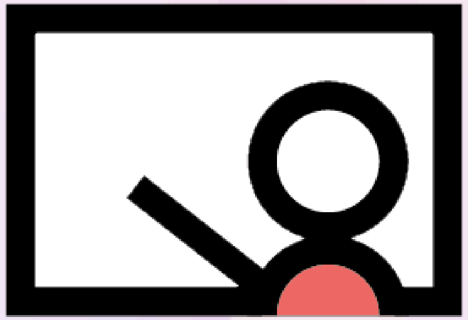
F♯ Training

Types

2025 April

Table of contents

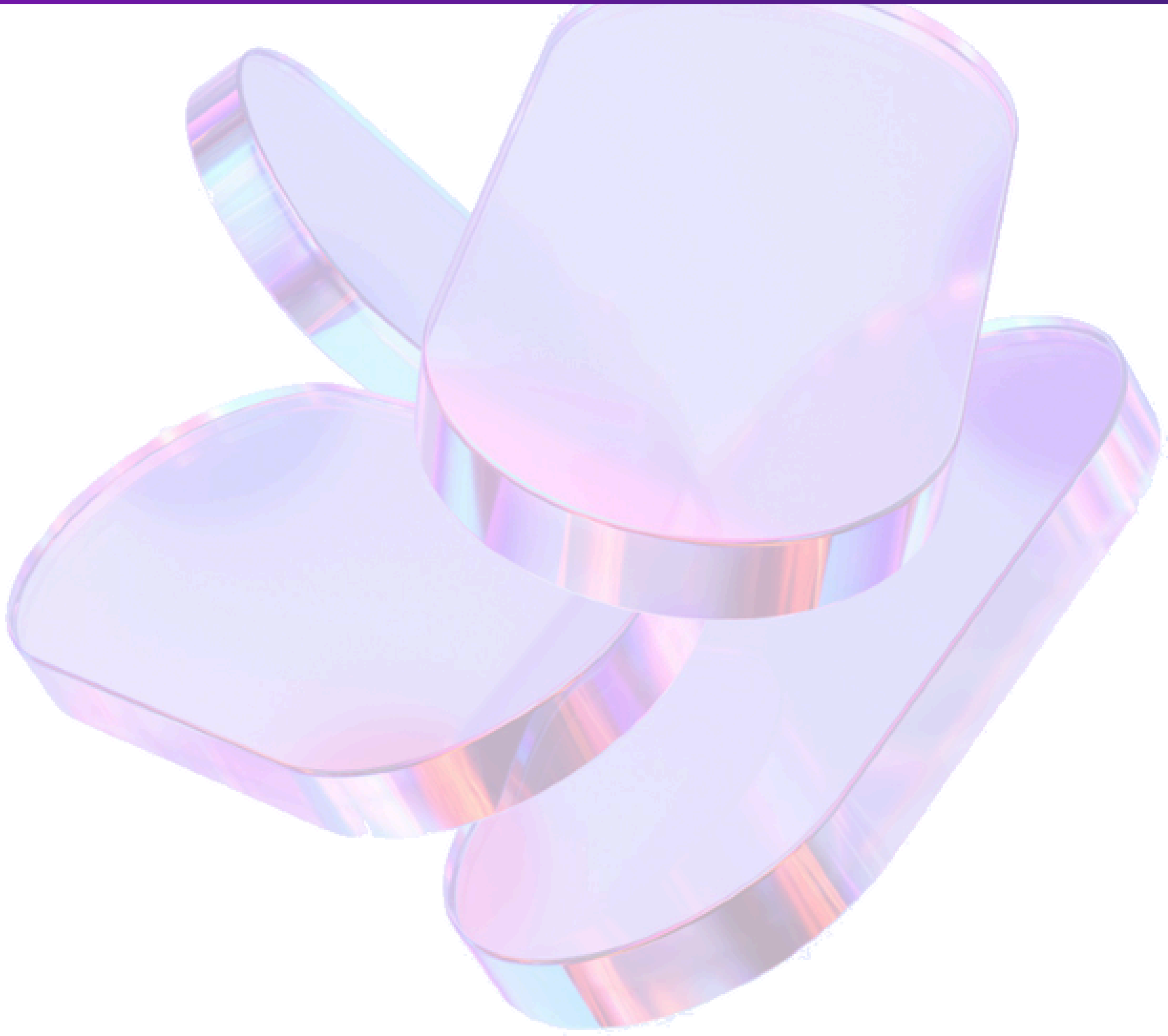
- → Overview
- → Tuples
- → Records
- → Unions
- → Enums
- → Anonymous records
- → Value types



1. Types Overview

.NET type classifications

1. Value types *vs* reference types
2. Primitive types *vs* composite types
3. Generic types
4. Types created from literal values
5. Algebraic types: sum *vs* product



Composite types

Created by combining other types
👉 F# type features stable and mature

Types	*Version*	Name	*Ref. type*	*Value type*
Types .NET		`class`	✅	❌
		`struct`, `enum`	❌	✅
Specific to C#	C# 3.0	Anonymous type	✅	❌
	C# 7.0	*Value tuple*	❌	✅
	C# 9.0	`record (class)`	✅	❌
	C# 10.0	`record struct`	❌	✅
Specific to F#		*Tuple, Record, Union*	✅ (default)	✅ (opt-in)
	F# 4.6	Anonymous *Record*	✅ (default)	✅ (opt-in)

Composite types (2)

Can be generic (except `enum`)

Location:

- ➔ *Top-level* : `namespace`, top-level `module` (F♯)
- ➔ *Nested* : `class` (C♯), `module` (F♯)
- ➔ Not definable in `let` bindings, `member`

In F♯, all type definitions are made with the `type` keyword
→ including classes, enums and interfaces!
→ but tuples don't need a type definition

Particularity of F♯ types / .NET types

Tuple, *Record*, *Union* are:

- ➔ Immutable by default
- ➔ Non-nullable by default
- ➔ Equality and structural comparison *(except with fields of `function` type)*
- ➔ `sealed`: cannot be inherited
- ➔ Deconstruction, with same syntax as construction 📍

Types with literal values

Literal values = instances whose type is inferred

- ➔ Primitive types: `true` (`bool`) - `"abc"` (`string`) - `1.0m` (`decimal`)
- ➔ Tuples C♯ / F♯ : `(1, true)`
- ➔ Anonymous types C♯ : `new { Name = "Joe", Age = 18 }`
- ➔ Records F♯ : `{ Name = "Joe"; Age = 18 }`

☝️ **Note :**

- ➔ Types must be defined beforehand ❗
- ➔ Exception: tuples and C♯ anonymous types: implicit definition

Algebraic data types (ADT)

> Composite types, combining other types by *product* or *sum*.

Let's take the types `A` and `B`, then we can create:

- ➔ The product type `A × B`:
  - ➔ Contains 1 component of type `A` AND 1 of type `B`.
  - ➔ Anonymous or named components
- ➔ Sum type `A + B`:
  - ➔ Contains 1 component of type `A` OR 1 of type `B`.

By extension, same for the product/sum types of N types.

Why *Sum* and *Product* terms?

It's related to the *number of values*:

- `bool` → 2 values: `true` and `false`
- `unit` → 1 value `()`
- `int` → infinite number of values

The number of values in the composed type will be:

- The sum of numbers for a *sum type*: `N(A) + N(B)`
- The product of numbers for a *product type*: `N(A) * N(B)`

Algebraic types *vs* Composite types

Type	Sum	Product
`enum`	✅	❌
Union F♯	✅	❌
`class` (1), `interface`, `struct`	❌	✅
Record F♯	❌	✅
Tuple F♯	❌	✅

(1) C♯ classes in the broadest sense:
→ including modern variations like *anonymous type*, *Value tuple* and *Record*

👉 In C♯, only 1 sum type: `enum`, very limited / union type 📍

Type abbreviation

Alias of another type: `type [name] = [existingType]`

Different use-cases:

```
// 1. Document code to avoid repetition
type ComplexNumber = float * float
type Addition<'num> = 'num → 'num → 'num // 👈 Also works with generics

// 2. Decouple (partially) usage / implementation
//    → Easier to change the implementation (for a stronger type)
type ProductCode = string
type CustomerId = int
```

⚠️ Deleted at compile time → *~~type safety~~*
→ Compiler allows `int` to be passed instead of `CustomerId` !

Type abbreviation (2)

💡 It's also possible to create an alias for a module 📍

```
module [name] = [existingModule]
```

⚠️ It's NOT possible to create an alias for a namespace (≠ C♯)

2. Tuple Type

Tuples: key points

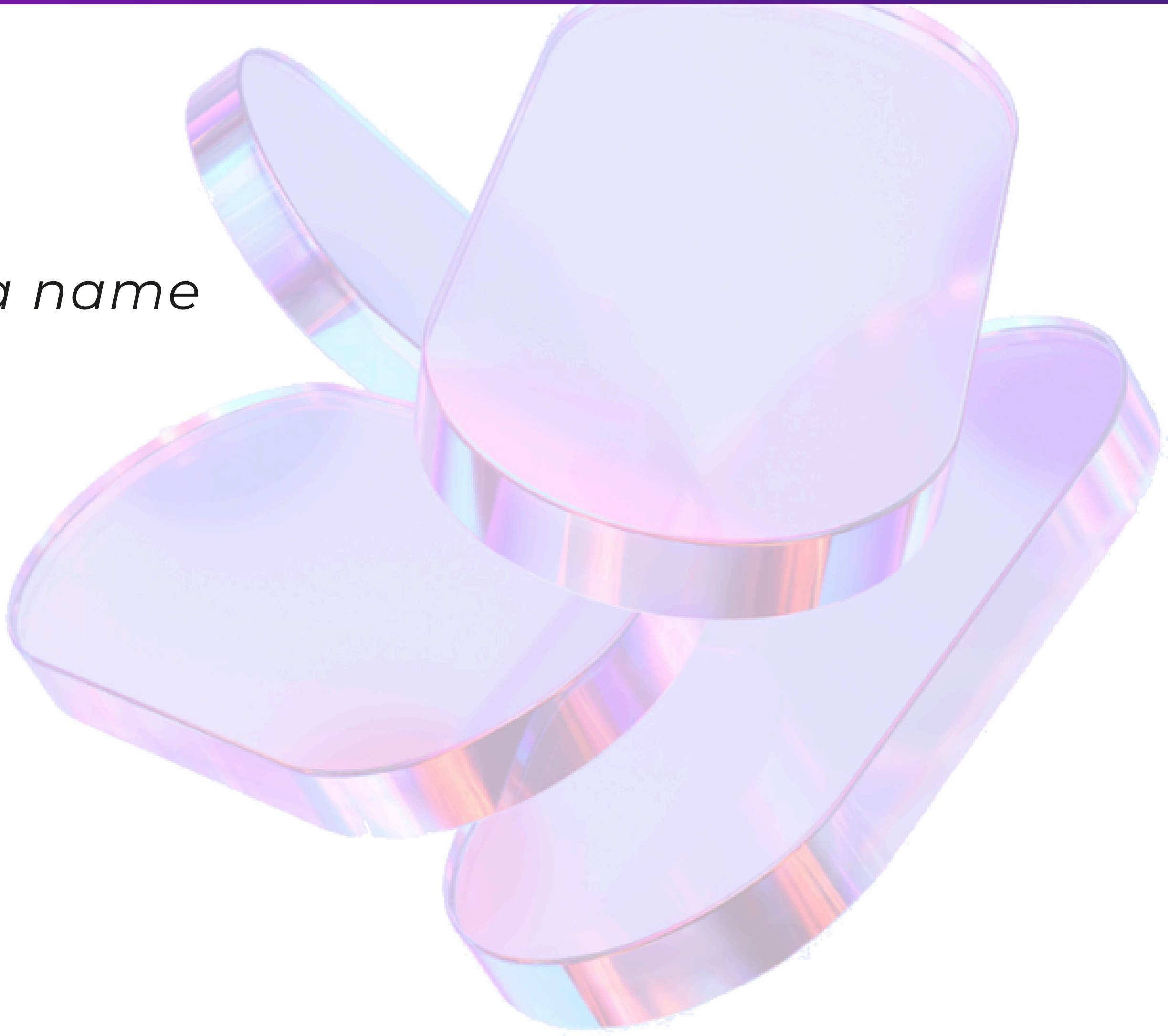
Types constructed from **literal values**

Anonymous types
but aliases can be defined to give them a name

Product types by definition
→ `*` sign in the type signature: `A * B`

Number of elements in the tuples:
- 👌 2 or 3 (`A * B * C`)
- ⚠️ > 3 : possible but prefer *Records*

Element order matters
→ `A * B` ≠ `B * A` *(if `A` ≠ `B`)*



Tuples: construction

Syntax of literals: `a,b` or `a, b` or `(a, b)`

- ➔ Comma `,`: symbol dedicated to tuples in F#
- ➔ Spaces ` ` are optional
- ➔ Parentheses `()` may be necessary

⚠️ **Pitfall:** the symbol used is different for literals *vs* types

- ➔ `,` for literal
- ➔ `*` for signature
- ➔ E.g. `true, 1.2` → `bool * float`

Tuples: deconstruction

- ➔ Same syntax as construction 👍
- ➔ All elements must appear in the deconstruction ⚠️
  - ➔ Use `_` *(discard)* to ignore one of the elements

```
let point = 1.0, 2.5
let x, y = point

let x, y = 1, 2, 3 // 💥 Error FS0001: Type incompatibility...
                   // ... Tuples have lengths other than 2 and 3

let result = System.Int32.TryParse("123") // (bool * int)
let _, value = result // Ignore the "bool"
```

Tuples in practice

Use a tuple for a data structure:

- ➔ Small: 2 to 3 elements
- ➔ Light: no need for element names
- ➔ Local: small scope

Immutable tuple:
→ modifications are made by creating a new tuple

```fsharp
let addOneToTuple (x, y, z) = x + 1, y + 1, z + 1
```

Tuples in practice (2)

Structural equality, but only between 2 tuples of the same signature!

```fsharp
(1,2) = (1,2)       // true
(1,2) = (0,0)       // false
(1,2) = (1,2,3)     // 💥 Error FS0001: Type incompatibility...
                    // ... Tuples have lengths other than 2 and 3
(1,2) = (1,(2,3))   // 💥 Error FS0001: This expression was supposed to have type `int`...
                    // ... but here it has type `'a * 'b`
```

Nesting of tuples using `()`

```fsharp
let doublet = (true,1), (false, "a")  // (bool * int) * (bool * string) → pair of pairs
let quadruplet = true, 1, false, "a"  // bool * int * bool * string → quadruplet
doublet = quadruplet                  // 💥 Error FS0001: Type incompatibility...
```

Tuples: pattern matching

Patterns recognized with tuples:

```
let print move =
    match move with
     | 0, 0 → "No move"                      // Constant 0
     | 0, y → $"Vertical {y}"                 // Variable y (≠ 0)
     | x, 0 → $"Horizontal {x}"
     | x, y when x = y → $"Diagonal {x}"      // Condition x and y equal
                                               // `x, x` is not a recognized pattern ❗
     | x, y → $"Other ({x}, {y})"
```

☝️ **Notes:**

- ➔ Patterns are ordered from specific to generic
- ➔ The last pattern `x, y` is the default one to deconstruct a tuple

Pairs

- ➔ 2-element tuples
- ➔ So common that 2 helpers are associated with them:
  - ➔ `fst` as *first* to extract the 1st element of the pair
  - ➔ `snd` as *second* to extract the 2nd element of the pair
  - ➔ ⚠️ Only works for pairs

```
let pair = 'a', "b"
fst pair  // 'a' (char)
snd pair  // "b" (string)
```

Pair Quiz 🕹️

1. **Implement `fst` and `snd`**

```
let fst ... ?
let snd ... ?
```

2. **What is the signature of this function?**

```
let toList (x, y) = [x; y]
```

Pair Quiz 🎲

1. How do you implement `fst` and `snd` yourself?

```
let inline fst (x, _) = x  // Signature : 'a * 'b → 'a
let inline snd (_, y) = y  // Signature : 'a * 'b → 'b
```

- ➔ Tuple deconstruction: `(x, y)`
- ➔ We *discard* one element using `_` wildcard
- ➔ Functions can be `inline`

Pair Quiz 🎲 🎲

2. Signature of `toList` ?

```
let inline toList (x, y) = [x; y]
```

- ➔ Returns a list with the 2 elements of the pair
- ➔ The elements are therefore of the same type
- ➔ There is no constraint on this type → generic `'a`

Answer : `x: 'a * y: 'a → 'a list`

3. Record Type

Records: key points

> Product type with named elements called *fields*.

Alternative to tuples when they are imprecise, for instance `float * float`:

- ➔ Point? Coordinates? Vector?
- ➔ Real and imaginary parts of a complex number?

Eleviate the doubt by naming both the type and its elements:

```fsharp
type Point = { X: float; Y: float }
type Coordinate = { Latitude: float; Longitude: float }
type ComplexNumber = { Real: float; Imaginary: float }
```

Records: declaration

Base syntax:

```fsharp
type RecordName =
    { Label1: type1
      Label2: type2
      … }
```

☝️ Field labels in PascalCase, not ~~camelCase~~ → see MS style guide

Complete syntax:

```fsharp
[ attributes ]                              // [<Struct>]
type [accessibility-modifier] RecordName =  // private, internal
    { [ mutable ] Label1: type1
      [ mutable ] Label2: type2
      … }
    [ member-list ]                         // Properties, methods…
```

Record declaration: formatting styles

- Single-line: properties separated by `;`
- Multi-line: properties separated by line breaks
  - 3 variations: *Cramped*, *Aligned*, *Stroustrup*

```fsharp
// Single line
type PostalAddress = { Address: string; City: string; Zip: string }
```

```fsharp
// Cramped: historical
type PostalAddress =
    { Address: string
      City: string
      Zip: string }
```

```fsharp
// Aligned: C#-like
type PostalAddress =
    {
        Address: string
        City: string
        Zip: string
    }
```

```fsharp
// Stroustrup: C++-like
type PostalAddress = {
    Address: string
    City: string
    Zip: string
}
```

Record: styles comparison

Criterion	Best styles 🏆
Compactness	Single-line, Cramped
Refacto Easiness *(re)indentation, fields (re)ordering*	Aligned, Stroustrup

☝️ **Recommendation:** *Strive for Consistency*
→ Apply consistently the same multi-line style across a repository
→ In addition, use the single-line style when relevant: line with < 80 chars

Record: styles configuration

Fantomas configuration in the `.editorconfig` file:

```
max_line_length = 180
fsharp_multiline_bracket_style = cramped | aligned | stroustrup

fsharp_record_multiline_formatter = number_of_items
fsharp_max_record_number_of_items = 3
# or
fsharp_record_multiline_formatter = character_width
fsharp_max_record_width = 120
```

🔗 https://fsprojects.github.io/fantomas/docs/end-users/Configuration.html#fsharp_record_multiline_formatter

Record members declaration styles

👉 Members are declared after the fields

Single-line

```fsharp
// `with` keyword required
type PostalAddress = { Address: string; City: string; Zip: string } with
    member x.ZipAndCity = $"{x.Zip} {x.City}"

// Or use line breaks (recommended when ≥ 2 members)
type PostalAddress =
    { Address: string; City: string; Zip: string }

    member x.ZipAndCity = $"{x.Zip} {x.City}"
    member x.CityAndZip = $"%s{x.City}, %s{x.Zip}"
```

Record member declaration styles (2)

Multi-line: *Cramped* and *Aligned*

☝️ 2 line breaks

```fsharp
type PostalAddress =
    { Address: string
      City: string
      Zip: string }

    member x.ZipAndCity = $"{x.Zip} {x.City}"
    member x.CityAndZip = $"%s{x.City}, %s{x.Zip}"
```

Record member declaration styles (3)

Multi-line: *Stroustrup*

☝️ `with` keyword + 1 line break + indentation

```
type PostalAddress = {
    Address: string
    City: string
    Zip: string
} with
    member x.ZipAndCity = $"{x.Zip} {x.City}"
    member x.CityAndZip = $"%s{x.City}, %s{x.Zip}"
```

Record expression for instanciation

- ➔ Same syntax as an anonymous C♯ object without the `new` keyword
- ➔ All fields must be populated, but in any order (but can be confusing)
- ➔ Same possible styles: single/multi-lines

```
type Point = { X: float; Y: float }
let point1 = { X = 1.0; Y = 2.0 }
let pointKo = { Y = 2.0 }           // 💥 Error FS0764
//            ~~~~~~~~~~~ FS0764: No assignment given for field 'X' of type 'Point'
```

⚠️ **Trap:** differences declaration / instanciation
- → `:` for field type in record declaration
- → `=` for field value in record expression

Record deconstruction

- ➔ Fields are accessible by "dotting" into the object
- ➔ Alternative: deconstruction
  - ➔ Same syntax for deconstructing a *Record* as for instantiating it 👍
  - ➔ Unused fields can be ignored 💡

```
let { X = x1 } = point1
let { X = x2; Y = y2 } = point1
```

Record deconstruction (2)

⚠️ Additional members *(properties)* cannot be deconstructed!

```
type PostalAddress =
    {
        Address: string
        City: string
        Zip: string
    }
    member x.CityLine = $"{x.Zip} {x.City}"

let address = { Address = ""; City = "Paris"; Zip = "75001" }

let { CityLine = cityLine } = address   // 💥 Error FS0039
//    ~~~~~~~~ The record label 'CityLine' is not defined
let cityLine = address.CityLine         // 👌 OK
```

Record: inference

- ➔ A record type can be inferred from the fields used 👍 but not with members ❗
- ➔ As soon as the type is inferred, IntelliSense will work

```
type PostalAddress =
    { Address: string
      City: string
      Zip: string }

let department address =
    address.Zip.Substring(0, 2) ▷ int
    //     ^^^^ 💡 Infer that address is of type `PostalAddress`.

let departmentKo zip =
    zip.Substring(0, 2) ▷ int
//  ~~~~~~~~~~~~~ Error FS0072: Lookup on object of indeterminate type
```

Record: pattern matching

Let's use an example: `inhabitantOf` is a function giving the inhabitants name *(in French)* at a given address *(in France)*

```
type Address = { Street: string; City: string; Zip: string }

let department { Zip = zip } = int zip[0..1] // Address → int

let private IleDeFrance = Set [ 75; 77; 78; 91; 92; 93; 94; 95 ]
let inIleDeFrance departmentNum = IleDeFrance.Contains(departmentNum) // int → bool

let inhabitantOf address = // Address → string
    match address with
    | { Street = "Pôle"; City = "Nord" } → "Père Noël"
    | { City = "Paris" } → "Parisien"
    | _ when department address = 78 → "Yvelinois"
    | _ when department address ▷ inIleDeFrance → "Francilien"
    | _ → "Français"
```

Record: name conflict

In F♯, typing is nominal, not structural as in TypeScript
→ Use qualification to resolve ambiguity
→ Even better: write ≠ types or put them in ≠ modules

```fsharp
type Person1 = { First: string; Last: string }
type Person2 = { First: string; Last: string }
let alice = { First = "Alice"; Last = "Jones"}  // val alice: Person2... (by proximity)

// ⚠️ Deconstruction
let { First = firstName } = alice   // Warning FS0667 (in F# 6)
//  ~~~~~~~~~~~~~~~~~~~~~  The labels of this record do not uniquely
//                         determine a corresponding record type

let { Person2.Last = lastName } = alice     // 👌 OK with qualification
let { Person1.Last = lastName } = alice     // 💥 Error FS0001
//                                   ~~~~~ Type 'Person1' expected, 'Person2' given
```

Record: modification

Record is immutable, but easy to get a modified copy
→ **copy and update** expression of a *Record*
→ use multi-line formatting for long expressions

```fsharp
// Single-line
let address2 = { address with Street = "Rue Vivienne" }

// Multi-line
let address3 =
    { address with
        City = "Lyon"
        Zip  = "69001" }
```

Record *copy-update*: C♯ / F♯ / JS

```csharp
// Record C♯ 9.0
address with { Street = "Rue Vivienne" }
```

```fsharp
// F♯ copy and update
{ address with Street = "Rue Vivienne" }
```

```javascript
// Object destructuring with spread operator
{ ...address, street: "Rue Vivienne" }
```

Copy-update limits (< F# 8)

Reduced readability with several nested levels

```fsharp
type Street = { Num: string; Label: string }
type Address = { Street: Street }
type Person = { Address: Address }

let person = { Address = { Street = { Num = "15"; Label = "rue Neuf" } } }

let person' =
    { person with
        Address =
          { person.Address with
              Street =
                { person.Address.Street with
                    Num = person.Address.Street.Num + " bis" } } }
```

Copy-update : F# 8 improvements

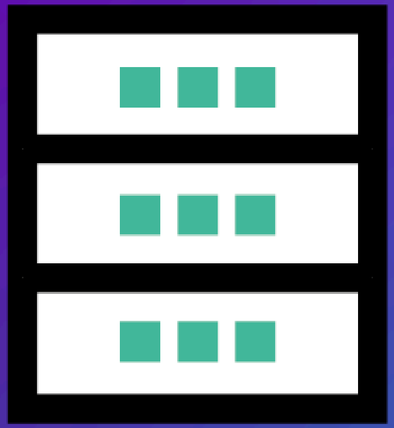
```fsharp
type Street = { Num: string; Label: string }
type Address = { Street: Street }
type Person = { Address: Address }

let person = { Address = { Street = { Num = "15"; Label = "rue Neuf" } } }

let person' =
    { person with
        Person.Address.Street.Num = person.Address.Street.Num + " bis" }
```

☝️ Usually we have to qualify the field: see `Person.`

4. Union Type



Unions: key points

- ➔ Exact term: *Discriminated Union (DU)*
- ➔ Sum type: represents an **OR**, a **choice** between several *Cases*
  - ➔ Same principle as for an `enum`, but on steroids 💪
- ➔ Each *case* must have a *Tag (a.k.a Label, Discriminator)*
- ➔ Each *case* **may** contain data
  - ➔ As Tuple: its elements can be named -- in camelCase 🙏

```fsharp
type Ticket =
    | Adult                  // no data → ≃ singleton stateless
    | Senior of int          // holds an 'int' (w/o more precision)
    | Child of age: int      // holds an 'int' named 'age'
    | Family of Ticket list  // holds a list of tickets
                             // recursive type by default (no 'rec' keyword)
```

Unions: declaration

On several lines: 1 line / *case*
→ ☝️ Line indented and starting with a `|`

On a single (short) line
→ 💡 No need for the 1st `|`

```fsharp
open System

type IntOrBool =
    | Int32 of Int32                        // 💡 Tag with the same name as the data
    | Boolean of Boolean

type OrderId = OrderId of int               // 👈 Single-case union
                                            // 💡 Tag with the same name as the parent union

type Found<'T> = Found of 'T | NotFound     // 💡 Generic union type (no auto generalization)
```

Unions declaration (2)

Cases can be used without **qualification**: `Int32` *vs* `IntOrBool.Int32`

Qualification can be forced with `RequireQualifiedAccess` attribute:
- Cases using common terms (e.g. `None`) → to avoid name collision
- Cases names are designed to read better/more explicitly with qualification

Cases must be named in **PascalCase** ❗
- Since F# 7.0, camelCase is allowed for `RequireQualifiedAccess` unions 💡

Unions declaration (3)

Field labels are helpful for:

- Adding meaning to a primitive type:
  → See `Ticket` previous example: `Senior of int` vs `Child of age: int`
- Distinguish between two fields of the same type
  → See example below:

```fsharp
type ComplexNumber =
    | Cartesian of Real: float * Imaginary: float
    | Polar of Magnitude: float * Phase: float
```

Unions: instanciation

Case ≃ **constructor**
→ Function called with any *case* data

```fsharp
type Shape =
    | Circle of radius: int
    | Rectangle of width: int * height: int

let circle = Circle 12         // Type: 'Shape', Value: 'Circle 12'
let rect = Rectangle(4, 3)     // Type: 'Shape', Value: 'Rectangle (4, 3)'

let circles = [1..4] |> List.map Circle     // 👈 Case used as function
```

Unions: name conflict

When 2 unions have tags with the same name
→ Qualify the tag with the union name

```
type Shape =
    | Circle of radius: int
    | Rectangle of width: int * height: int

type Draw = Line | Circle    // 'Circle' will conflict with the 'Shape' tag

let draw = Circle            // Type='Draw' (closest type) -- ⚠️ to be avoided as ambiguous

// Tags qualified by their union type
let shape = Shape.Circle 12
let draw' = Draw.Circle
```

Unions: get the data out

- Only via *pattern matching*.
- Matching a union type is **exhaustive**.

```fsharp
type Shape =
    | Circle of radius: float
    | Rectangle of width: float * height: float

let area shape =
    match shape with
    | Circle r -> Math.PI * r * r   // 💡 Same syntax as instantiation
    | Rectangle (w, h) -> w * h

let isFlat = function
    | Circle 0.
    | Rectangle (0., _)
    | Rectangle (_, 0.) -> true
    | Circle _
    | Rectangle _ -> false
```

Single-case unions

Unions with a single case encapsulating a type (usually primitive)

```
type CustomerId = CustomerId of int
type OrderId = OrderId of int

let fetchOrder (OrderId orderId) =    // 💡 Direct deconstruction without 'match' expression
    ...
```

- ➔ **Benefits** 👍
  - ➔ Ensures *type safety* unlike simple type alias
    → Impossible to pass a `CustomerId` to a function waiting for an `OrderId`
  - ➔ Prevents *Primitive Obsession* at a minimal cost
- ➔ **Trap** ⚠️
  - ➔ `OrderId orderId` looks like C# parameter definition

Enum style unions

All *cases* are empty = devoid of data
→ ≠ .NET `enum` based on numeric values 📍

Instantiation and pattern matching are done just with the *Case*.
→ The *Case* is no longer a ~~function~~ but a *singleton* value.

```fsharp
type Answer = Yes | No | Maybe
let answer = Yes

let print answer =
    match answer with
    | Yes   -> printfn "Oui"
    | No    -> printfn "Non"
    | Maybe -> printfn "Peut-être"
```

🔗 [“Enum” style unions | F# for fun and profit]

Unions .Is* properties

The compiler generates `.Is{Case}` properties for each case in a union

- Before F♯ 9: not accessible + we cannot add them manually 😒
- Since F♯ 9: accessible 👍

```fsharp
type Contact =
    | Email of address: string
    | Phone of countryCode: int * number: string

type Person = { Name: string; Contact: Contact }

let canSendEmailTo person =  // Person → bool
    person.Contact.IsEmail   // `.IsEmail` is auto-generated
```

Union (FP) *vs* Object Hierarchy (OOP)

👉 A union can usually replace a small *object hierarchy*.

Explanations

Behaviors/operations implementation:

- **OO:** *virtual methods* in separated classes
- **FP:** *functions* relying on **pattern matchings**
  → exhaustivity
  → avoid duplication by grouping cases
  → improve readability by flattening split cases in a single `match..with`

FP *vs* OOP

How we reason about the code *(at both design and reading time)*

- **FP: by functions** → how an operation is performed for the different cases
- **OOP: by objects** → how all operations are performed for a single case

Abstraction

- Objects are more abstract than functions
- Good abstraction is difficult to design
- The more abstract a thing is, the more stable it should be

👉 **FP is usually easier to write, to understand, to evolve**

FP *vs* OOP: Open-Closed Principle

It's easier to extend what's **Open.**

OOP: open hierarchy, closed operations
→ Painful to add an operation: in all classes 😓
→ Easy to add a class in the hierarchy 👍

FP: open operations, closed cases
→ Easy to add an operation 👍
→ Painful to add a case: in all functions 😓
- Still, it's usually easier in F♯: only 1 file to change

Adding a class = new concept in the domain → always tricky ⚠️
Adding an operation = new behavior for the existing domain concepts

5. Enum Type

Real .NET `enum`

Enum: declaration

Set of integer constants (`byte`, `int`...) or `char`

```
type ColorN =
    | Red   = 1
    | Green = 2
    | Blue  = 3
```

☝️ Note the syntax difference with a enum-like union:

```
type Color = Red | Green | Blue
```

Enum: underlying type

The underlying type is defined by means of literals defining member values:

- `1`, `2`, `3` → `int`
- `1uy`, `2uy`, `3uy` → `byte`
- Etc. - see Literals

→ Same type required for all members:

```
type ColorN =
    | Red   = 1
    | Green = 2
    | Blue  = 3uy
// 💥          ~~~
// This expression was expected to have type 'int' but here has type 'byte'
```

Enum: char based

💡 Enum can be based on `char` but not on `string`

```fsharp
type AnswerChar = Yes='Y' | No='N'  ✅

type AnswerStringKo = Yes="Y" | No="N"  // 💥 Error FS0951
// Literal enumerations must have type int, uint, int16, uint16, int64, uint64, byte, sbyte or char
```

Enum members naming

💡 Enum members can be in **camelCase**

```fsharp
type File = a='a' | b='b' | c='c'
```

Enum: usages

⚠️ Unlike unions, the use of an `enum` literal is necessarily **qualified**

```
type AnswerChar = Yes='Y' | No='N'

let answerKo = Yes  // 💥 Error FS0039
//                ~~~     The value or constructor 'Yes' is not defined.

let answer = AnswerChar.Yes   // 👌 OK
```

💡 We can force the qualification for union types too:

```
[<RequireQualifiedAccess>] // 👈
type Color = Red | Green | Blue
```

Enum: matching

⚠️ Unlike unions, *pattern matching* on enums is **not exhaustive**
→ See `Warning FS0104: Enums may take values outside known cases...`

```
type ColorN =
    | Red   = 1
    | Green = 2
    | Blue  = 3

let toHex color =
    match color with
    | ColorN.Red   -> "#FF0000"
    | ColorN.Green -> "#00FF00"
    | ColorN.Blue  -> "#0000FF"
    | _ -> invalidArg (nameof color) $"Color {color} not supported" // 👈
```

Enum: flags

Same principle as in C♯:

```
open System

[<Flags>]
type PermissionFlags =
    | Read    = 1
    | Write   = 2
    | Execute = 4

let permission = PermissionFlags.Read ||| PermissionFlags.Write

let canRead = permission.HasFlag PermissionFlags.Read
```

💡 Note the `|||` operator called "binary OR" (same as `|` in C♯)

Enum flags: binary notation

💡 **Hint:** use binary notation for flag values:

```fsharp
[<Flags>]
type PermissionFlags =
    | Read    = 0b001
    | Write   = 0b010
    | Execute = 0b100
```

Enum: values

`System.Enum.GetValues()` returns the list of members of an `enum`
⚠️ Weakly typed: `Array` (non-generic array)
💡 Use a helper like:

```
let enumValues<'a> () =
    Enum.GetValues(typeof<'a>)
    :?> ('a array)
    |> Array.toList

let allPermissions = enumValues<PermissionFlags>()
// val allPermissions: PermissionFlags list = [Read; Write; Execute]
```

Enum: conversion

```fsharp
let redValue = int ColorN.Red          // enum → int
let redAgain = enum<ColorN> redValue   // int → enum
let red: ColorN = enum redValue        // int → enum

// ⚠️ Use LanguagePrimitives for char enum
let n: AnswerChar = LanguagePrimitives.EnumOfValue 'N' // char → enum
let y = LanguagePrimitives.EnumToValue AnswerChar.Yes  // enum → char
```

Enum *vs* Union

Type	Data inside	Qualification	Exhaustivity
Enum	integers	Required	❌ No
Union	any	Optional	✅ Yes

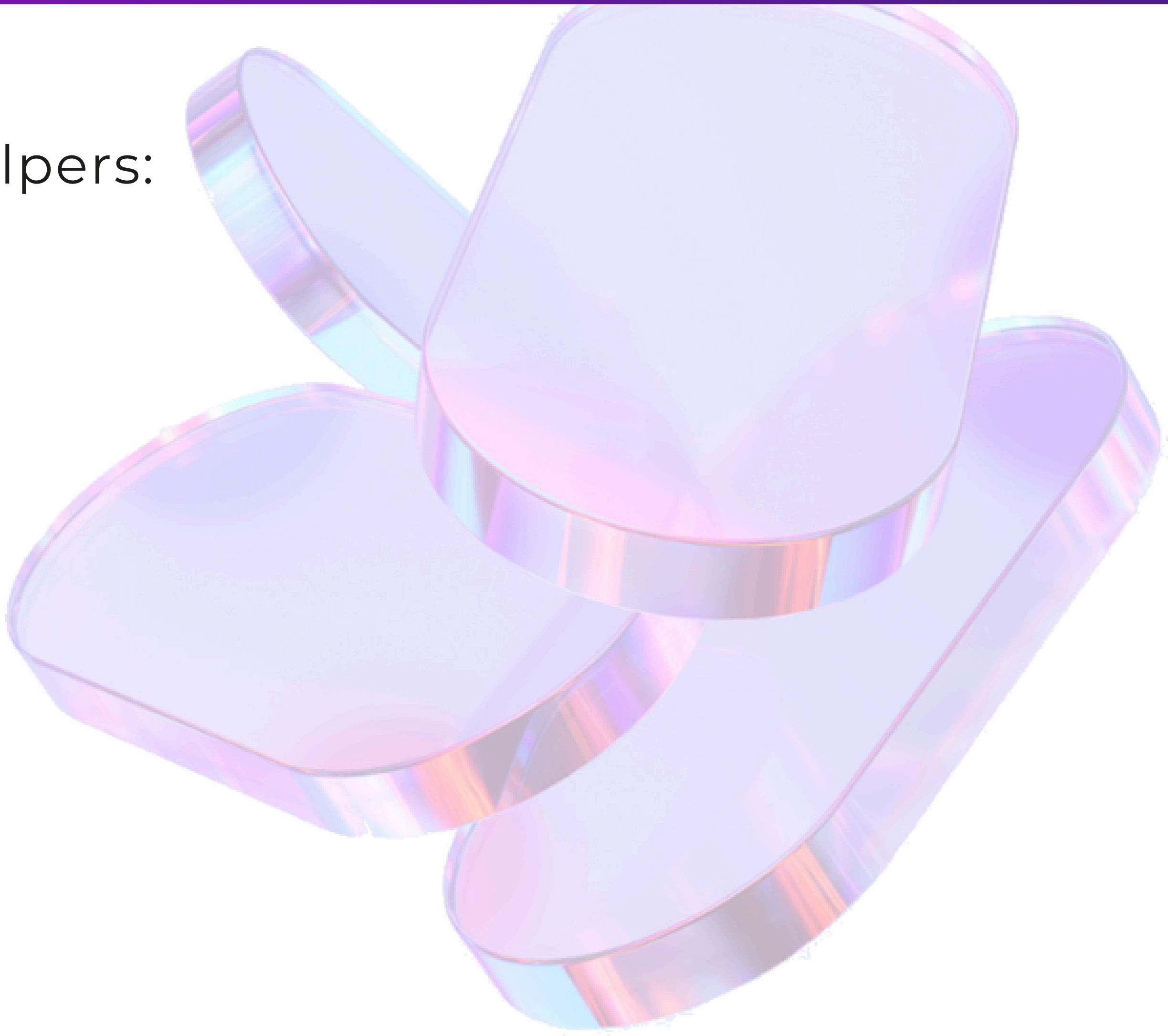
☝️ **Recommendation:**

- ➔ Prefer Union over Enum in most cases
- ➔ Choose an Enum for:
  - ➔ .NET Interop
  - ➔ int data
  - ➔ Flags feature

Enum: FSharpx.Extras

💡 NuGet package FSharpx.Extras
→ Includes an `Enum` module with these helpers:

- ➔ `parse<'enum>: string -> 'enum`
- ➔ `tryParse<'enum>: string -> 'enum option`
- ➔ `getValues<'enum>: unit -> 'enum seq`



6. Anonymous Record

Anonymous Record

- Since F♯ 4.6 *(March 2019)*
- Syntax: same as *Record* with "fat" braces `{| fields |}`
  - `{| Age: int |}` → signature
  - `{| Age = 15 |}` → instance
- Inline typing: no need to pre-define a named `type`
  - Alternative to *Tuples*
- Allowed in function input/output
  - ≠ Anonymous type C♯

Anonymous Record : benefits ✅

- Reduce *boilerplate*
- Improve interop with external systems (JavaScript, SQL...)

Examples *(more on this later)* :

➔ LINQ projection

➔ Customization of an existing record

➔ JSON serialization

➔ Inline signature

➔ Alias by module

✅ LINQ Projection

💡 Select a subset of properties

```
let names =
    query {
        for p in persons do
        select {| Name = p.FirstName |}
    }
```

In C♯, we would use an anonymous type:

```
var names =
    from p in persons
    select new { Name = p.FirstName };
```

🔗 F# vs C#: Anonymous Records by Krzysztof Kraszewski

✅ Customize an existing record

💡 An anonymous record can be instantiated from a record instance

```fsharp
type Person = { Age: int; Name: string }
let william = { Age = 12; Name = "William" }

// Add a field (Gender)
let william' = {| william with Gender = "Male" |}
            // {| Age = 12; Name = "William"; Gender = "Male" |}

// Modify fields (Name, Age: int => float)
let jack = {| william' with Name = "Jack"; Age = 16.5 |}
        // {| Age = 16.5; Name = "Jack"; Gender = "Male" |}
```

✅ JSON serialization: issue

😕 Unions can be serialized in an impractical format

```fsharp
#r "nuget: Newtonsoft.Json"
let serialize obj = Newtonsoft.Json.JsonConvert.SerializeObject obj

type CustomerId = CustomerId of int
type Customer = { Id: CustomerId; Age: int; Name: string; Title: string option }

serialize { Id = CustomerId 1; Age = 23; Name = "Abc"; Title = Some "Mr" }
```

```json
{
  "Id": { "Case": "CustomerId", "Fields": [ 1 ] }, // 👀
  "Age": 23,
  "Name": "Abc",
  "Title": { "Case": "Some", "Fields": [ "Mr" ] }  // 👀
}
```

✅ JSON serialization: solution

💡 Define an anonymous record to serialize a *customer*

```fsharp
let serialisable customer =
    let (CustomerId customerId) = customer.Id
    {| customer with
          Id = customerId
          Title = customer.Title |> Option.toObj |}

serialize (serialisable { Id = CustomerId 1; Age = 23; Name = "Abc"; Title = Some "Mr" })
```

```json
{
  "Id": 1, // ✅
  "Age": 23,
  "Name": "Abc",
  "Title": "Mr"   // ✅
}
```

✅ Signature *inline*

💡 Use an anonymous *inline* record to reduce cognitive load

```fsharp
type Title = Mr | Mrs
type Customer =
    { Age  : int
      Name : {| First: string; Middle: string option; Last: string |} // 👈
      Title: Title option }
```

Anonymous Record: Limits 🛑

```fsharp
// No inference from field usage
let nameKo x = x.Name  // 💥 Error FS0072: Lookup on object of indeterminate type...
let nameOk (x: {| Name:string |}) = x.Name

// No deconstruction
let x = {| Age = 42 |}
let {  Age = age  } = x  // 💥 Error FS0039: The record label 'Age' is not defined
let {| Age = age |} = x  // 💥 Error FS0010: Unexpected symbol '{|' in let binding

// No full objects merge
let banana = {| Fruit = "Banana" |}
let yellow = {| Color = "Yellow" |}
let banYelKo = {| banana with yellow |} // 💥 Error FS0609...
let banYelOk = {| banana with Color = "Yellow" |}

// No omissions
let ko = {| banYelOk without Color |}  // 💥 No 'without' keyword
```

7. Value Types

Struct F♯ Types

- Regular tuple/record/union are reference-types
- Possible to get them as value-types
  - Instances stored on the *Stack* rather than in the *Heap*
  - Records, Unions: `[<Struct>]` attribute
  - Tuples, Anonymous Records: `struct` keyword

Struct tuples & anonymous records

```fsharp
// Struct tuple
let a = struct (1, 'b', "Three") // struct (int * char * string)

// Struct anonymous record
let b = struct {| Num = 1; Char = 'b'; Text = "Three" |}
```

Struct records & unions

```fsharp
// Struct record
[<Struct>]
type Point = { X: float; Y: float }
let p = { X = 1.0; Y = 2.3 } // val p: Point = { X = 1.0; Y = 2.3 }

// Struct union: unique fields labels are required❗
[<Struct>]
type Multicase =
    | Int  of i: int
    | Char of c: char
    | Text of s: string
let t = Int 1 // val t: Multicase = Int 1
```

Struct: recommendations

⚖️ **Pros/Cons:**

- ➔ ✅ Efficient because no *garbage collection*
- ➔ ⚠️ Passed by value → memory pressure

🔗 F# coding conventions / Performance

> “ Consider structs for small types with high allocation rates ”

8. Wrap up 🌯

Quiz wrap up

```fsharp
// Match types with concepts (1 to many)
type Color1 = int * int * int
type Color2 = Red | Green | Blue
type Color3 = Red=1 | Green=2 | Blue=3
type Color4 = { Red: int; Green: int; Blue: int }
type Color5 = {| Red: int; Green: int; Blue: int |}
type Color6 = Color of Red: int * Green: int * Blue: int
type Color7 =
    | RGB of {| Red: int; Green: int; Blue: int |}
    | HSL of {| Hue: int; Saturation: int; Lightness: int |}

// A. Alias
// B. Enum
// C. Record
// D. Record anonyme
// E. Single-case union
// F. Union
// G. Union enum-like
// H. Tuple
```

Quiz wrap up

Types	Concepts
`type Color1 = int * int * int`	**H.** Tuple + **A.** Alias
`type Color2 = Red | Green | Blue`	**G.** Union enum-like
`type Color3 = Red=1 | Green=2 | Blue=3`	**B.** Enum
`type Color4 = { Red: int; Green: int… }`	**C.** Record
`type Color5 = {| Red: int; Green: int… |}`	**D.** Anonymous Record + **A.** Alias
`type Color6 = Color of Red: int * …`	**E.** Single-case union + **H.** Tuple
`type Color7 = RGB of {|…|} | HSL of {|…|}`	**F.** Union + **D.** Anonymous Record

Types Composition

Creating new types?
→ ❌ Algebraic data types do not support inheritance
→ ✅ By composition, in *sum/product types*
→ 💡 Extension of a *Record* into an anonymous *Record* with more fields

Combine 2 unions?
→ ❌ Not "flattenable" as in TypeScript ①
→ ✅ New parent union type ②

```
// French-suited cards
type Noir = Pique | Trefle // pikes or spades ♠ | clovers or clubs ♣
type Rouge = Coeur | Carreau // hearts ♥ | tiles or diamonds ♦
type CouleurKo = Noir | Rouge  // (1) ⚠️ not the expected union of Pique | Trefle | Coeur | Carreau
type Couleur = Noir of Noir | Rouge of Rouge // (2) ✅
let c1 = Noir Pique // Couleur
```

Conclusion

Lots of ways to model!

💡 Opportunity for:

- ➔ Team discussions
- ➔ Business domain encoding in types

Thanks 🙏