ranges::for_each() : " << std::endl;
print_collection(numbers);
std::ranges::for_each(numbers.begin(),numbers.end(),[](int& n){n*=2;});
print_collection(numbers);


//Sort
std::cout << std::endl;
std::cout << "std::ranges::sort() : " << std::endl;
print_collection(numbers);
std::ranges::sort(numbers.begin(),numbers.end());
print_collection(numbers);
```

```cpp
//Find
std::cout << std::endl;
std::cout << "std::ranges::find() : " << std::endl;
auto odd_n_position = std::ranges::find_if(numbers.begin(),numbers.end(),odd);

if (odd_n_position != std::end(numbers)) {
    std::cout << "numbers contains at least one odd number : " << *odd_n_position  << std::endl;
} else {
    std::cout << "numbers does not contain any odd number" << std::endl;
}

//Copying into outputstream on the fly
std::cout << std::endl;
std::cout << "numbers : " ;
std::ranges::copy(numbers.begin(),numbers.end(),std::ostream_iterator<int>(std::cout, " "));
```

std::ranges algorithms should be PREFERED

```
//Why you should prefer std::ranges algorithms from now on
std::list<int> numbers {11,2,6,4,8,3,17,9};
print_collection(numbers);

std::ranges::sort(numbers.begin(),numbers.end());// BAD!!!
```

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Projections

Some algorithms support projections

Points are ordered by distance by default

```
class Point
{
    friend std::ostream& operator<< (std::ostream& out , const Point& p);
public:
    Point() = default;
    Point(double x, double y) :
        m_x(x), m_y(y){
    }
    //Operators
    bool operator==(const Point& other) const;
    std::partial_ordering operator<=>(const Point& right) const;

private:
    double length() const;    // Function to calculate distance from the point(0,0)
public :
    double m_x{};
    double m_y{};
};

inline std::ostream& operator<< (std::ostream& out , const Point& p){
    out << "Point [ x : " << p.m_x << ", y : " << p.m_y <<
        " , length : " << p.length()    << " ]" ;
    return out;
}
```

Points are ordered by distance by default

```
double Point::length() const{
    return sqrt(pow(m_x - 0, 2) +  pow(m_y - 0, 2) * 1.0);
}

bool Point::operator==(const Point& other) const{
    return (this->length() == other.length());
}

std::partial_ordering Point::operator<=>(const Point& right) const{
    if(length() > right.length())
        return std::partial_ordering::greater;
    else if(length() == right.length())
        return std::partial_ordering::equivalent;
    else if(length() < right.length())
        return std::partial_ordering::less;
    else
        return std::partial_ordering::unordered;
}
```

Sorting without projection

```
//Sorting without projection : uses operator< as is
std::cout << std::endl;
std::cout << "Sorting points (default : based on length) : " << std::endl;
std::vector<Point> points { {10,90} ,{30,70}, {20,80} };

print_collection(points);

//Sorting with the default comparator
std::ranges::sort(points,std::less<>{}); // Default sort based on distance
print_collection(points);
```

Using lambda as a projection

```
//Sorting with a projection : The data is passed into the projection before
//it's passed into the comparator. std::less<> is going to compare two doubles
//instead of comparing two Points.
std::cout << std::endl;
std::cout << "projection on Point::m_x : " << std::endl;
print_collection(points);
std::ranges::sort(points,std::less<>{},[](auto const & p){
    return p.m_x;
});
print_collection(points);
```

Using public member as a projection

```
//Projecting with direct member variable
std::cout << std::endl;
std::cout << "projection on Point::m_y with direct member variables : " << std::endl;
print_collection(points);
std::ranges::sort(points,std::less<>{},&Point::m_y);
print_collection(points);
```

Projections with the for_each algorithm

```
//Projections with for_each
std::cout << std::endl;
std::cout << "Projections with for_each : " << std::endl;

auto print = [](const auto& n) { std::cout << " " << n; };
using pair = std::pair<int, std::string>;
std::vector<pair> pairs{{1,"one"}, {2,"two"}, {3,"tree"}};

std::cout << "project the pair::first: ";
std::ranges::for_each(pairs, print, [](const pair& p) { return p.first; });
std::cout << std::endl;

std::cout << "project the pair::first: ";
std::ranges::for_each(pairs, print, &pair::first);
std::cout << std::endl;

std::cout << "project the pair::second: ";
std::ranges::for_each(pairs, print, [](const pair& p) { return p.second; });
std::cout << std::endl;
```

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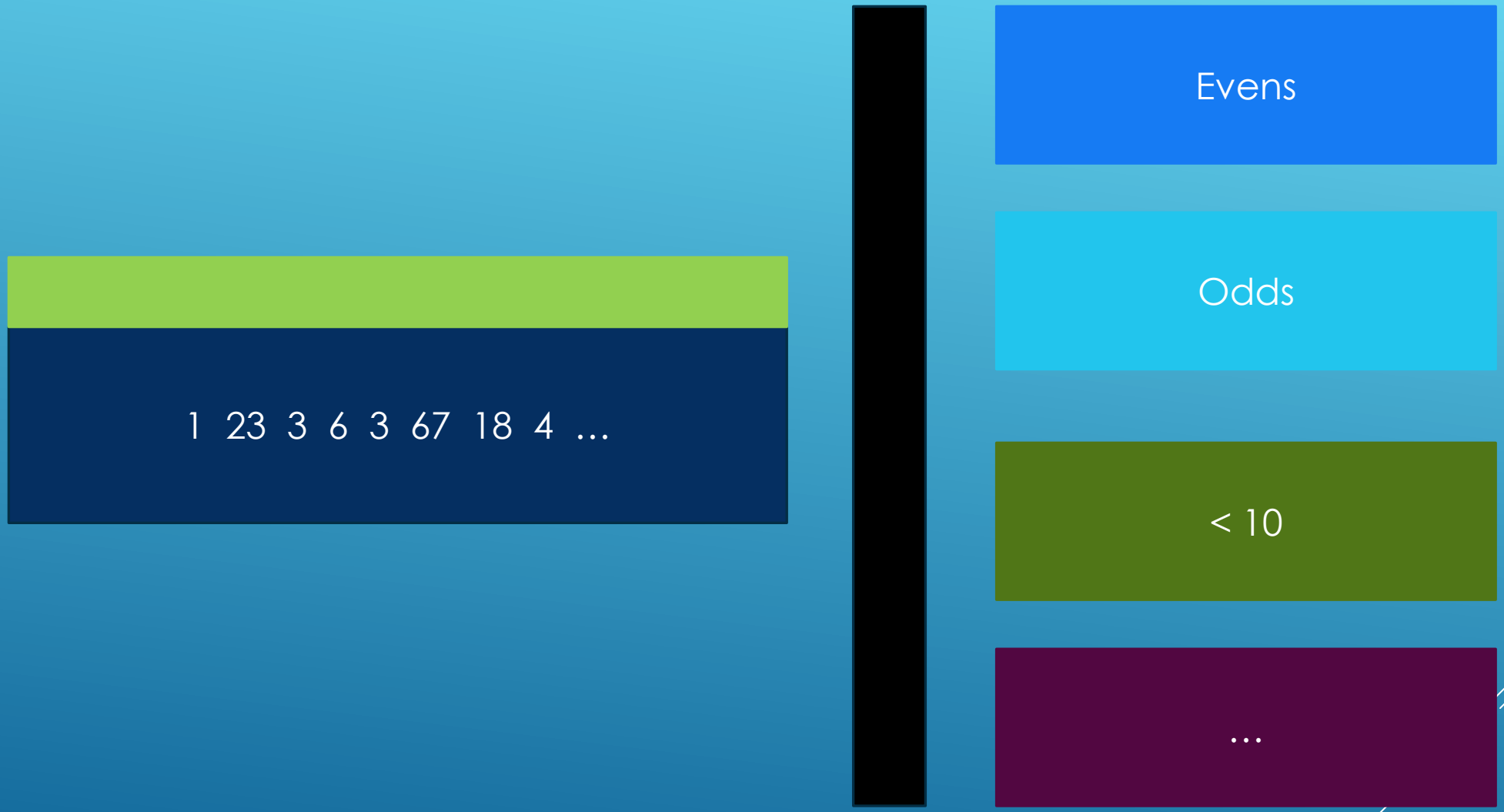
Views and range adaptors

- A view is a non owning range
- It's like a window we can set up to view some real data without setting up the infrastructure to store data
- Views are cheap to copy and pass around as function parameters by design.


1 23 3 6 3 67 18 4 ...
Evens
Odds
< 10
...

Filtering view

```
std::vector<int> vi {1,2,3,4,5,6,7,8,9};

//std::ranges::filter_view
std::cout <<std::endl;
std::cout << "std::ranges::filter_view : " << std::endl;
auto evens = [](int i){
    return (i %2) == 0;
};
std::cout << "vi : " ;
print(vi);
std::ranges::filter_view v_evens = std::ranges::filter_view(vi,evens); //No computation
std::cout << "vi evens : ";
print(v_evens); //Computation happens in the print function
//Print evens on the fly
std::cout << "vi evens : " ;
print(std::ranges::filter_view(vi,evens));
//Print odds on the fly
std::cout << "vi odds : " ;
print(std::ranges::filter_view(vi,[](int i){
    return (i%2)!=0;
}));
```

Filtering view

```
void print(auto  view){
    for(auto i : view){ // Computation happens here.
        std::cout << i << " ";
    }
    std::cout << std::endl;
}
```

Transform_view

```
//std::ranges::transform_view
std::cout <<std::endl;
std::cout << "std::ranges::transform_view : " << std::endl;
std::ranges::transform_view v_transformed = std::ranges::transform_view(vi,[](int i){
    return i * 10;
});
std::cout << "vi : " << std::endl;
print(vi);
std::cout << "vi transformed : " ;
print(v_transformed);
```

```
//std::ranges::take_view
std::cout <<std::endl;
std::cout << "std::ranges::take_view : " << std::endl;
std::ranges::take_view v_taken = std::ranges::take_view(vi,5);
std::cout << "vi : " ;
print(vi);
std::cout << "vi taken : ";
print(v_taken);


//std::ranges::take_while_view : takes elements as long as the predicate condition
//is met
std::cout <<std::endl;
std::cout << "std::views::take_while : " << std::endl;
vi = {1,11,23,131,2,3,4,5,6,7,8,9};
std::ranges::take_while_view v_taken_while = std::ranges::take_while_view(vi,[](int i){
    return (i%2)!=0;
});
std::cout << "vi : ";
print(vi);
std::cout << "vi taken_while : ";
print(v_taken_while);
```

```
//std::ranges::drop_view : drop n first elements
std::cout <<std::endl;
std::cout << "std::ranges::drop_view : " << std::endl;
vi = {1,11,23,131,2,3,4,5,6,7,8,9};
std::ranges::drop_view v_drop = std::ranges::drop_view(vi,5);
std::cout << "vi : ";
print(vi);
std::cout << "vi_drop : ";
print(v_drop);

//std::views::drop_while_view : drops elements as long as the predicate is met
std::cout <<std::endl;
std::cout << "std::ranges::drop_while_view : " << std::endl;
vi = {1,11,23,4,2,3,4,5,6,7,8,9};
std::ranges::drop_while_view v_drop_while = std::ranges::drop_while_view(vi,[](int i){
    return (i%2)!=0;
});
std::cout << "vi : ";
print(vi);
std::cout << "v_drop_while : ";
print(v_drop_while);
```

Compiler errors while constructing some views directly

```
std::cout << std::endl;
using pair = std::pair<int, std::string>;
std::vector<pair> numbers{{1,"one"}, {2,"two"}, {3,"tree"}};

//Compiler error when you build views explicitly. Don't understand why yet
//auto k_view = std::ranges::keys_view(numbers);
//auto v_view = std::ranges::values_view(numbers);

/* ...

auto k_view = std::views::keys(numbers);
auto v_view = std::views::values(numbers);
print(k_view);
print(v_view);
```

Filter range adaptor

```
//Filter range adaptor example
 vi = {1,2,3,4,5,6,7,8,9};

//std::ranges::filter_view
std::cout <<std::endl;
std::cout << "std::views::filter : " << std::endl;
std::cout << "vi : " ;
print(vi);
auto v_evens_1 = std::views::filter(vi,evens); //No computation
std::cout << "vi evens : ";
print(v_evens); //Computation happens in the print function
//Print evens on the fly
std::cout << "vi evens : " ;
print(std::views::filter(vi,evens));
//Print odds on the fly
std::cout << "vi odds : " ;
print(std::views::filter(vi,[](int i){
    return (i%2)!=0;
}));
```

Student type

```
struct Student{
    friend std::ostream& operator<<(std::ostream& out, const Student& s){
        out << "Student [ name : " << s.m_name << ", age : " << s.m_age << "]";
        return out;
    }
    auto operator <=>(const Student& s) const= default;
    std::string m_name;
    unsigned int m_age;
};
```

Students in a classroom

```
//Students example
std::cout << std::endl;
std::cout << "students example : " << std::endl;

std::vector<Student> class_room {{"Mike",12},{"John",17},{"Drake",14},{"Mary",16}};
std::cout << std::endl;
std::cout << "classroom : " << std::endl;
for( auto& s : class_room){
    std::cout << "    " <<  s << std::endl;
}

std::ranges::sort(class_room,std::less<>{},&Student::m_age);
std::cout << std::endl;
std::cout << "classroom (after sort) : " << std::endl;
for( auto& s : class_room){
    std::cout << "    " <<  s << std::endl;
}

std::cout << "students under 15 : " ;
print(std::views::take_while(class_room,[](const Student& s){return (s.m_age <15);}));
```

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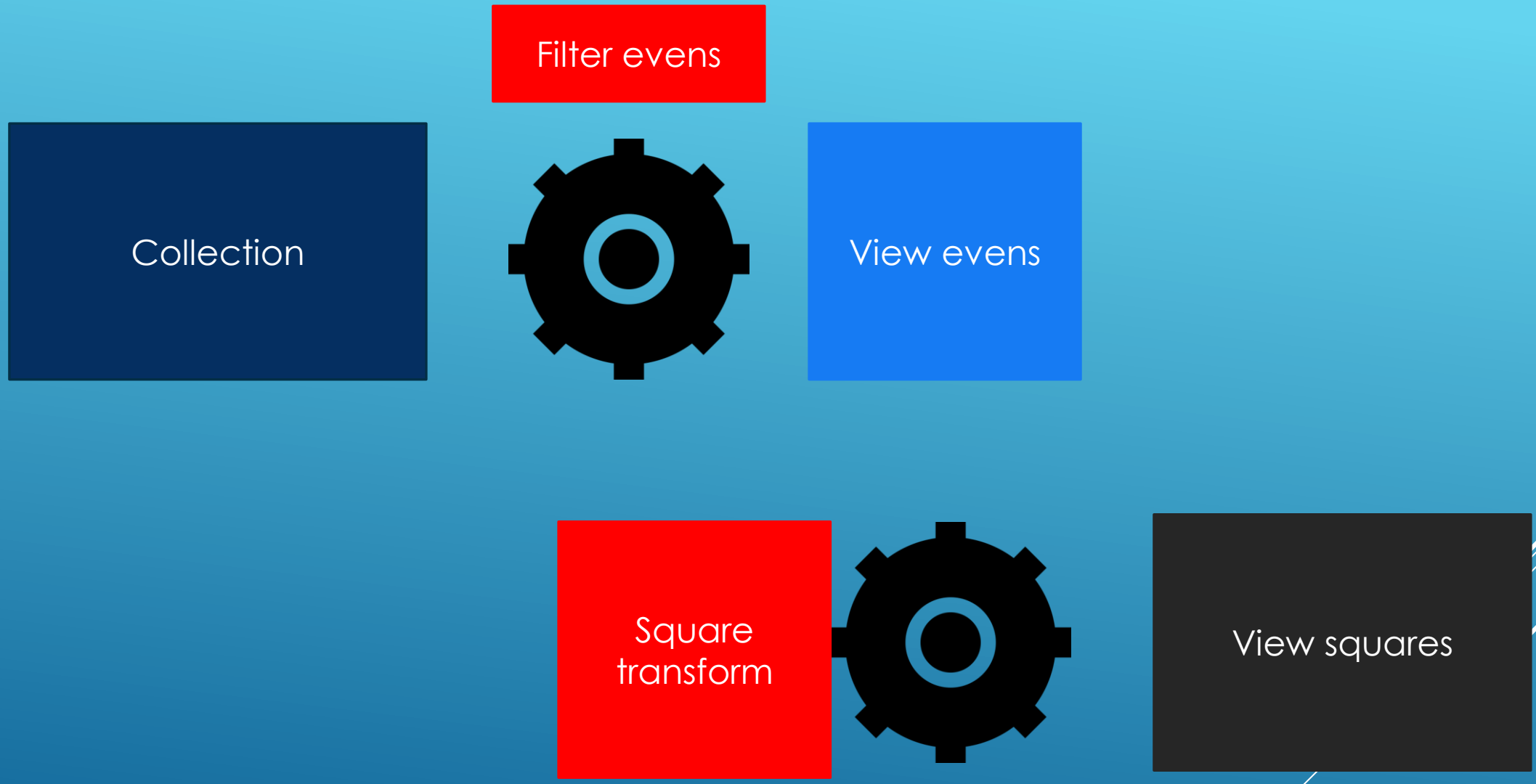
View composition and pipe operator

Composing multiple views


Filter evens
Collection
View evens
Square transform
View squares

Raw function composition

```
std::vector<int> vi {1,2,3,4,5,6,7,8,9};

auto even = [](int n){return n%2==0;};
auto my_view =  std::views::transform(std::views::filter(vi,even) ,[](auto  n){return n*=n;});
std::cout << "vi transformed : ";
print(my_view);
```

Pipe operator

```
std::vector<int> vi {1,2,3,4,5,6,7,8,9};

auto even = [](int n){return n%2==0;};
auto my_view =  vi | std::views::filter(even)
                   | std::views::transform([](auto  n){return n*=n;});
std::cout << "vi transformed : ";
print(my_view);
```

Pipe operator

```
//classroom done as map : Keys are sorted by default
//std::unordered_map<std::string,unsigned int> classroom    {
std::map<std::string,unsigned int> classroom    {
                                                    {"John",11},{"Mary",17},
                                                    {"Steve",15},{"Lucy",14},{"Ariel",12}
                                                };

 //Print out the names
 //auto names_view = std::views::keys(classroom);
 auto names_view = classroom | std::views::keys;
 std::cout << "names : ";
 std::ranges::copy(names_view, std::ostream_iterator<std::string>(std::cout, " "));

 //Print out the ages :
 std::cout << std::endl;
 auto ages_view = std::views::values(classroom);
 std::cout << "ages : " ;
 std::ranges::copy(ages_view,std::ostream_iterator<unsigned int>(std::cout," "));
```

```
//Print names in reverse : this doesn't work if you store the data in an
//unordered_map. The reason is the unoredered_map doesn't have reverse iterators,
//that are needed to set up a reverse view.

std::cout << std::endl;
std::cout << "names in reverse : ";
std::ranges::copy(std::views::keys(classroom) | std::views::reverse ,
                  std::ostream_iterator<std::string>(std::cout, " "));
```

```cpp
//Pick names that come before the letter "M" in the alphabet
std::cout << std::endl;
auto before_M = [](const std::string& name){
    return  (static_cast<unsigned char>(name[0]) < static_cast<unsigned char>('M'));
};

std::cout << "names before M : ";
std::ranges::copy(classroom | std::views::keys | std::views::filter(before_M),
          std::ostream_iterator<std::string>(std::cout, " "));
```

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Range factories

Producing views out of the blue

iota

```
//Generate an infinite sequence of numbers
auto infinite_view = std::views::iota(1); // Stores the compuation
//Numbers are generated lazily, on the fly, as we need them in each iteration
for(auto i : infinite_view){
    std::cout << i << std::endl;
}

//Loop through the view on the fly
for(auto i : std::views::iota(1)){
    std::cout << i << std::endl;
}

//Limit the range : provide an upper limit, upper limit not included.
for(auto i : std::views::iota(1,20)){
    std::cout << i << std::endl;
}

//Limit the range : Use view composition with | operator
for(auto i : std::views::iota(1) | std::views::take(20)){
    std::cout << i << std::endl;
}
```

iota

```
//Raw function composition
for(auto i : std::views::take(std::views::iota(1) , 20)){
    std::cout << i << std::endl;
}
```

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Ranges Library in C++20 : Summary

- Range algorithms
- Projections
- Views and view adaptors
- Function composition
- Range factories