FSC103

Data Structures

- Lecture will begin shortly
- Download class materials from university.xamarin.com

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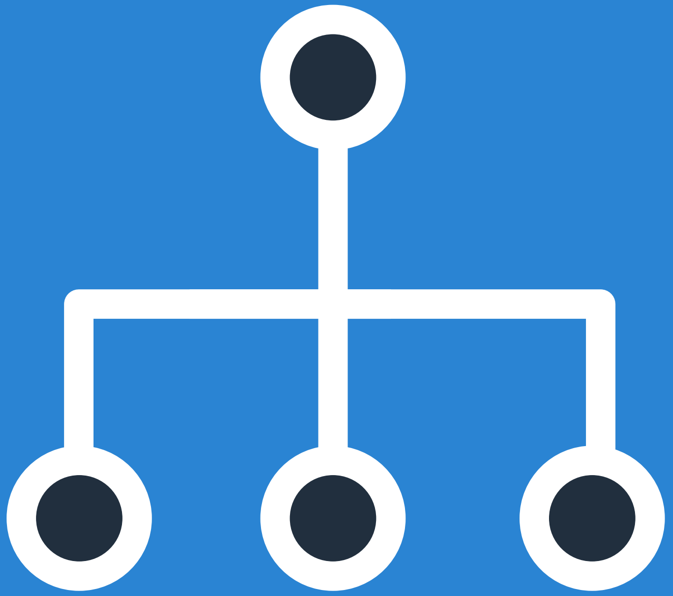
Objectives

1. Utilize arrays and lists
2. Organize and transform data using data structures



Utilize arrays and lists

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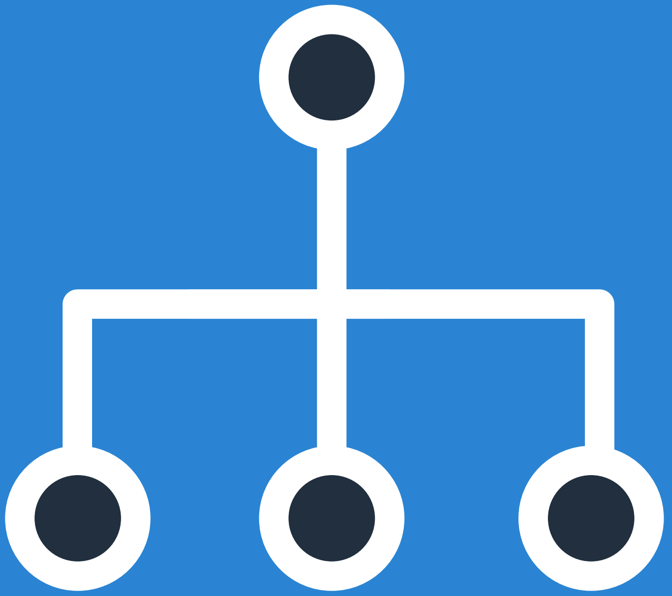
Tasks

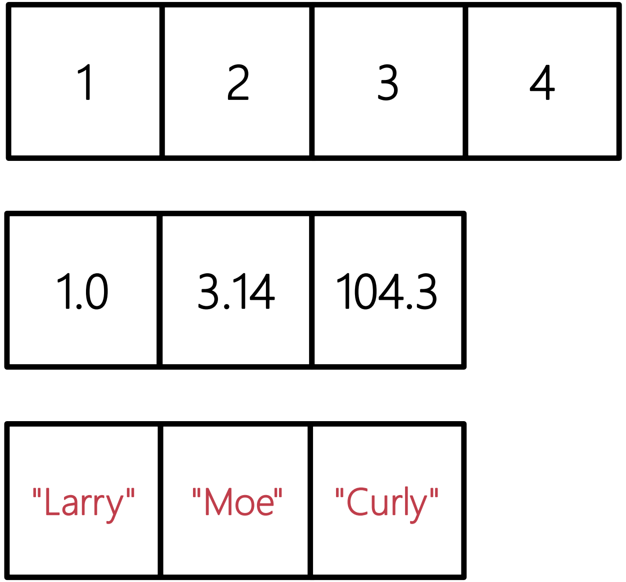
1. Store data in an array
2. Store data in a list
3. Compare list and array



What is an Array?

- Arrays are fixed size sequences of **homogenous** data

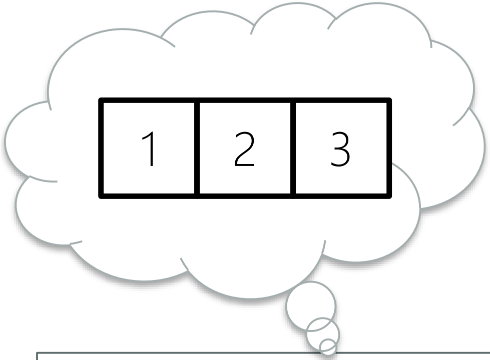
- F# uses `System.Array` under the covers so any created arrays can be passed into other .NET code



Creating Arrays

- Arrays are defined by providing data in between `[|` and `|]`

- Must be initialized with data – this determines the type and size of the array

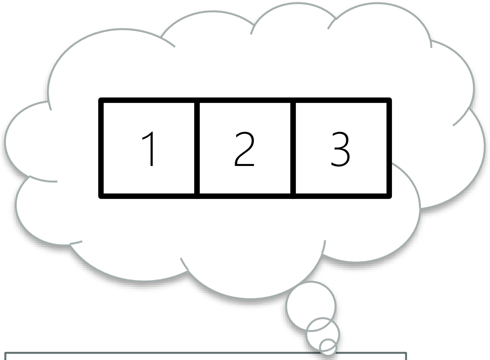



```
let array1 = [|1; 2; 3|]
```

initializing values are delimited by semicolons

Creating Arrays

- Arrays are defined by providing data in between [| and |]
- Must be initialized with data – this determines the type and size of the array



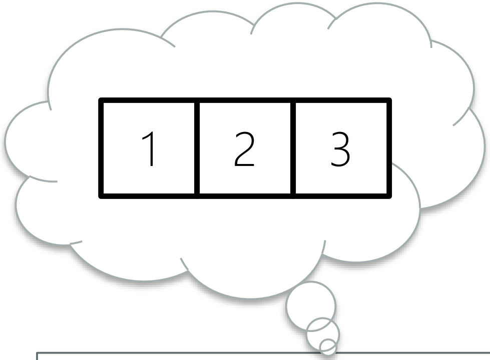

```
let array1 =
  [|
     1
     2
     3
  |]
```

… or can put elements on a separate line, then semicolon is *optional*

Creating Arrays

- Arrays are defined by providing data in between `[|` and `|]`

- Must be initialized with data – this determines the type and size of the array




```
let array1 = [| 1..3 |]
```

can also specify a *sequence* where F# provides the intermediate values, this is *very powerful*

Other ways to create arrays

- F# also include several functions that are included in the **`Array`** module to create and initialize array types

```
let array1 = Array.empty<int>     // int[] with no elements

let array2 = Array.create 3 1.0  // [| 1.0; 1.0; 1.0; |]

let array3 = Array.zeroCreate 3  // [| 0; 0; 0 |]

let array3 = Array.init 3 (fun n -> n.ToString())
// [| "0"; "1"; "2" |] (function is passed index)
```

Accessing Arrays

- Array indices start at zero and elements can be accessed using the dot (.) operator combined with brackets ([and])

```
let evens = [| 0..2..10 |]    // = [| 0; 2; 4; 6; 8; 10 |]

evens.[1]                     // = 2
evens.[0..2]                  // = [| 0; 2; 4 |]
evens.[..4]                   // = [| 0; 2; 4; 6; 8 |]
evens.[3..]                   // = [| 6; 8; 10 |]
```

always returns a **new value** – either a single value, or a new array with the requested subset of data

Modifying arrays

- The array size and shape is fixed, but the data inside can be changed

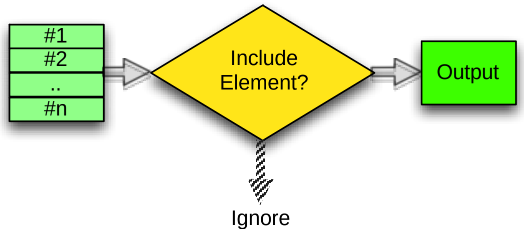
```
let array1 = [| 1; 2; 3; |]

let n = array1.[1]

array1.[1] <- n + 1    // [| 1; 3; 3; |]
```

we use the **assignment operator** to assign a value into the array after it has been created

Specialized Array Operations

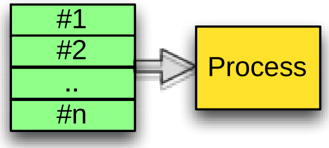
❖ `Collections.Array` module provides array operations to:

Filter



Transform

Process



Filtering elements

❖ Filter operation is used to return a new array that contains elements which are matched with the passed predicate filter function

```
let nums = [| 0..12 |]    // 0-12 inclusive

Array.filter (fun n -> n%2 = 0) nums
```

```
[| 0; 2; 4; 6; 8; 10; 12 |]
```

source array is passed as 2nd parameter

lambda filter is passed as 1st parameter and returns true / false for each item

Transforming elements

- Map operation is used to return a new array with the elements transformed by the passed transformation function

```
let nums = [| 0..5 |] // 0-5 inclusive

Array.map (fun n -> n*2) nums
```

```
[| 0; 2; 4; 6; 8; 10 |]
```

Processing arrays

- `Array.Iter` operation can be used to process each element in the array with a passed processing function

```
let nums = [| 0..5 |] // 0-5 inclusive

Array.iter (fun n -> printfn "%i" n) nums
```

```
0
1
2
3
4
5
```

`Array.iter` is similar to the C# `foreach` statement – it processes each item in the array individually but returns no direct result

Other Array operations

- Array also includes operations to perform common mathematical calculations, prefer these methods over manual iteration + calculations

```
let x = Array.average nums
```

returns the average of the #s in the array

```
let x = Array.max nums
```

returns the max # in the array

```
let x = Array.min nums
```

returns the min # in the array

```
let sorted = Array.sort nums
```

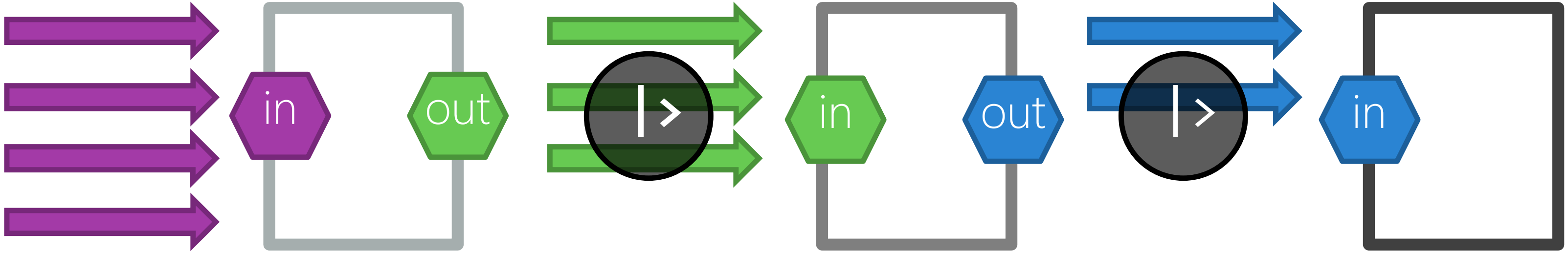
returns the array in sorted order

```
let total = Array.sum nums
```

returns the sum of the #s in the array

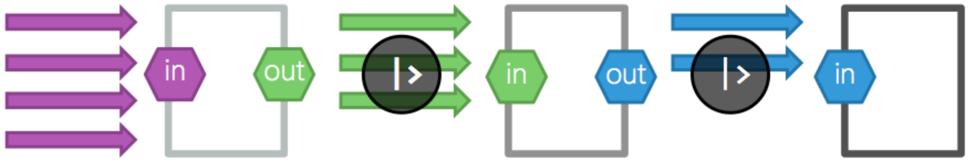
Pipelining

❖ Common to use pipelining (|>) + operations to process arrays



Pipelining

❖ Common to use pipelining (|>) + operations to chain functions




```
let nums = [| 0..4 |]
nums
   |> Array.filter (fun n -> n%2 = 0)
   |> Array.sum
```

first get all the even #s

sum the result from filter

pipeline operator

```
val it : int = 6
```

Parallel Arrays

- Can parallelize some operations by adding `.parallel` before the operation function call

```
open System.IO    // include System.IO namespace

let files = Directory.GetFiles(@"C:\", "*.txt")

Array.parallel.iter (fun fn -> File.Encrypt(fn)) files
```

Take all the text files on the C: drive (Windows) and encrypt each file using Windows file system encryption – this is done in parallel so we are encrypting several files simultaneously on multi-core machines

Beware: you must be performing a fair amount of CPU or I/O bound work to make this effective, otherwise the operation will be slower than if it were done serially

Lists

- An F# *list* is a singly-linked-list data structures storing homogenous data

```
let evens= [0..2..10]
```

no parallel bars – creates a list

```
Array.toList [|0..2..10|]
```

can also turn array into list
(or vice-versa)

Adding elements to a list

- You cannot update elements of a list, but you can create a new list by adding elements to the front, this is done in O(1) time as it is not necessary to copy the old list

```
let list1 = [1;2;3;4]          // 1-4 in the list

let list2 = 0::list1           // [0;1;2;3;4]
```

this is referred to as the cons operator and it prepends elements to the list. There is no operator to *append* to the list, because it wouldn't be efficient for a singly-linked list

Combining lists

- Can also combine lists to create a new list which contains both – this is also an efficient operation because the list data is not duplicated

```
let list1 = [ 1;2;3;4 ]
let list2 = [ 5;6;7;8 ]

let list3 = list1 @ list2     // [ 1;2;3;4;5;6;7;8 ]
```

concatenation operator which combines two lists together to generate a third unique list

List Operations

- List has many of the same operations as array, but also has some unique functions for working with the list
  - head
  - tail
  - recursion
  - pattern matching

```
let list = [1;2;3;4]

// Define recursive function
// named "sum" to sum all the
// elements in a list
// parameter "values"
let rec sum values =
   match values with
   | [] -> 0
   | head::tail -> head +
                   sum(tail)

let total = sum list   // 10
```

Should I use lists or arrays?

- F# programmers tend to prefer list over array for many cases, but the parallelization support in array can be very helpful for CPU intensive calculations

Use Lists for:

- Variable size
- Supports recursion
- Head/Tail pattern matching

Use Arrays for:

- Parallelization
- Mutable elements
- C# interop

Individual Exercise

Working with arrays and lists in the REPL

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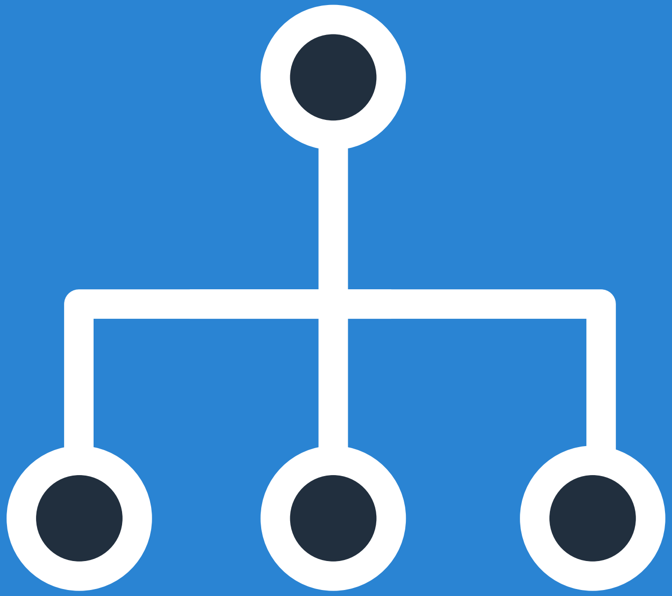
Summary

1. Store data in an array
2. Store data in a list
3. Compare list and array



Organize and transform data using data structures

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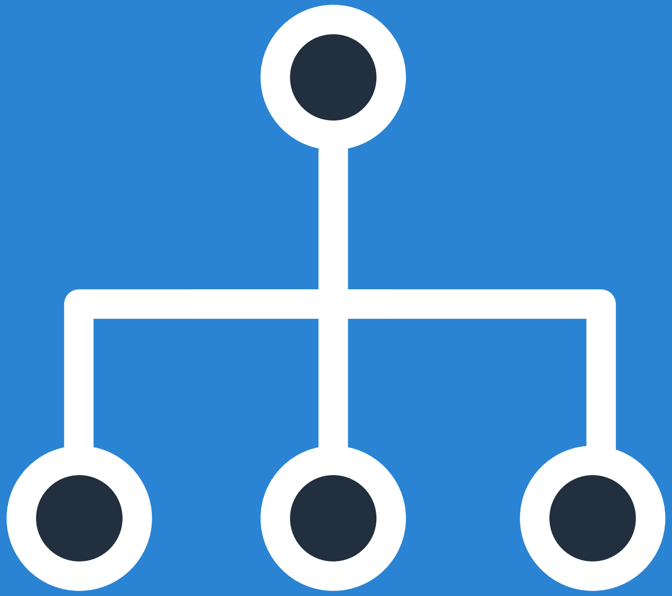
Tasks

1. Discuss tuples
2. Describe sequences and their uses
3. Create and utilize records
4. Compose discriminated unions



Tuples

- A *tuple* is a grouping of unnamed but ordered values, possibly of different types

```
// Tuple of two integers: ( 1, 2 )

// Tuple of strings: ( "Rachel", "Helen", "Mark" )

// Tuple that has mixed types: ( "BillG", 2014, 20240332. )

// Tuple of integer expressions: ( a + 1, b + 1)
```

Under the covers, this construct creates a .NET **`Tuple<T1,T2,T3,…>`** type

Passing tuples as parameters

- Tuples are commonly used as parameters to functions

```
let average (a, b) =
    (a + b) / 2.0
...
average (10., 20.)
```

```
val it : float = 15.0
```

Working with tuples

- F# will allow you to choose the first or second item in a pair tuple using the `fst` and/or `snd` keywords

```
// Tuple of two integers: ( 1, 2 )
```

```
fst ( 1, 2 )
```

```
( 1, 2 ) |> fst
```

```
val it : int = 1
```

```
snd ( 1, 2 )
```

```
( 1, 2 ) |> snd
```

```
val it : int = 2
```

Getting values from tuples

- Common to use pattern matching to assign names to tuple elements

```
let (a, b) = (1, 2)
printfn "%d : %d" a b
```

```
1 : 2
```

Use underscore as *wildcard* match

```
let (_, _, c) = (1, 2, 3)
```

```
val c : int = 3
```

Pattern matching tuples

- Can also use formal match expression to process values

```
let greeting (name, language) =
    match (name, language)  with
    | ("Yoda", _) -> "Greetings Master"
    | (name, "English") -> "Hello " + name
    | (_, "French") -> "Bonjour!"
    | (name, _) when language.StartsWith("Span") -> "Hola, " + name
    | (name, "Klingon") -> "nuqneH" + name
    | _ -> "Error!"
```

Type signature

- When you display a tuple, the * symbol is used to separate the components in the type signature

string   int[]

```
let data = (0, "pumpkin", 18., [0;1;2;3]);;
```

int   float

```
val data : int * string * float * int list = (0, "pumpkin",
18.0, [0; 1; 2; 3])
```

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What are sequences?

- Sequences are a logical series of elements of one type that may be iterated in a forward-only, read-only fashion
- Can be created explicitly through the `seq` keyword, or implicitly by an `IEnumerable<T>`

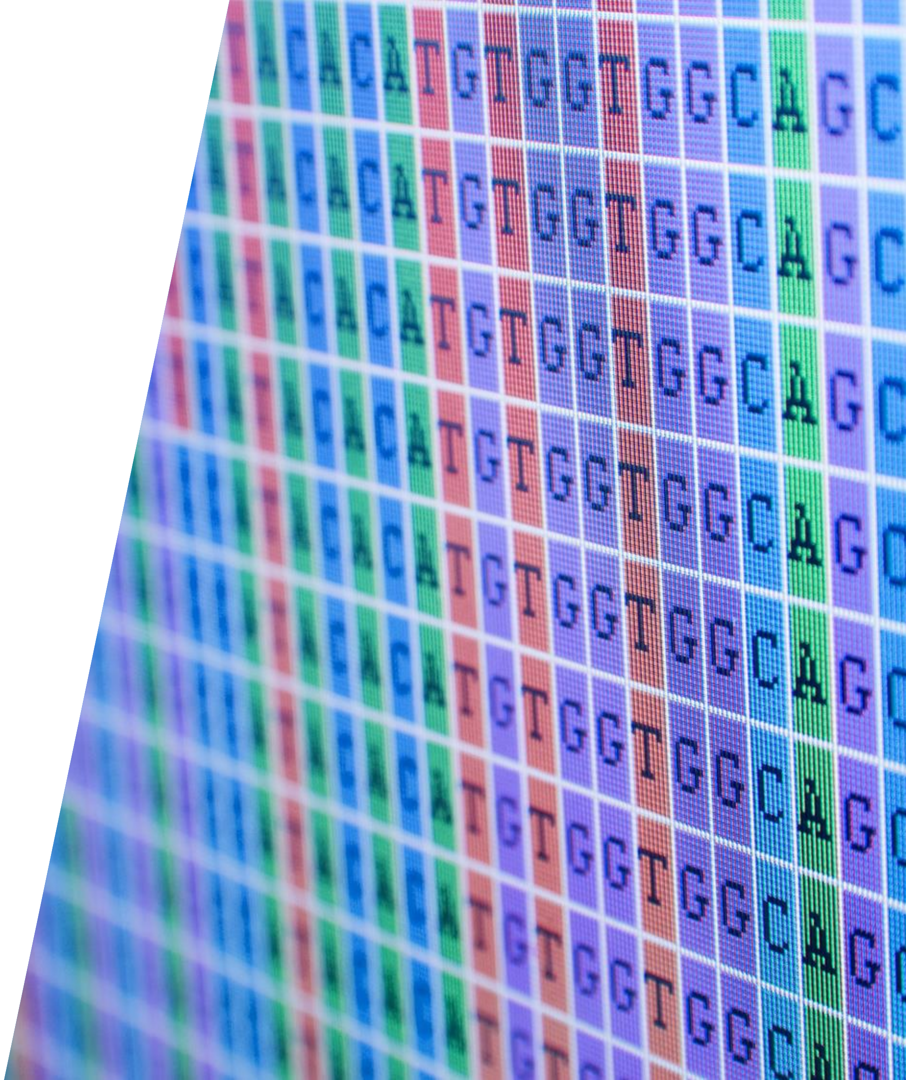
```
seq {0..10..100}
```

Creates a sequence of multiples of tens from 0 to 100

Why use sequences?

❖ Sequences are useful when you have **large amounts of data**, but only want to use certain parts of it at one time, for example in genomics or never-ending series

❖ Sequences are *lazily evaluated* so they only generate the values as the client requests them



Creating Sequences

- Sequences can be generated from functions

```
let phi = (1. + sqrt 5.) / 2.
let fibonacci = Seq.initInfinite (fun index ->
    let num = float index
    (((phi ** num)) - ((-phi) ** -num)) / sqrt 5. |> int64)
printfn "%A" fibonacci
```

```
seq [0L; 1L; 1L; 2L; 3L;...]
```

`Seq.initInfinite` creates a sequence from a supplied function using the integer index of the item to return, the **`fibonacci`** function here will generate as many numbers as requested (up to **`Int32.MaxValue`**)

Creating Sequences

❖ Sequences can be generated from functions

```
let ByTwos current =
   current |> Seq.unfold (fun num -> Some(num, num+2))

printfn "%A" <| ByTwos 1
```

```
seq [1; 3; 5; 7; ...]
```

`Seq.unfold` generates each value based on the prior value and is passed an initial value to start the generation

Creating Sequences

- Sequences can also be generated from **`IEnumerable`**

```
Brie, France
Cambozola, Germany
Cheddar, England
Fontina, Denmark
Gorgonzola, Italy
Havarti, Denmark
Limburger, Germany
Parmesan, Italy
```

```fsharp
let cheeses = File.ReadLines("cheeses")
    |> Seq.cast<string>
```

Read all the lines in with a **`StreamReader`** and create a new sequence in memory

Note: **`Seq.cast`** is not strictly necessary in this case since strings are being returned already and **`IEnumerable`** is automatically turned into sequences in F#

Explicit sequences

- Can also generate sequences using the **yield** keyword, and combine sequences with the **yield!** keyword

```
let names = seq {
    yield "Rachel";
    yield "Helen";
    yield "Mark";
    yield! [ "Adrian", "Glenn", "René" ] // Subsequence
    ...
}
```

```
val it : seq<string> = seq ["Rachel"; "Helen"; "Mark"; "Adrian";
                            "Glenn", "René"]
```

Sequence Expressions

- Expressions can also generate sequences, most common form is to use the **do-yield** keywords

```
let squares = seq { for i in 1 .. 10 do yield (i, i*i) }

Seq.iter (fun (n,n2) -> printfn "%d squared is %d" n n2)
    <| squares
```

`Collections.Seq` contains a variety of useful functions including support for filtering, combining and iterating sequences

```
1 squared is 1
2 squared is 4
3 squared is 9
4 squared is 16
...
```

Sequence Operations

❖ Sequences have many of the same capabilities as lists and arrays

```
let x = Seq.average nums
```

```
val nums : seq<float>
val x : float = 10.5
```

```
let x = Seq.min nums
```

```
val nums : seq<float>
val x : float = 1.0
```

```
let sort = Seq.sort nums
```

```
val nums : seq<float>
val sort : seq<float>
```

```
let total = Seq.sum nums
```

```
val nums : seq<float>
val total : float = 210.0
```

Individual Exercise

Create a sequence of triangular numbers

What are records?

- Records are simple aggregates of named heterogeneous values

```
type Point = { x : float; y : float; }
```

```
type Person = {
    Id : int
    Name : string
    Email : string
}
```

semicolons are used to separate the values defined as part of the record, they are *optional* if the values are listed on separate lines

Records actually generate a .NET class with public properties, the big advantage to records is when you start *using* them

Creating records

- Records are *inferred* when you create a new variable – remember F# always knows all the types you have defined up to that point

```
let helen = { Id = 1; Name = "Helen"; Email = "..."; }
```

There is no mention of the **`Person`** record type – instead, F# figures out what you want based on the fields being assigned here

Creating records

- When there are record conflicts, the instance can declare the record type as part of the field definitions

```
type Point = { x : float; y : float; }
type Point3D = { x : float; y : float; z : float; }
```

```
let pt = { x = 10.; y = 20.; }
```

Ambiguous – which record should be used?

Creating records

- When there are record conflicts, the instance can declare the record type as part of the field definitions

```
type Point = { x : float; y : float; }
type Point3D = { x : float; y : float; z : float; }
```

```
let pt = { Point.x = 10.; y = 20.; }
```

Can define the record as part of one or more of the fields to indicate which one to use

Comparing records

- F# records are **compared by value**, so two records with the same values are considered equal

```
type Point = { x : float; y : float; }

let pt1 = { x = 100.; y = 200.; }
let pt2 = { x = 100.; y = 200.; }

printfn "%s" |< if pt1 = pt2 then "Equal" else "Not Equal"
```

```
Equal
```

This works for other .NET languages as well, F# implements both `IComparable` and `IEquatable` as well as overriding the `Equals` and `GetHashCode` methods

Making records mutable

- Records, like all data structures, are immutable by default, but you can declare fields to be explicitly changeable using the **mutable** keyword

```
type recipe = { mutable A: string; mutable B: string;
                mutable C: string }

let pieRecipe = { A = "flour"; B = "water"; C = "salt"; }

pieRecipe.C <- "sugar"      // Change the value
printfn "%s" pieRecipe.C
```

```
sugar
```

Copying records

- Copying a record duplicates all of the fields in the source record with the requested changes

```
let mark = { Id = 1; Name = "Mark"; ... }
...
let jen = { mark with Name = "Jenny" }
```

mark	
Name	"Mark"
Id	1
LastUpdated	2014-12-01

jen	
Name	"Jenny"
Id	1
LastUpdated	2014-12-01

Individual Exercise

Create a record type using tuples

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What is a discriminated union?

- A discriminated union (DU) is a type which includes a closed set of known values – similar to an `enum` in C# or a `union` in C/C++

- Unlike `enum`s, DUs will **always** be one of the specified values and cannot be used as bit flags

```
type Fruit =
        | Apple
        | Pear
        | Raspberry
        | Kiwi
        | Banana
        | Grape
        | Blueberry
        | Tangerine
```

Using a discriminated union

- Can assign a DU directly to a variable, F# infers the type being created

```
type Fruit =
     | Apple
     | Pear
     | Raspberry
     | Kiwi
     | Banana
     | Grape
     | Blueberry
     | Tangerine
```

Must select one of the known values – cannot use casts or assign unknown values

```
let forbiddenFruit = Apple
...
printfn "%A" forbiddenFruit
```

```
Apple
```

Under the covers, F# creates a static property for each known `Fruit` value on the discriminated union type

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Discriminated Union field types

- Discriminated Unions can have a field type associated with each value

```
type Shape =
     | Circle of radius : float
     | Square of size : uint32
     | Rectangle of length : (double * double)
```

each supported value can have a different associated *type*, here for example we use a **tuple** for the rectangle width/height value

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Discriminated Union field types

- Discriminated Unions can have a field type associated with each value

```
type Shape =
     | Circle of radius : float
     | Square of size : uint32
     | Rectangle of length : (double * double
```

```
let shape1 = Circle radius = 50.
let shape2 = Rectangle length = (50.,25.)
```

Based on the selected field, the value is initialized with the appropriate type

assigned variables select *one* of the defined values to use – this approach is used instead of inheritance (e.g. a **Shape** base class)

Discriminated Union field types

- Discriminated Unions can have a field type associated with each value

```
type Shape =
     | Circle of float
     | Square of uint32
     | Rectangle of (double * double)
```

```
let shape1 = Circle 50.
let shape2 = Rectangle (50.,25.)
```

Can also leave off the field name in the definition and assignment

Under the covers, F# actually generates an abstract **Shape** class with concrete versions for each value you create – but that's all hidden away with syntactic sugar!

Discriminated Union field types

- Can associate *multiple* values for a given identifier using the asterisk (*) as a separator

```
identifier [of [fieldname1 :] type1 [* [fieldname2 :] type2 ...]
```

```
type Shape =
     | Circle of radius : float
     | Square of size : uint32
     | Rectangle of length : double * double
     | Prism of width : double * height : double
```

```
let shape1 = Prism (width = 10., height = 5.)
```

Individual Exercise

Convert C# code into a discriminated union

Flash Quiz

Flash Quiz

① What symbol do you use to separate components in a tuple?

a) |>

b) _

c) *

Flash Quiz

① What symbol do you use to separate components in a tuple?

a) |>

b) _

c) *

Flash Quiz

② Records __________ (select all that apply)

a) Can have multiple constructors
b) Cannot be compared
c) Can contain different types of data
d) Are immutable

Flash Quiz

② Records __________ (select all that apply)

a) Can have multiple constructors

b) Cannot be compared

c) Can contain different types of data

d) Are immutable

Flash Quiz

③ Which of these two examples employ the proper syntax of a record expression?

a) A is correct
b) A and B are both correct
c) B is correct

A

```
let me = { Id = 1234; Name="Mark"; }
```

B

```
let me = {
      Id = 1234
      Name="Mark"
}
```

Flash Quiz

③ Which of these two examples employ the proper syntax of a record expression?

a) A is correct

b) A and B are both correct

c) B is correct

A

```
let me = { Id = 1234; Name="Mark"; }
```

B

```
let me = {
      Id = 1234
      Name="Mark"
}
```

Summary

1. Discuss tuples
2. Describe sequences and their uses
3. Create and utilize records
4. Compose discriminated unions

Where are we going from here?

- You now know about some of the common data structures you use in F#
- In the next course, we will look at how to match patterns in F# which can replace the common **`if-else`** statement

Thank You!

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