# Say Goodbye to the For Loop with High Order Functions

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

I have no idea either.

# Agenda

- Problem
- Map
- Filter
- Fold
- Theory

# Problem Statment

# Realistic 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 53202?

# 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#

# 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

# 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

# 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

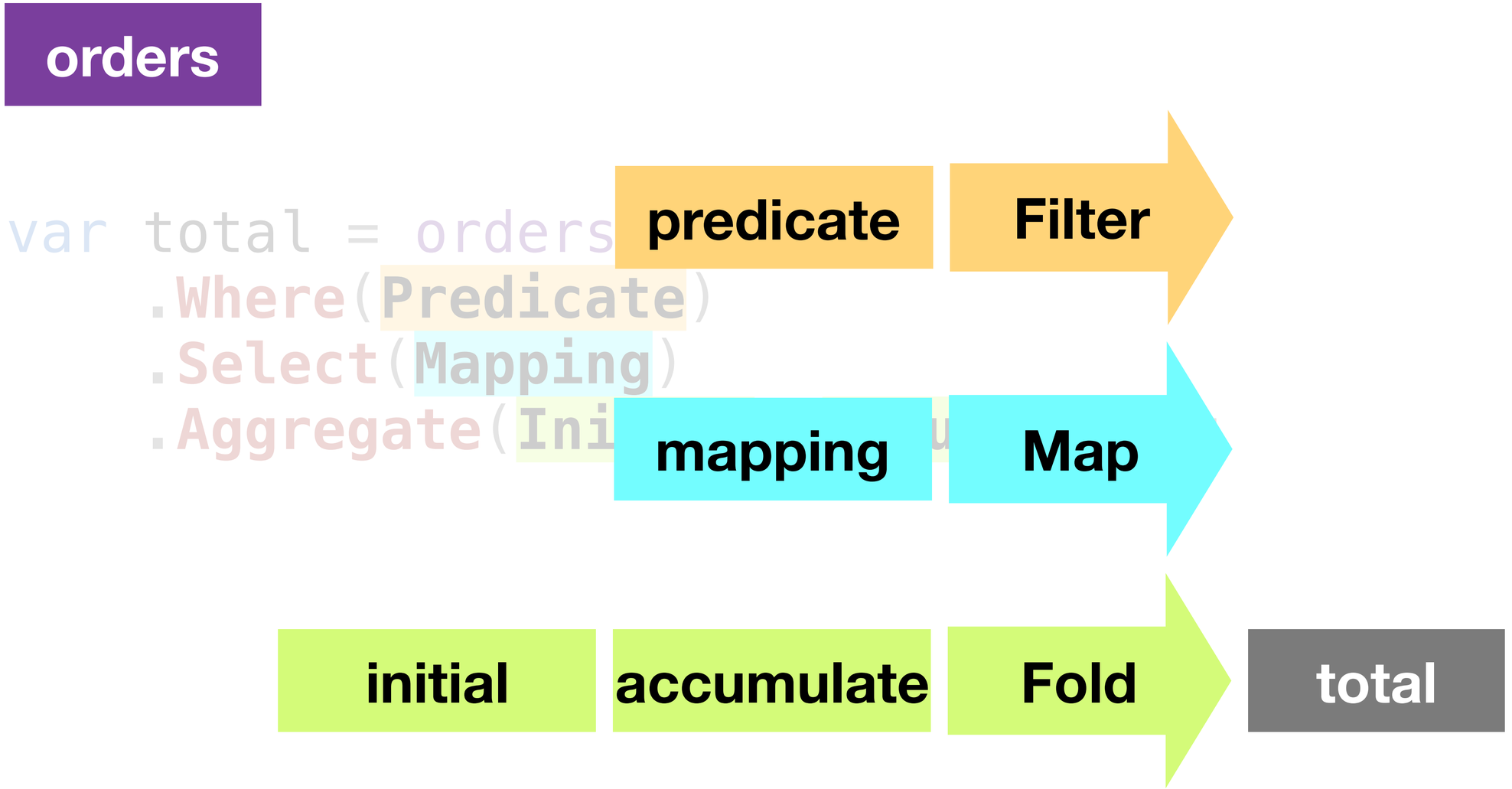
```
var total = orders
    .Where(Predicate)
    .Select(Mapping)
    .Aggregate(Initial, Accumulate);
```

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

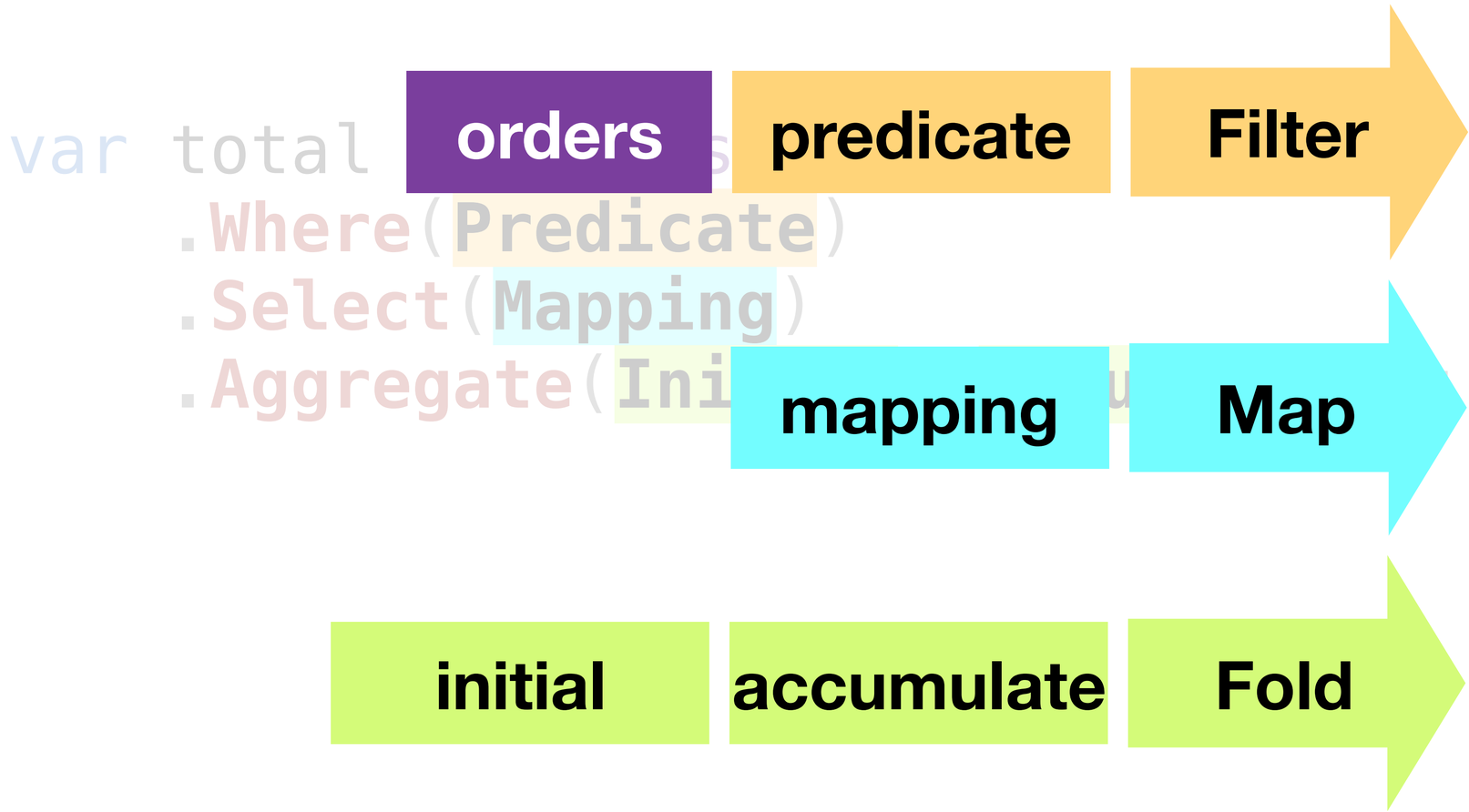
C#

# Flow

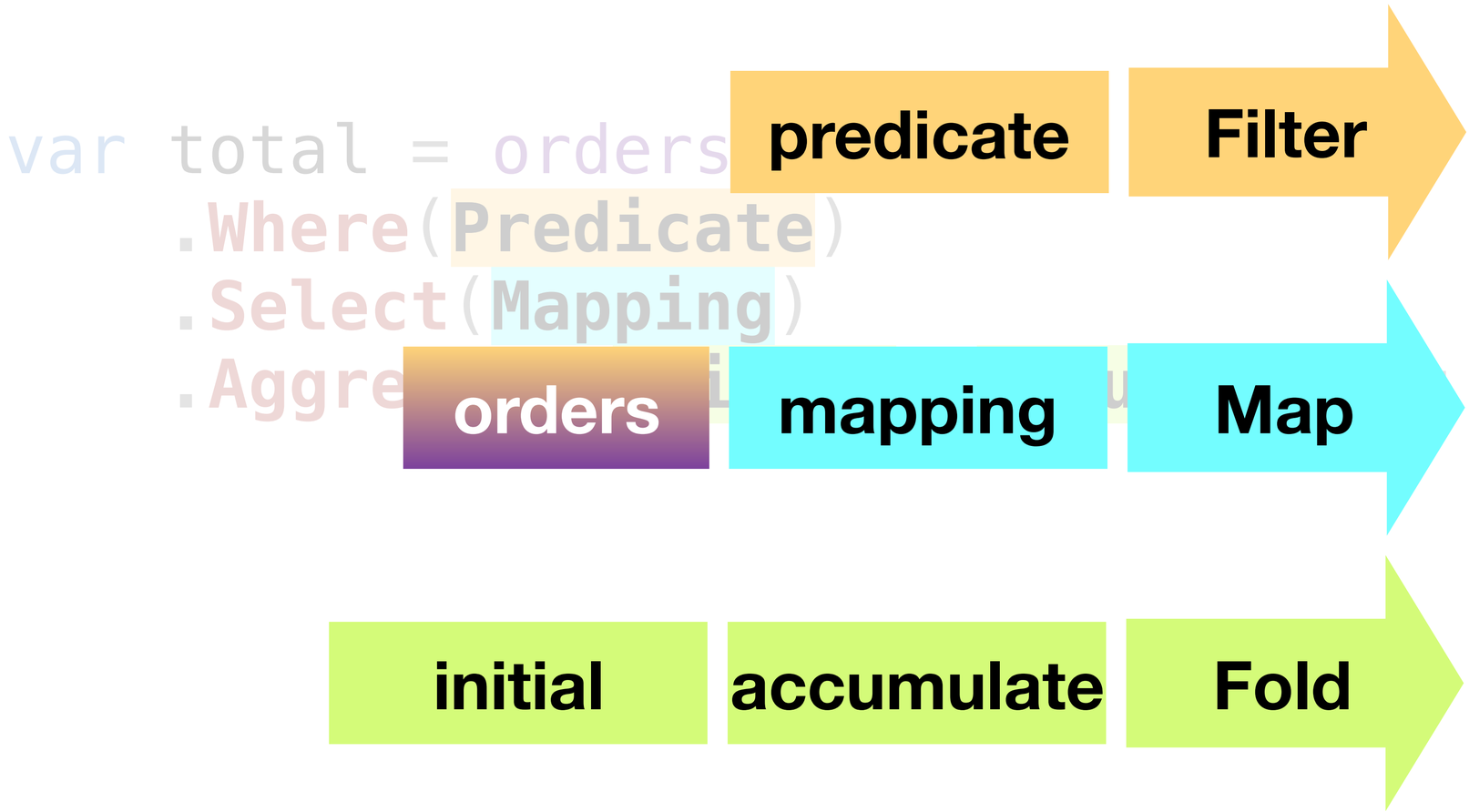
# Flow


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

# Flow

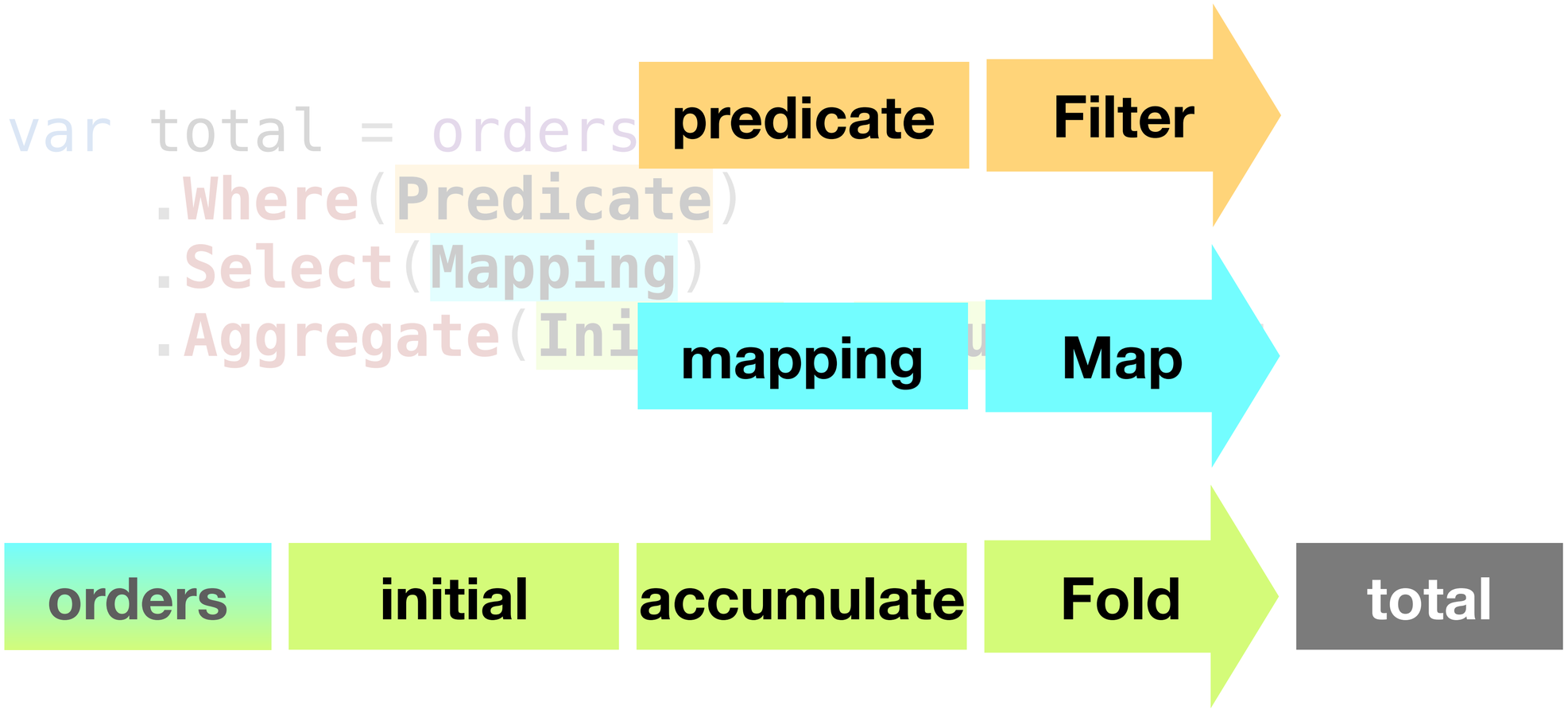

orders
predicate
Filter
mapping
Map
initial
accumulate
Fold

# Flow


predicate
Filter
orders
mapping
Map
initial
accumulate
Fold

# Flow

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

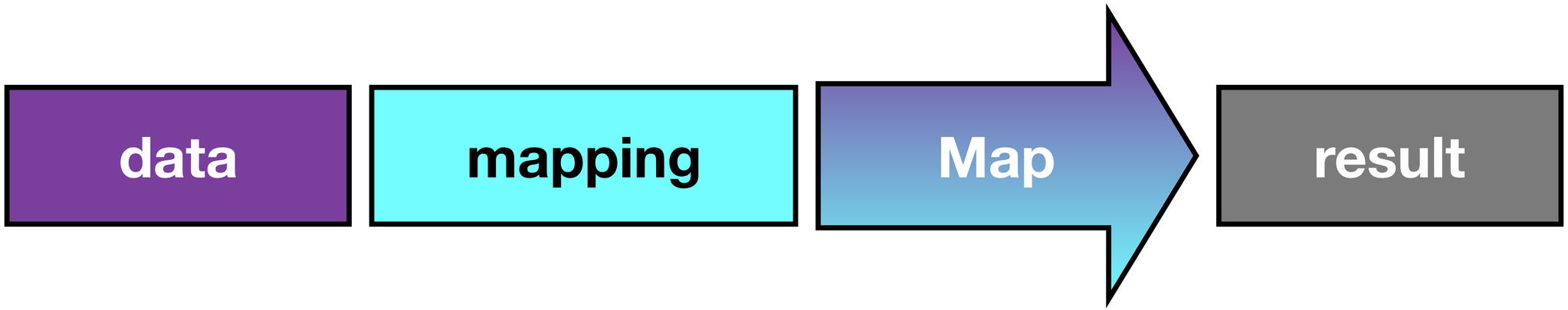


# Higher Order Functions

# Map

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

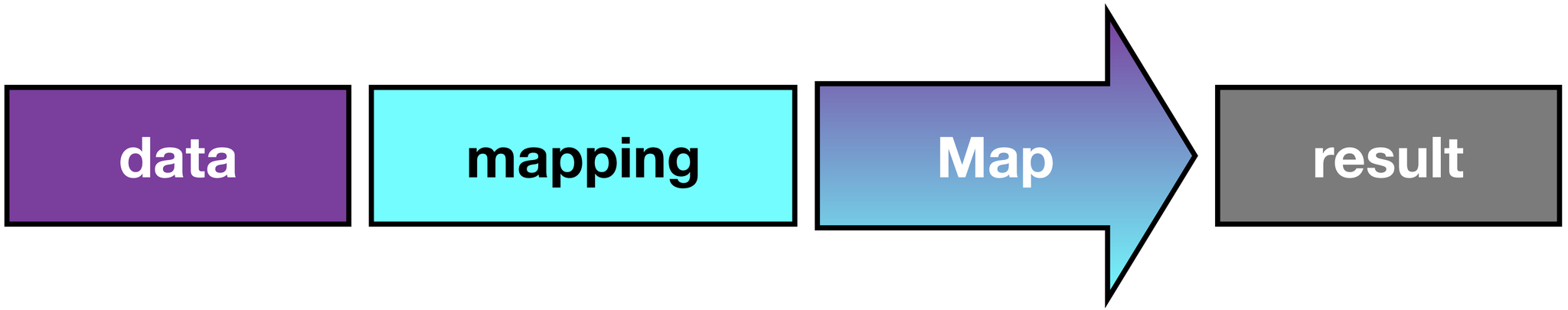
# Map



# Map

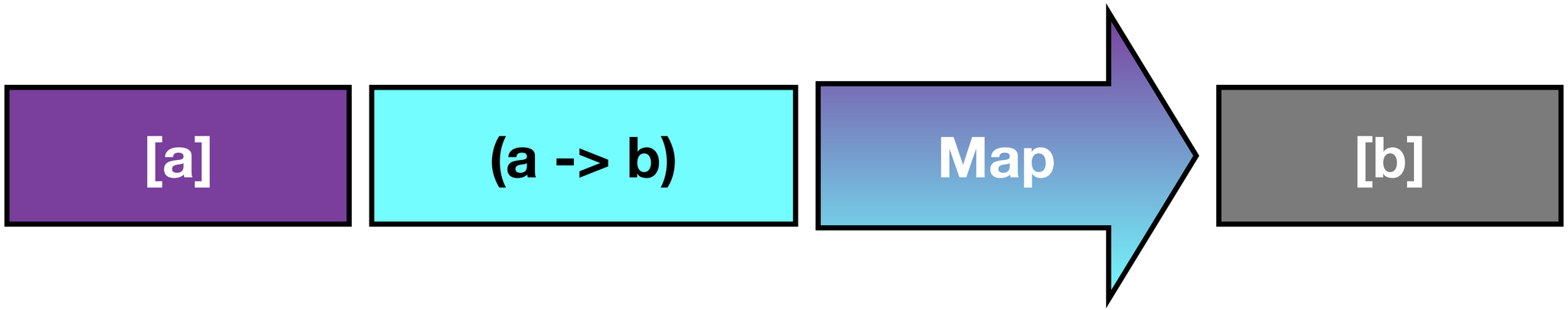
**[a] -> (a -> b) -> [b]**

# Map




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

# Map



```
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#

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

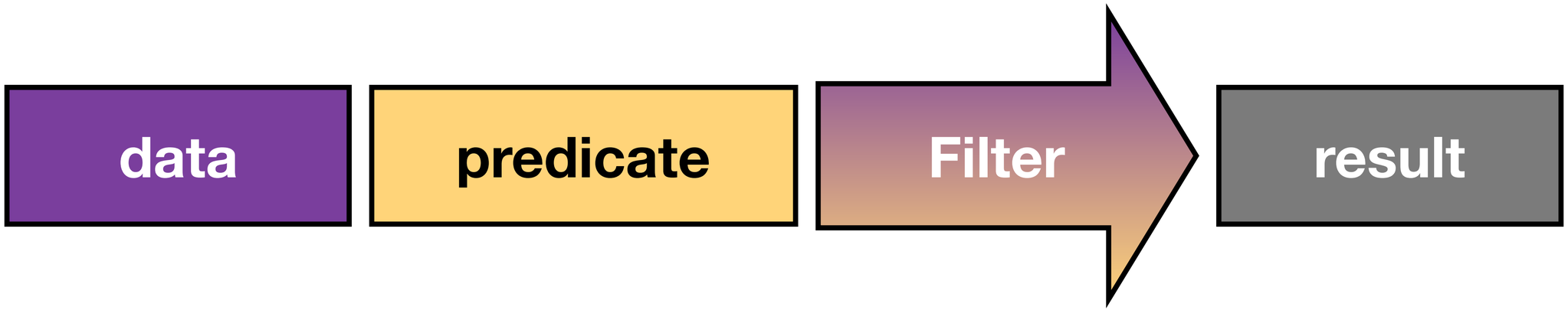
C#

# Filter

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

C#

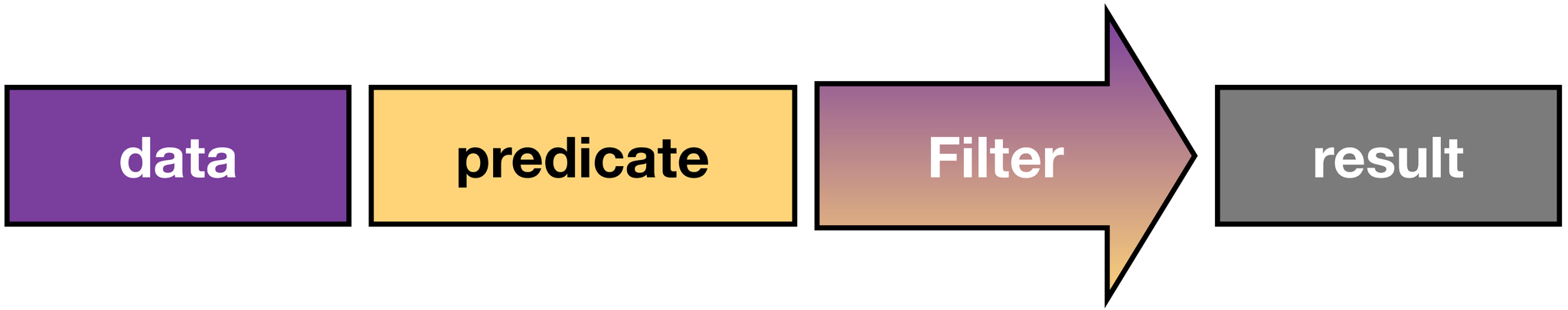
# Filter



# Filter

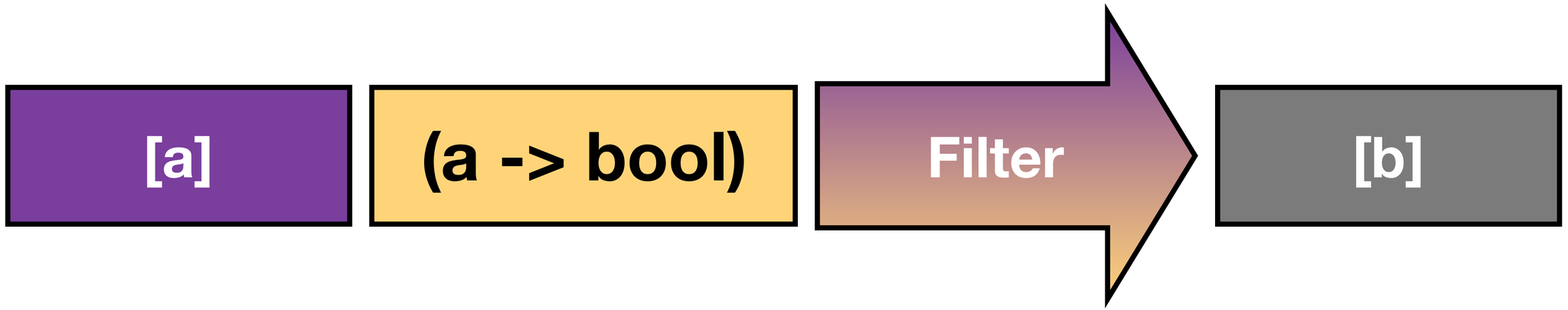
**[a] -> (a -> bool) -> [a]**

# Filter




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

# Filter



```
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)
        result.Add(item);
}
```

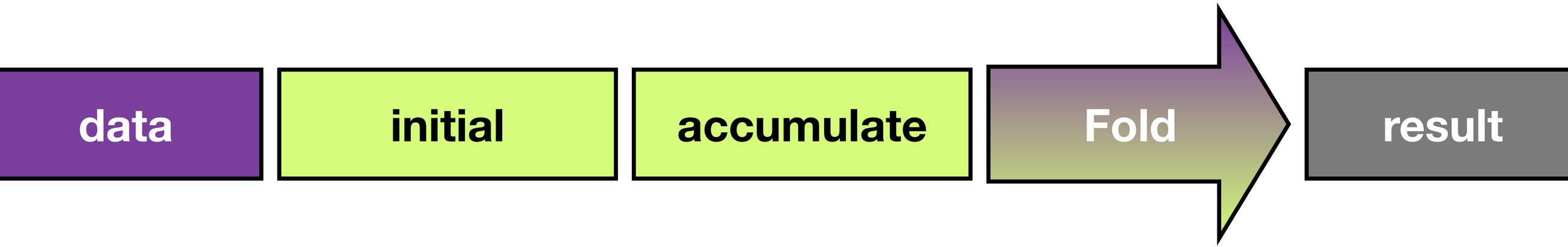
C#

# Fold

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

C#

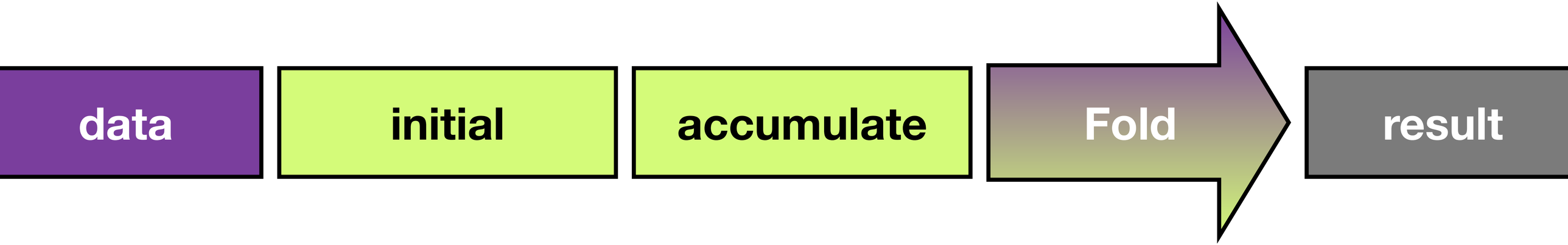
# Fold



# Fold

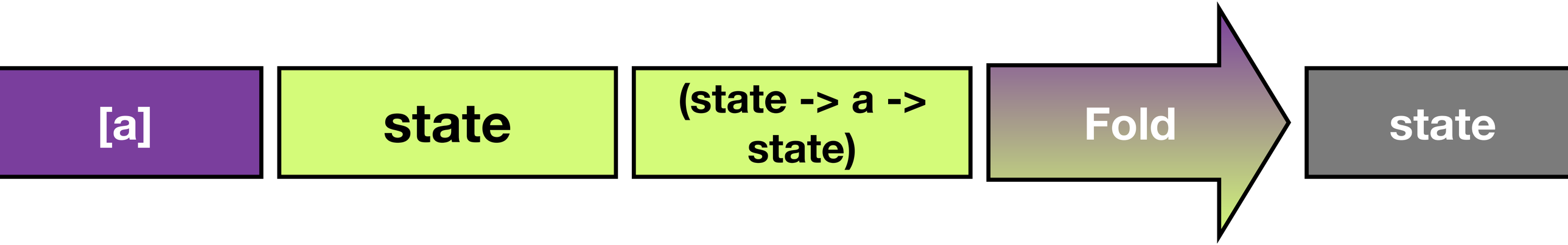
**[a] -> state -> (state -> a -> state) -> state**

# Fold




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

# Fold



```
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#

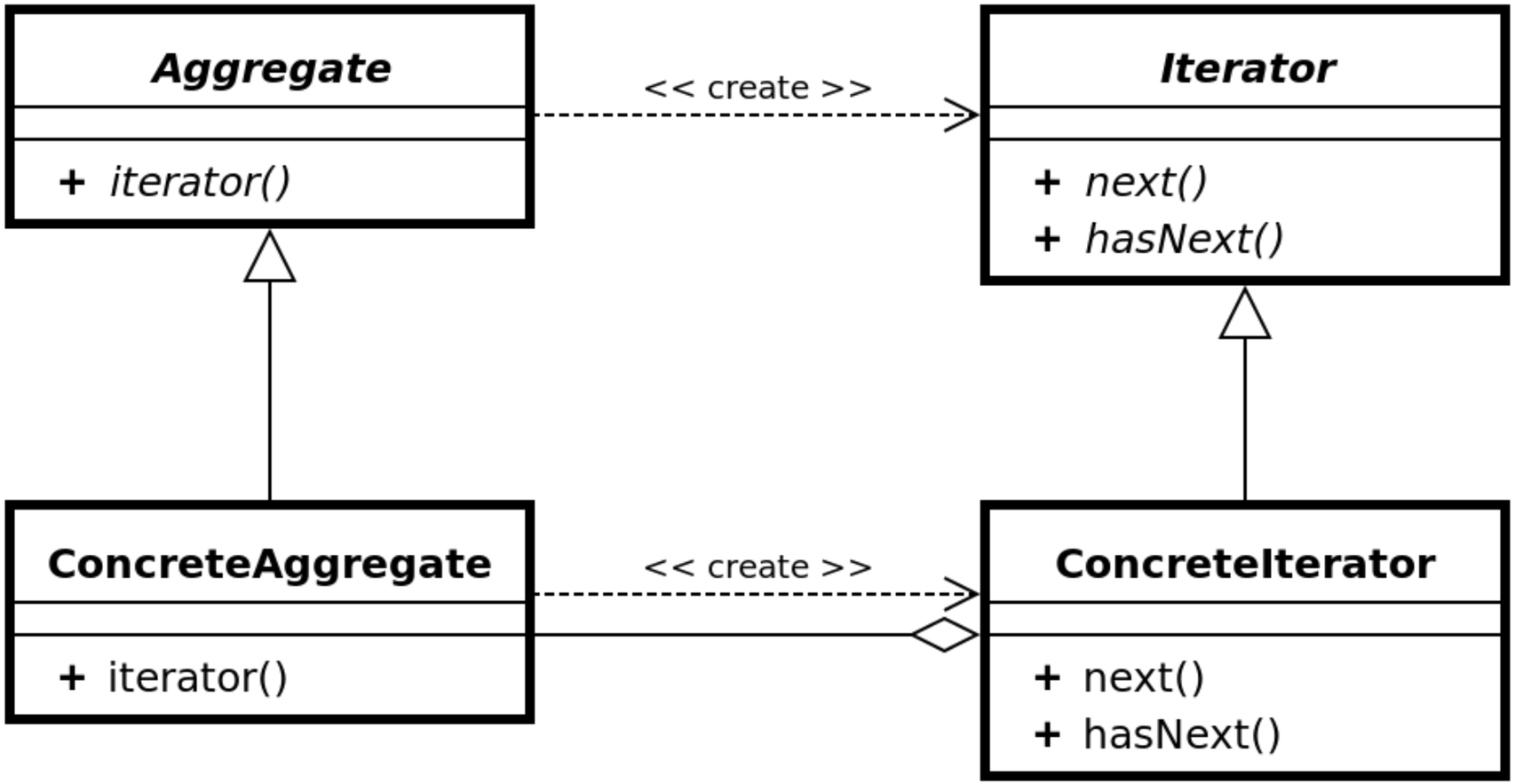
```
var result = Initial;
foreach(var item in source)
{
    result = Accumulate;
}
```

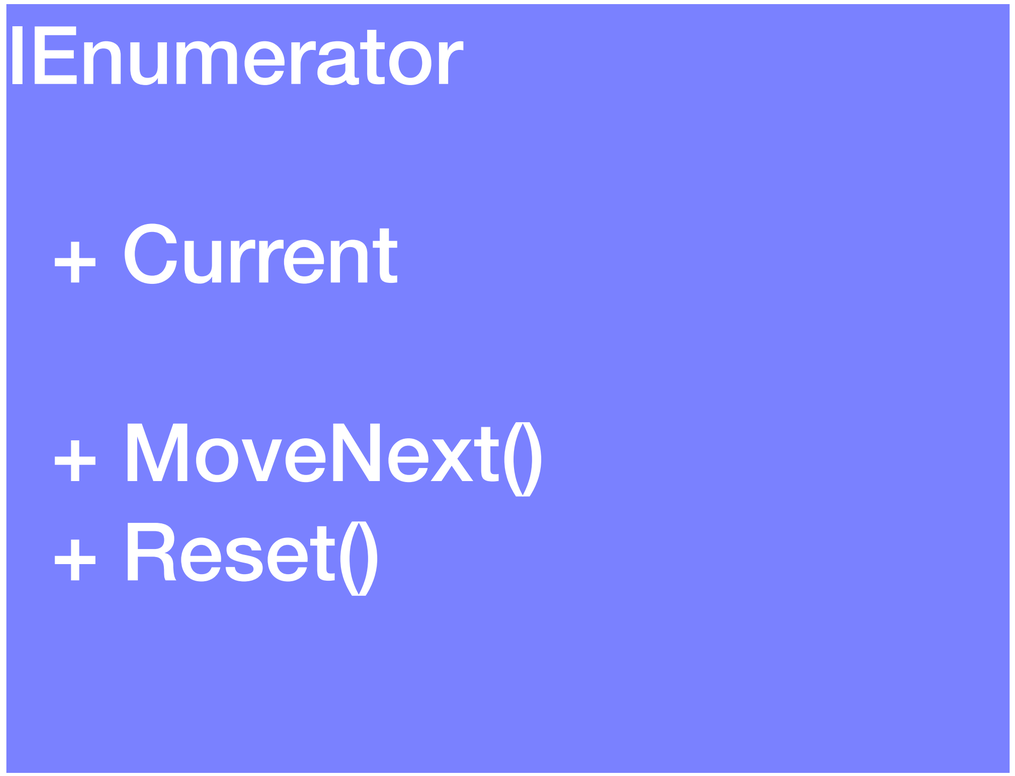
C#

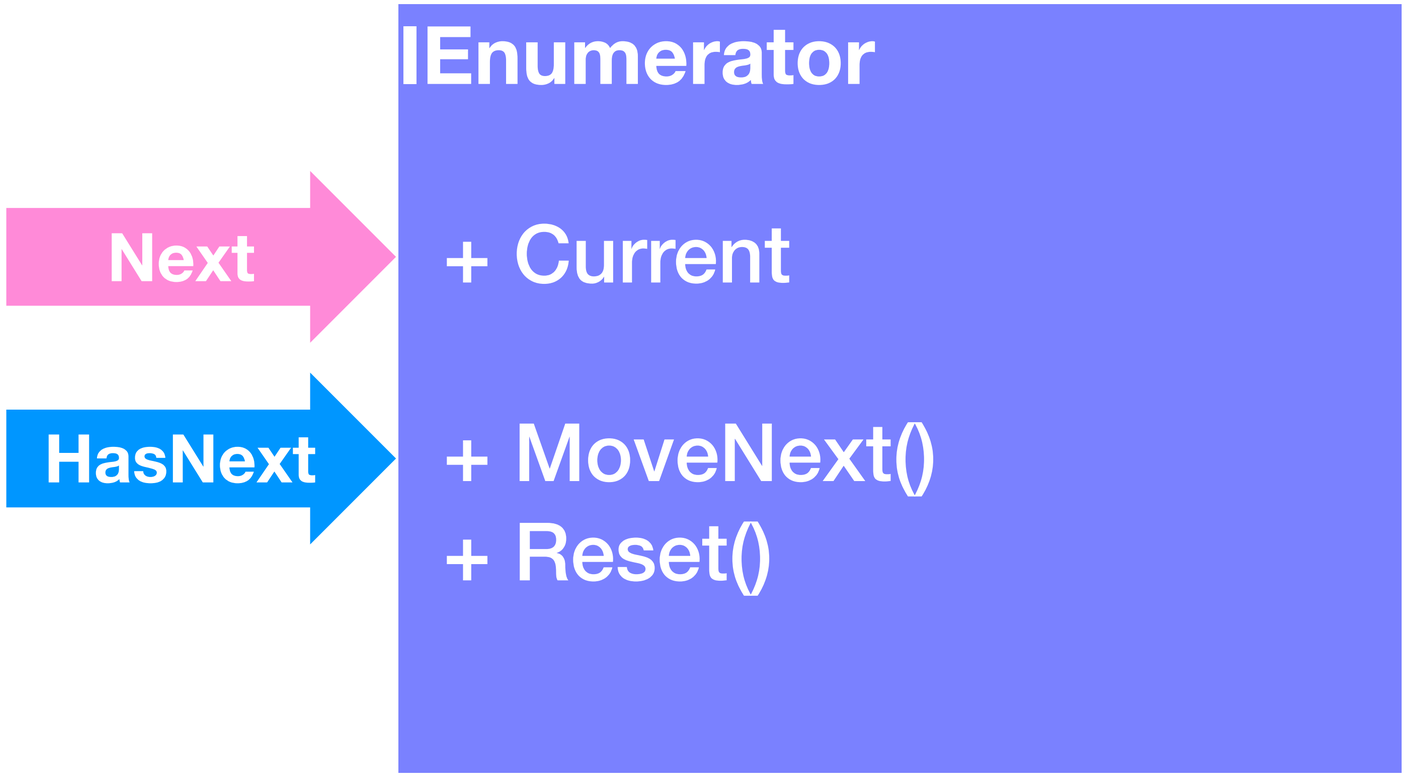
# Higher Order Functions in C#

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);
    }
}
```

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

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

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

# Map

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

C#

```
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#

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

  public override bool HasNext()
  {
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          Dispose();
          return false;
      }

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

C#

```
private sealed class SelectArrayIterator<TSource, TResult> : Iterator<TResult>, IPartition<TResult>
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  public override bool HasNext()
  {
      if (_state < 1 | _state == _source.Length + 1)
      {
          Dispose();
          return false;
      }

      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;
  Function

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

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

C#

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

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

C#

# Filter

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

C#

```
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;
    private readonly Func<TSource, bool> _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))
            {
                _current = item;
                return true;
            }
        }

        Dispose();
        return false;
    }
```

C#

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

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

    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 (Function(item))
            {
                Next = item;
                return true;
            }
        }

        Dispose();
        return false;
    }
```

C#

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

    Dispose();
    return false;
}
```

C#

# Fold

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

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;
    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,
TAccumulate seed, Function)
{
    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 = Function(result, Next);
    }


    return result;
}
```

C#

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


return result;
```

C#

# LINQ Execution

# Code

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

C#

# 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#

# 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#

# Theory

# 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 *fold* ∘ iterator *map* ∘ iterator *filter* =
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*)

# Universal Principal

# C# List Comprehension

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

C#

# JavaScript

# PowerShell

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

# F#

# 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

# Thank you

# Next Steps

# Example Code

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

# Images

- UML Iterator Pattern, By Trashtoy - My own work written with text editor., Public Domain, https://commons.wikimedia.org/w/index.php?curid=1698830

- PowerShell Logo, https://upload.wikimedia.org/wikipedia/commons/2/2f/PowerShell_5.0_icon.png

# 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