

Základy LINQu

13. dubna 2019

LINQ neboli Language Integrated Query je sada jazykových funkcí pro psaní strukturovaných typově bezpečných dotazů přes lokální kolekce objektů a vzdálená data. LINQ byl představen v C # 3.0 a frameworku 3.5.

Základní jednotky dat v LINQ jsou sekvence a prvky. Sekvence je libovolný objekt, který implementuje obecné IEnumerable rozhraní a prvek je každá položka v sekvenci. V následujícím příkladu jsou názvy sekvencemi a Tom, Ríša a Jindra jsou prvky:

```
string [] names = {"Tom", "Ríša", "Jindra"};
```

Sekvence, jako je tato, nazýváme lokální sekvencí , protože reprezentuje lokální sbírku objektů v paměti. Operátor dotazu je metoda, která transformuje sekvenci. Typický dotazovací operátor přijme vstupní sekvenci a vydá transformovanou výstupní sekvenci. Ve třídě Enumerable v System.Linq existuje kolem 40 operátorů dotazů, všechny implementovány jako metody statického rozšíření. Ty se nazývají standardní operátory dotazů.

Jednoduchý dotaz

Dotaz je výraz, který transformuje sekvence jedním nebo více operátory dotazů. Nejjednodušší dotaz obsahuje jednu vstupní sekvenci a jeden operátor. Například můžeme použít operátor *Where* na jednoduchém poli, abychom mohli extrahovat jména, jejichž délka je nejméně čtyři znaky, takto:

```
string[] names = { "Tom", "Ríša", "Jindra" };

IEnumerable<string> filteredNames =
    System.Linq.Enumerable.Where ( names, n => n.Length >= 4 );
foreach (string n in filteredNames) Console.Write (n + "|");
// Ríša|Jindra|
```

Protože standardní operátory dotazů jsou implementovány jako metody rozšíření, můžeme volat *Where* přímo na *names* jakoby to byla metoda instance:

```
IEnumerable<string> filteredNames =
    System.Linq.Enumerable.Where ( names, n => n.Length >= 4 );
```

(Chcete-li kompilovat, musíte importovat *System.Linq* pomocí direktivy *using*.) Metoda *Where* v *System.Linq.Enumerable* má následující deklaraci:

```
static IEnumerable<TSource> Where<TSource> ( this IEnumerable<TSource> source, Func
    <TSource, bool> predicate )
```

Kde *source* je vstupní sekvence; *predicate* je delegát, který je vyvolán na každém vstupním prvku. Metoda *Where* vybere všechny prvky, pro které delegát vrací hodnotu true. Interně je generován kód pro iterátor:

```
foreach (TSource element in source)
    if (predicate (element))
        yield return element;
```

Projekce (Select)

Je aplikací funkce na každý prvek vstupní sekvence.

```
string[] names = { "Tom", "Ríša", "Jindra" };

IEnumerable<string> upperNames = names.Select (n => n.ToUpper());
foreach (string n in upperNames)
    Console.Write (n + "|");
// TOM|RÍŠA|JINDRA|
```

S použitím anonymního typu

```
var query = names.Select (n => new { Name = n, Length = n.Length });
foreach (var row in query)
```

```
Console.WriteLine (row);  
// { Name = Tom, Length = 3 }  
// { Name = Ríša, Length = 4 }  
// { Name = Jindra, Length = 5 }
```

(SelectMany)

```
double[] t = {1, 2, 3};  
var coordinates = t.SelectMany(x=>new double[] { x, x*x, Pow(x,3)});  
// coordinates { 1, 1, 1, 2, 4, 8, 3, 9, 27}
```

Filtry

```
int[] numbers = { 10, 9, 8, 7, 6 };  
IEnumerable<int> firstThree = numbers.Take (3);  
// firstThree je { 10, 9, 8 }  
IEnumerable<int> lastTwo = numbers.Skip (3);  
// lastTwo je { 7, 6 }  
var whileGreater7 = numbers.TakeWhile(n=>n>7);  
// whileGreater7 je { 10, 9, 8 }  
var skipGreater7 = numbers.SkipWhile(n=>n>7);  
// skipGreater7 je { 7, 6 }
```

```
numbers = { 10, 9, 8, 7, 6, 8, 10 };  
var distinct = numbers.Distinct();  
// distinct je { 10, 9, 8, 7, 6 }
```

Elementy

```
int[] numbers = { 10, 9, 8, 7, 6 };  
int firstNumber = numbers.First(); // 10  
int lastNumber = numbers.Last(); // 6  
int secondNumber = numbers.ElementAt (2); // 8  
int firstOddNum = numbers.First (n => n%2 == 1); // 9
```

Agregace

```
int[] numbers = { 10, 9, 8, 7, 6 };  
int count = numbers.Count(); // 5  
int min = numbers.Min(); // 6  
int max = numbers.Max(); // 10  
double avg = numbers.Average(); // 8  
int evenNums = numbers.Count (n => n % 2 == 0); // 3  
int maxRemainderAfterDivBy5 = numbers.Max (n => n % 5); // 4
```

Kvantifikátory

```
int[] numbers = { 10, 9, 8, 7, 6 };  
bool hasTheNumberNine = numbers.Contains (9); // true  
bool hasMoreThanZeroElements = numbers.Any(); // true  
bool hasOddNum = numbers.Any (n => n % 2 == 1); // true  
bool allOddNums = numbers.All (n => n % 2 == 1); // false
```

Množinové operace

```
int[] seq1 = { 1, 2, 3 }, seq2 = { 3, 4, 5 };  
IEnumerable<int> concat = seq1.Concat (seq2), // { 1, 2, 3, 3, 4, 5 }  
union = seq1.Union (seq2); // { 1, 2, 3, 4, 5 }  
IEnumerable<int> common = seq1.Intersect (seq2), // { 3 }  
difference1 = seq1.Except (seq2), // { 1, 2 }  
difference2 = seq2.Except (seq1); // { 4, 5 }
```

Odložená aplikace dotazu

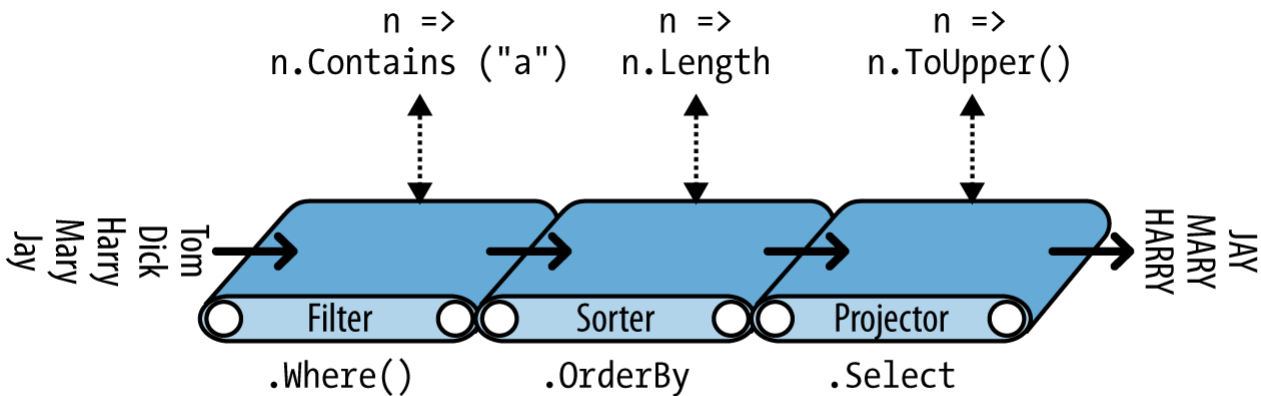
```
var numbers = new List<int> { 1 };  
IEnumerable<int> query = numbers.Select (n => n * 10); numbers.Add (2); // Přidáme  
další prvek  
foreach (int n in query)
```

```
Console.Write (n + "|"); // 10|20|

var numbers = new List<int>() { 1, 2 };
List<int> timesTen = numbers .Select (n => n * 10) .ToList(); // Aplikace dotazu do
    typu List<int>
numbers.Clear();
Console.WriteLine (timesTen.Count); // Stále 2, kešování
```

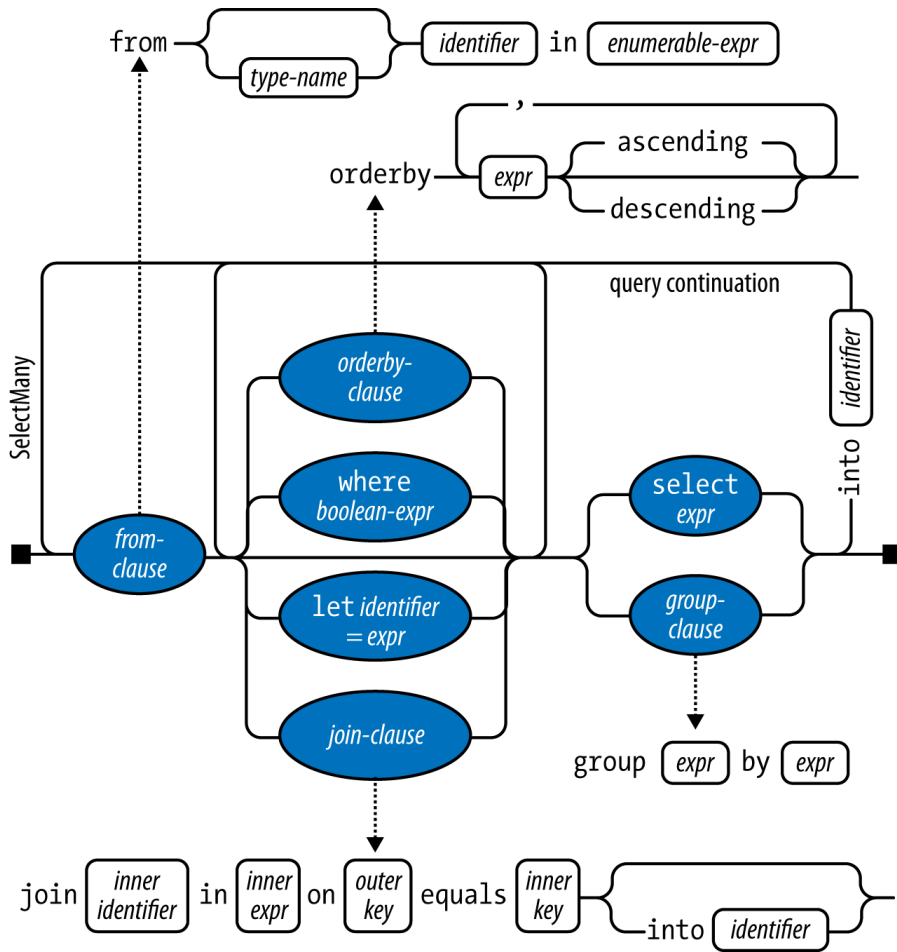
Kompozice dotazovacích operátorů

```
string[] names = { "Tom", "Ríša", "Jindra", "Marie", "Jan" };
IEnumerable<string> query = names
    .Where (n => n.Contains ("a"))
    .OrderBy (n => n.Length)
    .Select (n => n.ToUpper());
foreach (string name in query)
    Console.Write (name + "|"); // JAN|RÍŠA|MARIE|JINDRA|
```



Dotazovací jazyk LINQu

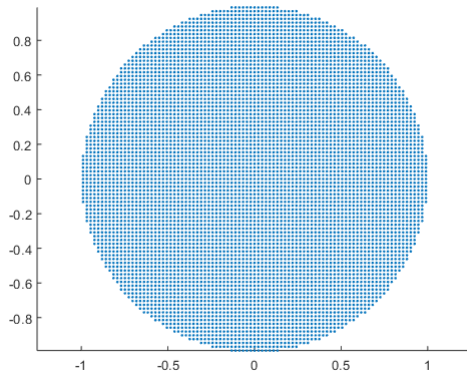
```
IEnumerable<string> query = from n in names
    where n.Contains("a")
    orderby n.Length
    select n.ToUpper();
```

Příklad

```
double l=1.1, r=1;
var n = 100;
var e = Enumerable.Range(0,n+1);
var h=2*l/n;
var x = from i in e select -l+i*h;
var grid = from cx in x
            from cy in x
            select new {x=cx,y=cy};
var domain = from p in grid
              where Norm(p.x,p.y) <= r
              select p;

double Norm(double x, double y) => Sqrt(Pow(x,2)+Pow(y,2));
```



Příklad

```
namespace ME
{
    public struct Coordinate
    {
        public int id;
        public double value;
        public bool boundary;
        public override string ToString()
        {
            return string.Format($"{nameof(Coordinate)}( id={id}, boundary={
                boundary}, value={value} )");
        }
    }
}
```

```

    }
}

public struct Point
{
    public int id, idx, idy;
    public bool boundary;
    public override string ToString()
    {
        return string.Format($"{nameof(Point)}( id={id} idx={idx} idy={idy}
            boundary={boundary})");
    }
}

public struct Point3
{
    public int id, idx, idy, idz;
    public bool boundary;
    public override string ToString()
    {
        return string.Format($"{nameof(Point)}( id={id} idx={idx} idy={idy} idz
            ={idz} boundary={boundary})");
    }
}
}

```

```
using System;
```

```

using System.Collections.Generic;
using System.Linq;

namespace ME
{
    public static class Ex
    {
        public static void Dump<T>(this IEnumerable<T> collection, string name, int
            max = 5)
        {
            int n = collection.Count();
            IEnumerable<string> s;
            if (n > 2 * max)
                s = collection
                    .Take(max).Select((a, i) => string.Format($"{name} [{i}] = {a}")
                        )
                    .Append("...")
                    .Concat(collection.Skip(n - max).Select((a, i) => string.Format
                        ($"{name} [{n - max + i}] = {a}")));
            else
                s = collection.Select((a, i) => string.Format($"{name} [{i}] = {a}")
                    );
            foreach (var item in s)
            {
                Console.WriteLine(item);
            }
        }

        public static IEnumerable<Coordinate> LinSpace(double a, double b, int n)
    }
}

```

```

{
    n--;
    return
    Enumerable.Range(0, n).Select((r, i) => new Coordinate { id = i,
        boundary = i == 0, value = a + r * (b - a) / n }).
        Append(new Coordinate { id = n, boundary = true, value = b });
}

public static IEnumerable<Point> Grid(IEnumerable<Coordinate> x,
    IEnumerable<Coordinate> y)
{
    var xy = from px in x
        from py in y
        select new { idx = px.id, idy = py.id, bdry = px.boundary ||
            py.boundary };
    return xy.Select((a, i) => new Point { id = i, idx = a.idx, idy = a.idy
        , boundary = a.bdry });
}

public static IEnumerable<Point3> Grid(IEnumerable<Coordinate> x,
    IEnumerable<Coordinate> y, IEnumerable<Coordinate> z)
{
    var xyz = from px in x
        from py in y
        from pz in z
        select new { idx = px.id, idy = py.id, idz = pz.id, bdry = px
            .boundary || py.boundary || pz.boundary };
    return xyz.Select((a, i) => new Point3 { id = i, idx = a.idx, idy = a.
        idy, idz = a.idz, boundary = a.bdry });
}

```

```

    }

    public static IEnumerable<double[]> Grid(IEnumerable<Coordinate> x,
        IEnumerable<Coordinate> y, Func<double, double, double> f)
    {
        return
            from px in x
            from py in y
            select new double[] { px.value, py.value, f(px.value, py.value) };
    }

    public static IEnumerable<double[]> Grid(IEnumerable<Coordinate> x,
        IEnumerable<Coordinate> y, IEnumerable<Coordinate> z, Func<double,
        double, double, double> f)
    {
        return
            from px in x
            from py in y
            from pz in z
            select new double[] { px.value, py.value, pz.value, f(px.value, py.
                value, pz.value) };
    }
}
}

```

```
using System;
```

```

using System.Linq;
using MathNet.Numerics.LinearAlgebra;

namespace ME
{
    class Program
    {
        static void Main(string[] args)
        {
            int n = 6, m = 11;
            var x = Ex.LinSpace(0, 2, n);
            var y = Ex.LinSpace(0, 1, m);
            x.Dump(nameof(x));
            y.Dump(nameof(y));
            var grid = Ex.Grid(x, y);
            grid.Dump(nameof(grid));
            var B = Matrix<double>.Build.Dense(n,m);
            foreach (var p in grid)
            {
                B[p.idx, p.idy] = p.boundary ? 1 : 0;
            }
            Console.WriteLine(B);
            var xa = x.ToArray();
            var ya = y.ToArray();
            var xyz = Ex.Grid(x,y,(a,b)=>a+b);
            var XYZ=Matrix<double>.Build.DenseOfRows(xyz);
            Console.WriteLine(XYZ);
        }
    }
}

```



```
}
```

```
x[0] = Coordinate( id=0, boundary=True, value=0 )
x[1] = Coordinate( id=1, boundary=False, value=0.4 )
x[2] = Coordinate( id=2, boundary=False, value=0.8 )
x[3] = Coordinate( id=3, boundary=False, value=1.2 )
x[4] = Coordinate( id=4, boundary=False, value=1.6 )
x[5] = Coordinate( id=5, boundary=True, value=2 )
y[0] = Coordinate( id=0, boundary=True, value=0 )
y[1] = Coordinate( id=1, boundary=False, value=0.1 )
y[2] = Coordinate( id=2, boundary=False, value=0.2 )
y[3] = Coordinate( id=3, boundary=False, value=0.3 )
y[4] = Coordinate( id=4, boundary=False, value=0.4 )
...
y[6] = Coordinate( id=6, boundary=False, value=0.6 )
y[7] = Coordinate( id=7, boundary=False, value=0.7 )
y[8] = Coordinate( id=8, boundary=False, value=0.8 )
y[9] = Coordinate( id=9, boundary=False, value=0.9 )
y[10] = Coordinate( id=10, boundary=True, value=1 )
grid[0] = Point( id=0 idx=0 idy=0 boundary=True)
grid[1] = Point( id=1 idx=0 idy=1 boundary=True)
grid[2] = Point( id=2 idx=0 idy=2 boundary=True)
grid[3] = Point( id=3 idx=0 idy=3 boundary=True)
grid[4] = Point( id=4 idx=0 idy=4 boundary=True)
...
grid[61] = Point( id=61 idx=5 idy=6 boundary=True)
grid[62] = Point( id=62 idx=5 idy=7 boundary=True)
grid[63] = Point( id=63 idx=5 idy=8 boundary=True)
grid[64] = Point( id=64 idx=5 idy=9 boundary=True)
```

```
grid[65] = Point( id=65 idx=5 idy=10 boundary=True)
```

```
DenseMatrix 6x11-Double
```

```
1 1 1 1 1 1 1 1 1 1 1
1 0 0 0 0 0 0 0 0 0 1
1 0 0 0 0 0 0 0 0 0 1
1 0 0 0 0 0 0 0 0 0 1
1 0 0 0 0 0 0 0 0 0 1
1 1 1 1 1 1 1 1 1 1 1
```

```
DenseMatrix 66x3-Double
```

```
0 0 0
0 0.1 0.1
0 0.2 0.2
0 0.3 0.3
0 0.4 0.4
0 0.5 0.5
0 0.6 0.6
0 0.7 0.7
.. .. ..
2 0.7 2.7
2 0.8 2.8
2 0.9 2.9
2 1 3
```

Join (příklad z MSDN dokumentace)

```

using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;

namespace ME
{
    public class JoinDemonstration
    {
        #region Data
        class Product
        {
            public string Name { get; set; }
            public int CategoryID { get; set; }
        }

        class Category
        {
            public string Name { get; set; }
            public int ID { get; set; }
        }

        // Specify the first data source.
        List<Category> categories = new List<Category>()
        {
            new Category() { Name="nápoje", ID=001},
            new Category() { Name="koření", ID=002},
        }
    }
}

```

```

        new Category(){Name="zelenina", ID=003},
        new Category(){Name="obiloviny", ID=004},
        new Category(){Name="ovoce", ID=005}
    };

    // Specify the second data source.
    List<Product> products = new List<Product>()
    {
        new Product{Name="káva", CategoryID=001},
        new Product{Name="čaj", CategoryID=001},
        new Product{Name="pepř", CategoryID=002},
        new Product{Name="kmín", CategoryID=002},
        new Product{Name="mrkev", CategoryID=003},
        new Product{Name="zelí", CategoryID=003},
        new Product{Name="jablka", CategoryID=005},
        new Product{Name="hrušky", CategoryID=005},
    };
    #endregion

    public static void Example()
    {
        JoinDemonstration app = new JoinDemonstration();

        app.InnerJoin();
        app.GroupJoin();
        app.GroupInnerJoin();
        app.GroupJoin3();
        app.LeftOuterJoin();
    }

```

```

        app.LeftOuterJoin2();
    }

    void InnerJoin()
    {
        var innerJoinQuery =
            from category in categories
            join prod in products on category.ID equals prod.CategoryID
            select new { Category = category.ID, Product = prod.Name };

        Console.WriteLine("InnerJoin:");
        foreach (var item in innerJoinQuery)
        {
            Console.WriteLine("{0,-10}{1}", item.Product, item.Category);
        }
        Console.WriteLine("InnerJoin: {0} items in 1 group.", innerJoinQuery.
            Count());
        Console.WriteLine(System.Environment.NewLine);
    }

    void GroupJoin()
    {
        var groupJoinQuery =
            from category in categories
            join prod in products on category.ID equals prod.CategoryID into
            prodGroup
            select prodGroup;
    }

```

```

int totalItems = 0;
Console.WriteLine("Simple GroupJoin:");
foreach (var prodGrouping in groupJoinQuery)
{
    Console.WriteLine("Group:");
    foreach (var item in prodGrouping)
    {
        totalItems++;
        Console.WriteLine("    {0,-10}{1}", item.Name, item.CategoryID);
    }
}
Console.WriteLine("Unshaped GroupJoin: {0} items in {1} unnamed groups",
    totalItems, groupJoinQuery.Count());
Console.WriteLine(System.Environment.NewLine);
}

void GroupInnerJoin()
{
    var groupJoinQuery2 =
        from category in categories
        orderby category.ID
        join prod in products on category.ID equals prod.CategoryID into
            prodGroup
        select new
        {
            Category = category.Name,
            Products = from prod2 in prodGroup

```

```

        orderby prod2.Name
        select prod2
    };

    int totalItems = 0;

    Console.WriteLine("GroupInnerJoin:");
    foreach (var productGroup in groupJoinQuery2)
    {
        Console.WriteLine(productGroup.Category);
        foreach (var prodItem in productGroup.Products)
        {
            totalItems++;
            Console.WriteLine("  {0,-10} {1}", prodItem.Name, prodItem.
                CategoryID);
        }
    }
    Console.WriteLine("GroupInnerJoin: {0} items in {1} named groups",
        totalItems, groupJoinQuery2.Count());
    Console.WriteLine(System.Environment.NewLine);
}

void GroupJoin3()
{
    var groupJoinQuery3 =
        from category in categories

```

```

        join product in products on category.ID equals product.CategoryID
        into prodGroup
    from prod in prodGroup
    orderby prod.CategoryID
    select new { Category = prod.CategoryID, ProductName = prod.Name };

int totalItems = 0;

Console.WriteLine("GroupJoin3:");
foreach (var item in groupJoinQuery3)
{
    totalItems++;
    Console.WriteLine("    {0}:{1}", item.ProductName, item.Category);
}

Console.WriteLine("GroupJoin3: {0} items in 1 group", totalItems,
    groupJoinQuery3.Count());
Console.WriteLine(System.Environment.NewLine);
}

void LeftOuterJoin()
{
    var leftOuterQuery =
        from category in categories
        join prod in products on category.ID equals prod.CategoryID into
        prodGroup
        select prodGroup.DefaultIfEmpty(new Product() { Name = "Nic!",
            CategoryID = category.ID });
}

```



```

int totalItems = 0;

Console.WriteLine("Left Outer Join:");

foreach (var prodGrouping in leftOuterQuery)
{
    Console.WriteLine("Group:", prodGrouping.Count());
    foreach (var item in prodGrouping)
    {
        totalItems++;
        Console.WriteLine("  {0,-10}{1}", item.Name, item.CategoryID);
    }
}

Console.WriteLine("LeftOuterJoin: {0} items in {1} groups", totalItems,
    leftOuterQuery.Count());
Console.WriteLine(System.Environment.NewLine);
}

void LeftOuterJoin2()
{
    var leftOuterQuery2 =
        from category in categories
        join prod in products on category.ID equals prod.CategoryID into
            prodGroup
        from item in prodGroup.DefaultIfEmpty()
        select new { Name = item == null ? "Nic!" : item.Name, CategoryID =
            category.ID };
}

```

```

        Console.WriteLine("LeftOuterJoin2: {0} items in 1 group",
            leftOuterQuery2.Count());

        int totalItems = 0;

        Console.WriteLine("Left Outer Join 2:");

        foreach (var item in leftOuterQuery2)
        {
            totalItems++;
            Console.WriteLine("{0,-10}{1}", item.Name, item.CategoryID);
        }
        Console.WriteLine("LeftOuterJoin2: {0} items in 1 group", totalItems);
    }

    /*
    InnerJoin:
    káva      1
    čaj       1
    pepř      2
    kmín      2
    mrkev     3
    zelí      3
    jablka    5
    hrušky    5
    InnerJoin: 8 items in 1 group.

```

```

Simple GroupJoin:
Group:
    káva      1
    čaj       1
Group:
    pepř      2
    kmín      2
Group:
    mrkev     3
    zelí      3
Group:
Group:
    jablka    5
    hrušky    5
Unshaped GroupJoin: 8 items in 5 unnamed groups

```

```

GroupInnerJoin:
nápoje
    čaj       1
    káva      1
koření
    kmín      2
    pepř      2
zelenina
    mrkev     3
    zelí      3
obiloviny

```

```
ovoce
  hrušky      5
  jablka      5
GroupInnerJoin: 8 items in 5 named groups
```

```
GroupJoin3:
  káva:1
  čaj:1
  pepř:2
  kmín:2
  mrkev:3
  zelí:3
  jablka:5
  hrušky:5
GroupJoin3: 8 items in 1 group
```

```
Left Outer Join:
Group:
  káva      1
  čaj      1
Group:
  pepř      2
  kmín      2
Group:
  mrkev     3
  zelí     3
Group:
```

```
Nic!      4
Group:
  jablka   5
  hrušky   5
LeftOuterJoin: 9 items in 5 groups
```

```
LeftOuterJoin2: 9 items in 1 group
Left Outer Join 2:
káva      1
čaj       1
pepř      2
kmín      2
mrkev     3
zelí      3
Nic!      4
jablka    5
hrušky    5
LeftOuterJoin2: 9 items in 1 group
*/
}
```

Linq to XML

```
using System;
using System.Collections.Generic;
```

```

using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Xml.Linq;
using static System.Console;

namespace ME
{
    public class XML
    {
        public static void Example()
        {
            var points = new XElement("Points",
                new XElement("Point", new XAttribute("id", 1), new
                    XAttribute("x", 0.0), new XAttribute("y", 0.0)),
                new XElement("Point", new XAttribute("id", 2), new
                    XAttribute("x", 1.0), new XAttribute("y", 0.0)),
                new XElement("Point", new XAttribute("id", 3), new
                    XAttribute("x", 1.0), new XAttribute("y", 1.0)),
                new XElement("Point", new XAttribute("id", 4), new
                    XAttribute("x", 0.0), new XAttribute("y", 1.0)));

            var triangles = new XElement("Triangles",
                new XElement("Triangle", new XAttribute("id1", 1), new
                    XAttribute("id2", 2), new XAttribute("id3", 3)),
                new XElement("Triangle", new XAttribute("id1", 1), new
                    XAttribute("id2", 3), new XAttribute("id3", 4)));
        }
    }
}

```

```

var xdoc =
    new XDocument( new XElement("Triangulation", points, triangles));
WriteLine(xdoc);
xdoc.Save("tri.xml");

var q1 = xdoc.Descendants("Point").Where(p=>(double)p.Attribute("x")
    ==0);
foreach (var item in q1) WriteLine(item);
var q2 = from p in xdoc.Descendants("Point") where (double)p.Attribute(
    "x") == 0 select p.Attribute("id");
foreach (var item in q2) WriteLine(item);

}
/*
<Triangulation>
  <Points>
    <Point id="1" x="0" y="0" />
    <Point id="2" x="1" y="0" />
    <Point id="3" x="1" y="1" />
    <Point id="4" x="0" y="1" />
  </Points>
  <Triangles>
    <Triangle id1="1" id2="2" id3="3" />
    <Triangle id1="1" id2="3" id3="4" />
  </Triangles>
</Triangulation>
<Point id="1" x="0" y="0" />
<Point id="4" x="0" y="1" />
id="1"

```

```
        id="4"  
        */  
    }  
}
```

Kvalitní triangulace kruhu a Linq a XML data format pro ParaView

```
using System.Collections.Generic;  
using static System.Math;  
using MathNet.Numerics.LinearAlgebra;  
  
namespace ME  
{  
    public class Triangulation  
    {  
        public static double tol = 1E-7;  
        public double[] x, y;  
        public int[][] tri;  
  
        public struct Edge  
        {  
            public int i1, i2;
```



```

    public Edge(int i1, int i2)
    {
        if (i1 < i2)
        {
            this.i1 = i1;
            this.i2 = i2;
        }
        else
        {
            this.i2 = i1;
            this.i1 = i2;
        }
    }
}

public class Triangle
{
    public int[] i;
    public IEnumerable<Edge> Edges
    {
        get
        {
            yield return new Edge(i[0], i[1]);
            yield return new Edge(i[1], i[2]);
            yield return new Edge(i[2], i[0]);
        }
    }
}

public static Triangulation Circle(int n)

```

```

{
    double b = Sqrt(3) / 2, a = 0.5;
    double[] x0 = { 0, 1, a, -a, -1, -a, a };
    double[] y0 = { 0, 0, b, b, 0, -b, -b };
    double[] r0 = { 0, 1, 1, 1, 1, 1, 1 };
    var lx = new List<double>(x0);
    var ly = new List<double>(y0);
    var lr = new List<double>(r0);
    var lt = new List<int[]>();
    for (int i = 0; i < 5; i++)
        lt.Add(new int[] { 0, i + 1, i + 2 });
    lt.Add(new int[] { 0, 6, 1 });
    var ie = new List<int>(3);
    var edges = new Dictionary<Edge, int>();
    for (int i = 0; i < n; i++)
    {
        var lt2 = new List<int[]>();
        edges.Clear();
        foreach (var it in lt)
        {
            var T = new Triangle { i = it };
            ie.Clear();
            foreach (var e in T.Edges) Mid(e);
            lt2.Add(new int[] { ie[0], ie[1], ie[2] });
            lt2.Add(new int[] { it[0], ie[0], ie[2] });
            lt2.Add(new int[] { it[1], ie[1], ie[0] });
            lt2.Add(new int[] { it[2], ie[2], ie[1] });
        }
        lt = lt2;
    }
}

```

```

}

return new Triangulation { x = lx.ToArray(), y = ly.ToArray(), tri = lt
    .ToArray() };

void Mid(Edge e)
{
    int i;
    if (edges.ContainsKey(e))
        i = edges[e];
    else
    {
        var x = (lx[e.i1] + lx[e.i2]) / 2;
        var y = (ly[e.i1] + ly[e.i2]) / 2;
        var r = Sqrt(x * x + y * y);
        var r1 = lr[e.i1];
        if (Abs(r1 - lr[e.i2]) < tol)
        {
            var d = r1 / r;
            x *= d;
            y *= d;
            r = r1;
        }
        i = lx.Count;
        lx.Add(x); ly.Add(y); lr.Add(r);
        edges.Add(e, i);
    }
    ie.Add(i);
}

```

```

    }

    public static bool inCircle(double[] x, double[] y)
    {
        var A = Matrix<double>.Build.Dense(4, 4);
        for (int i = 0; i < 4; i++)
            A.SetRow(i, new double[] { 1, x[i], y[i], x[i] * x[i] + y[i] * y[i]
                });
        return A.Determinant() < 0;
    }
}

```

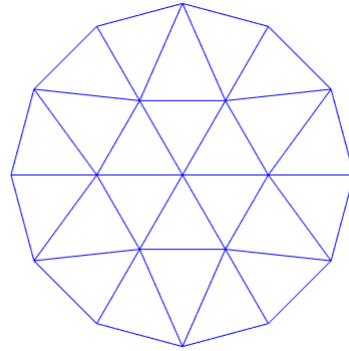
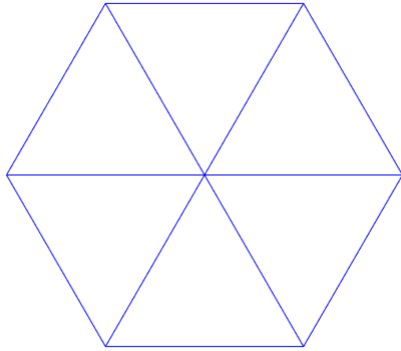
Matlab

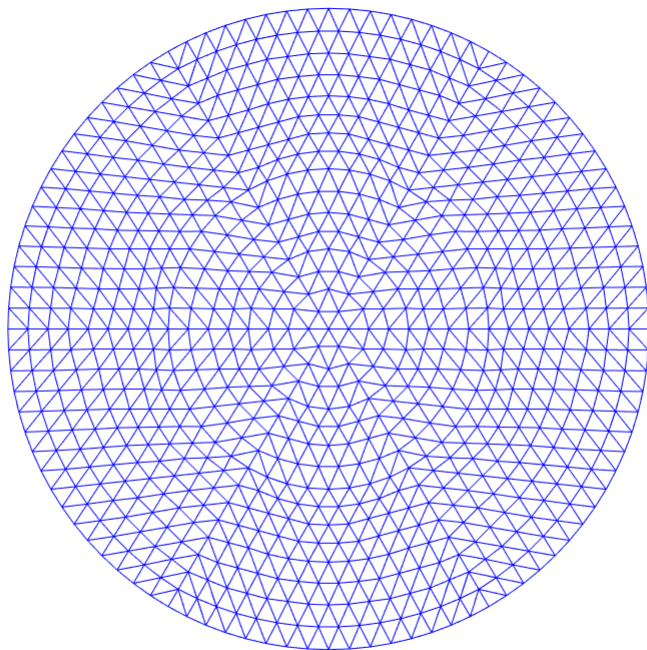
```

clear;clc;close;
asm=NET.addAssembly([pwd '\Mesh.dll']);
tic
msh=ME.Triangulation.Circle(1);
toc
x=double(msh.x);
y=double(msh.y);
tri=double(msh.tri)+1;

triplot(tri,x,y); hold on
axis equal; axis off

```





Linq2XML

```
using System.Linq;
using System.Xml.Linq;
using static System.Console;
using static System.Math;

namespace ME
{
    public class XML
    {

        static double f(double x, double y) => Sin(5 * x)/3 + Cos(3 * y)/5;
        public static void Example()
        {
            var T = Triangulation.Circle(4);
            var p = T.x.Zip(T.y, (x, y) => string.Format($"{x} {y} {f(x,y)} "));
            var tri = T.tri.Select(t => string.Format($"{t[0]} {t[1]} {t[2]} "));
            var off = Enumerable.Range(0, T.tri.Length).Select(t => string.Format(
                $"{3 * (t+1)} "));
            var tp = Enumerable.Range(0, T.tri.Length).Select(t => "5 ");
            var points = new XElement("Points", new XElement("DataArray", new
                XAttribute("type", "Float64"), new XAttribute("NumberOfComponents",
                "3"), new XAttribute("format", "ascii"), p));

            var triangles = new XElement("Cells", new XElement("DataArray", new
                XAttribute("type", "UInt32"), new XAttribute("Name", "connectivity"
                ), new XAttribute("format", "ascii"), tri),
```

```

        new XElement("DataArray", new
            XAttribute("type", "UInt32"),
            new XAttribute("Name", "
                offsets"), new XAttribute("
                format", "ascii"), off),
        new XElement("DataArray", new
            XAttribute("type", "UInt8"),
            new XAttribute("Name", "types
                "), new XAttribute("format",
                "ascii"), tp));

var xdoc = new XDocument(new XElement("VTKFile", new XAttribute("type",
    "UnstructuredGrid"), new XAttribute("version", "0.1"),
    new XElement("UnstructuredGrid",
        new XElement("Piece", new XAttribute("
            NumberOfPoints", T.x.Length), new
            XAttribute("NumberOfCells", T.tri.
                Length),
            points,
            triangles))));

WriteLine(xdoc);
xdoc.Save("tri.vtu");
    }
}
}

```