LINQ

Type safe Queries

THIS DOCUMENT COVERS

- Introduction

Prerequisites

Before we can understand LINQ queries we need to introduce some prerequisites.

- Enumerators
- Enumerables
- Foreach statements
- Iterators

ENUMERATORS

An enumerator is a read-only forward cursor over a collection of elements. We define enumerators by implementing the `IEnumerator<T>` interface.

Listing 1 Simple Enumerator

```
public class SimpleEnumerator : IEnumerator<int>
{
    public int Current => i;

    object IEnumerator.Current => i;

    public void Dispose() {}

    public bool MoveNext() => i++ < 4;

    public void Reset() =>  i = -1;

    private int i = -1;
}
```

We can use an our enumerator as follows

```
var e = new SimpleEnumerator();
```

```
while (e.MoveNext())
    WriteLine(e.Current);
```

ENUMERABLES

Enumerables produce enumerators.

Listing 2Enumerable

```
public class SimpleEnumerable : IEnumerable<int>
{
    public IEnumerator<int> GetEnumerator()
    {
          return new SimpleEnumerator();
    }

    IEnumerator IEnumerable.GetEnumerator()
    {
          return GetEnumerator();
    }
}
```

Enumerators are consumed by foreach statements

```
var e = new SimpleEnumerable();

foreach (var element in e)
    WriteLine(e);
```

FOREACH STATEMENTS

Foreach statements consume enumerables. If the compiler sees a foreach statement like this

Listing 3Foreach Statements

```
var sequence = new List<int>( new [] {1,2,3});

foreach (var element in sequence)
{
    WriteLine(element);
}
```

It generates something along the lines of this

```
using (IEnumerator<int> en = sequence.GetEnumerator())
{
    while (en.MoveNext())
          WriteLine(en.Current);
}
```

ITERATORS

Iterators provide an elegant means of creating enumerators and enumerables. The following code uses iterators to produce an enumerable whose enuerators walk over the first n items in the fibonacci sequence from 0 to n-1

Listing 4 Iterators

```
IEnumerator<int> GetFibonacci(int numEntries)
{
    for (int i = 0, current = 0, next = 1, nextnext = 1;
 i < numEntries; i++)
    {
          yield return current;

          nextnext = current + next;
          current = next;
          next = nextnext;
    }
}
```

Basics

LINQ enables one to write type-safe queries on enumerable collections. The basic concepts are

- Sequence — Any collection that implements `IEnumerable<T>`
- Element — A single constituent of the collection
- Query operator — A method that transforms one sequence into another
- Query — A combination of query operators that performs a transform

The following piece of code shows all four together

Listing 5 Linq Basics

```
// 1. A sequence is any collection implementing IEnumerable<T>
IEnumerable<int> sequence = new int[] {0,1,2,3,4};

// 2. An element is a single constituent of the sequence
foreach (var element in sequence)
    WriteLine(element);

// 4. Queries combine query operators
IEnumerable<int> output = sequence
    .Where(s => s%2 ==0)
    .Select(s => s*s);
…

// 3. Query operators transform sequences
public static class QueryOperators
{
    public static IEnumerable<T> Where<T>(this IEnumerable<T> input,
           Func<T,bool> predicate)
    {
          foreach (var element in input)
                if ( predicate(element))
                      yield return element;
    }

public static IEnumerable<TOut> Select<TOut,TIn>(this IEnumerable<TIn>
input, Func<TIn,TOut> trans)
    {
          foreach (var element in input)
                yield return trans(element);
    }
}
```

Query operators are implemented as extension methods that take an enumerable argument representing an input sequence and a delegate that applies some transformation to create an output sequence. As such query operators are easily composed into queries. Most query operators are not executed when they are constructed. Instead they are executed when they are enumerated. Delayed or lazy execution provides the following benefits.

- Decouples construction from execution
- Allows one to construct a query in multiple steps
- One can re-evaluate a query by enumerating it again

> **EXCEPTIONS TO LAZY EXECUTION**
>
> The following operators are exceptions which cause immediate execution
>
> Single element or scalar values such as *First* or *Count*, *ToArray*, *ToList*, *ToDictionary*, *ToLookup*

How LINQ works

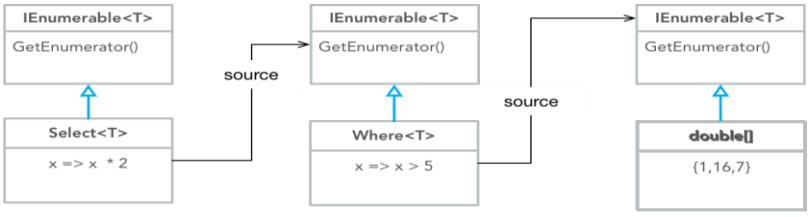
We consider three aspects of the following query

1. Static structure of the decorator after query instantiation
2. Data Flow during query execution
3. Control flow during execution (Sequence diagram)

Consider the following simple LINQ query

```
var input = new [] {1,16,7};
var output = input.Where(i => i > 5)
                  .Select(i => i * 2);
```

Figure 1 Static Structure On Creation



Listing 6 Data Flow On Execution

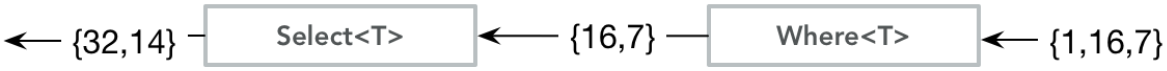
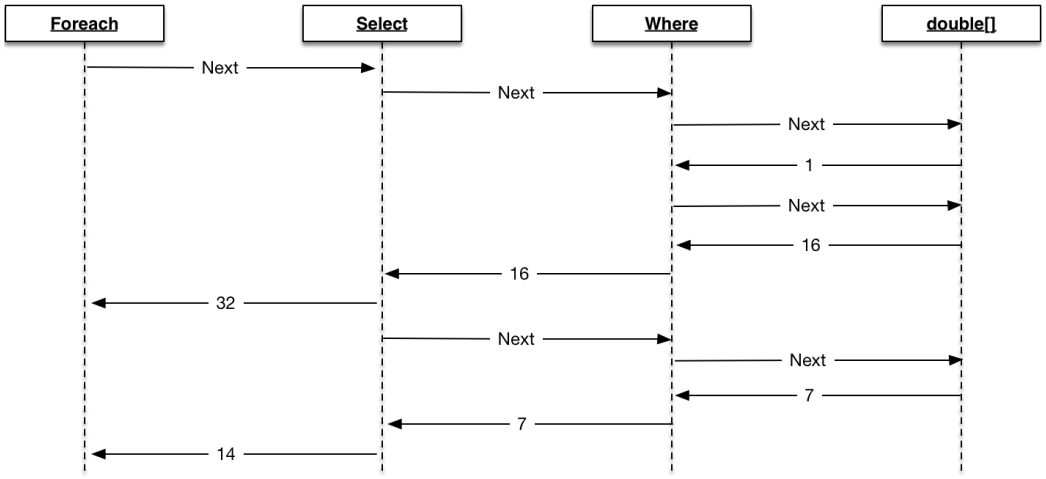


Figure 2 Control Flow On Execution



Operator List

Where

Listing 7 Where Implementation

```
public static IEnumerable<T> Where<T>(this IEnumerable<T> source,
          Func<T,bool> predicate)
{
    foreach (var element in source)
          if (predicate(element))
                yield return element;
}

public static IEnumerable<T> Where<T>(this IEnumerable<T> source,
    Func<T,int, bool> predicate)
{
    int i = 0;
    foreach (var element in source)
          if (predicate(element,i++))
                yield return element;
}
```

Listing 8 Where examples

```
IEnumerable<string> sanat = new[] { "Äiti", "Suomi", "Ranta", "Isi",
"Sisu", "Edessä" };

// Example one basic filtration {"Äiti", "Suomi","Isi","Sisu""}
IEnumerable<string> os1 = sanat.Where(e => e.Contains("i"));
WriteLine(os1); //

// Example two Index Filtration {"Äiti", "Ranta","Sisu""}
IEnumerable<string> os2 = sanat.Where((e, i) => i % 2 == 0);
```

ToDictionary/ToArray/ToList/ToLookup

ToArray and ToList are self-explanatory. A lookup is superficially like a dictionary, but it is not the same. It allows multiple values to share the same key. So, it generates a structure that maps from key to a grouping.

Take, Skip, TakeWhile, SkipWhile, Distinct

Listing 9Take,TakeWhile,SkipWhile,Distinct examples

```
IEnumerable<string> sanat = new[] {"Äiti",
"Suomi","Ranta","Isi","Sisu","Edessä"};

WriteLine(sanat.Take(2)); // {"Äiti", "Suomi"}
WriteLine(sanat.Skip(2)); // {"Ranta","Isi","Sisu","Edessä"}

WriteLine(sanat.Take(2)); // {"Äiti", "Suomi"}
WriteLine(sanat.Skip(2).Take(2)); // {"Ranta","Isi"}
WriteLine(sanat.Skip(4).Take(2)); // {"Sisu","Edessä"}

WriteLine(sanat.TakeWhile(e => e.Contains("i"))); // {"Äiti", "Suomi"}
WriteLine(sanat.SkipWhile(e => e.Contains("i"))); //
{"Ranta","Isi","Sisu","Edessä"}

WriteLine(new[] { "Moi", "MOI",
"MoI"}.Distinct(StringComparer.InvariantCultureIgnoreCase)); // {Moi}
```

Select

IMPLEMENTING SELECT

Listing 10 Select Implementation

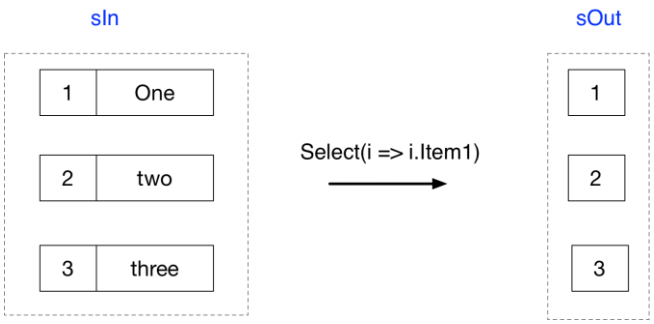
```
public static IEnumerable<TResult> Select<TIn,TResult>(this
IEnumerable<TIn> source, Func<TIn,TResult> project)
{
    foreach (var element in source)
          yield return project(element);
}

public static IEnumerable<TResult> Select<TIn,TResult>(this
IEnumerable<TIn> source, Func<TIn,int, TResult> project)
{
    int i = 0;
    foreach (var element in source)
          yield return project(element,i++);

}
```

THE BASIC CASE

Select is a projection operator. It maps input sequences onto output sequences. The output sequences have the same number of elements as the input sequences.

Listing 11 Select – Basic Projection

```
IEnumerable<(int, string)> sIn =
      new[] { (1, "one"), (2, "two"), (3, "three") };

// Projecting using fluent syntax
IEnumerable<int> sOut = sIn.Select(i => i.Item1);
```

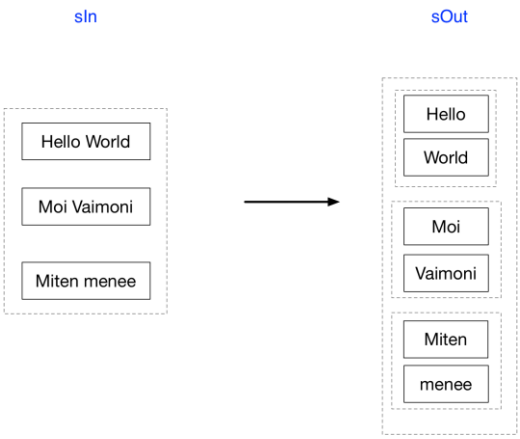


CORRELATED SUBQUERIES

We can insert subqueries inside select clauses. If the subquery references the elements of the outer query we call the query a correlated sub query.

Listing 12 Correlated Subquery

```
IEnumerable<string> sIn =
    new[] { "Hello World", "Moi Vaimoni", "Miten menee" };

// Correlated Subquery in fluent syntax
IEnumerable<IEnumerable<string>> sOut =
    sIn
          .Select(i => i
                .Split()
                .Select(j => j));
```

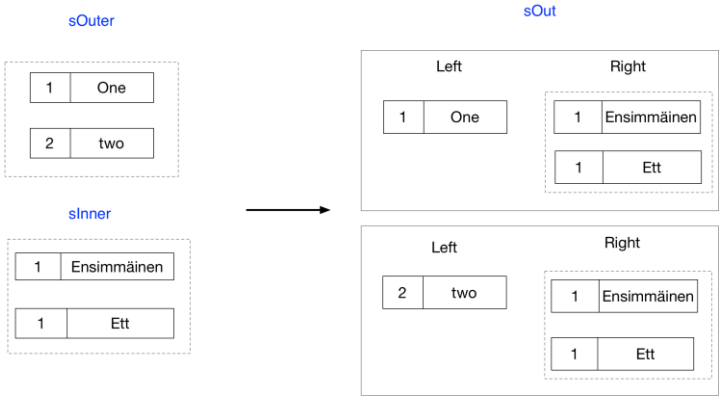


CROSS PRODUCT (UN-FLATTENED)

Uncorrelated queries mean when the sub query does not reference the elements of the outer query. Using select this generates a kind of hierarchical cross product type result. It is not quite a cross product as per a relational database as there is no flattening

Listing 13 Uncorrelated Subqueries - Cross Product

```
IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
IEnumerable<(int, string)> sInner
          =new[] { (1, "Ensimmäinen"), (1, "Ett") };


IEnumerable<((int, string), IEnumerable<(int, string)>)> sOut2 =
    sOuter.Select(i => (Left: i, Right: sInner.Select(j => j)));
```

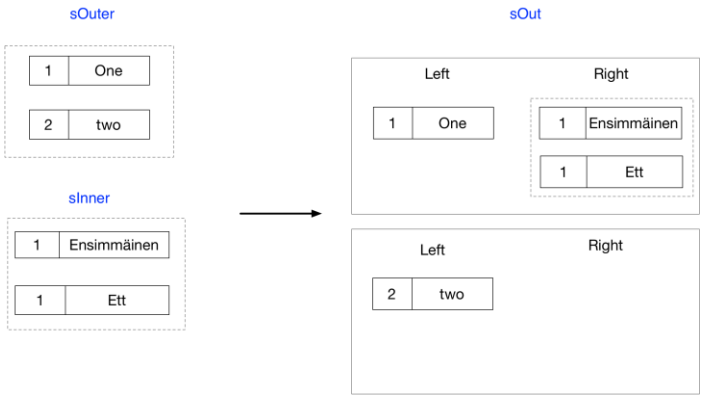


LEFT OUTER JOIN (UN-FLATTENED)

The following code shows how to perform a left outer join style query using select. Unlike a relational database join the data in not flattened. We will show how to flatten the data in the section on SelectMany. This is an inefficient way to perform a left equi-join. In the section on GroupJoin we will show how to achieve this result in a more efficient means using GroupJoin which uses a lookup internally to prevent multiple linear traversals of the inner sequence.

Listing 14 Left Outer Join

```
IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
IEnumerable<(int, string)> sInner = new[] { (1, "Ensimmäinen"), (1, "Ett") };


IEnumerable<((int, string) Left, IEnumerable<(int, string)> Right)> sOut
     = sOuter.Select(outerEl =>
     {
             return (Left: outerEl,
                     Right: sInner.Where(innerEl => outerEl.Item1 == innerEl.Item1));
     });
```



SelectMany

IMPLEMENTING SELECTMANY

```
public static IEnumerable<TR> SelectMany<TS, TR>(
      this IEnumerable<TS> source,
      Func<TS, IEnumerable<TR>> project)
{
  foreach (var element in source)
      foreach (var subelement in project(element))
            yield return subelement;
}

public static IEnumerable<TR> SelectMany<TS,TC, TR>(
  this IEnumerable<TS> source,
  Func<TS, IEnumerable<TC>> collSelector,
  Func<TS, TC, TR> resultSelector)
{
  foreach (var sourceElement in source)
  {
      foreach (var subelement in collSelector(sourceElement))
      {
            yield return resultSelector(sourceElement, subelement);
      }
  }
}

public static IEnumerable<TResult> SelectMany<TIn, TResult>(
  this IEnumerable<TIn> source,
  Func<TIn, int, IEnumerable<TResult>> project)
{
  int i = 0;
  foreach (var element in source)
      foreach (var subelement in project(element, i++))
            yield return subelement;
}
```

SelectMany can be used to carry out the following

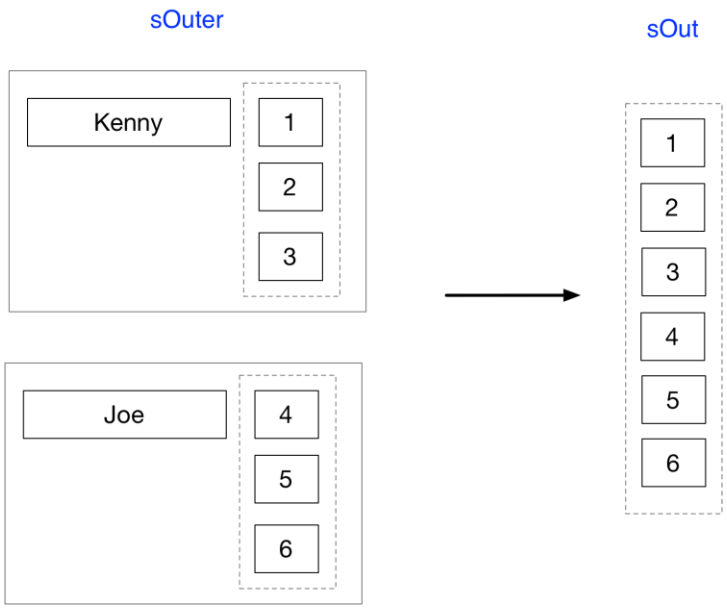
- Subsequence concatenation / flattening
- Cross Joins
- Non-equi joins
- Inner joins
- Left outer joins

We now consider each in turn

FLATTENING SUBSEQUENCE

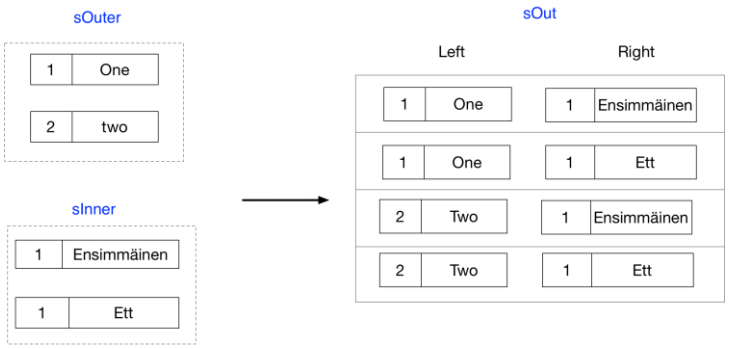
Listing 15 SelectMany - Flattening subsequence

```
IEnumerable<(string, int[])> sIn =
    new[] { ("Kenny", new[] { 1, 2, 3 }), ("Joe", new[] { 4, 5, 6 }) };

// Flattening/Concatenating subsequence using SelectMany - Fluent Syntax
IEnumerable<int> seq2 = sIn
    .SelectMany(s => s.Item2);
```



CROSS JOINS

```
IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
IEnumerable<(int, string)> sInner = new[] { (1, "Ensimmäinen"), (1, "Ett") };

IEnumerable<((int, string), (int, string))> sOut = sOuter
       .SelectMany(elOut => sInner.Select(elIn => (Left:elOut, Right:elIn)));
```



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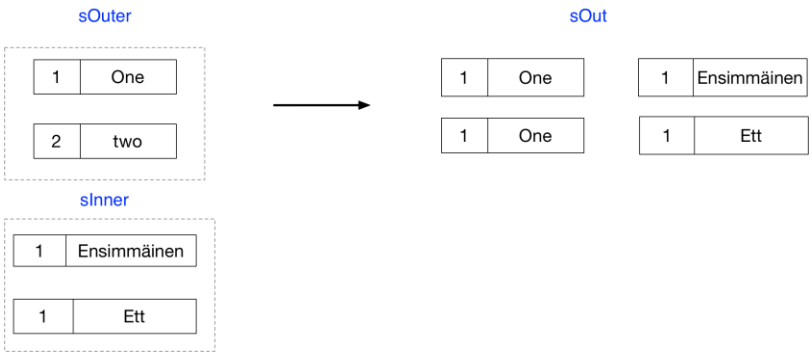
INNER JOIN (FLATTENED)

The following performs an inner join using SelectMany. This code is inefficient as it requires a complete traversal of the inner sequence for each element of the outer sequence

```
IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
IEnumerable<(int, string)> sInner = new[] { (1, "Ensimmäinen"), (1,
"Ett") };

var sOut = sOuter.SelectMany(outerEl =>
    sInner
          .Where(innerEl => outerEl.Item1 == innerEl.Item1)
          .Select(inner => (outerEl, inner)));
```



Join

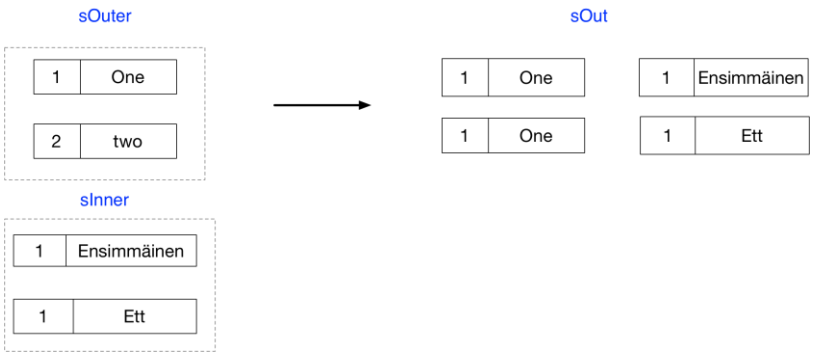
Join carries out efficient, flattened inner joins on local object sequences

Implementing Join

```
public static IEnumerable<TResult> Join<TOuter, TInner, TKey, TResult>(
  this IEnumerable<TOuter> outer,
  IEnumerable<TInner> inner,
  Func<TOuter, TKey> outerKeySelector,
  Func<TInner, TKey> innerKeySelector, Func<TOuter,
  TInner, TResult> resultSelector)
{
  var lookup = inner.ToLookup(innerKeySelector);

  foreach (var outerEl in outer)
    foreach (var innerEl in lookup[outerKeySelector(outerEl)])
       yield return resultSelector(outerEl, innerEl);
}
```

Inner Join (Flattened)

```
  IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
  IEnumerable<(int, string)> sInner = new[] { (1, "Ensimmäinen"), (1,
  "Ett") };

  IEnumerable<((int, string), (int, string))> sOut =
      sOuter.Join(
            sInner,
            outerEl => outerEl.Item1,
            innerEl => innerEl.Item1,
            (outerEl, innerEl) => (Left:outerEl, Right:innerEl));
```



GroupJoin

GroupJoin can be used to perform efficient inner and left-outer joins on local collections

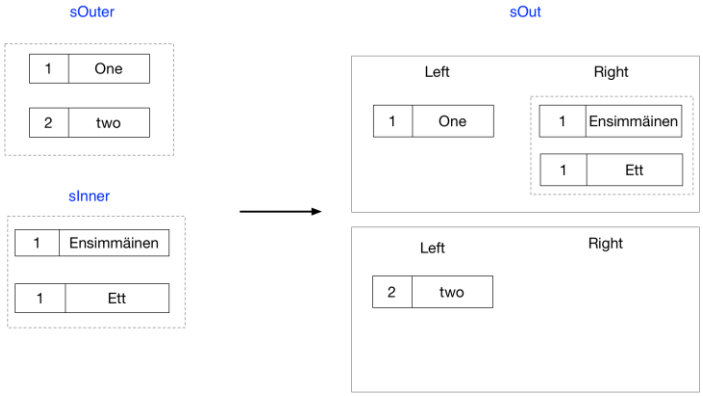
IMPLEMENTING GROUPJOIN

```
public static IEnumerable<TRes> GroupJoin<TRes, TOuter, TInner, TKey>(
    IEnumerable<TOuter> sOuter,
    IEnumerable<TInner> sInner,
    Func<TOuter, TKey> outerKeySelector,
    Func<TInner, TKey> innerKeySelector,
    Func<TOuter, IEnumerable<TInner>, TRes> resultSector
)
{
    ILookup<TKey, TInner> lookup =
          sInner.ToLookup(innerEl => innerKeySelector(innerEl));

    foreach (TOuter outerEl in sOuter)
    {
          // Convert the element from the outer sequence to its key
          TKey outerElKey = outerKeySelector(outerEl);

          // Use the outer element key to lookup all matching
          // inner sequence elements using the lookup for efficiency
          IEnumerable<TInner> matchingInnerEls = lookup[outerElKey];

          // Map the current outer element, a sequence of matching
          // inner elementsto a single result element.
          TRes result = resultSector(outerEl, matchingInnerEls);
          yield return result;
    }
}
```

LEFT OUTER JOIN (UN-FLATTENED)

This is much more efficient than using select as the

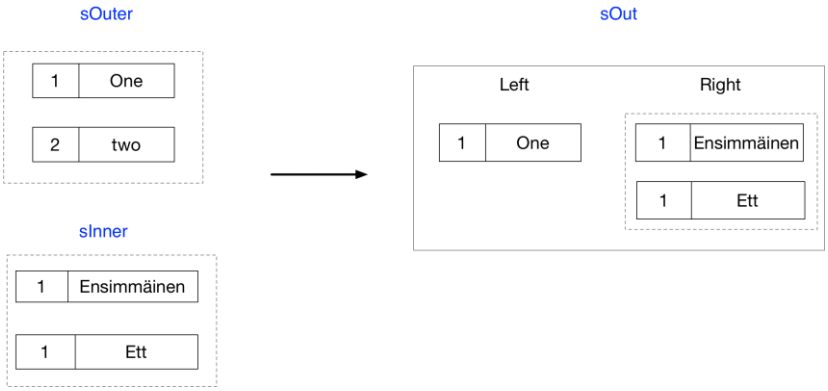
```
IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
IEnumerable<(int, string)> sInner = new[] { (1, "Ensimmäinen"), (1, "Ett") };

IEnumerable<((int, string), IEnumerable<(int, string)>)> sOut =
       sOuter.GroupJoin(
       sInner,
       outerEl => outerEl.Item1,
       innerEl => innerEl.Item1,
       (outerEl, innerMatches) => (Left: outerEl, RightMatches: innerMatches));
```



INNER JOIN (UN-FLATTENED)

To perform an inner join we filter the results of the previous section

```
IEnumerable<(int, string)> sOuter = new[] { (1, "one"), (2, "two"), };
IEnumerable<(int, string)> sInner = new[] { (1, "Ensimmäinen"), (1, "Ett") };

IEnumerable<((int, string), IEnumerable<(int, string)>)> sOut =
  sOuter.GroupJoin(
       sInner,
       outerEl => outerEl.Item1,
       innerEl => innerEl.Item1,
       (outerEl, innerMatches) => (Left: outerEl, RightMatches: innerMatches))
       .Where(resultEl => resultEl.RightMatches.Any())
```



Left Outer Join Flattened

Join enables us to do flattened inner joins. Group Join givens us hierarchical left outer joins. If we want to obtain flat left outer joins we need to combine GroupJoin with SelectMany as follows.

```
IEnumerable<(int, string)> sOuter = new[]
     { (1, "one"), (2, "two"), (3, "three"), (4, "four") };

IEnumerable<(int, string)> sInner = new[]
     { (1, "Ensimmäinen"), (1, "Ett"), (2, "Kaksi"), (2, "Tva"), (3, "Kolme") };

// Group Join gives us a hierarchical left outer join
IEnumerable<((int, string) OuterEl, IEnumerable<(int, string)> InnerEls)>
     leftOuterHierarchical = sOuter.GroupJoin(
            sInner,
            outerEl => outerEl.Item1,
            innerEl => innerEl.Item1,
            (outEl, innerMatches) => (OutEl: outEl, InEls: innerMatches));

// SelectMany flattens.
IEnumerable<(string, string)> outSeq = leftOuterHierarchical
     .SelectMany(hierarchicalEl => hierarchicalEl.InnerEls.DefaultIfEmpty(),
            (hierarchicalEl, innerEl) =>
            (hierarchicalEl.OuterEl.Item2, innerEl.Item2));
```

OrderBy/ThenBy/OrderByDescencing/ThenByDescending

```
string[] seq = {"Four","Two", "One","Three"};

// {Two,One,Four,Three}
seq.OrderBy(s => s.Length);

// {Three,Four,Two,One}
seq.OrderByDescending(s => s.Length);

// {One,Two,Four,Three}
seq.OrderBy(s => s.Length).ThenBy(s => s);

// {Three,Four,Two,One}
seq
    .OrderByDescending(s => s.Length)
    .ThenByDescending(s => s)
```

Aggregation

Aggregation can lead to some surprising results if we do not use a seed. Especially where we want to parallelize, we need a function that can combine sub results which is both commutative and associative

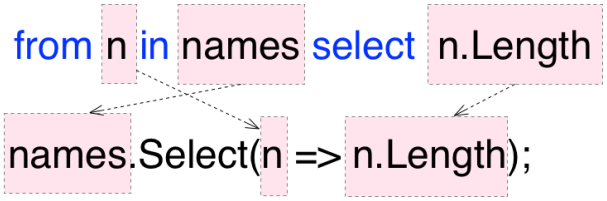
```
int[] s = new[] {2,3,4};

// 27 rather than 29
s.Aggregate ((x, y) => x+y*y).Dump();

// Fix with seed
s.Aggregate (0,(x, y) => x+y*y).Dump();

// For parallelisation we often specify a separate function
// for combining intermediate results. This function must be
// assocaite and commutative
s.AsParallel().Aggregate (()=>0,(a,e) => a+e*e,(a1,a2) =>
a1+a2,a=>a).Dump();
```

Query Syntax

LINQ also supports an alternative syntax called query syntax. Query syntax supports only a subset of the LINQ operators.

Range variables

The following shows how a very simple query syntax query is mapped by the compiler to a fluent query. Notice how the range variable **n**, defined in the query, maps to the left-hand side of the lambda expression in the generated fluent query. The expression to the right of select maps to the right-hand side of the lambda in the fluent query



Transparent identifiers

Let allows a query syntax query to introduce a second range variable which keeping the original range variable in scope. The following query uses the let keyword to introduce a new range variable.

```
var names = new[] { "Wren", "Bill", "Bob", "Will" };

IEnumerable<(char,string)> s1 =
    from  n in names
    let   c = n[0]
    orderby c
    select  (c,n);
```

Notice how the select clause can now reference two range variables. If we consider how we might translate this to fluent syntax we can see the compiler is doing some extra work for us.

```
IEnumerable<(char,string)> s2 =
    names
          .Select(n => new {c=n[0], n=n})
          .OrderBy(x => x.c)
          .Select(x => (x.c,x.n));
```

Notice how we had to use an anonymous type to support the extra range variable **c**. This is what the compiler does, and it is known as transparent identifiers.

Ordering

The following shows how to implement ordering using query syntax

```
IEnumerable<string> s1 =
    from  n in names
    orderby n.Length,n
    select  n.ToUpper();
```

we can map this to fluent syntax as follows

```
IEnumerable<string> s2 =
    names
    .OrderBy(n => n.Length)
    .ThenBy(n => n)
    .Select(n => n.ToUpper());
```

If we want to order by in descending order we can use the following

```
IEnumerable<string> s3 =
    from n in names
    orderby n.Length descending, n descending
    select n.ToUpper();
```

SelectMany

We can generate a SelectMany in query syntax by using two from clauses.

```
IEnumerable<char> q1 =
    from  n in names
    from  c in n
    select  c;
```

The corresponding fluent syntax is as follows

```
IEnumerable<char> f1 =
    names.SelectMany(n => n);
```

If, however we have anything after the select clause in the query expression the compiler uses a transparent identifier to make both range range variables available for subsequent queries

```
IEnumerable<char> q2 =
    from n in names
    from c in n
    where n == "Kenny" && c == 'n'
    select Char.ToUpper(c);
```

The following shows how we can do this with anonymous types as the compiler might with transparent identifiers

```
IEnumerable<char> f2 =
    names
          .SelectMany(n => n, (n, c) => new {n,c})
          .Where(x => x.n=="Kenny" && x.c=='n')
          .Select(x => Char.ToUpper(x.c));
```

Join

We can join two sequences using the keyword join as follows

```
var s1 =
    from ol in outerSeq
    join il in innerSeq on ol.Item1 equals il.Item1
    select (ol.Item2,il.Item2);
```

This can be translated into a fluent query as follows. Notice the final select (projection) is mapped directly to the projection function argument of Join

```
var f1 = outerSeq.Join(
    innerSeq,
    ol=>ol.Item1,
    il=>il.Item1,
    (ol,il) => (ol.Item2,il.Item2));
```

If, however we have anything after the select clause in the query expression the compiler uses a transparent identifier to make both range variables available for subsequent queries

```
var s2 =
    from ol in outerSeq
    join il in innerSeq on ol.Item1 equals il.Item1
    where ol.Item2 == "one" && il.Item2 == "Ett"
    select (ol.Item2, il.Item2);
```

The following shows how we can express this using anonymous types in a similar fashion to what the compiler would do with transparent identifiers.

```
var f2 = outerSeq
    .Join(
          innerSeq,
          ol => ol.Item1,
          il => il.Item1,
          (ol, il) => new {ol,il})
    .Where(x=>x.ol.Item2 == "one" && x.il.Item2 == "Ett")
    .Select(x => (x.ol.Item2, x.il.Item2));
```

GroupJoin

We can specify a group join using query syntax as follows. We specify an into clause directly after the join clause

> **INTO AND GROUPJOIN OR QUERY CONTINUATION**
>
> If a query syntax query contains an `into` clause directly after a `join` clause it is translated as a `GroupJoin`. After `select` or `group` it causes query continutation which is quite different

```
var s1 =
    from ol in outerSeq
    join il in innerSeq on ol.Item1 equals il.Item1
    into matches
    select (ol.Item2,matches);
```

We can translate this into fluent syntax as follows.

```
var f1 = outerSeq.GroupJoin(
    innerSeq,
    ol=>ol.Item1,
    il=>il.Item1,
    (ol,il) => (ol.Item2,il));
```

As with join if there is only a simple select after the group join the select is implemented simply as the projection expression passed to the GroupJoin operator. If there is anything else then the compiler has to use a transparent identifier.

```
var q2 =
    from ol in outerSeq
    join il in innerSeq on ol.Item1 equals il.Item1
    into matches
    where ol.Item2 == "one" && matches.Count() == 2
    select (ol.Item2, matches);
```

The following shows how we can express this using anonymous types in a similar fashion to what the compiler would do with transparent identifiers.

```
var f2 = outerSeq
    .GroupJoin(
          innerSeq,
          ol => ol.Item1,
          il => il.Item1,
          (ol, matches) => new {ol,matches})
    .Where(x=>x.ol.Item2 == "one" && x.matches.Count() == 2)
    .Select(x => (x.ol.Item2, x.matches));
```

Left Outer Join

A left outer join is a little bit tricky. A join performs flattening but gives us an inner join. A group join gives us outer join like functionality without flattening. The solution is to use groupjoin together with a select many to flatten. The query syntax is as follows

```
IEnumerable<(string, string)> q1 =
    from outerEl in outerSeq
    join innerEl in innerSeq on outerEl.Item1 equals innerEl.Item1
    into matches
    from e in matches.DefaultIfEmpty()
    select default((int, string)).Equals(e)
          ? (outerEl.Item2, "")
          : (outerEl.Item2, e.Item2);
```

And the fluent query is as follows. Note we add a function to simply the result generation and default check.

```
(string, string) ResGenFunc((int, string) outerEl, (int, string) innerEl)
=>
    default((int, string)).Equals(innerEl)
          ? (outerEl.Item2, "")
          : (outerEl.Item2, innerEl.Item2);

IEnumerable<(string, string)> f1 =
    outerSeq
          .GroupJoin( innerSeq,
                          oel => oel.Item1,
                          inel => inel.Item1,
                          (oel, inEls) => inEls
                                                .DefaultIfEmpty()
                                                .Select(innerEl =>
ResGenFunc(oel, innerEl)))
          .SelectMany(el => el);
```

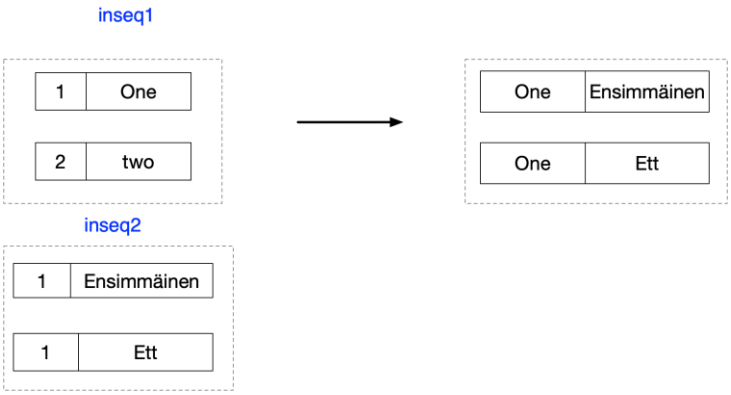
Joining

Implementing Join

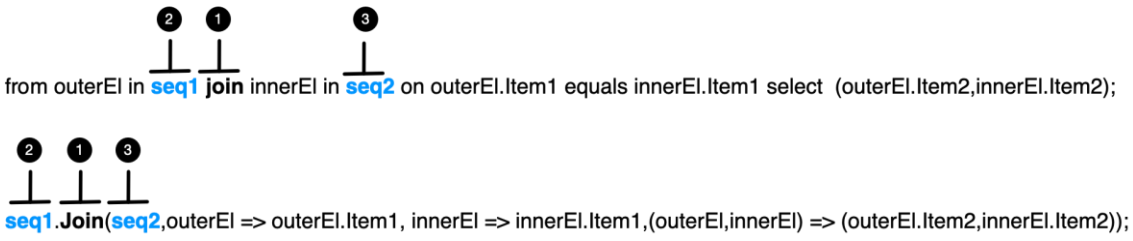
```
public static IEnumerable<TResult> Join<TOuter, TInner, TKey, TResult>(
  this IEnumerable<TOuter> outer,
  IEnumerable<TInner> inner,
  Func<TOuter, TKey> outerKeySelector,
  Func<TInner, TKey> innerKeySelector, Func<TOuter,
  TInner, TResult> resultSelector)
{
  var lookup = inner.ToLookup(innerKeySelector);

  foreach (var outerEl in outer)
    foreach (var innerEl in lookup[outerKeySelector(outerEl)])
       yield return resultSelector(outerEl, innerEl);
}
```

INNER JOINS

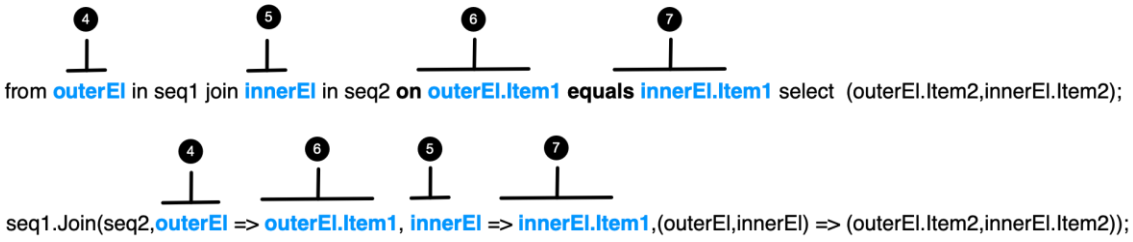
```
(int, string)[] outerSeq = { (1, "one"), (2, "two"), };
(int, string)[] innerSeq = { (1, "Ensimmäinen"), (1, "Ett") };

var res1 =
    from outer in outerSeq
    join inner in innerSeq
    on outer.Item1 equals inner.Item1
    select (outer.Item2,inner.Item2);
```



Let us consider how the query with a join is mapped to the operator Enumerable.Join. First consider the sequences and the contextual keyword join. The keyword join instructs the compiler to invoke the `Join` operator on the sequence defined in the expression before the `join` keyword to the expresion defined after the `in` keyword.

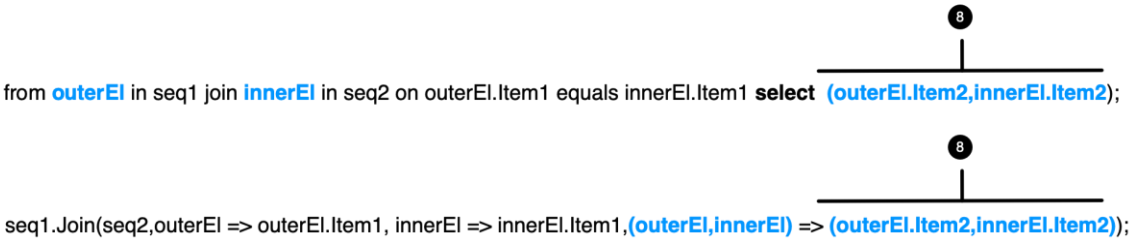


Then the keywords `on` and `equals` are used to define the keys of the outer an inner sequence respectively



> The order of the key selectors is important. For the first key selector after the on keyword only the range varaible of the outer sequence is in scope. For the second key selector only the range variable of the second sequence is in scope.

Finally we consider how the query expression maps to the final projection function parameter of the join operator. In our simple query expression there is nothing after the join other than a simple select. In this case the selet is directly mapped into the selector function



In the case where we have something other than a simple select after the join the compiler has to work some **transparent idenfier** magic to make sure the elements from both the inner and outer sequences are available to operators after the join.

Example One

Listing 16Query Syntax

```
var names = new List<String> (new[] { "Wren", "Bill", "Bob", "Will" });

IEnumerable<string> s1 =
    from  n in names
    where n.StartsWith("W")
    orderby n
    select  n.ToUpper();
```

Listing 17 Fluent Syntax

```
IEnumerable<string> s2 = names
    .Where(n => n.StartsWith("W"))
    .OrderBy(n => n)
    .Select(n => n.ToUpper());
```

Example Two

This example shows a situation where query syntax is more elegant than the corresponding fluent syntax query. We have two range variabes in the query syntax query which remain in scope for subsequent clauses. Note how the orderby and select access both range variables. In this example we are flattening

Listing 18Query Syntax

```
IEnumerable<string> parit = new[] { "Minun äiti", "Suomi on Mun", "Iso
ranta", "Sanan isi", };

// A SelectManyQuery which wants to access both the outer elements and the
// flattened inner elements can be easier to write in query syntax.

from p in parit
from s in p.Split()
where s.Contains("u")
orderby p,s
select $"{p} -> {s}"
```

Listing 19 Fluent Syntax

```
parit
  .SelectMany(pari => pari.Split().Select(sana => ( pari, sana)))
  .Where( x=> x.sana.Contains("u"))
  .OrderBy(x=>x.pari)
  .OrderBy(x=>x.sana)
  .Select(x => $"{x.pari} -> {x.sana}")
```

Subqueries

Projecting

Subqueries

We can write quite inefficient queries using subqueries in LINQ

```
string[] names = new[] {"Kenny", "John", "Bob", "Jimmy","Rob"};

var enumerable1 = from n in names
                  where n.Length == names.Min(s => s.Length)
                  select n;
```

We can make this code much more efficient by restructuring as follows

```
var min = names.Min(s => s.Length);
IEnumerable<string> enumerable2 = from n in names
                                  where n.Length == min
                                  select n;
```

Questions

What is LINQ?

A language feature that enables us to write type safe queries over any collection that implements `IEnumerable<T>`

What inspired LINQ?

The functional programming paradigm

What are the basic elements

- Sequences
- Elements
- Query operators
- Queries

What do lambda expressions in query operators always operate on?
Individual elements

Do query operators alter the input sequence?
No, they always generate a new sequence

What does LINQ query comprise?
A pipeline of operators that accept and return ordered sequences

What does an SQL query comprise?
A netwoek of clauses working on unordered sets

How is deferred execution implemented?
Query operators provide deferred execution by returning decorator sequences.

What are the advantages of deferred execution?

- Decouples construction from execution
- Allows one to construct a query in multiple steps
- You can re-evaluate a query by enumerating it again.

What are the exceptions that return immediately?

ToList, ToArray, ToDictionary, ToLookup

Single element or scalar operators such as First or Count

How do decorator sequences differ from traditional collection classes?

In general a decorator sequence has no storage of its own to store elements

What does it have instead?

A reference to another sequence supplied at runtime

What happens when you request data from a decorator?

It must in turn ask for data from its wrapped input sequence

What happens when you chain query operators?

A chain of decorators are created

What happens when you enumerate a query?

You query the original input sequence transformed through a layering chain of decorators

What happens if you call ToList() on query?

The whole chain is collapsed into a single list