Say Goodbye to the For Loop with High Order Functions

by Mike Harris

Pop Quiz

What do these do?

```c
main ()
{
  int i, j, k, l;
  float x[8][2][8][2];


  for (i = 0; i < 8; i++)
    for (j = i; j < 8; j++)
      for (k = 0; k < 2; k++)
  for (l = 0; l < 2; l++)
    {
      if ((i == j) && (k == l))
        x[i][k][j][l] = 0.8;
      else
        x[i][k][j][l] = 0.8;
      if (x[i][k][j][l] < 0.0)
        abort ();
    }


  exit (0);
}
```

C

```c
int f(void)
{
  static _Complex double t;
  int i, j;
  for(i = 0;i<2;i++)
    for(j = 0;j<2;j++)
      t = .5 * 1.0;
  return t;
}
```

C

```c
int n;


void foo (int i)
{
  int a, b;


  if (!i)
    for (a = 1; a < 4; a++)
      if (a)
  for (b = 1; b < 3; b++)
    foo (b);


  n++;
}
```

C

Answers

I have no idea either.

Covered

- Map
- Filter
- Fold

Problem Statement

Find the total for 53202?

Order

+ Zip
+ Price
+ Quantity

Data

```
IList<(int Zip, double Price, int Quantity)> orders =
    new List<(int Zip, double Price, int Quantity)> {
        (53202, 1.89, 3),
        (60191, 1.99, 2),
        (60060, 0.99, 7),
        (53202, 1.29, 8),
        (60191, 1.89, 2),
        (53202, 0.99, 3)
    };
```

C#

Find the total for **Zip** 53202, where subtotal is **Price** times **Quantity**.

Solution: For Loop

```
var total = 0.0;
for (int i = 0; i < orders.Count(); i++)
{
    if (orders[i].Zip == 53202)
        total += orders[i].Price * orders[i].Quantity;
}
```

C#

Solution: Foreach Loop

```
var total = 0.0;
foreach (var order in orders)
{
    if (order.Zip == 53202)
        total += order.Price * order.Quantity;
}
```

C#

Parts of the For Loop Solution

Foreach Loop

```
var total = 0.0;
foreach (var order in orders)
{
    if (order.Zip == 53202)
        total += order.Price * order.Quantity;
}
```

C#

Foreach Loop

```
var total = 0.0;
foreach (var order in orders)
{
    if (Predicate)
        total += order.Price * order.Quantity;
}
```

C#

Foreach Loop

```
var total = 0.0;
foreach (var order in orders)
{
    if (Predicate)
        total += Mapping;
}
```

C#

Foreach Loop

```
var total = 0.0;
foreach (var order in orders)
{
    if (Predicate)
        Accumulate += Mapping;
}
```

C#

Foreach Loop

```
var Initial
foreach (var order in orders)
{
    if (Predicate)
        Accumulate += Mapping;
}
```

C#

LINQ

Solution: LINQ

```
var total = orders
    .Where(order => order.Zip == 53202)
    .Select(order => order.Price * order.Quantity)
    .Aggregate(0.0, (sub, amount) => sub + amount);
```

C#

LINQ

```
var total = orders
      .Where(Predicate)
      .Select(order => order.Price * order.Quantity)
      .Aggregate(0.0, (sub, amount) => sub + amount);
```

C#

LINQ

```
var total = orders
      .Where(Predicate)
      .Select(Mapping)
      .Aggregate(0.0, (sub, amount) => sub + amount);
```

C#

LINQ

```
var total = orders
      .Where(Predicate)
      .Select(Mapping)
      .Aggregate(0.0, Accumulate);
```

C#

LINQ

```
var total = orders
      .Where(Predicate)
      .Select(Mapping)
      .Aggregate(Initial, Accumulate);
```

C#

Compare

Compare

LINQ

```
var total = orders
    .Where(Predicate)
    .Select(Mapping)
    .Aggregate(Initial, Accumulate);
```

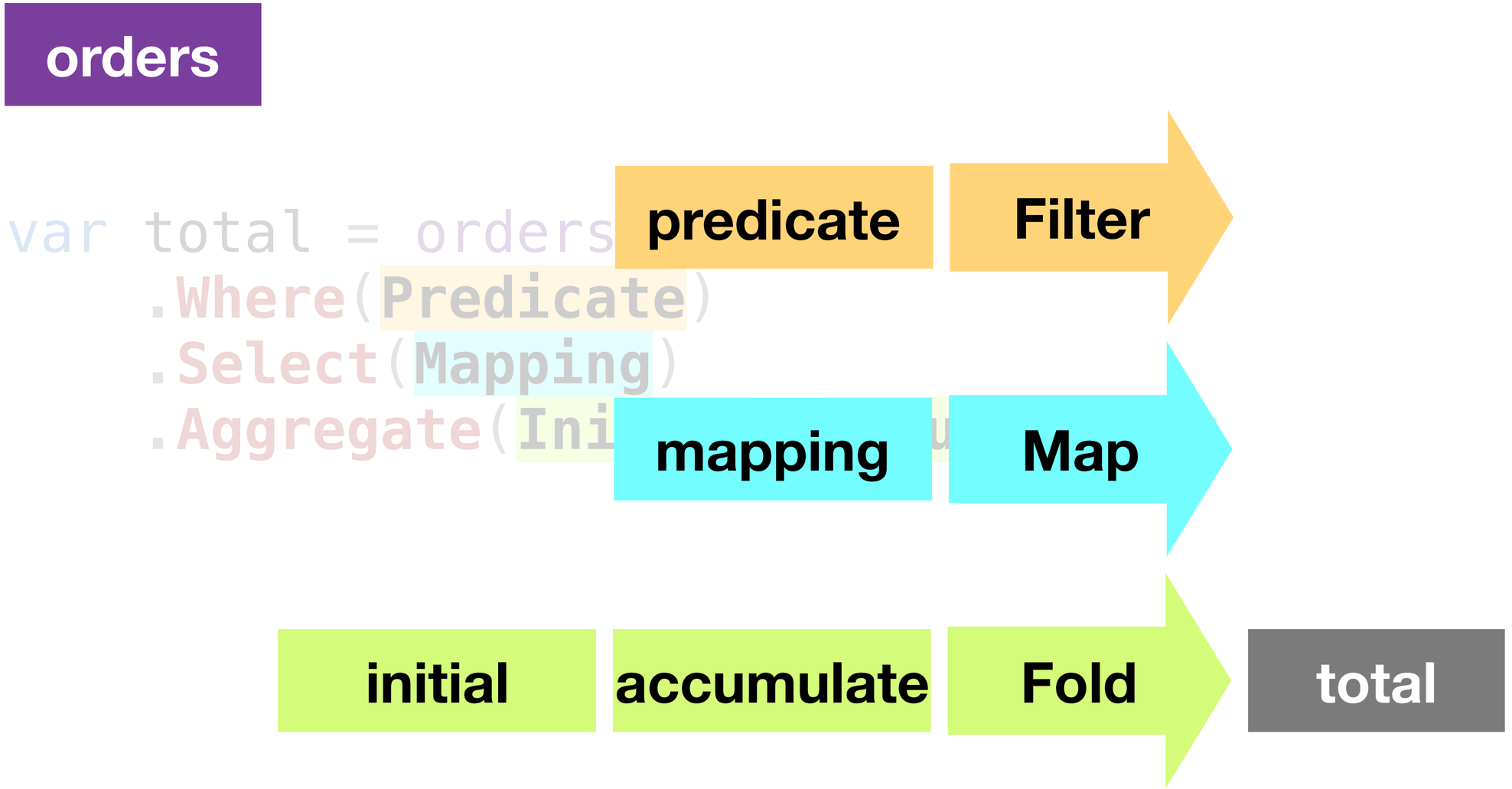
For Loop

```
var Initial
foreach (var order in orders)
{
    if (Predicate)
        Accumulate += Mapping;
}
```

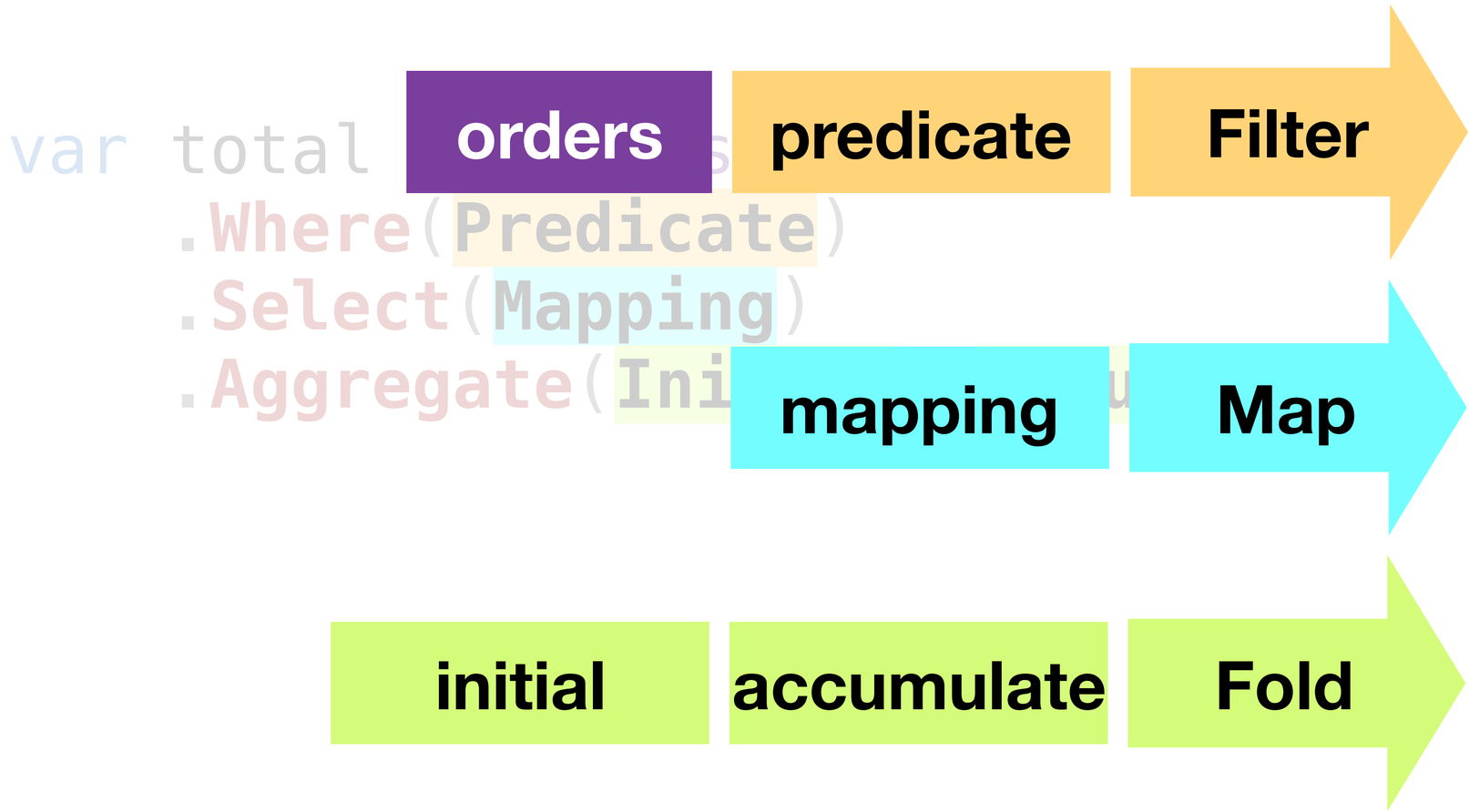
C#

Flow

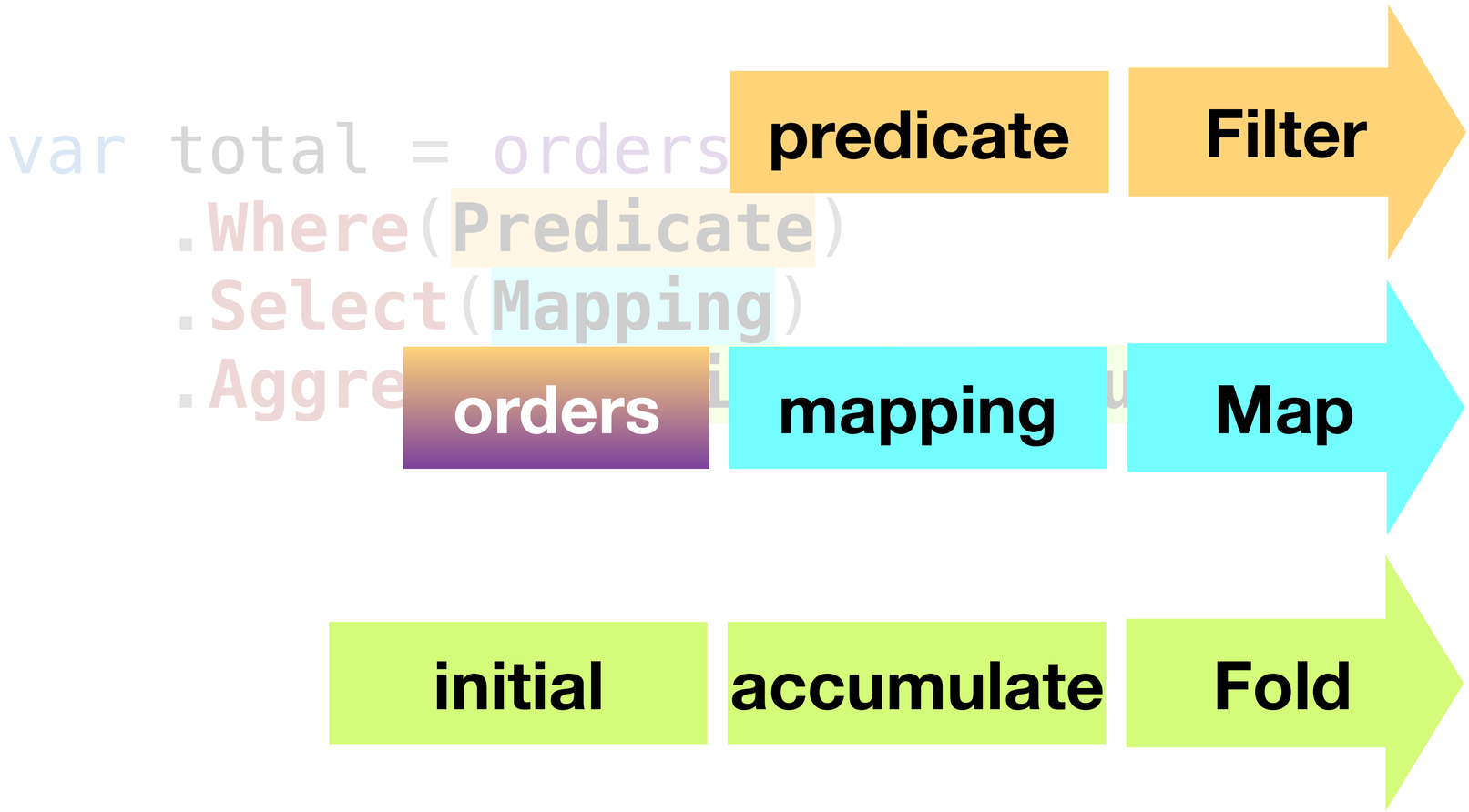
Flow


orders
var total = orders
.Where(Predicate)
.Select(Mapping)
.Aggregate(Ini
predicate
Filter
mapping
Map
initial
accumulate
Fold
total

Flow

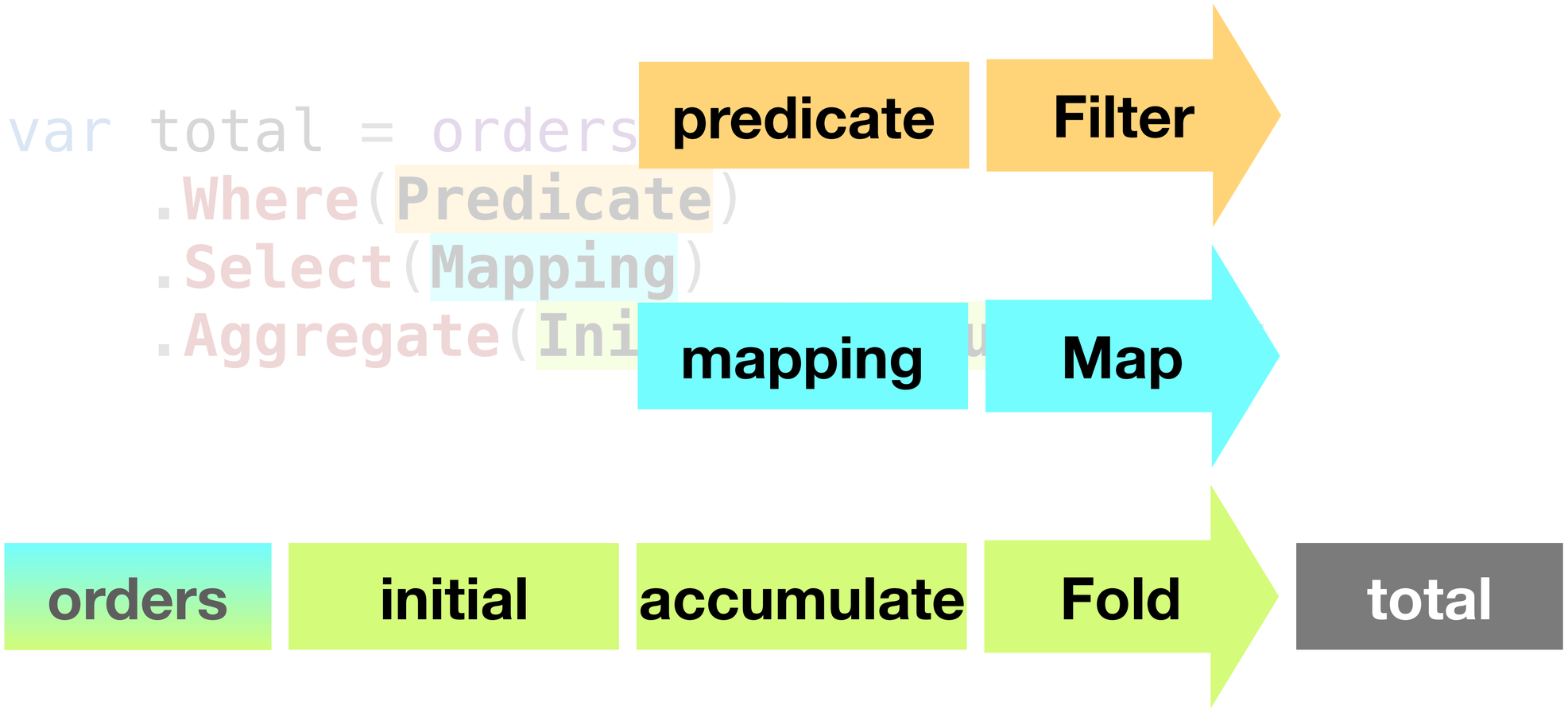

orders
predicate
Filter
mapping
Map
initial
accumulate
Fold

Flow


predicate
Filter
orders
mapping
Map
initial
accumulate
Fold

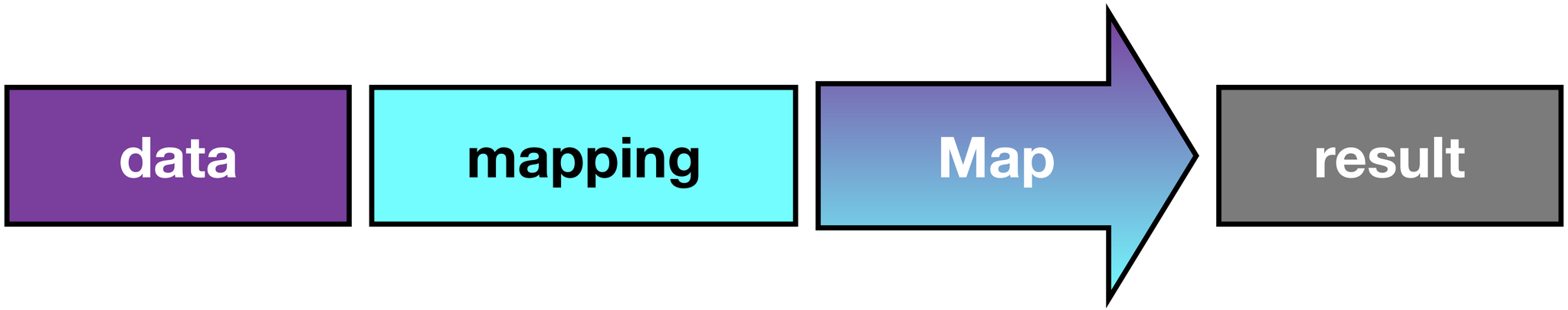
Flow

```
var total = orders
    .Where(Predicate)
    .Select(Mapping)
    .Aggregate(Ini
```

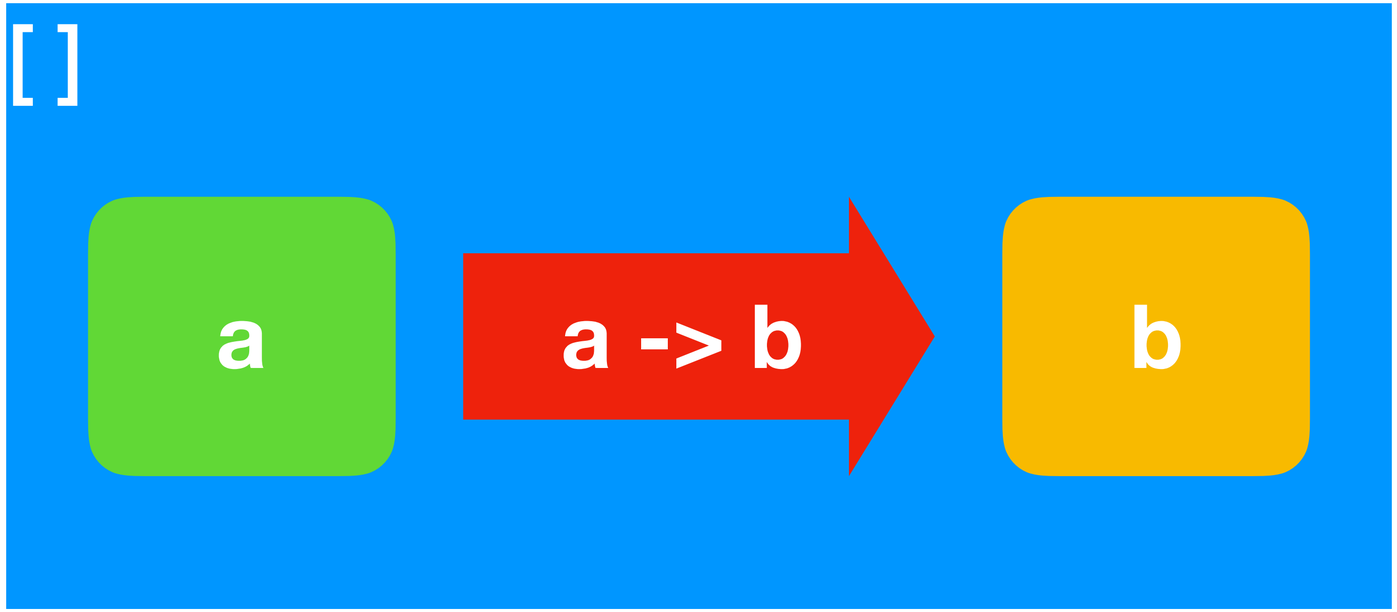


Higher Order Functions

Map

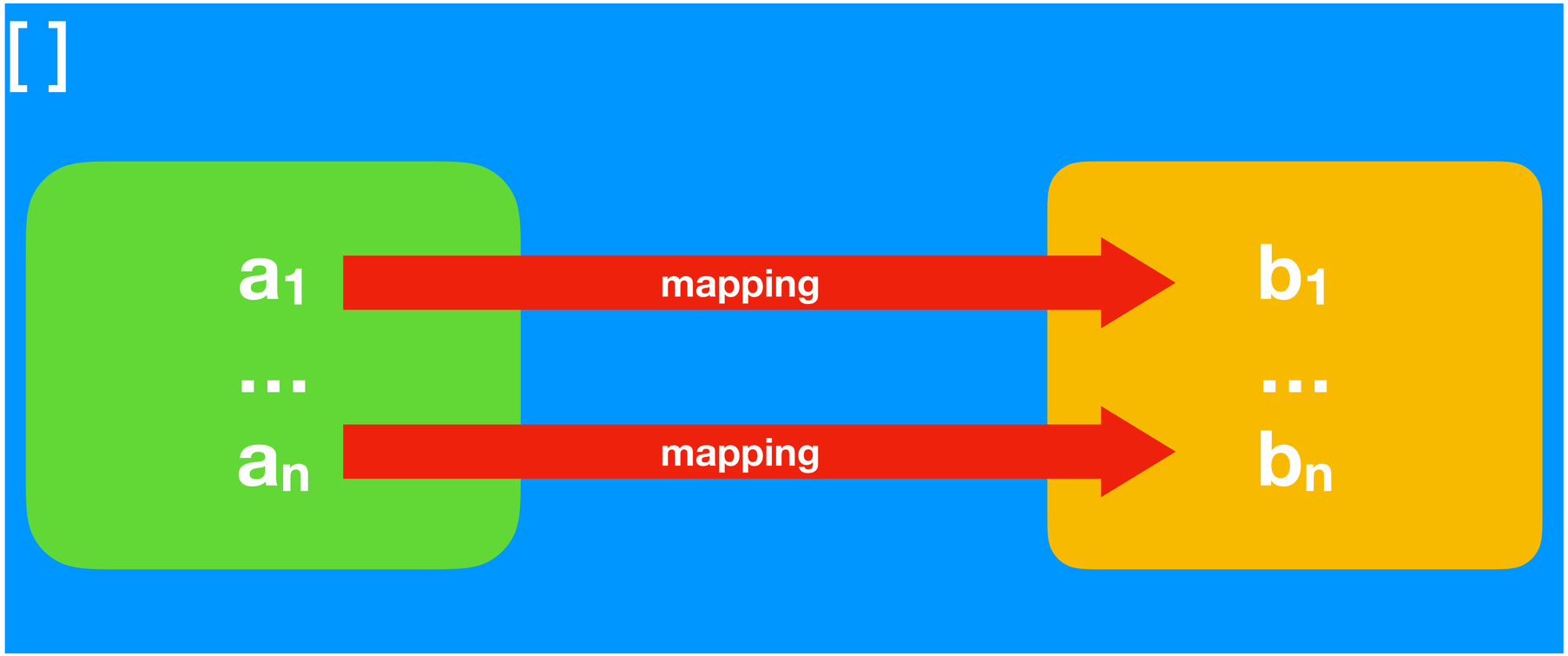


Map

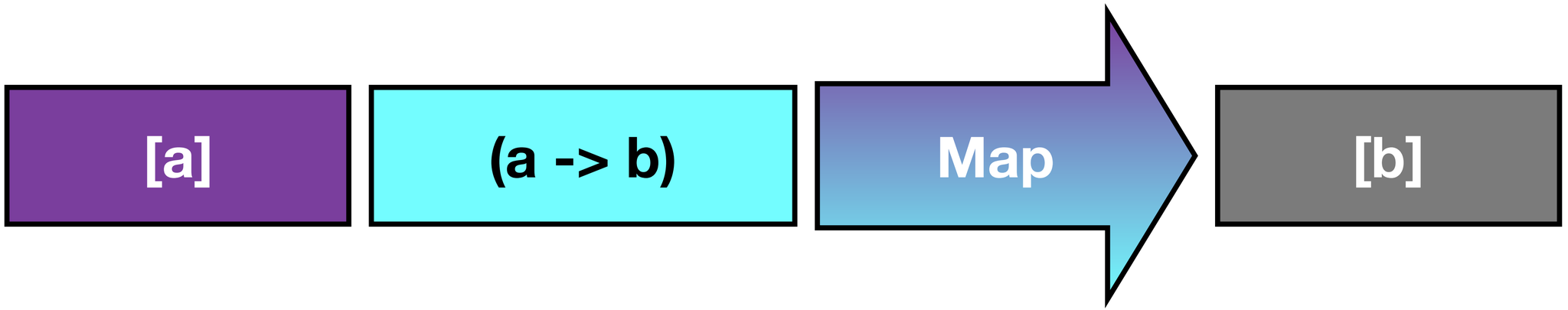


[a] -> (a -> b) -> [b]

Map



Map



[a] -> (a -> b) -> [b]

```
public static IEnumerable<U> Map<T, U>(
    this IEnumerable<T> source, Func<T, U> mapping)
{
    var result = new List<U>();
    foreach(var item in source)
    {
        result.Add(mapping(item));
    }

    return result;
}
```

C#

```
public static IEnumerable<U> Map<T, U>(
    this IEnumerable<T> source, Func<T, U> mapping)
{
    var result = new List<U>();
    foreach(var item in source)
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    }

    return result;
}
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C#

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var result = new List<U>();
foreach(var item in source)
{
    result.Add(mapping(item));
}
```
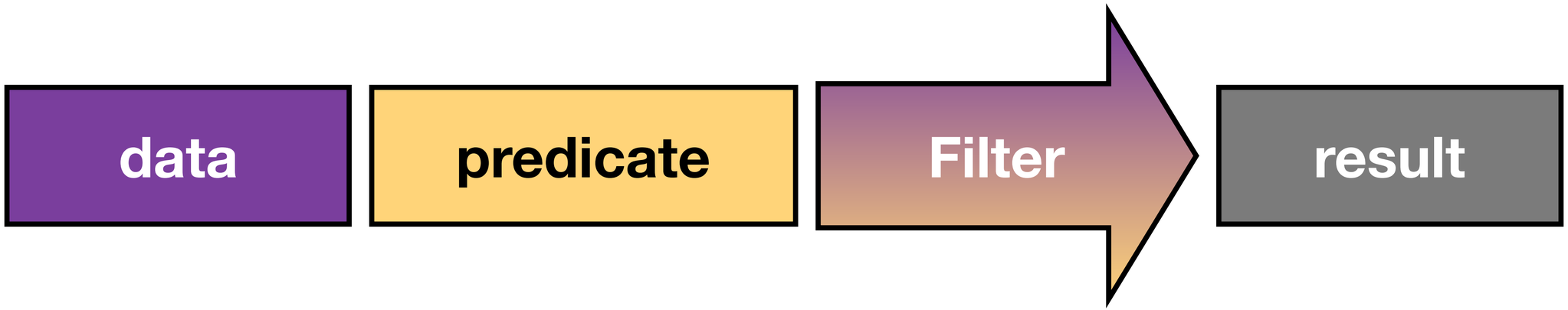

C#

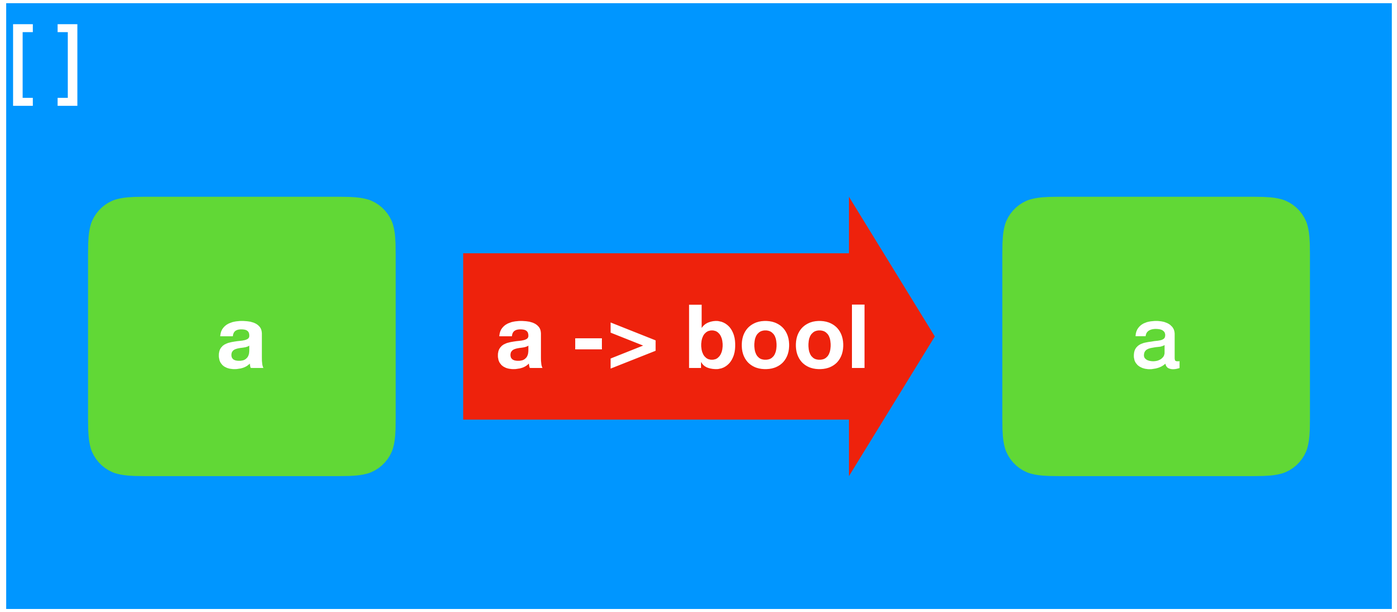
```
var result = new List<U>();
foreach(var item in source)
{
    result.Add(Mapping);
}
```

C#

Filter

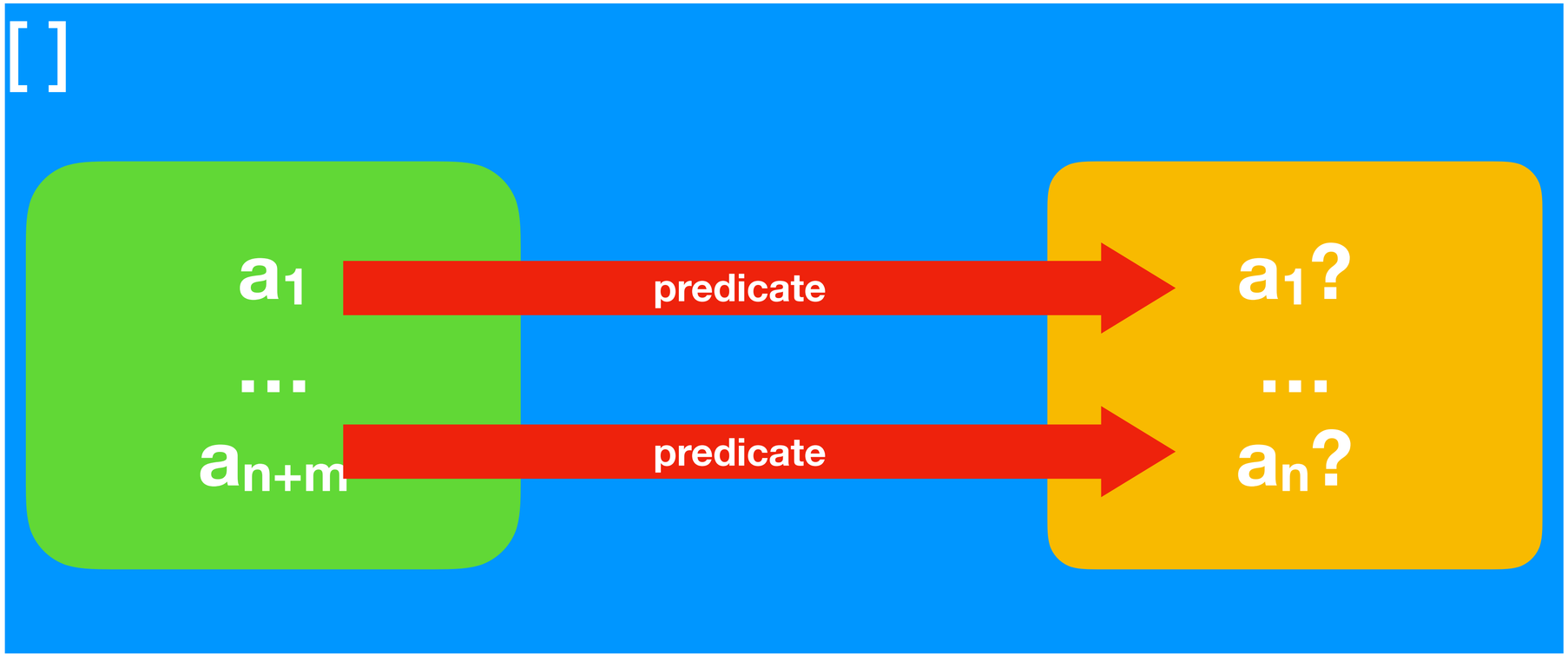


Filter

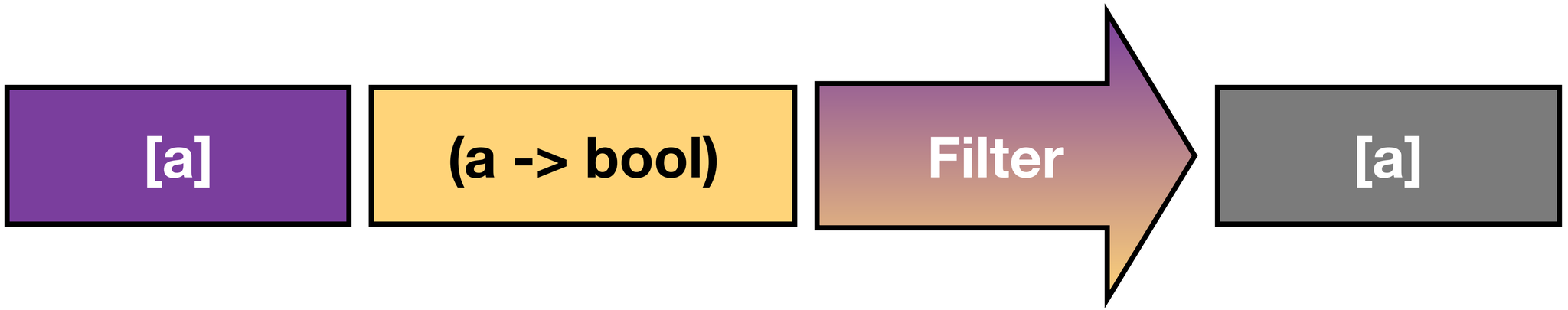


[a] -> (a -> bool) -> [a]

Filter



Filter



[a] -> (a -> bool) -> [a]

```
public static IEnumerable<T> Filter<T>(
    this IEnumerable<T> source, Func<T, bool> predicate)
{
    var result = new List<T>();
    foreach(var item in source)
    {
        if (predicate(item))
            result.Add(item);
    }

    return result;
}
```

C#

```
public static IEnumerable<T> Filter<T>(
    this IEnumerable<T> source, Func<T, bool> predicate)
{
    var result = new List<T>();
    foreach(var item in source)
    {
        if (predicate(item))
            result.Add(item);
    }

    return result;
}
```

C#

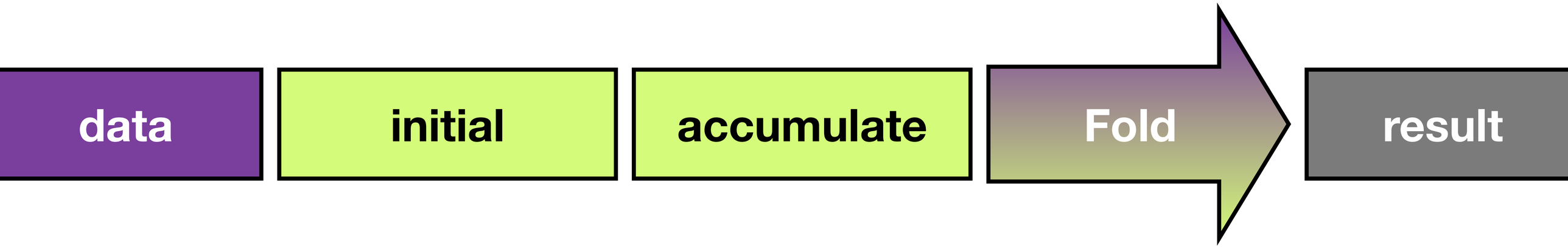
```
var result = new List<T>();
foreach(var item in source)
{
    if (predicate(item))
        result.Add(item);
}
```

C#

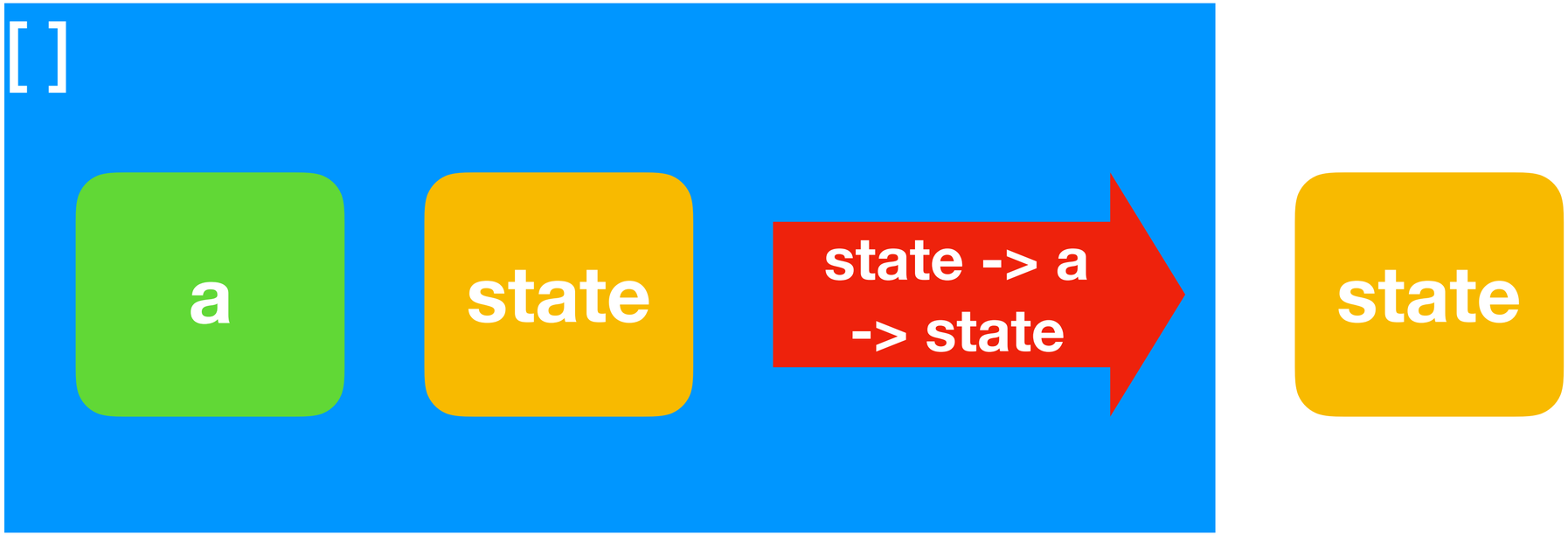
```
var result = new List<T>();
foreach(var item in source)
{
    if (Predicate)
        result.Add(item);
}
```

C#

Fold

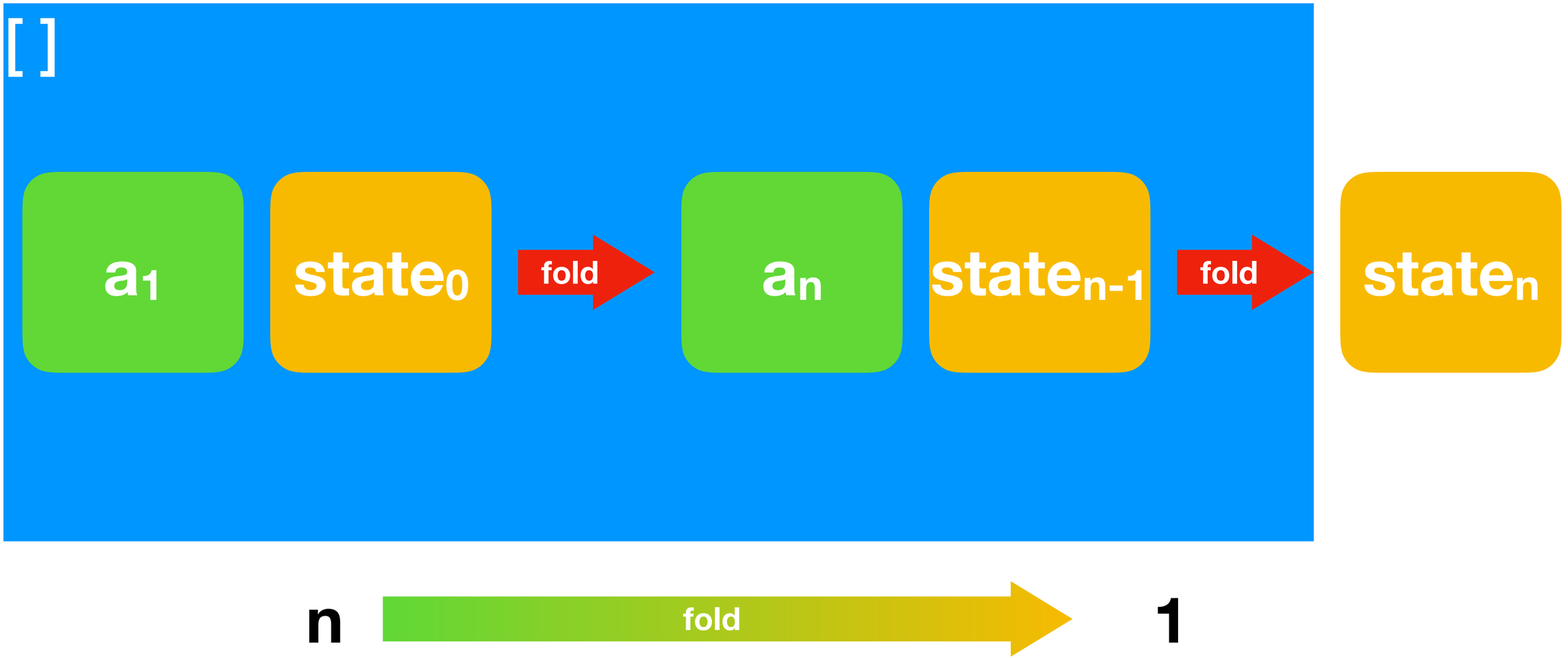


Fold

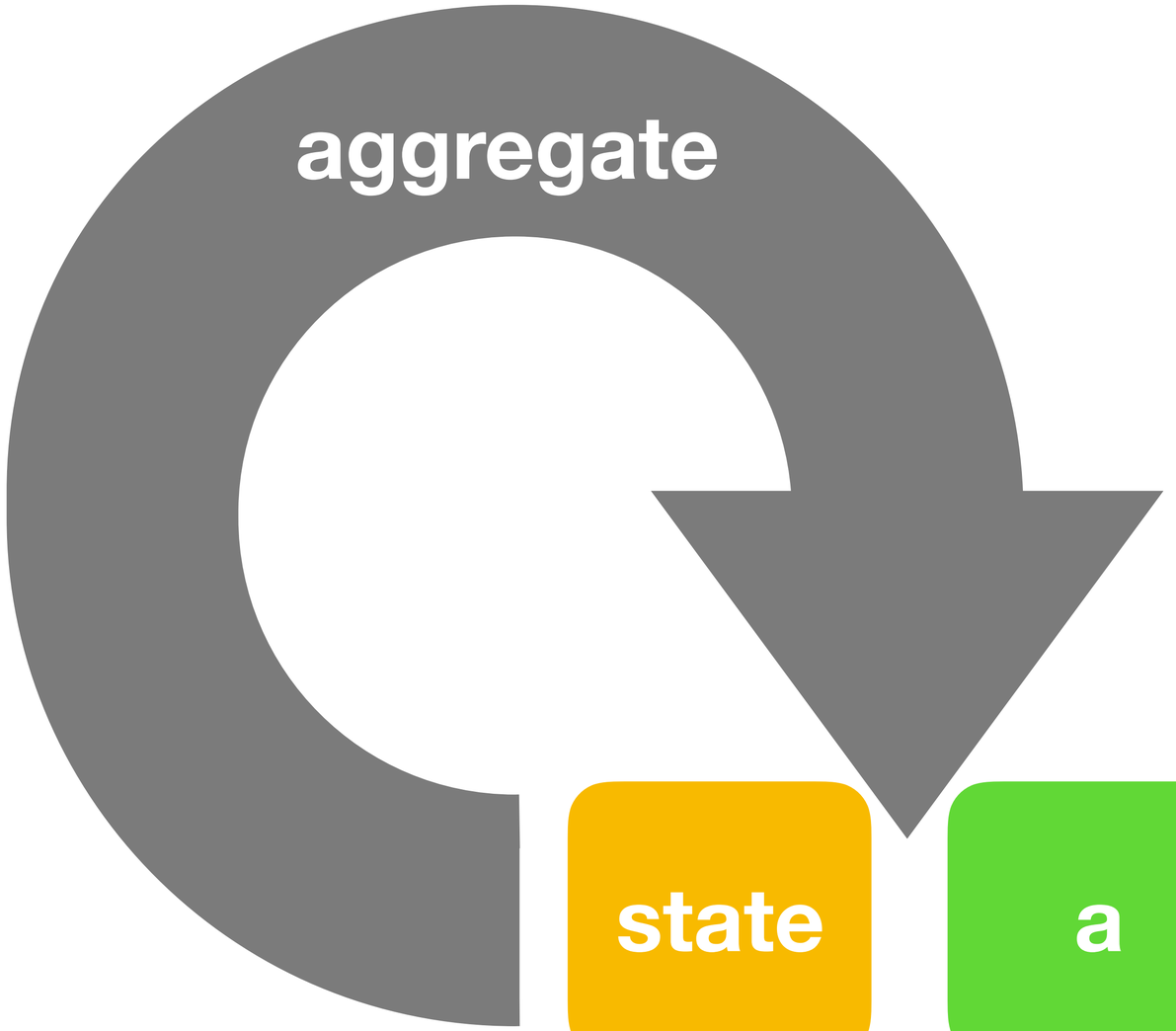


[a] -> state -> (state -> a -> state) -> state

Fold

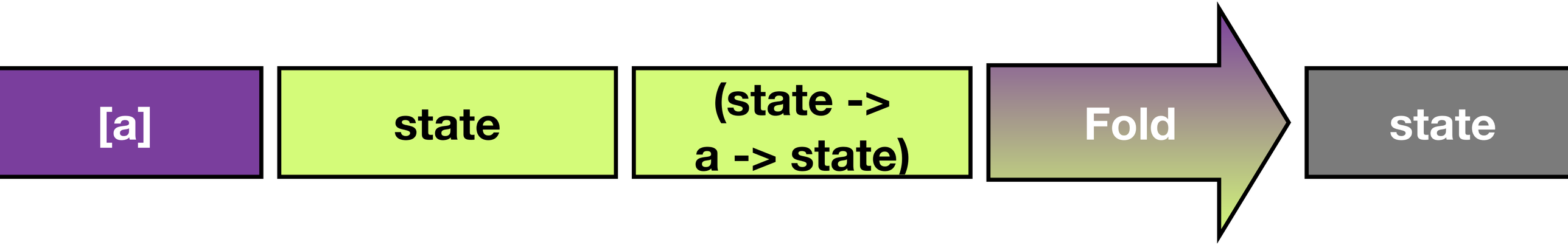


Fold



state a a a

Fold



[a] -> state -> (state -> a -> state) -> state

```
public static U Fold<T, U>(
    this IEnumerable<T> source,
    U initial,
    Func<U, T, U> accumulate)
{
    var result = initial;
    foreach(var item in source)
    {
        result = accumulate(result, item);
    }

    return result;
}
```

C#

```
public static U Fold<T, U>(
    this IEnumerable<T> source,
    U initial,
    Func<U, T, U> accumulate)
{
    var result = initial;
    foreach(var item in source)
    {
        result = accumulate(result, item);
    }

    return result;
}
```

C#

```
var result = initial;
foreach(var item in source)
{
    result = accumulate(result, item);
}
```

C#

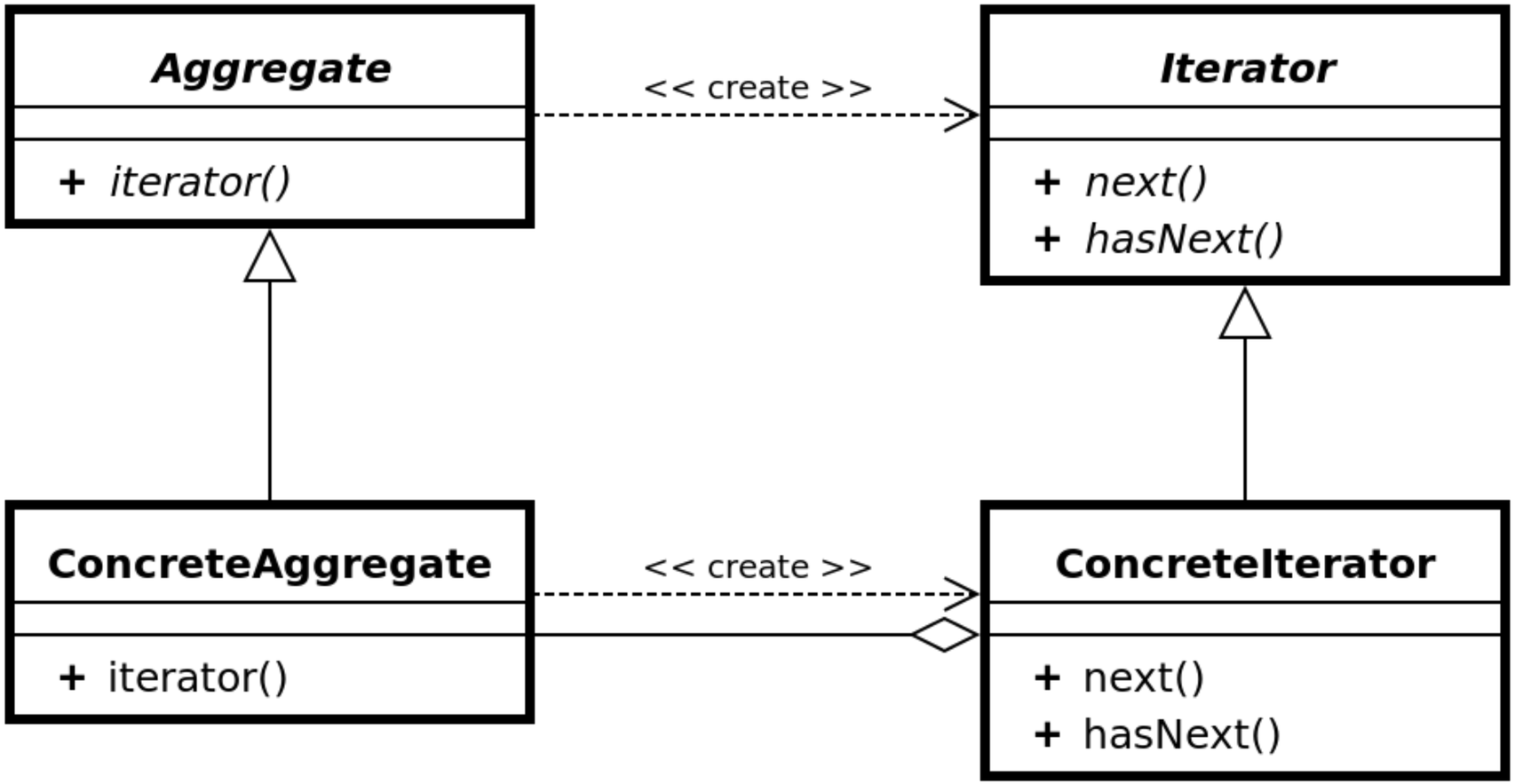
```
var result = Initial;
foreach(var item in source)
{
    result = Accumulate;
}
```

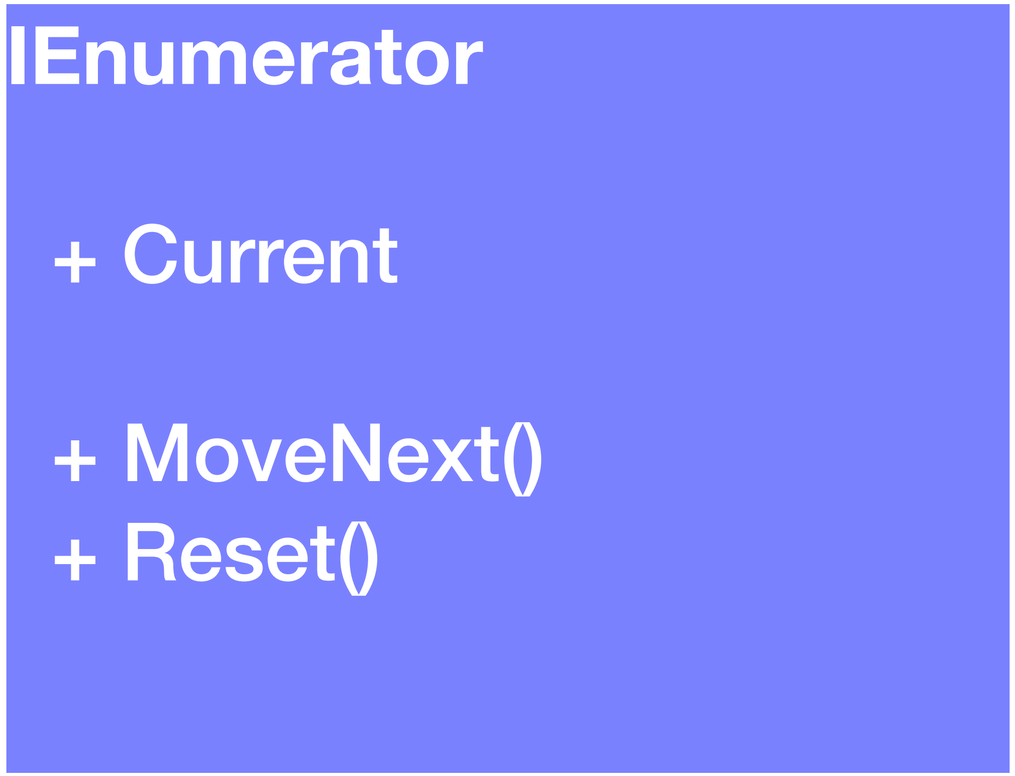
C#

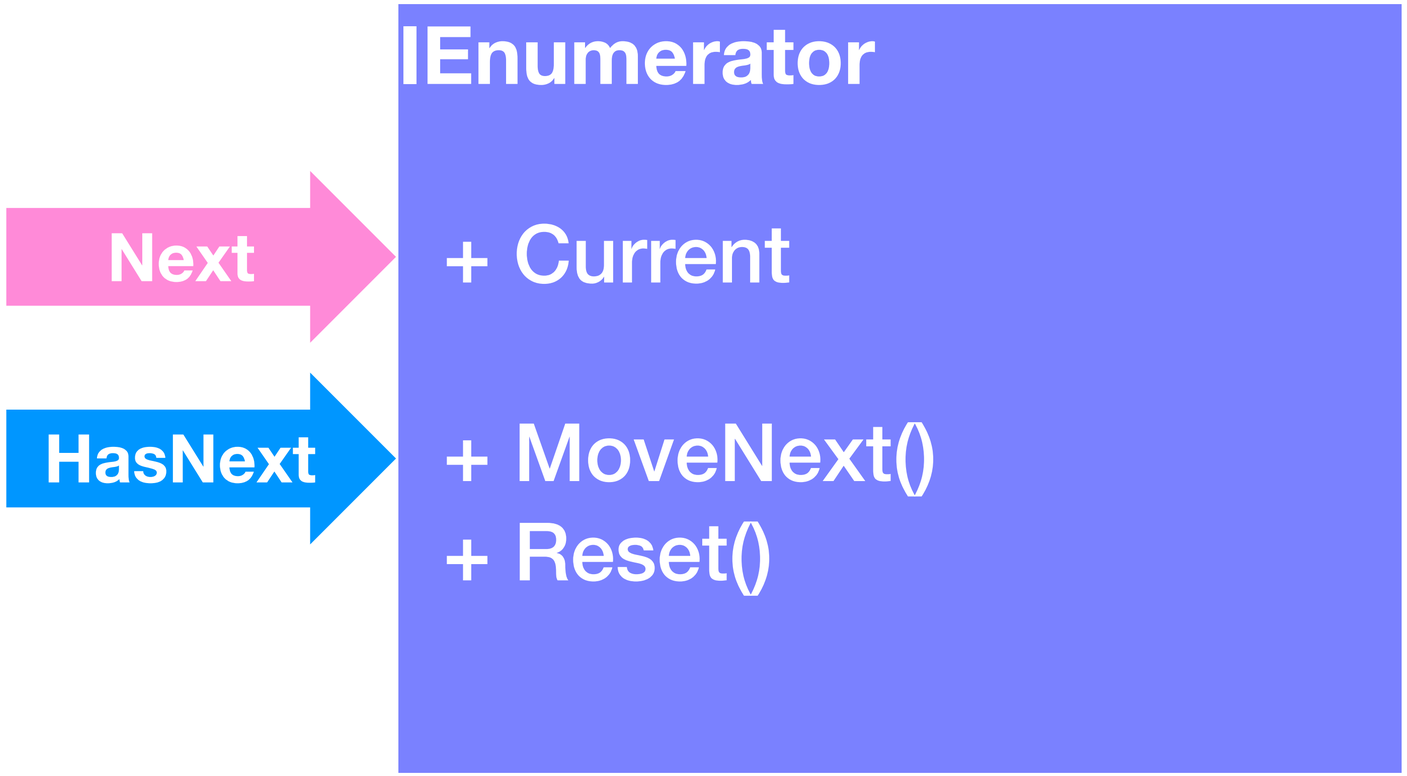
Higher Order Functions in C#

C#

Iterator Pattern


Aggregate
+ iterator()
<< create >>
Iterator
+ next()
+ hasNext()
ConcreteAggregate
+ iterator()
<< create >>
ConcreteIterator
+ next()
+ hasNext()


IEnumerator
+ Current
+ MoveNext()
+ Reset()


IEnumerator
Next
+ Current
HasNext
+ MoveNext()
+ Reset()

```
public static void Iterate<T>(
    this IEnumerator<T> source, Action<T> f)
{
    while(source.MoveNext())
    {
        f(source.Current);
    }
}
```

C#

```
public static void Iterate<T>(
    this IEnumerator<T> source, Action<T> f)
{
    while(HasNext)
    {
        f(source.Current);
    }
}
```

C#

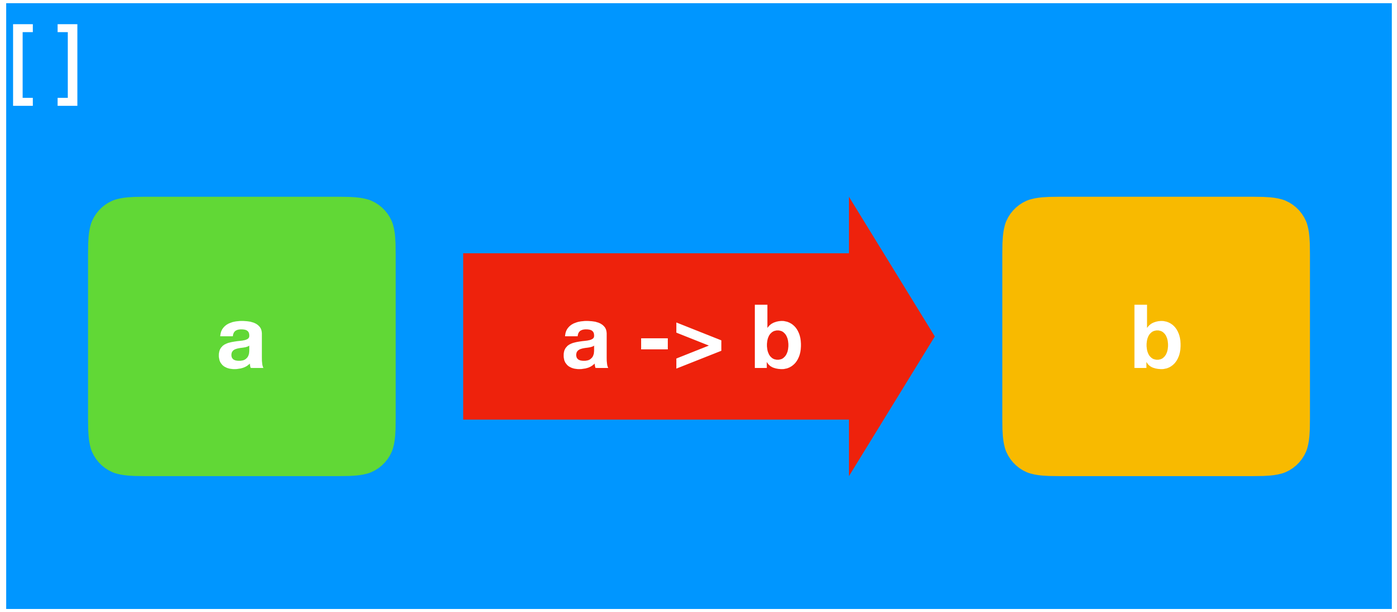
```
public static void Iterate<T>(
    this IEnumerator<T> source, Action<T> f)
{
    while(HasNext)
    {
        f(Next);
    }
}
```

C#

```
public static void Iterate<T>(
    this IEnumerator<T> source, Function)
{
    while(HasNext)
    {
        Function(Next);
    }
}
```

C#

Map



[a] -> (a -> b) -> [b]

```
private sealed class SelectArrayIterator<TSource, TResult> : Iterator<TResult>, IPartition<TResult>
{
  private readonly TSource[] _source;
  private readonly Func<TSource, TResult> _selector;

  public override bool MoveNext()
  {
      if (_state < 1 | _state == _source.Length + 1)
      {
          Dispose();
          return false;
      }

      int index = _state++ - 1;
      _current = _selector(_source[index]);
      return true;
  }
```

C#

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private sealed class SelectArrayIterator<TSource, TResult> : Iterator<TResult>, IPartition<TResult>
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          Dispose();
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      }

      int index = _state++ - 1;
      Next = _selector(_source[index]);
      return true;
  }
```

C#

```
private sealed class SelectArrayIterator<TSource, TResult> : Iterator<TResult>, IPartition<TResult>
{
  private readonly TSource[] _source;
  Mapping

  public override bool HasNext()
  {
      if (_state < 1 | _state == _source.Length + 1)
      {
          Dispose();
          return false;
      }

      int index = _state++ - 1;
      Next = Mapping(_source[index]);
      return true;
  }
```

C#

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private sealed class SelectArrayIterator<TSource, TResult> : Iterator<TResult>, IPartition<TResult>
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          return false;
      }

      int index = _state++ - 1;
      Next = Mapping(_source[index]);
      return true;
  }
```

C#

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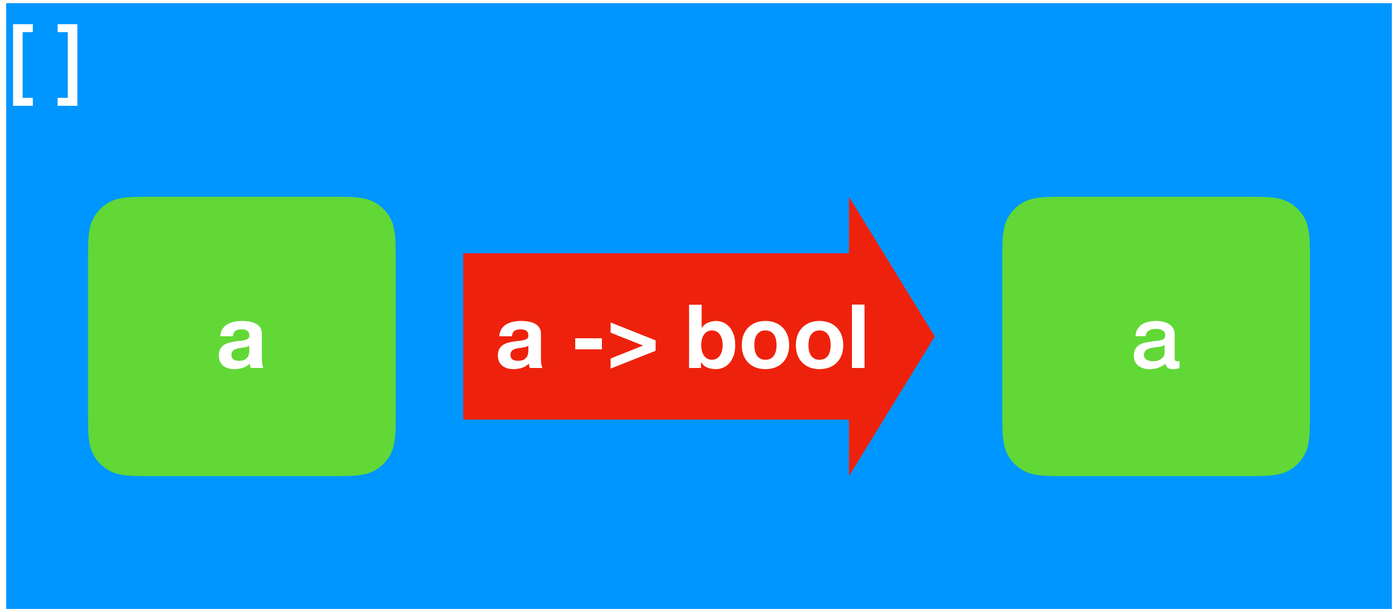
public override bool HasNext()
{
    if (_state < 1 | _state == _source.Length + 1)
    {
        Dispose();
        return false;
    }

    int index = _state++ - 1;
    Next = Mapping(_source[index]);
    return true;
}
```

C#

Filter



[a] -> (a -> bool) -> [a]

```
internal sealed class WhereArrayIterator<TSource> : Iterator<TSource>, IIListProvider<TSource>
{
    private readonly TSource[] _source;
    private readonly Func<TSource, bool> _predicate;

    public override bool MoveNext()
    {
        int index = _state - 1;
        TSource[] source = _source;

        while (unchecked((uint)index < (uint)source.Length))
        {
            TSource item = source[index];
            index = _state++;
            if (_predicate(item))
            {
                _current = item;
                return true;
            }
        }

        Dispose();
        return false;
    }
```

C#

```
internal sealed class WhereArrayIterator<TSource> : Iterator<TSource>, IIListProvider<TSource>
{
    private readonly TSource[] _source;
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    {
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        {
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            index = _state++;
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            {
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C#

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    public override bool HasNext()
    {
        int index = _state - 1;
        TSource[] source = _source;

        while (unchecked((uint)index < (uint)source.Length))
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            TSource item = source[index];
            index = _state++;
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C#

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internal sealed class WhereArrayIterator<TSource> : Iterator<TSource>, IIListProvider<TSource>
{
    private readonly TSource[] _source;
    Predicate

    public override bool HasNext()
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        int index = _state - 1;
        TSource[] source = _source;

        while (unchecked((uint)index < (uint)source.Length))
        {
            TSource item = source[index];
            index = _state++;
            if (Predicate(item))
            {
                Next = item;
                return true;
            }
        }

        Dispose();
        return false;
    }
```

C#

```
internal sealed class WhereArrayIterator<TSource> : Iterator<TSource>, IIListProvider<TSource>
{
    private readonly TSource[] _source;
    Predicate
```

```
    public override bool HasNext()
    {
        int index = _state - 1;
        TSource[] source = _source;

        while (unchecked((uint)index < (uint)source.Length))
        {
            TSource item = source[index];
            index = _state++;
            if (Predicate(item))
            {
                Next = item;
                return true;
            }
        }

        Dispose();
        return false;
    }
```

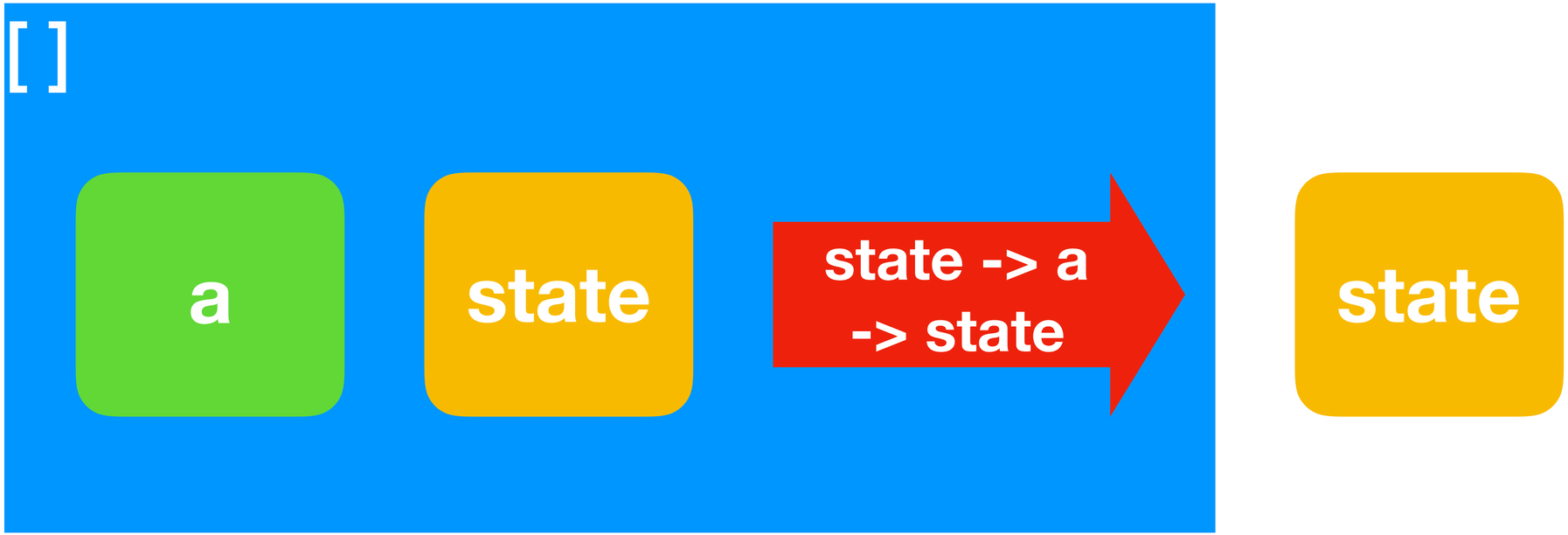
C#

```
public override bool HasNext()
{
    while (index < source.Length))
    {
        TSource item = source[index];
        index = _state++;
        if (Predicate(item))
        {
            Next = item;
            return true;
        }
    }

    Dispose();
    return false;
}
```

C#

Fold



[a] -> state -> (state -> a -> state) -> state

```
public static TAccumulate Aggregate<TSource, TAccumulate>(this IEnumerable<TSource> source,
TAccumulate seed, Func<TAccumulate, TSource, TAccumulate> func)
{
    if (source == null)
    {
        throw Error.ArgumentNull(nameof(source));
    }

    if (func == null)
    {
        throw Error.ArgumentNull(nameof(func));
    }

    TAccumulate result = seed;
    foreach (TSource element in source)
    {
        result = func(result, element);
    }


    return result;
}
```

C#

```
public static TAccumulate Aggregate<TSource, TAccumulate>(this IEnumerable<TSource> source,
TAccumulate seed, Func<TAccumulate, TSource, TAccumulate> func)
{
    if (source == null)
    {
        throw Error.ArgumentNull(nameof(source));
    }

    if (func == null)
    {
        throw Error.ArgumentNull(nameof(func));
    }

    TAccumulate result = seed;
    HasNext (TSource element in source)
    {
        result = func(result, element);
    }


    return result;
}
```

C#

```
public static TAccumulate Aggregate<TSource, TAccumulate>(this IEnumerable<TSource> source,
TAccumulate seed, Func<TAccumulate, TSource, TAccumulate> func)
{
    if (source == null)
    {
        throw Error.ArgumentNull(nameof(source));
    }

    if (func == null)
    {
        throw Error.ArgumentNull(nameof(func));
    }

    TAccumulate result = seed;
    HasNext (TSource Next in source)
    {
        result = func(result, Next);
    }


    return result;
}
```

C#

```
public static TAccumulate Aggregate<TSource, TAccumulate>(this IEnumerable<TSource> source,
Initial, Accumulate)
{
    if (source == null)
    {
        throw Error.ArgumentNull(nameof(source));
    }

    if (func == null)
    {
        throw Error.ArgumentNull(nameof(func));
    }

    TAccumulate result = Initial;
    HasNext (TSource Next in source)
    {
        result = Accumulate(result, Next);
    }


    return result;
}
```

C#

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public static TAccumulate Aggregate<TSource, TAccumulate>(this IEnumerable<TSource> source,
Initial, Accumulate)
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    TAccumulate result = Initial;
    HasNext (TSource Next in source)
    {
        result = Accumulate(result, Next);
    }

    return result;
}
```

C#

```
TAccumulate result = Initial;
HasNext (TSource Next in source)
{
    result = Accumulate(result, Next);
}

return result;
```

C#

LINQ Order of Execution

Data

```
IList<(int Zip, double Price, int Quantity)> orders =
    new List<(int Zip, double Price, int Quantity)> {
        (53202, 1.89, 3),
        (60191, 1.99, 2),
        (60060, 0.99, 7),
        (53202, 1.29, 8),
        (60191, 1.89, 2),
        (53202, 0.99, 3)
    };
```

C#

In what order does this execute?

```
var total = orders
    .Where(order => order.Zip == 53202)
    .Select(order => order.Price * order.Quantity)
    .Aggregate(0.0, (sub, amount) => sub + amount);
```

C#

In what order does this execute?

```
var spy = new List<string>();

orders
    .Where(order =>
       { spy.Add("filter"); return order.Zip == 53202; })
    .Select(order =>
       { spy.Add(“map");
         return order.Price * order.Quantity; })
    .Aggregate(0.0, (sub, amount) =>
       { spy.Add("fold"); return sub + amount; });
```

C#

Answer

```
new List<string> {
        "filter", "map", "fold",
        "filter",
        "filter",
        "filter", "map", "fold",
        "filter",
        "filter", "map", "fold"
},
```

C#

Data

```
IList<(int Zip, double Price, int Quantity)> orders =
    new List<(int Zip, double Price, int Quantity)> {
        (53202, 1.89, 3), //“filter", "map", "fold",
        (60191, 1.99, 2), //"filter",
        (60060, 0.99, 7), //"filter",
        (53202, 1.29, 8), //“filter", "map", "fold",
        (60191, 1.89, 2), //"filter",
        (53202, 0.99, 3)  //“filter", "map", "fold",
    };
```

C#

Does exactly what we want

```
var total = orders
      .Where(order => order.Zip == 53202)
      .Select(order => order.Price * order.Quantity)
      .Aggregate(0.0, (sub, amount) => sub + amount);
```

C#

Fusion Property of Iterators

Fusion Property of Iterators

$$\text{iterator } f \circ \text{iterator } g = \text{iterator } (f \circ g)$$

Foreach Loop

```
var total = 0.0;
foreach (var order in orders)
{
    if (order.Zip == 53202)
        total += order.Price * order.Quantity;
}
```

C#

Foreach Loop

```
var total = 0.0;
Iterate (var order in orders)
{
    Filter(order.Zip == 53202)
        Fold(+, Map(order.Price * order.Quantity));
}
```

C#

Foreach Loop

iterator *filter* |> iterator *map* |> iterator *fold*

Foreach Loop

iterator *filter* |> iterator *map* |> iterator *fold* =
(iterator *fold* (iterator *map* (iterator *filter*)))

Foreach Loop

iterator *filter* |> iterator *map* |> iterator *fold* =
(iterator *fold* (iterator *map* (iterator *filter*))) =
iterator *fold* ∘ iterator *map* ∘ iterator *filter*

Foreach Loop

iterator *filter* |> iterator *map* |> iterator *fold* =
(iterator *fold* (iterator *map* (iterator *filter*))) =
iterator *fold* ∘ iterator *map* ∘ iterator *filter* =
iterator (*fold* ∘ *map* ∘ *filter*)

Foreach Loop

iterator *filter* |> iterator *map* |> iterator *fold* =
iterator (*fold* ∘ *map* ∘ *filter*)

LINQ

```
var total = orders
    .Where(order => order.Zip == 53202)
    .Select(order => order.Price * order.Quantity)
    .Aggregate(0.0, (sub, amount) => sub + amount);
```

C#

LINQ

```
var total = orders
      .Filter(order => order.Zip == 53202)
      .Map(order => order.Price * order.Quantity)
      .Fold(0.0, (sub, amount) => sub + amount);
```

C#

LINQ

iterator *filter* |> iterator *map* |> iterator *fold* =
iterator (*filter* ∘ *map* ∘ *fold*)

Higher Order Functions
Learn once use everywhere.

C# List Comprehension

```
(from order in orders
 where order.Zip == 53202
 select new {Amount = order.Price * order.Quantity})
.Sum(order => order.Amount);
```

C#

JavaScript

```
orders
   .filter(order => order.zip === 53202)
   .map(order => order.price * order.quantity)
   .reduce((sub, amount) => sub + amount, 0.0);
```

PowerShell

```
($orders |
  Where-Object { $_.Zip -eq 53202 } |
  Select-Object @{
    Name =“Amount";
    Expression = {$_.Price * $_.Quantity} } |
  Measure-Object Amount -Sum).Sum
```

F#

```
orders
   |> List.filter (fun x -> x.Zip = 53202)
   |> List.map (fun x -> x.Price * (double x.Quantity))
   |> List.sum
```

T-SQL

```
select distinct
  sum(price * quantity) over (partition by zip)
  from (
    values
      (53202, 1.89, 3),
      (60191, 1.99, 2),
      (60060, 0.99, 7),
      (53202, 1.29, 8),
      (60191, 1.89, 2),
      (53202, 0.99, 3)
  ) as orders(zip, price, quantity)
  where zip = 53202
```

T-SQL

… and on and on

Compare

LINQ

```
var total = orders
    .Where(Predicate)
    .Select(Mapping)
    .Aggregate(Initial, Accumulate);
```

For Loop

```
var Initial
foreach (var order in orders)
{
    if (Predicate)
        Accumulate += Mapping;
}
```

C#

Thank you

Mike Harris

Say Goodbye to the For Loop
with High Order Functions
https://bit.ly/2uUmIlM

@MikeMKH

Next Steps

- Enrico Buonanno, Functional Programming in C# [book]
  https://www.manning.com/books/functional-programming-in-c-sharp

- Scott Wlaschin, F# for Fun and Profit [blog]
  https://fsharpforfunandprofit.com/

- Mark Seemann, From Design Patterns to Category Theory [blog]
  http://blog.ploeh.dk/2017/10/04/from-design-patterns-to-category-theory/

Example Code

- C#, https://github.com/MikeMKH/talks/tree/master/say-goodbye-to-the-for-loop-with-higher-order-functions/csharp
- JavaScript, https://github.com/MikeMKH/talks/tree/master/say-goodbye-to-the-for-loop-with-higher-order-functions/javascript
- PowerShell, https://github.com/MikeMKH/talks/tree/master/say-goodbye-to-the-for-loop-with-higher-order-functions/powershell
- F#, https://github.com/MikeMKH/talks/tree/master/say-goodbye-to-the-for-loop-with-higher-order-functions/fsharp
- T-SQL, https://github.com/MikeMKH/talks/tree/master/say-goodbye-to-the-for-loop-with-higher-order-functions/sql

Images

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- Self photo by Kelsey Harris taken at StrangeLoop

gcc Source Code

- example 1, https://github.com/gcc-mirror/gcc/blob/e11be3ea01eaf8acd8cd86d3f9c427621b64e6b4/gcc/testsuite/gcc.c-torture/execute/930614-2.c#L1-L20
- example 2, https://github.com/gcc-mirror/gcc/blob/e11be3ea01eaf8acd8cd86d3f9c427621b64e6b4/gcc/testsuite/gcc.c-torture/compile/pr25513.c#L1-L9
- example 3, https://github.com/gcc-mirror/gcc/blob/e11be3ea01eaf8acd8cd86d3f9c427621b64e6b4/gcc/testsuite/gcc.c-torture/compile/pr43186.c#L1-L15

LINQ Source Code

- Select, https://github.com/dotnet/corefx/blob/a673a117846205fc1a5c648c29451ff3da83554d/src/System.Linq/src/System/Linq/Select.cs#L199-L226
- Where, https://github.com/dotnet/corefx/blob/a673a117846205fc1a5c648c29451ff3da83554d/src/System.Linq/src/System/Linq/Where.cs#L198-L255
- Aggregate, https://github.com/dotnet/corefx/blob/a673a117846205fc1a5c648c29451ff3da83554d/src/System.Linq/src/System/Linq/Aggregate.cs#L40-L59