F#

Succinct, Expressive, Efficient Functional Programming for .NET

The F# Team

Microsoft Developer Division, Redmond

Microsoft Research, Cambridge

Topics

- What is F# about?
- Some Simple F# Programming
- A Taste of Parallel/Reactive with F#

What is F# about?

Or: *Why is Microsoft investing in functional programming anyway?*

Simplicity

Economics

Fun! Fun! Fun!

Simplicity

Code!

```
//F#
open System
let a = 2
Console.WriteLine a
```

```
//C#
using System;

namespace ConsoleApplication1
{
  class Program
  {
    static int a()
    {
        return 2;
    }
    static void Main(string[] args)
    {
        Console.WriteLine(a);
    }
  }
}
```

Code!

```
//F#
open System
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```
//C#
using System;

namespace ConsoleApplication1
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    static int a()
    {
        return 2;
    }
    static void Main(string[] args)
    {
        Console.WriteLine(a);
    }
  }
}
```

More Noise Than Signal!

Pleasure

```
type Command = Command of (Rover -> unit)
let BreakCommand     = Command(fun rover -> rover.Accelerate(-1.0))
let TurnLeftCommand  = Command(fun rover -> rover.Rotate(-5.0<degs>))
```

Pain

```
  abstract class Command
   {
       public virtual void Execute();
   }
   abstract class MarsRoverCommand : Command
   {
       protected MarsRover Rover { get; private
     set; }

       public MarsRoverCommand(MarsRover rover)
       {
           this.Rover = rover;
       }
   }
   class BreakCommand : MarsRoverCommand
   {
       public BreakCommand(MarsRover rover)
           : base(rover)
       {
       }
       public override void Execute()
       {
           Rover.Rotate(-5.0);
       }
   }
class TurnLeftCommand : MarsRoverCommand
   {
       public TurnLeftCommand(MarsRover rover)
           : base(rover)
       {
       }
       public override void Execute()
       {
           Rover.Rotate(-5.0);
       }
   }
```

Pleasure

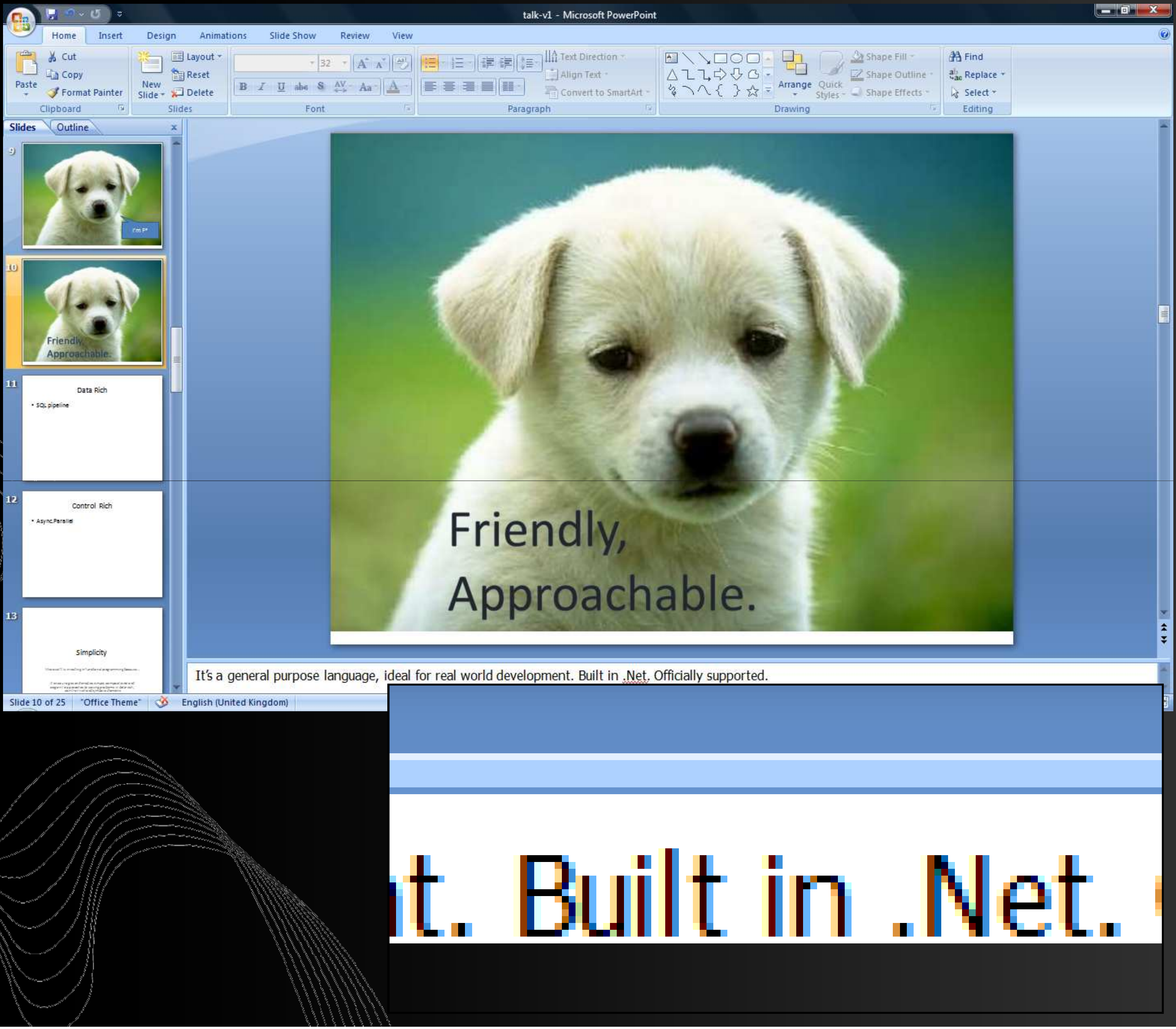
```
let rotate(x,y,z) = (z,x,y)

let reduce f (x,y,z) = f x + f y + f z
```

Pain

```
Tuple<V,T,U> Rotate(Tuple<T,U,V> t)
{
    return new Tuple<V,T,U>(t.Item3,t.Item1,t.Item2);
}

int Reduce(Func<T,int> f,Tuple<T,T,T> t)
{
    return f(t.Item1) + f(t.Item2) + f (t.Item3);
}
```



Friendly, Approachable.

It's a general purpose language, ideal for real world development. Built in .Net. Officially supported.

t. Built in .Net.

Economics

Fun! Fun! Fun!

F#: Combining Paradigms

Functional

- Strong Typing
- Type Inference
- Data Types and Patterns
- 1st Class Functions
- Meta-Programming
- Workflows and Agents

Objects

- .NET OO Model
- Interoperable
- Compact type-inferred classes

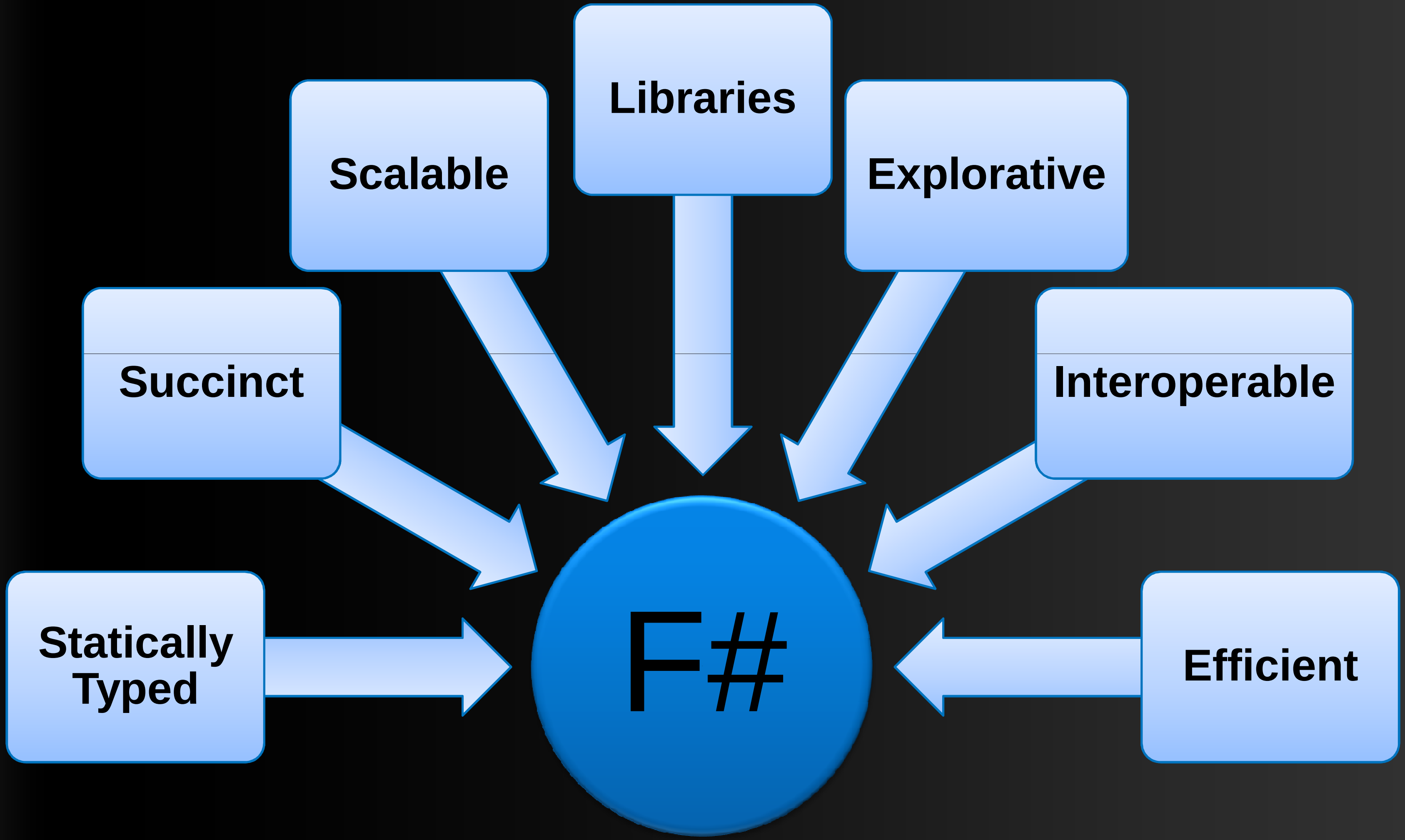
.NET

- Visual Studio
- Libraries
- Tools
- Concurrency
- LINQ

Tools

- F# Compiler
- F# Interactive
- Visual Studio Integration
- Debug
- Lex and Yacc

F#: The Combination Counts!



Libraries

Scalable

Explorative

Succinct

Interoperable

Statically Typed

Efficient

F#

F#: Combining Paradigms

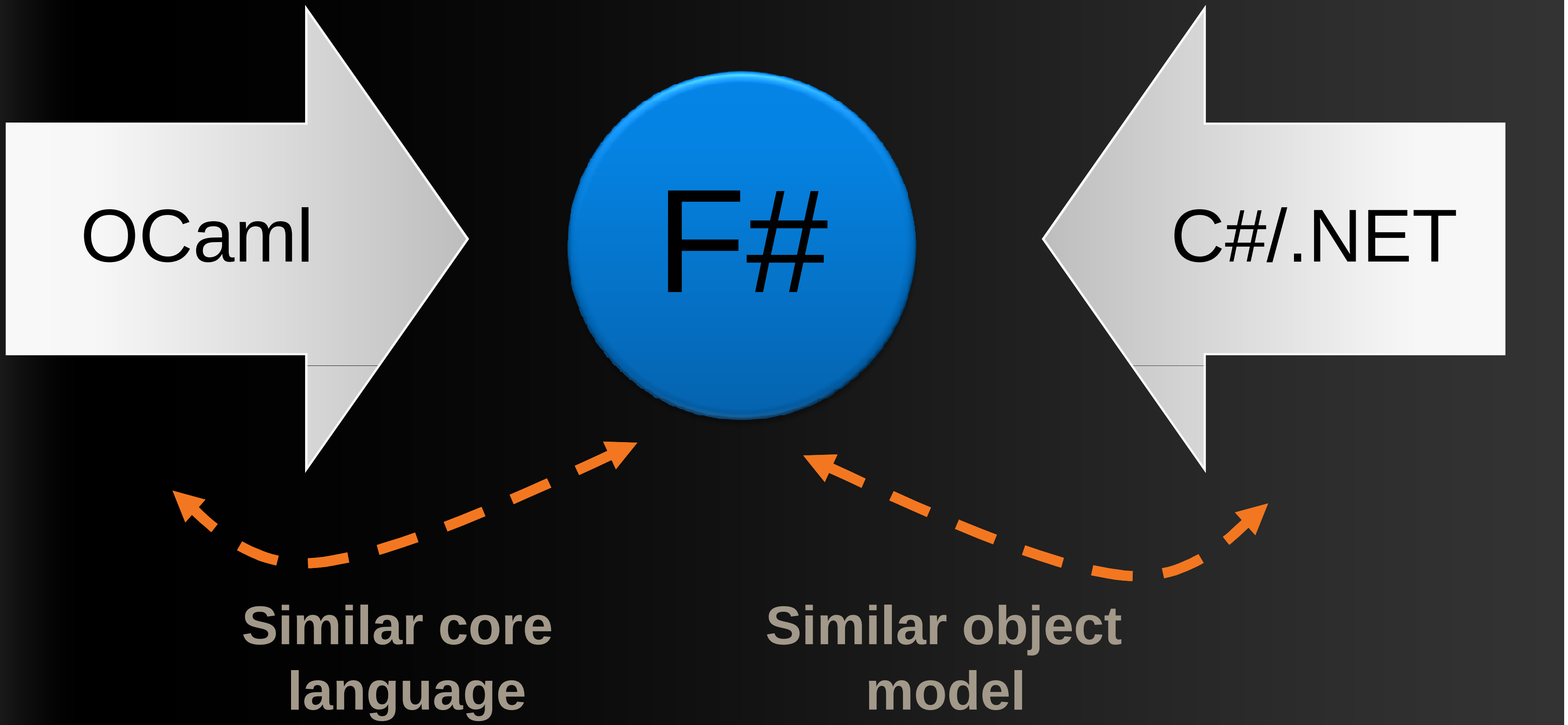
I've been coding in F# lately, for a production task.

F# allows you to ***move smoothly*** *in your programming style... I start with pure functional code, shift slightly towards an object-oriented style, and in production code, I sometimes have to do some imperative programming.*

I can ***start with a pure idea****, and still* ***finish my project with realistic code****. You're never disappointed in any phase of the project!*

Julien Laugel, Chief Software Architect, www.eurostocks.com

F#: Influences



The Path to Mastering F#

Topic	Covered Today
Scoping and “let”	✓
Tuples	✓
Pattern Matching	✓
Working with Functions	✓
Sequences, Lists, Options	✓
Records and Unions	✓
Basic Imperative Programming	✓
Basic Objects and Types	✓
The F# Libraries	✗
Advanced Functional/Imperative	✗
Advanced Functional/OO	✗
Language Oriented Programming	✓ **(later)**
Parallel and Asynchronous	✓ **(later)**

Quick Tour

Comments

```
// comment

(* comment *)

/// XML doc comment
let x = 1
```

Quick Tour

Overloaded Arithmetic

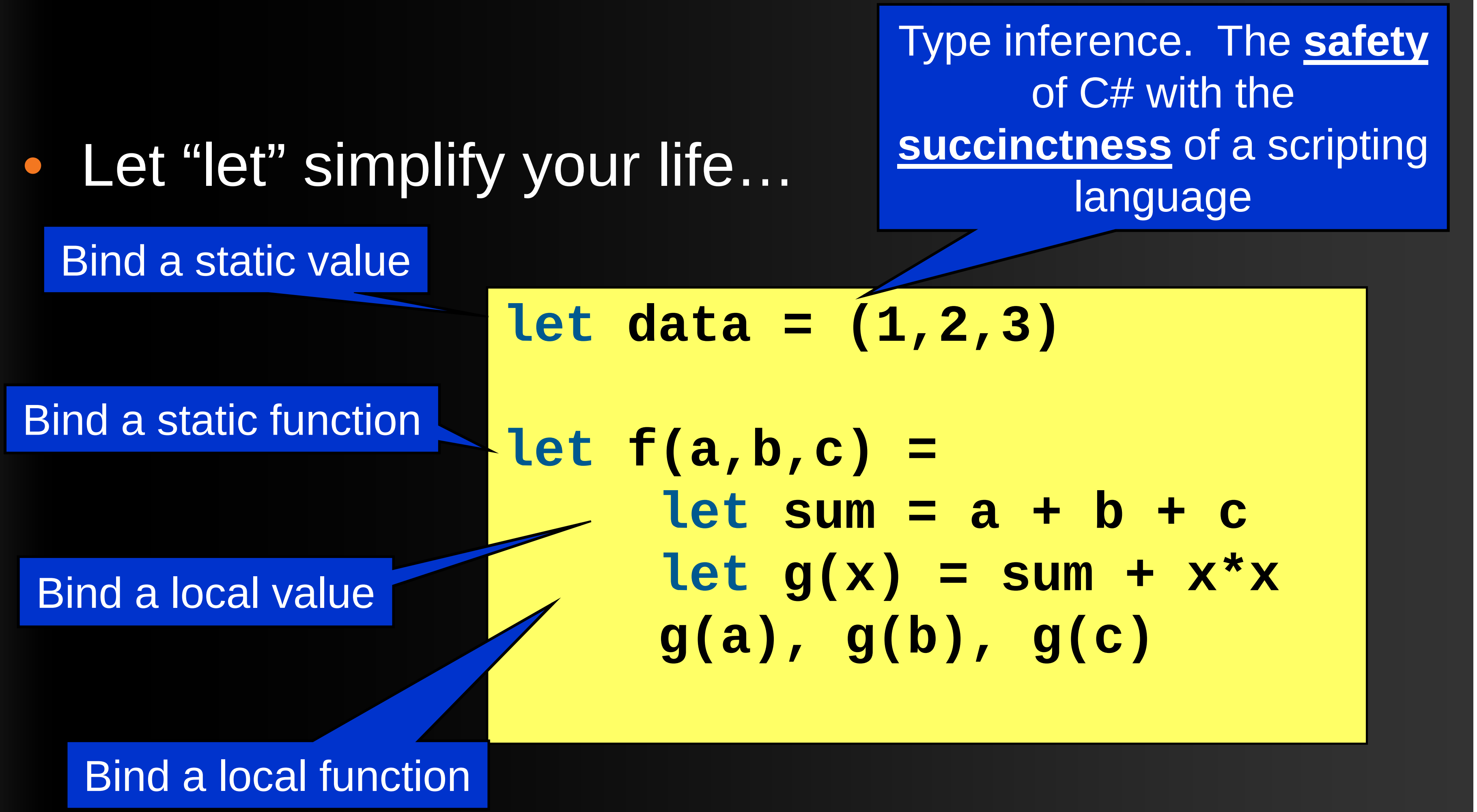
`x + y`	**Addition**
`x - y`	**Subtraction**
`x * y`	**Multiplication**
`x / y`	**Division**
`x % y`	**Remainder/modulus**
`-x`	**Unary negation**

Booleans

`not` *`expr`*	**Boolean negation**
`expr` `&&` *`expr`*	**Boolean “and”**
`expr` `||` *`expr`*	**Boolean “or”**

Orthogonal & Unified Constructs

- Let “let” simplify your life…



Type inference. The **safety** of C# with the **succinctness** of a scripting language

Bind a static value

Bind a static function

Bind a local value

Bind a local function

```
let data = (1,2,3)

let f(a,b,c) =
     let sum = a + b + c
     let g(x) = sum + x*x
     g(a), g(b), g(c)
```

Demo: Let’s WebCrawl…

Orthogonal & Unified Constructs

- Functions: like delegates + unified and simple

```
(fun x -> x + 1

let f(x) = x + 1

(f,f)

val f : int -> int
```

One simple mechanism, many uses

ymous
tion v

Declare a
functio

A pair
of functio

A function type

```
predicate = 'a -> bool

send = 'a -> unit

threadStart = unit -> unit

comparer = 'a -> 'a -> int

hasher = 'a -> int

equality = 'a -> 'a -> bool
```

F# - Functional

```
let f x = x+1

let pair x = (x,x)

let fst (x,y) = x

let data = (Some [1;2;3], Some [4;5;6])

match data with
| Some(nums1), Some(nums2) -> nums1 @ nums2
| None, Some(nums)   -> nums
| Some(nums), None   -> nums
| None, None         -> failwith "missing!"
```

F# - Functional

```
List.map        Seq.fold

Array.filter    Lazy           Set.union

Map    LazyList    Events    Async...

[ 0..1000 ]
[ for x in 0..10 -> (x, x * x) ]
[| for x in 0..10 -> (x, x * x) |]
seq { for x in 0..10 -> (x, x * x) }
```

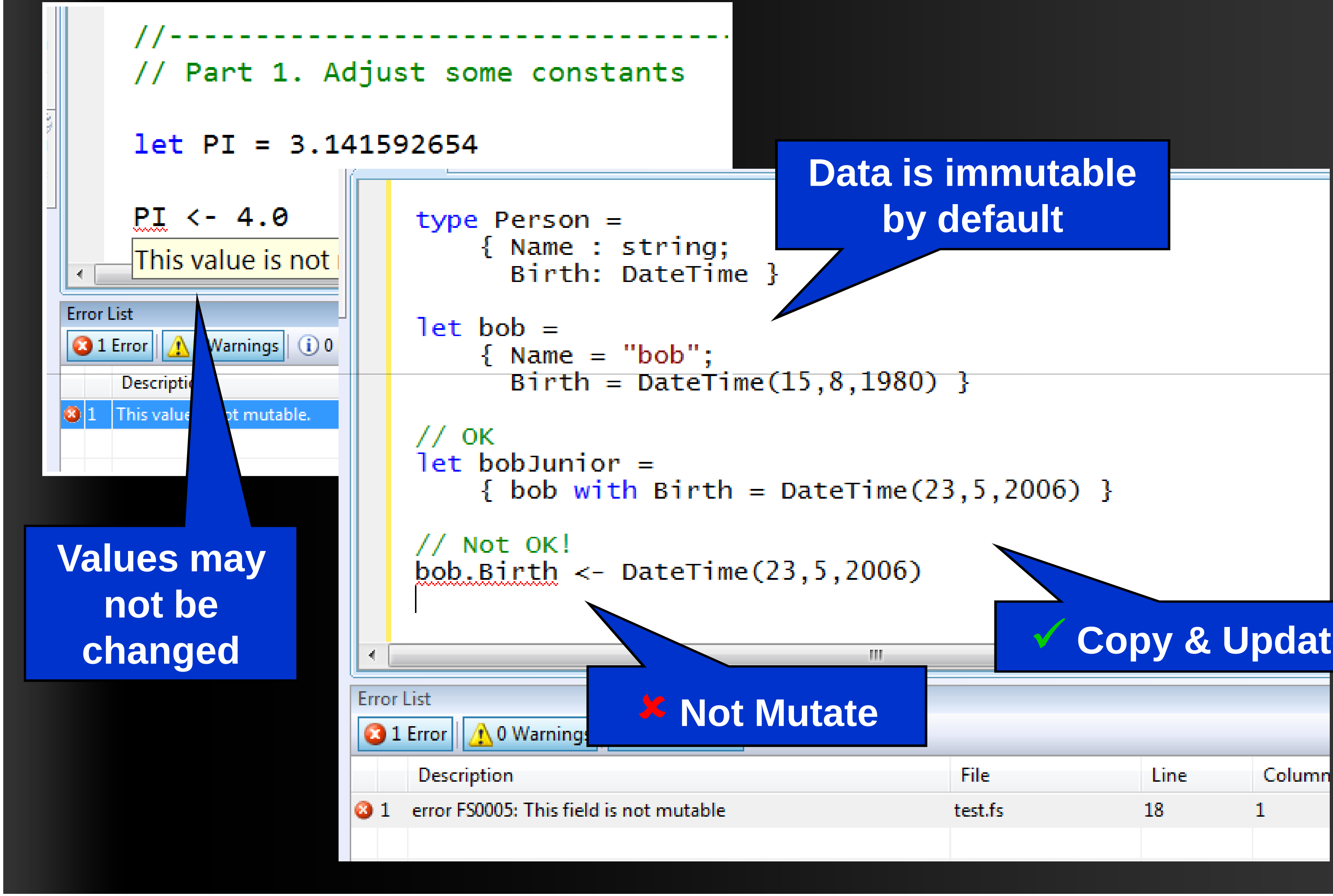
Range Expressions

List via query

Array via query

IEnumerable via query

Immutability the norm…



```
//-----------------------------------
// Part 1. Adjust some constants

let PI = 3.141592654

PI <- 4.0
```

This value is not

Error List

		Descripti
●	1	This value ot mutable.

```
type Person =
    { Name : string;
      Birth: DateTime }

let bob =
    { Name = "bob";
      Birth = DateTime(15,8,1980) }

// OK
let bobJunior =
    { bob with Birth = DateTime(23,5,2006) }

// Not OK!
bob.Birth <- DateTime(23,5,2006)
```

Error List

		Description	File	Line	Column
●	1	error FS0005: This field is not mutable	test.fs	18	1

Data is immutable by default

Values may not be changed

✓ Copy & Update

✗ Not Mutate

In Praise of Immutability

- Immutable objects can be relied upon
- Immutable objects can transfer between threads
- Immutable objects can be aliased safely
- Immutable objects lead to (different) optimization opportunities

F# - Imperative + Functional

Using .NET collections

```
open System.Collections.Generi

let dict = new Dictionary<int,string>(1000)

dict.[17] <- "Seventeen"
dict.[1000] <- "One Grand"

for (KeyValue(k,v)) in dict do
    printfn "key = %d, value = %s" k v
```

F# - Imperative + Functional

“use” =
C# “using”

```
open System.IO
open System.Collections.Generic

let readAllLines(file) =
    use inp = File.OpenText file
    let res = new List<_>()
    while not(inp.EndOfStream) do
        res.Add(inp.ReadLine())
    res.ToArray()
```

F# - Sequences

Sequence Expressions and On -demand I/O

```
open System.IO
let rec allFiles(dir) =
  seq
   { for file in Directory.GetFiles(dir) do
        yield file
     for sub in Directory.GetDirectories(dir) do
        yield! allFiles(sub) }

allFiles(@"C:\WINDOWS") |> Seq.take 100 |> show
```

Weakly Typed? Slow?

```
//F#
#light
open System
let a = 2
Console.WriteLine(a)
```

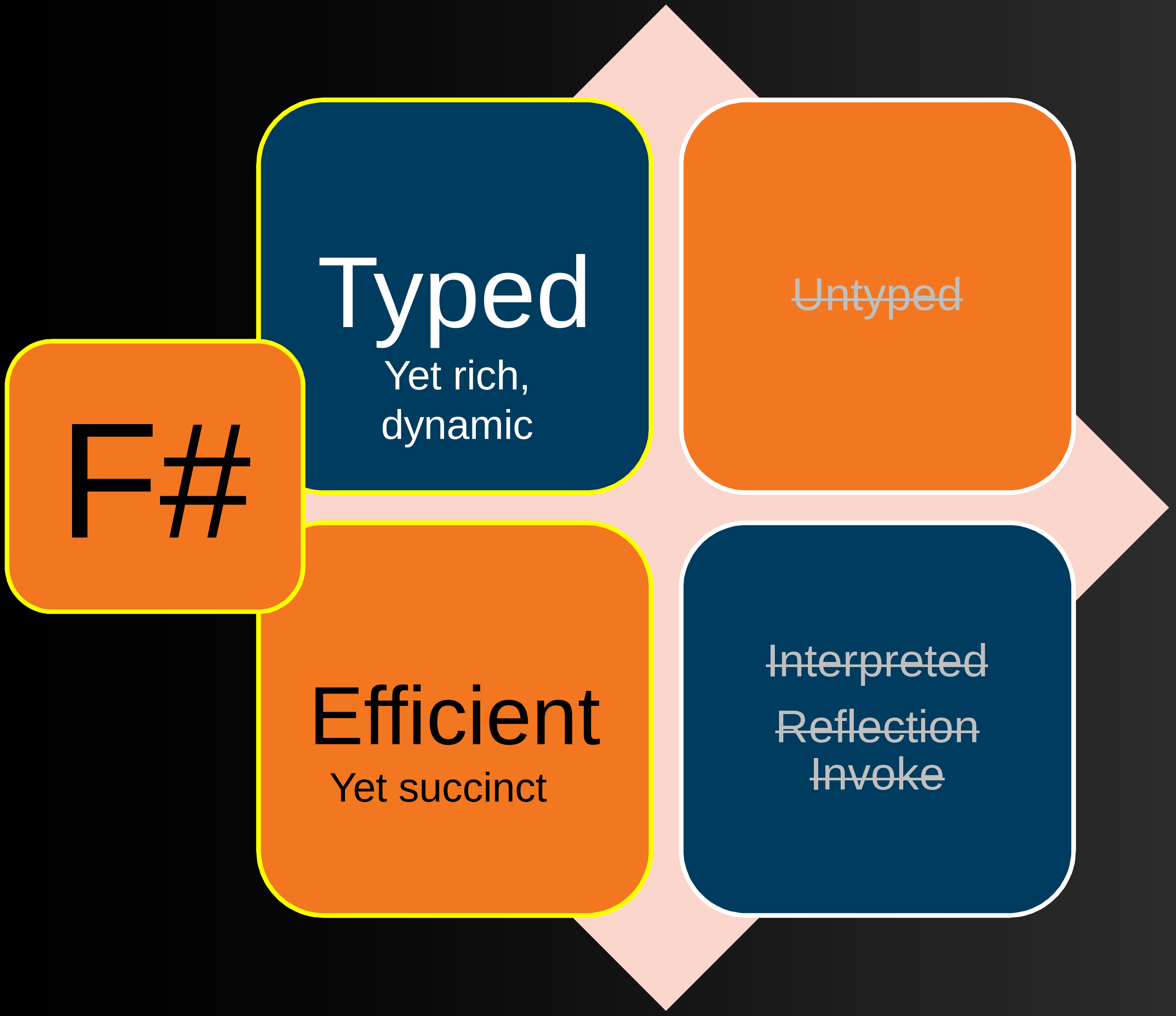
```
//C#
using System;

namespace ConsoleApplication1
{
    class Program
    {
        static int a()
        {
            return 2;
        }

           tic void Main(string[] args)

            Console.WriteLine(a);
```

Looks Weakly typed?
Maybe Dynamic?



F#

Typed

Yet rich,
dynamic

~~Untyped~~

Efficient

Yet succinct

~~Interpreted~~

~~Reflection~~
~~Invoke~~

F# - Imperative + Functional

Read lines on demand

```
open System.IO
let allLines =
  seq { use inp = File.OpenText "test.txt"
        while not(inp.EndOfStream) do
            yield (inp.ReadLine()) }
```

Pipelines

```
allLines
   |> Seq.truncate 1000
   |> Seq.map (fun s -> uppercase s,s)
   |> Seq.to_array
```

Why Object-Oriented Programming

- Builds reusable components
- Scalable design
- Easier maintenance
- Language of .NET/Java

Objects

Class Types

```
type ObjectType(args) =

    let internalValue = expr
    let internalFunction args = expr
    let mutable internalState = expr

    member x.Prop1 = expr
    member x.Meth2 args = expr
```

Constructing Objects

```
new FileInfo(@"c:\misc\test.fs")
```

Interface Types

```
type IObject =
  interface ISimpleObject
  abstract Prop1 : type
  abstract Meth2 : type -> type
```

F# - Objects + Functional

```
type Vector2D(dx:double,dy:double) =
   member v.DX = dx
   member v.DY = dy
   member v.Length = sqrt(dx*dx+dy*dy)
   member v.Scale(k) = Vector2D(dx*k,dy*k)
```

Inputs to object construction

Exported properties

Exported method

F# - Objects + Functional

```
type Vector2D(dx:double,dy:double) =
    let norm2 = dx*dx+dy*dy
    member v.DX = dx
    member v.DY = dy
    member v.Length = sqrt(norm2)
    member v.Norm2 = norm2
```

Internal (pre-computed) values and functions

F# - Objects + Functional

Immutable inputs

```
type HuffmanEncoding(freq:seq<char*int>) =

    ...
    < 50 lines of beautiful functional code>
    ...

     member x.Encode(input: seq<char>) =
          encode(input)

     member x.Decode(input: seq<char>) =
          decode(input)
```

Internal tables

Publish access

F# - Objects + Functional

```
type Vector2D(dx:double,dy:double) =

   let mutable currDX = dx

   let mutable currDX = dy

   member v.DX = currDX

   member v.DY = currDY

   member v.Move(x,y) =
        currDX <- currDX+x
        currDY <- currDY+y
```

Internal state

Publish internal state

Mutate internal state

F# - Language Oriented

Embedded Language

```
type PropLogic =
    | And of PropLogic * PropLogic
    | Not of PropLogic
    | True

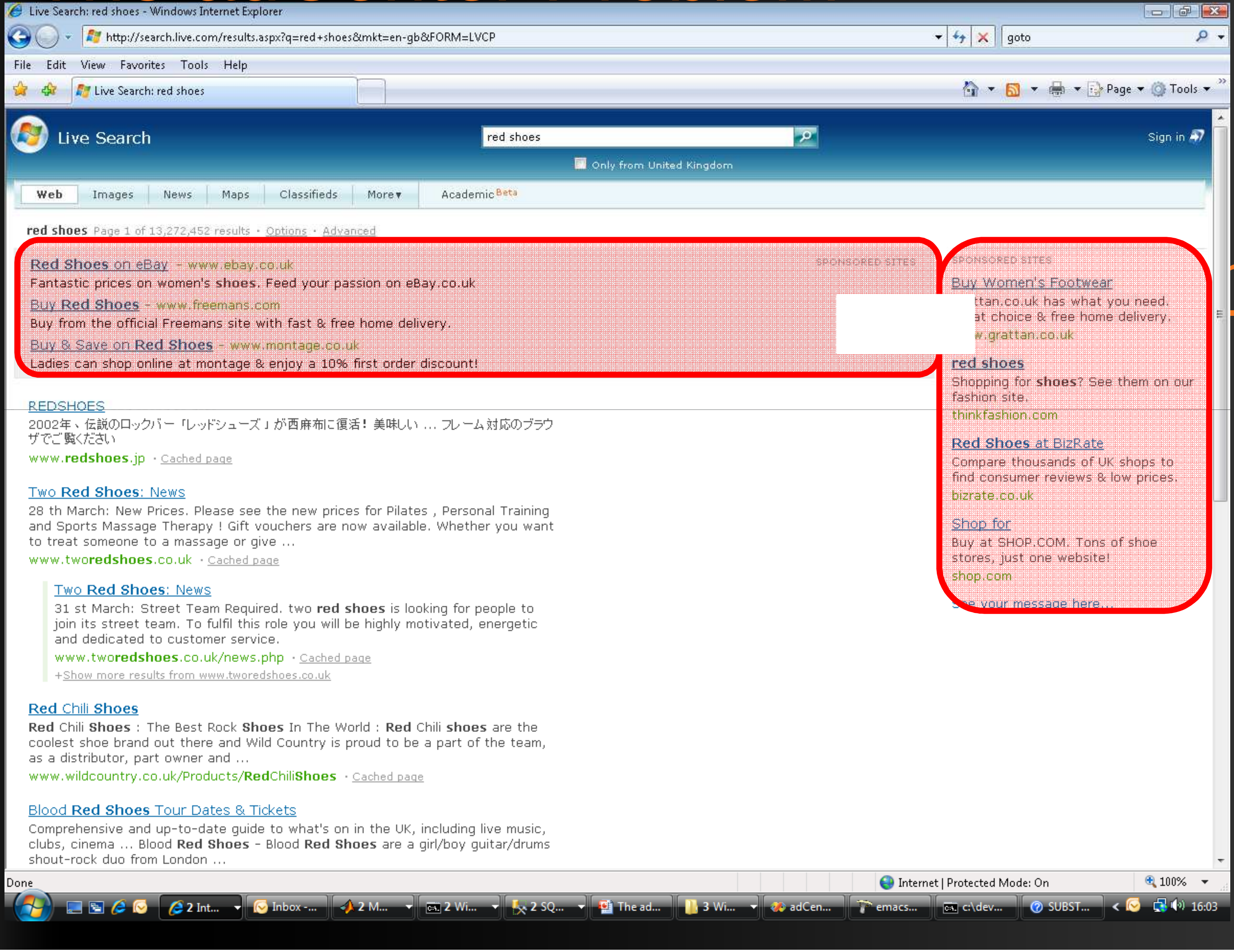
let rec Eval(prop) =
    match prop with
    | And(a,b) -> Eval(a) && Eval(b)
    | Not(a) -> not (Eval(a))
    | True -> true
```

Crisp Semantics

Case Study

The adPredict Competition

The adCenter Problem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F# and adCenter

- 4 week project, 4 machine learning experts
- 100million probabilistic variables
- Processes 6TB of training data
- Real time processing

AdPredict: What We O

- Quick Coding
- Agile Coding
- Scripting
- Performance
- Memory-Faithful
- Succinct
- Symbolic
- .NET Integration

F#’s powerful type inference means less typing, more thinking

Type-inferred code is easily refactored

“Hands-on” exploration.

Immediate scaling to massive data sets

mega-data structures, 16GB machines

Live in the **domain**, not the language

Schema compilation and “Schedules”

Especially Excel, SQL Server

F# Async/Parallel

Concurrent programming with shared state…

…can be hard

F# - Concurrent/Reactive/Parallel

- **Concurrent**: *Multiple threads* of execution
- **Parallel**: These execute *simultaneously*
- **Asynchronous**: Computations that complete "*later*"
- **Reactive**: *Waiting* and *responding* is normal

Why is it so hard?

- To get 50 web pages in parallel?
- To get from thread to thread?
- To create a worker thread that reads messages?
- To handle failure on worker threads?

Why isn’t it this easy?

```
let ProcessImages() =
    Async.Run
      (Async.Parallel
         [ for i in 1 .. numImages -> ProcessImage(i) ])
```

Why isn’t it this easy?

```
let task =
    async { ...
            do! SwitchToNewThread()
            ...
            do! SwitchToThreadPool()
            ...
            do! SwitchToGuiThread()
            .... }
```

Simple Examples

Compute 22 and 7 in parallel

```
Async.Parallel [ async { -> 2*2 + 3*6 };
                 async { -> 3 + 5 - 1 } ]
```

Get these three web pages and wait until all have come back

```
Async.Parallel [WebRequest.Async "http://www.live.com
                WebRequest.Async "http://www.yahoo.com ,
                WebRequest.Async "http://www.google.com" ]
```

```
let parArrMap f (arr: _[]) =
   Async.Run (Async.Parallel [| for x in arr -> async { -> f x } |])
```

Naive Parallel Array Map

Taming Asynchronous I/O

```
using System;
using System.IO;
using System.Threading;

public class BulkImageProcAsync
{
    public const String ImageBaseName
    public const int numImages = 200
    public const int numPixels = 512

    // ProcessImage has a simple O(N
    // of times you repeat that loop
    // bound or more IO-bound.
    public static int processImageRe

    // Threads must decrement NumImag
    // their access to it through a
    public static int NumImagesToFin
    public static Object[] NumImagesM
    // WaitObject is signalled when
    public static Object[] WaitObjec
    public class ImageStateObject
    {
        public byte[] pixels;
        public int imageNum;
        p
    }
```

```
public static void ReadInImageCallback(IAsyncResult as
{
    ImageStateObject state = (ImageStateObject)asyncRe
    Stream stream = state.fs;
    int bytesRead = stream.EndRead(asyncResult);
    if (bytesRead != numPixels)
        throw new Exception(String.Format
            ("In ReadInImageCallback, got the wrong nu
            "bytes from the image: {0}.", bytesRead));
    ProcessImage(state.pixels, state.imageNum);
    stream.Close();

    // Now write out the image.
    // Using asynchronous I/O here appears not to be b
    // It ends up swamping the threadpool, because the
    // threads are blocked on I/O requests that were j
    // the threadpool.
    FileStream fs = new FileStream(ImageBaseName + sta
        ".done", FileMode.Create, FileAccess.Write, Fi
        4096, false);
    fs.Write(state.pixels, 0, numPixels);
    fs.Close();

                                        much memory.
                                        ible is a good

                                         now.

    }
}
```

```
    public static void ProcessImagesInBulk()
    {
        Console.WriteLine("Processing images...  ");
        long t0 = Environment.TickCount;
        NumImagesToFinish = numImages;
        AsyncCallback readImageCallback = new
            AsyncCallback(ReadInImageCallback);
        for (int i = 0; i < numImages; i++)
        {
            ImageStateObject state = new ImageStateObject();
            state.pixels = new byte[numPixels];
            state.imageNum = i;
            // Very large items are read only once, so you can make the
            // buffer on the FileStream very small to save memory.
            FileStream fs = new FileStream(ImageBaseName + i + ".tmp",
                FileMode.Open, FileAccess.Read, FileShare.Read, 1, true);
            state.fs = fs;
            fs.BeginRead(state.pixels, 0, numPixels, readImageCallback,
                state);
        }

        // Determine whether all images are done being processed.
        // If      block until all are finished.
        bool mustBloc
        lock (NumImagesMutex)
        {
            if (NumImagesToFinish > 0)
                mustBlock = true;
        }
        if (mustBlock)
        {
            Console.WriteLine("All worke
                " Blocking until they complete. numLeft: {0}",
                NumImagesToFinish);
            Monitor.Enter(WaitObject);
            Monitor.Wait(WaitObject);
            Monitor.Exit(WaitObject);
        }
        long t1 = Environment.TickCount;
        Console.WriteLine("Total time processing images: {0}ms",
            (t1 - t0));
    }
}
```

```
let ProcessImageAsync () =
    async { let  inStream  = File.OpenRead(sprintf "Image%d.tmp" i)
            let! pixels    = inStream.ReadAsync(numPixels)
            let  pixels'   = TransformImage(pixels,i)
            let  outStream = File.OpenWrite(sprintf "Image%d.done" i)
            do!  outStream.WriteAsync(pixels')
            do   Console.WriteLine "done!"  }

let ProcessImagesAsyncWorkflow() =
    Async.Run (Async.Parallel
                 [ for i in 1 .. numImages -> ProcessImageAsync i ])
```

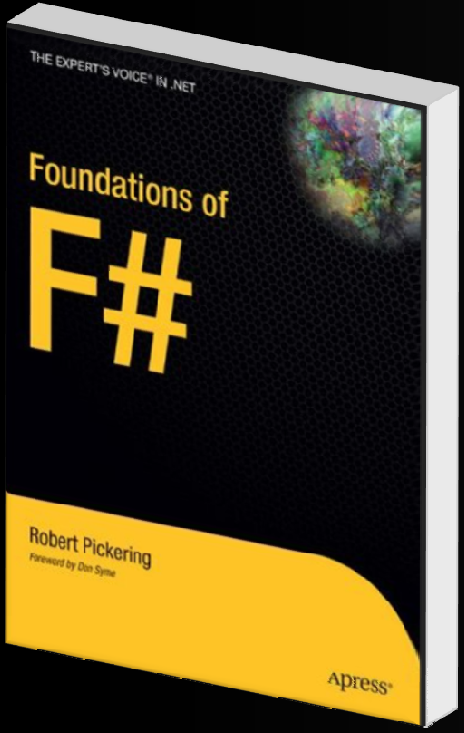
Processing 200 images in parallel

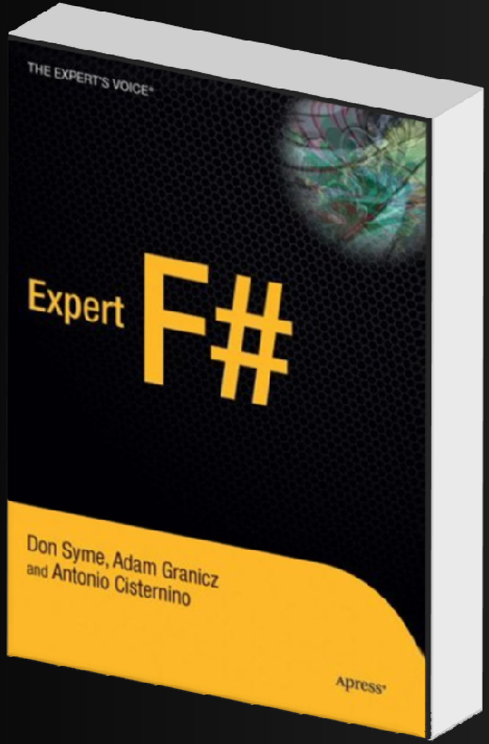
8 Ways to Learn

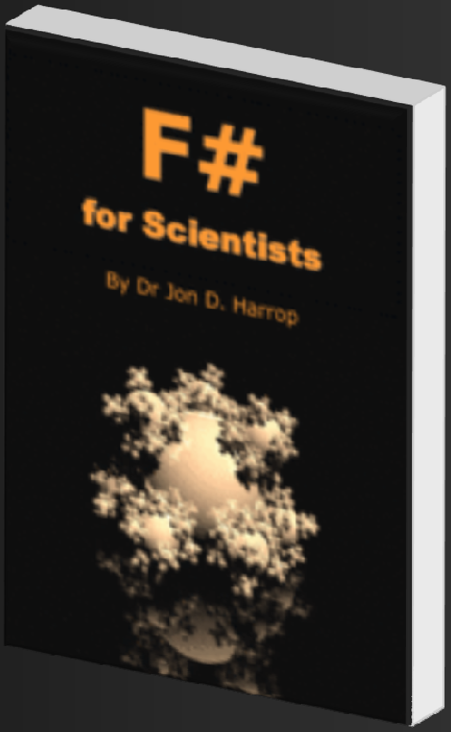
- FSI.exe
- Samples Included
- Go to definition
- Lutz’ Reflector

- http://cs.hubfs.net
- Codeplex Fsharp Samples
- Books
- ML

Books about F#







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Getting F#

- September CTP released (1.9.6)
  - Focus on Simplicity, Regularity, Correctness

- Next stop “Visual Studio 2010”

Questions & Discussion

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