CMPT 373
Software Development Methods

Thinking in Sequences: Find, Filter, Map, & Reduce

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Operations on Collections

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- This is pervasive at all levels
  - Data structures
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  - …
- And it is *error prone* and *easy to overcomplicate*

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determine their average enrollment date offset
grouped by GPA in 0.5 increments.

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  if (students[i].year >= 3) {
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What is challenging?

There is at least 1
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- Significant effort is spent on handling
  common corner cases of collections instead of *goal oriented logic*
- Breaking the problem apart into pieces helps clarify these steps

Slight Improvements

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If we want to do better, we need to separate the *higher level operations*

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std::vector<Student> selected;
selected.reserve(students.size());
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std::vector<BucketData> projected(selected.size());
std::ranges::transform(selected, projected.begin(),
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auto remainder = std::span{projected};
while (!remainder.empty()) {
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Was all that a waste?!

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Most languages today make them *simple* & *efficient*.

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We can actually break it down
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Most things you do are a combination of these steps.
This shrinks the solution space!

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  - Reduce – accumulate, reduce
  - Find – find, find_if
- One of the first things you should do in a new language is figure out how these are spelled
  - Java (streams), C# (LINQ), Python (builtins+comprehensions), C++ (STL & ranges)

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students				
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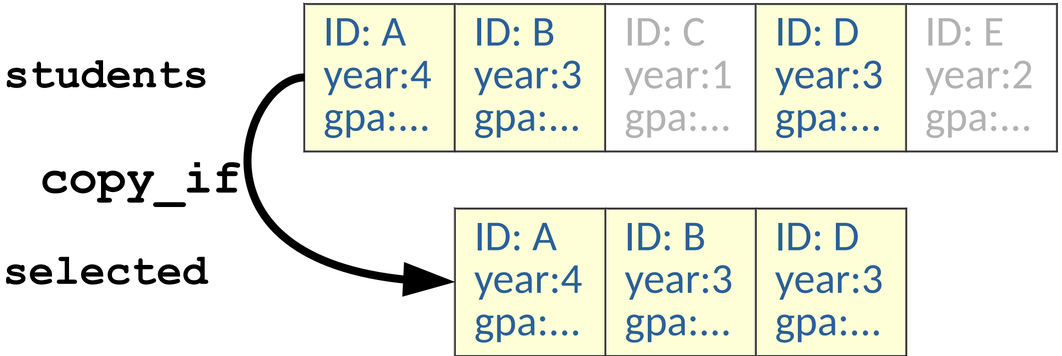

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Filter

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students

ID: A year:4 gpa:…	ID: B year:3 gpa:…	ID: C year:1 gpa:…	ID: D year:3 gpa:…	ID: E year:2 gpa:…

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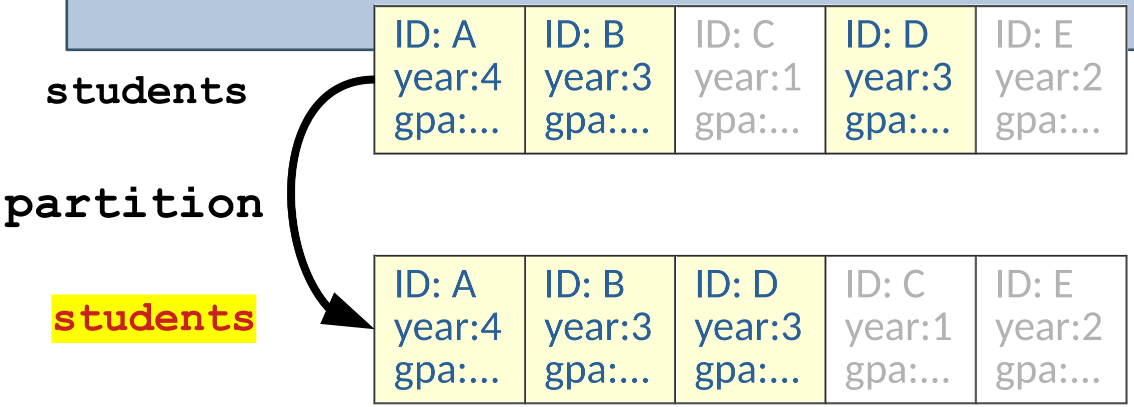

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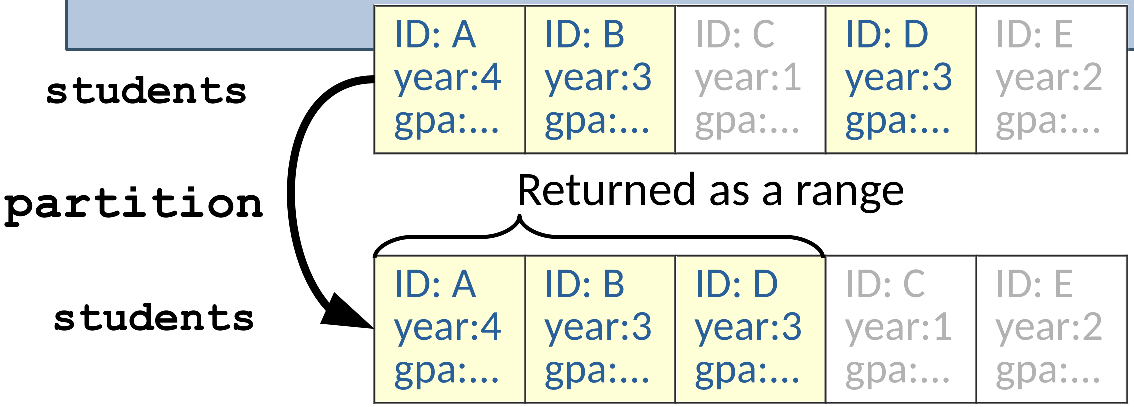

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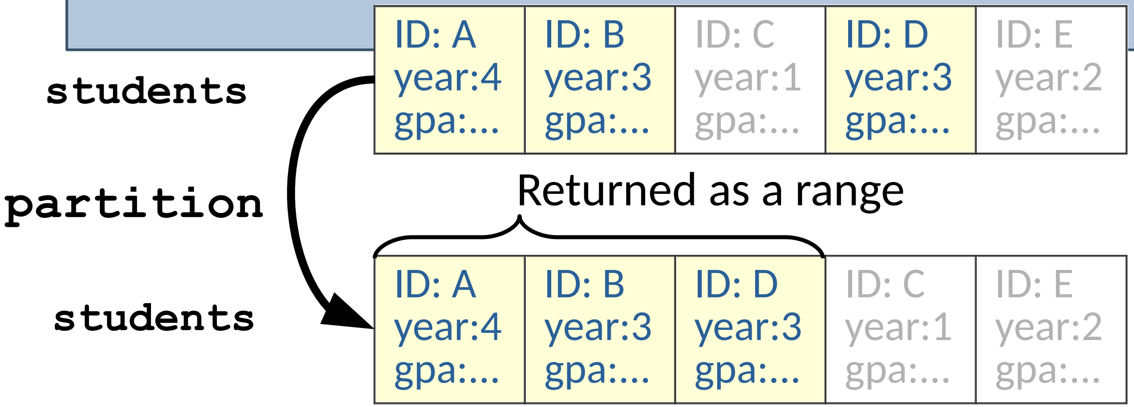

Mutability makes it one line

Map

- Apply a function to each element of a collection and store the result as desired
  - std::transform

```
std::vector<BucketData> projected(selected.size());
std::ranges::transform(selected, projected.begin(),
  [] (const Student& s) {
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});
```

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});
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selected	ID: A year:4 gpa:…	ID: B year:3 gpa:…	ID: D year:3 gpa:…
projected			

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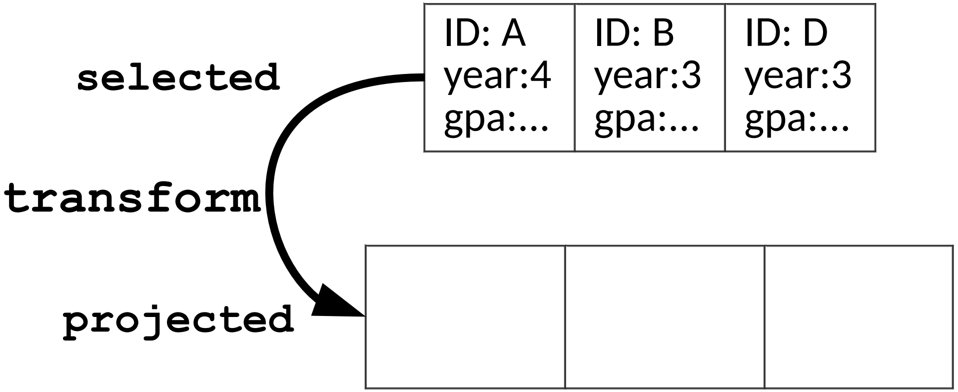

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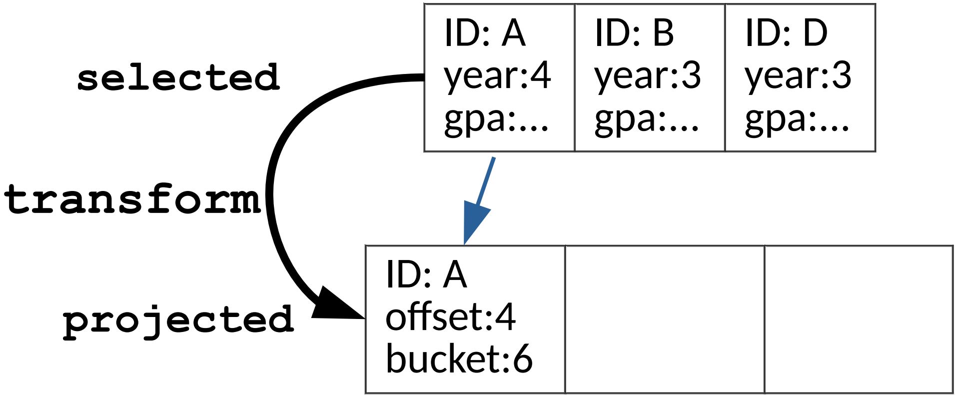

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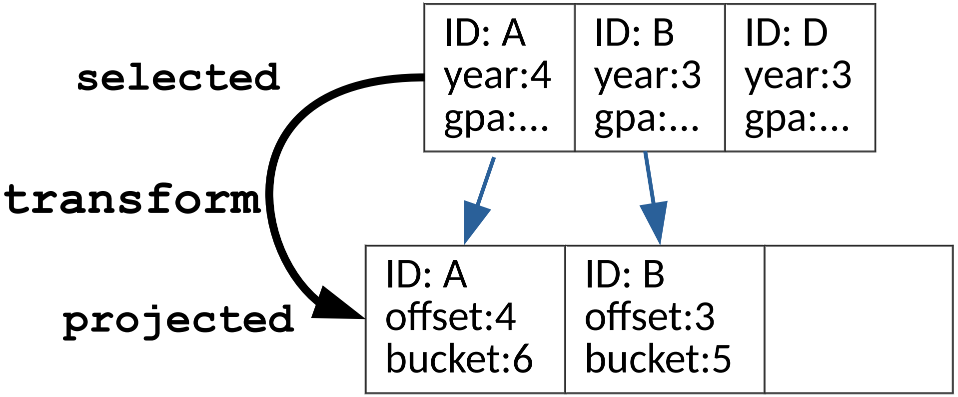

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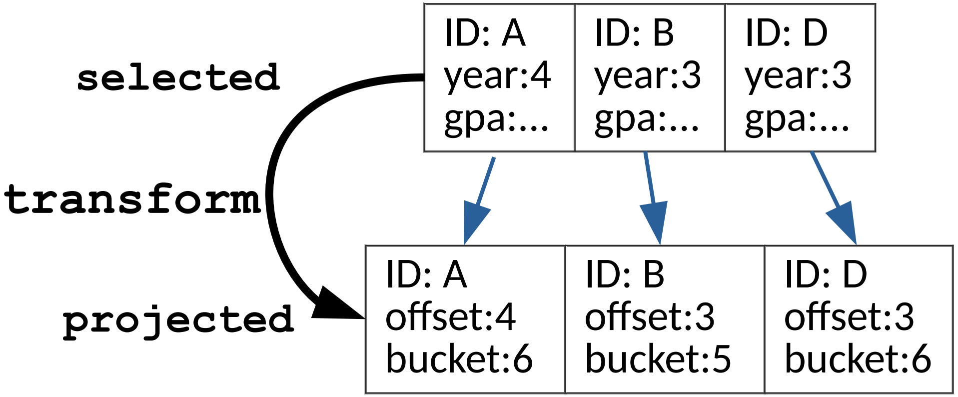

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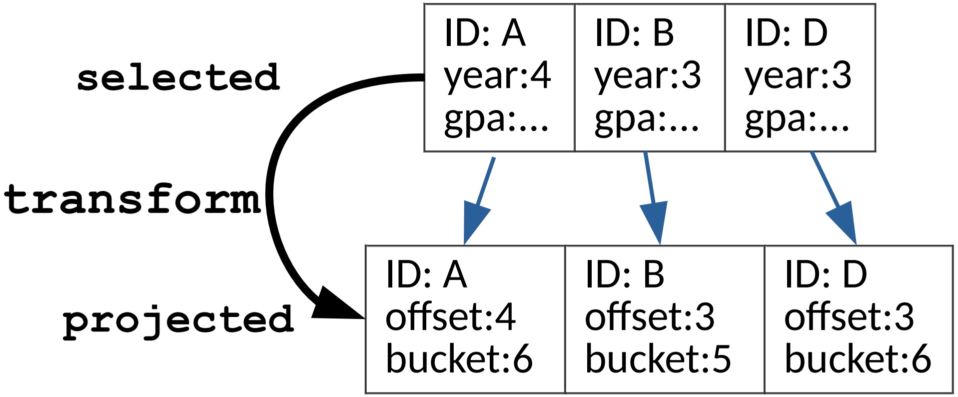

The resulting type can be different, but this is not required

Reduce

- Combine results of processing different elements
  - std::accumulate, std::reduce

```
std::vector numbers = { 0, 1, 2, 3, 4, 5, 6, 7 };
auto sum = ...
```

Reduce

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std::vector numbers = { 0, 1, 2, 3, 4, 5, 6, 7 };
auto sum = std::accumulate(numbers.begin(), numbers.end());
```

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```
std::vector numbers = { 0, 1, 2, 3, 4, 5, 6, 7 };
auto sum = std::accumulate(numbers.begin(), numbers.end());

auto product = std::accumulate(numbers.begin(), numbers.end(),
                                ...
```

Reduce

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std::vector numbers = { 0, 1, 2, 3, 4, 5, 6, 7 };
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- Reduce operations take
  - An *initial value*

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```

- Reduce operations take
  - An initial value
  - A *function* consuming the value computed so far & current element to compute a new value

Reduce

```
std::vector numbers = { 3, 5, 1, 2 };
auto product = std::accumulate(numbers.begin(), numbers.end(),
                               1, std::multiplies{});
```

3	5	1	2

So far: 1

Reduce

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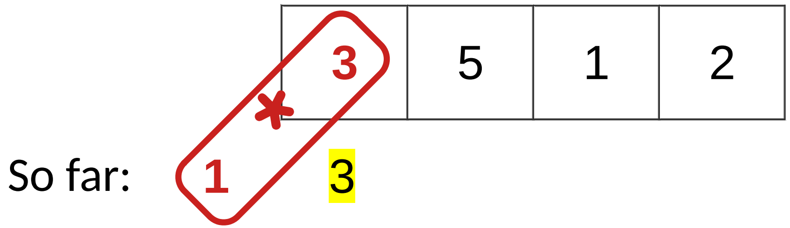
```



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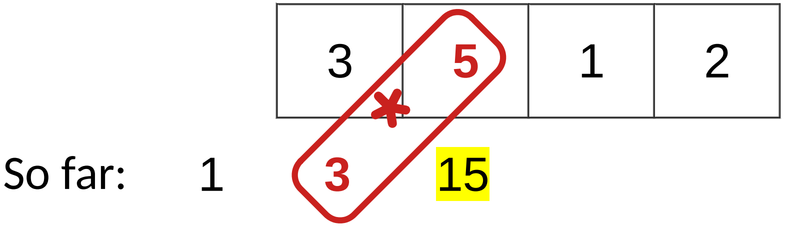

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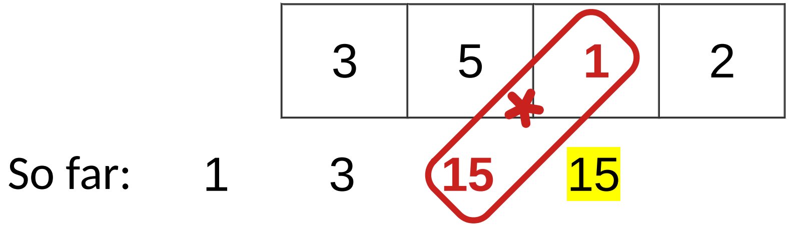

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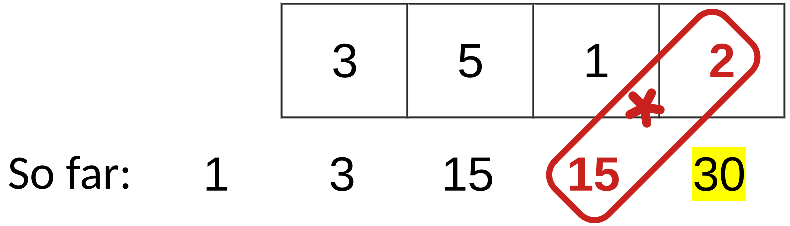

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```

3	5	1	2

So far: 1 3 15 15 **30**

Reduce

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So far:	1	3	15	15	30

- Reduce operations explicitly capture the inductive nature of loops

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- Reduce operations explicitly capture the inductive nature of loops
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  - When all iterations have completed,
    the final result should be the intended goal

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So far: ""

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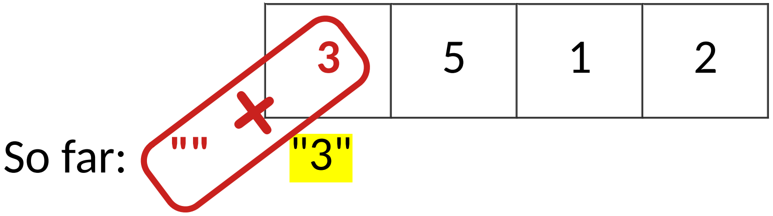

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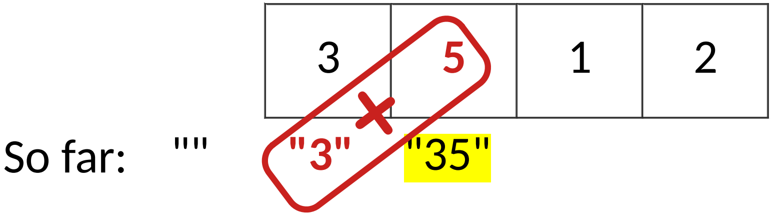

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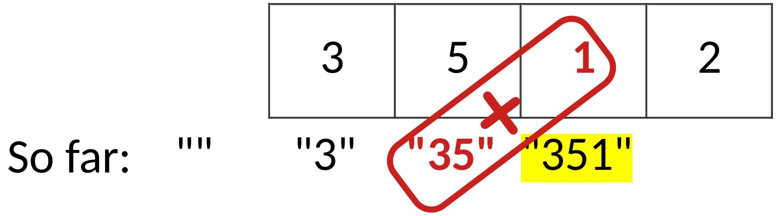

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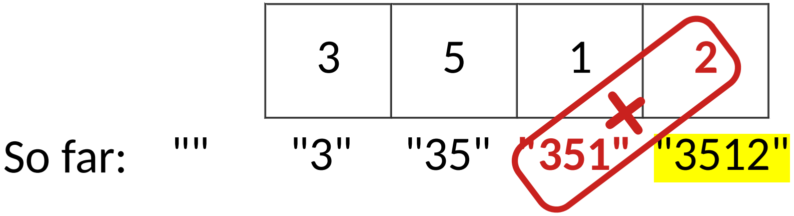

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So far: ""	"3"	"35"	"351"	"3512"

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	3	5	1	2
So far: ""	"3"	"35"	"351"	"3512"

But do remember, concatenating strings like this is a poor *goal*.

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Generality of Reduce

- In fact, this means most functions on loops can be written via a reduce!

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any_of(auto& collection, auto predicate) {
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    [](bool sofar, auto& element) { return sofar || predicate(element); });
}
```

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```
auto
max(auto& collection, auto minimum) {
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    [](auto sofar, auto& element) {
      return (element > sofar) ? element : sofar;
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}
```

```
auto
count_if(auto& collection, auto predicate) {
  return std::accumulate(collection.begin() collection.end(), 0,
    [predicate](auto sofar, auto& element) {
      return sofar + (predicate(element) ? 1 : 0);
  });
}
```

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bool
any_of(auto& collection, auto predicate) {
  return std::ranges::find_if(collection, predicate) != collection.end();
}
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  - Some schools prefer to teach just filter, map, and reduce
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```

While reduce processes the entire list,
this stops at the first match

Can we now make this clearer? (a bit)

Mutability & selection of how to connect the core ingredients affects the simplicity

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```
auto selected = std::ranges::partition(students,
  [](const Student& s) { return s.year >= 3; });
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auto selected = std::ranges::partition(students,
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};

std::ranges::sort(selected, {}, getBucket);
```

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};

std::ranges::sort(selected, {}, getBucket);

std::array<std::span<BucketData>,9> buckets;
auto remainder = std::span{projected};
while (!remainder.empty()) {
  auto foundEnd = std::ranges::find_if(remainder,
    [remainder](const auto& s) { return s.bucket != remainder.front().bucket; });
  buckets[remainder.front().bucket] = std::span{remainder.begin(), foundEnd};
  remainder = std::span{foundEnd, remainder.end()};
}
```

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  buckets[remainder.front().bucket] = std::span{remainder.begin(), foundEnd};
  remainder = std::span{foundEnd, remainder.end()};
}

std::array<float,9> averages;
std::ranges::transform(buckets, averages.begin(), [](auto& bucket) {
  return std::accumulate(bucket.begin(), bucket.end(), 0.0f,
                 [](float sofar, const auto& student) { return sofar + student.offset; })
      / (bucket.empty() ? 1 : bucket.size()); });
```

Mutability & selection of how to connect the core ingredients affects the simplicity

So why was the “improvement” complicated

- Operating eagerly requires (e.g.)
  - First selecting all data and storing it
  - Then mapping all data and storing it
  - Then grouping all data and storing it
  - Then analyzing all data and storing it

```
std::vector<Student> selected;
selected.reserve(students.size());
std::ranges::copy_if(students, std::back_inserter(selected),
  [](const Student& s) { return s.year >= 3; });

struct BucketData { int offset; int bucket; };
std::vector<BucketData> projected(selected.size());
std::ranges::transform(selected, projected.begin(),
  [] (const Student& s) { return BucketData{min(int(s.gpa / 0.5), 8), s.offset}; });

std::ranges::sort(projected, {}, &BucketData::bucket);

std::array<std::span<BucketData>,9> buckets;
auto remainder = std::span{projected};
while (!remainder.empty()) {
  auto foundEnd = std::ranges::find_if(remainder,
    [remainder](const auto& s) { return s.bucket != remainder.front().bucket; });
  buckets[remainder.front().bucket] = std::span{remainder.begin(), foundEnd};
  remainder = std::span{foundEnd, remainder.end()};
}

std::array<float,9> averages;
std::ranges::transform(buckets, averages.begin(), [](auto& bucket) {
  return std::accumulate(bucket.begin(), bucket.end(), 0.0f,
                   [](float sofar, const auto& student) { return sofar + student.offset; })
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- Instead, most languages compose operations *lazily*
  - Look at one element
    - Select it, map it, group it, & store it *as necessary*
  - Proceed to the next element
- The APIs express operations to construct these lazy operations, removing this boilerplate!

Streaming Collections APIs

- Streaming APIs work lazily on potentially infinite sequences of data

```
auto whichStudents = [](const Student& s) { return s.year >= 3; };
auto getBucket = [] (const Student& s) { return min(int(s.gpa / 0.5), 8); };

auto average = [] (auto range) {
  if (range.empty()) { return 0; } else {
    return ranges::fold(range, 0.0f,
      [](auto sofar, auto& datum) { return sofar + datum.offset; }) / range.size();
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auto bucketable = students
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  | to<std::vector>();
std::ranges::sort(bucketable, {}, getBucket);
auto averages = bucketable
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  | views::group_by([] (const auto& s1, const auto& s2) {
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Or eventually.
Do you see why this is not already the default?

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  | actions::group_by_key(get
  | std::ranges::views::trans
```

```
struct EnrollmentData { int offset; int count; };
std::array<EnrollmentData,9> buckets;
buckets.fill(EnrollmentData{0, 0});

for (unsigned i = 0; i < students.size(); ++i) {
  if (students[i].year >= 3) {
    int bucket = int(students[i].gpa / 0.5);
    buckets[bucket].offset += students[i].enrollment;
    buckets[bucket].count  += 1;
  }
}

std::array<float> averages;
for (unsigned bucket = 0; bucket < buckets.size(); ++bucket) {
  averages[bucket] = buckets[bucket].offset /
    float(buckets[bucket].count ? buckets[bucket].count : 0);
}
```

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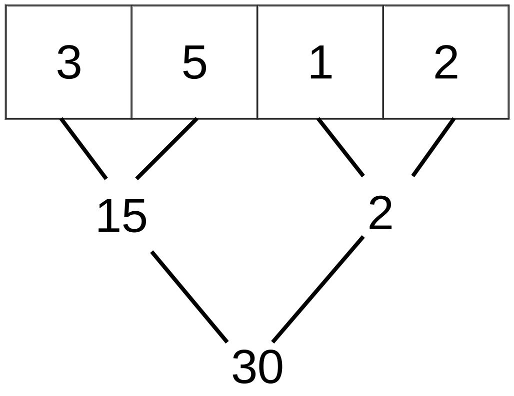

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- Break your problems down into sequences of find, filter, map, and reduce operations
- When possible, use streaming APIs for these operations for even better clarity & performance