FUNCTIONAL PROGRAMMING WITH F#

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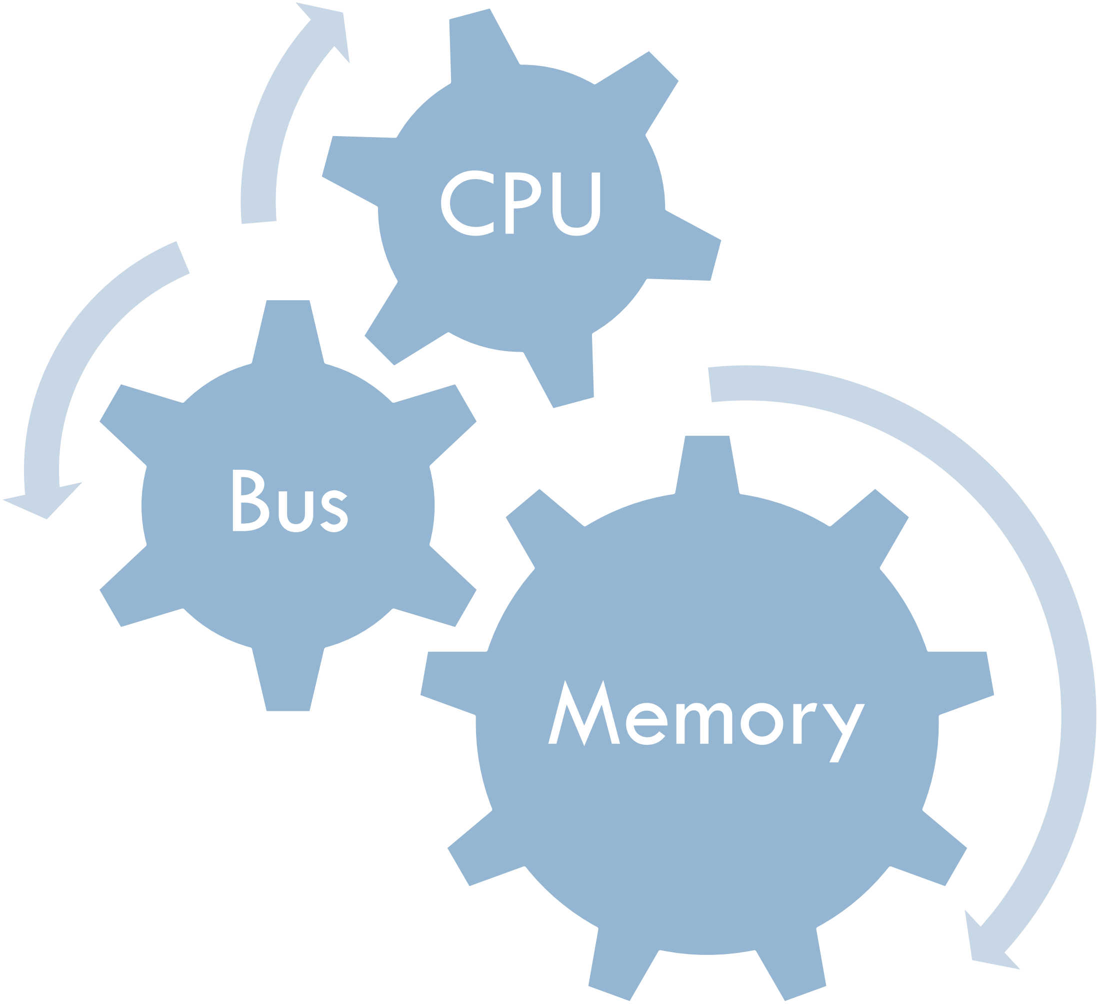
Microsoft

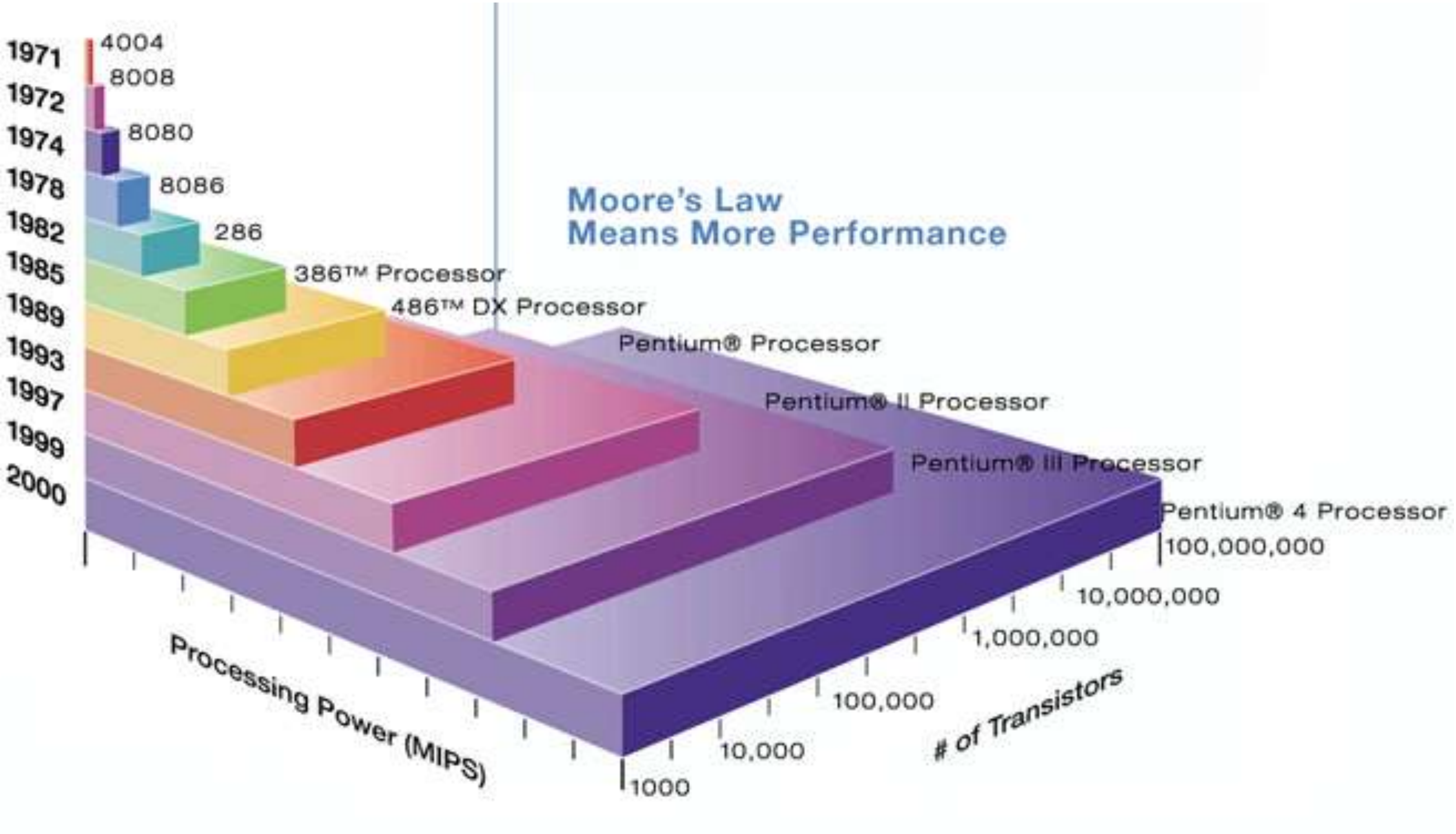
Alan ring v Alonzo Church

Cage Match to the Death!

The Von Neumann bottleneck



Moore's Law to the Rescue?



Agenda

- **Intro to Functional Programming**
- Intro to F#
- Functional Programming via F#
  - Higher order functions
  - Language Oriented Programming
  - Asynchronous workflows

What is **object-oriented** programming?

Object-oriented programming is a style of programming that enables you:

- Reuse code (via **classes**)

- Eliminate bugs (via **encapsulating, data hiding**)

An **object-oriented** language is one which supports object-oriented programming natively.

C# is a popular **object-oriented** language for .NET

What is **functional** programming?

Functional programming is a style of programming that enables you:

- Reuse code (via **function composition**)
- Eliminate bugs (via **immutability**)

A **functional** language is one which functional programming natively.

F# is a popular **functional** language for .NET

Functional Programming

- Emphasis is on **what** is to be computed not **how** it happens
- Data is immutable
- Functions are data too

Wha compute

Pattern Matching

```
// Fibonacci numbers
// 1, 1, 2, 3, 5, 8, 13, ...
let rec fibonacci =
    function
    | 0 | 1 -> 1
    | 2 -> 2
    | 3 -> 3
    | 4 -> 5
    | x -> fibonacci (x - 1) + fibonacci (x - 2)
```

Discriminated Unions

```
type Suit = Heart | Diamond | Club | Spade

type Card =
    | Ace   of Suit
    | King  of Suit
    | Queen of Suit
    | Jack  of Suit
    | ValueCard of int * Suit

let deck = [
    for suit in [Heart; Diamond; Club; Spade] do
        for value in 2 .. 10 do
            yield ValueCard(value, suit)

        yield Jack(suit); yield Queen(suit)
        yield King(suit); yield Ace(suit)
    ]
```

on Co

```
// Size of the 'My Pictures' folder in MB
let sizeOfMyPicturesFolder =
    filesUnderFolder ( GetFolderPath(SpecialFolder.MyPicture
    |> Seq.map GetFileInfo
    |> Seq.map GetFileSize
    |> Seq.fold (+) 0L
    |> ConvertBytesToMB
```

Haskell is really good at being expressive…

```
qsort []     = []
qsort (x:xs) = qsort (filter (< x) xs) ++ [x] ++ qsort (filter (>= x) xs)
```

List Comprehensions

Data is immutable

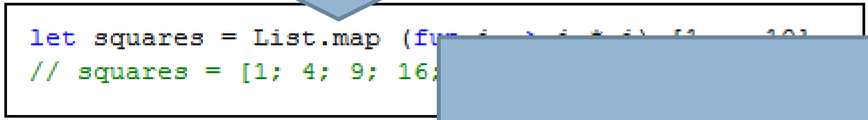
```
x = x + 1;
```

Data is immutable (continued)

- Why should a function in C never return a pointer?
- Why should you make a copy of an internal array before returning it from your class?
- Why is multi-threading so damn hard?

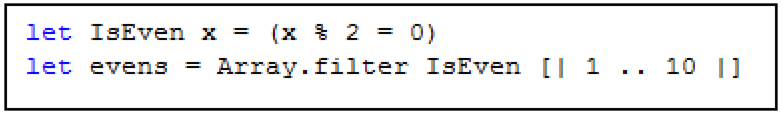
Functions are data too

Lambdas

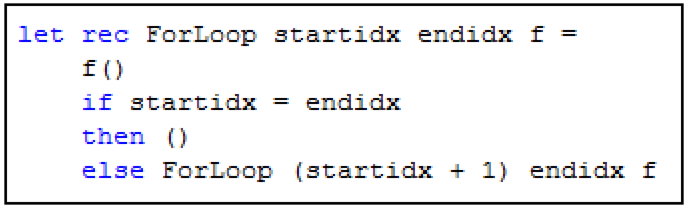


```
let squares = List.map (fu
// squares = [1; 4; 9; 16;
```

Higher order functions

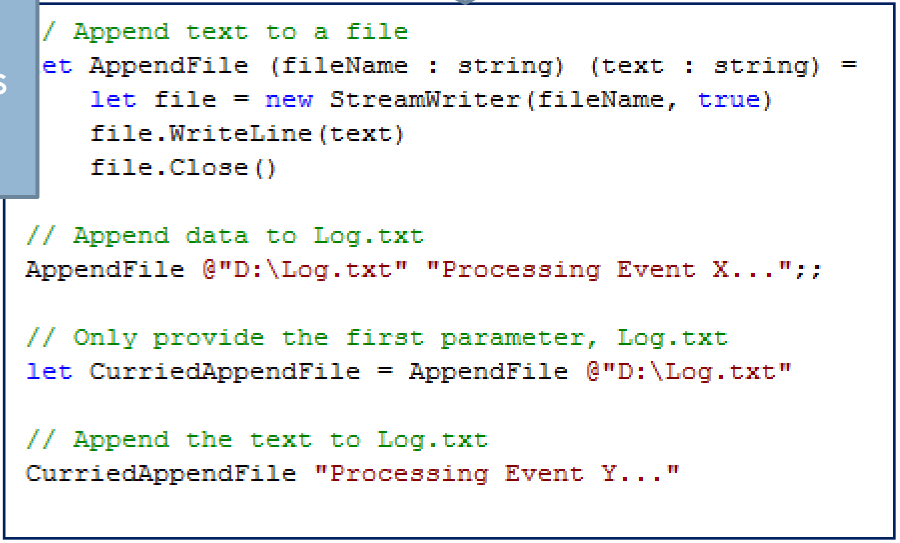


```
let IsEven x = (x % 2 = 0)
let evens = Array.filter IsEven [| 1 .. 10 |]
```



```
let rec ForLoop startidx endidx f =
    f()
    if startidx = endidx
    then ()
    else ForLoop (startidx + 1) endidx f
```

Currying



```
/ Append text to a file
et AppendFile (fileName : string) (text : string) =
    let file = new StreamWriter(fileName, true)
    file.WriteLine(text)
    file.Close()

// Append data to Log.txt
AppendFile @"D:\Log.txt" "Processing Event X...";;

// Only provide the first parameter, Log.txt
let CurriedAppendFile = AppendFile @"D:\Log.txt"

// Append the text to Log.txt
CurriedAppendFile "Processing Event Y..."
```

Agenda

- Intro to Functional Programming
- **Intro to F#**
- What functional programming offers
  - Higher order functions
  - Language Oriented Programming
  - Asynchronous workflows

Introducing F#

F# is a .NET programming language

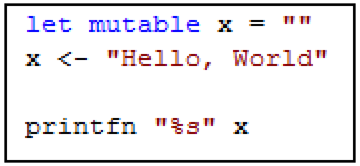
F# is

- Functional
- Imperative
- Object Oriented

Imperative

- Side effects

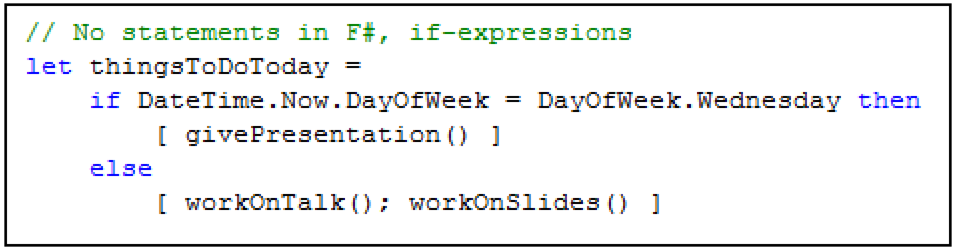
- Ability to declare and mutate variables



```
let mutable x = ""
x <- "Hello, World"

printfn "%s" x
```

- Control flow (while, for, if, exceptions, etc.)



```
// No statements in F#, if-expressions
let thingsToDoToday =
    if DateTime.Now.DayOfWeek = DayOfWeek.Wednesday then
        [ givePresentation() ]
    else
        [ workOnTalk(); workOnSlides() ]
```

Object Oriented (and .NET)

- Classes and Interfaces
- Polymorphism and Inheritance
- Delegates and Events
- Structs and Enums

First-class Citizen of .NET

- Tools
  - Visual Studio
  - FXCop
  - SQL Server
- Libraries
  - Managed DirectX
  - Visual Studio Tools for Office
  - WinForms, WCF, WPF

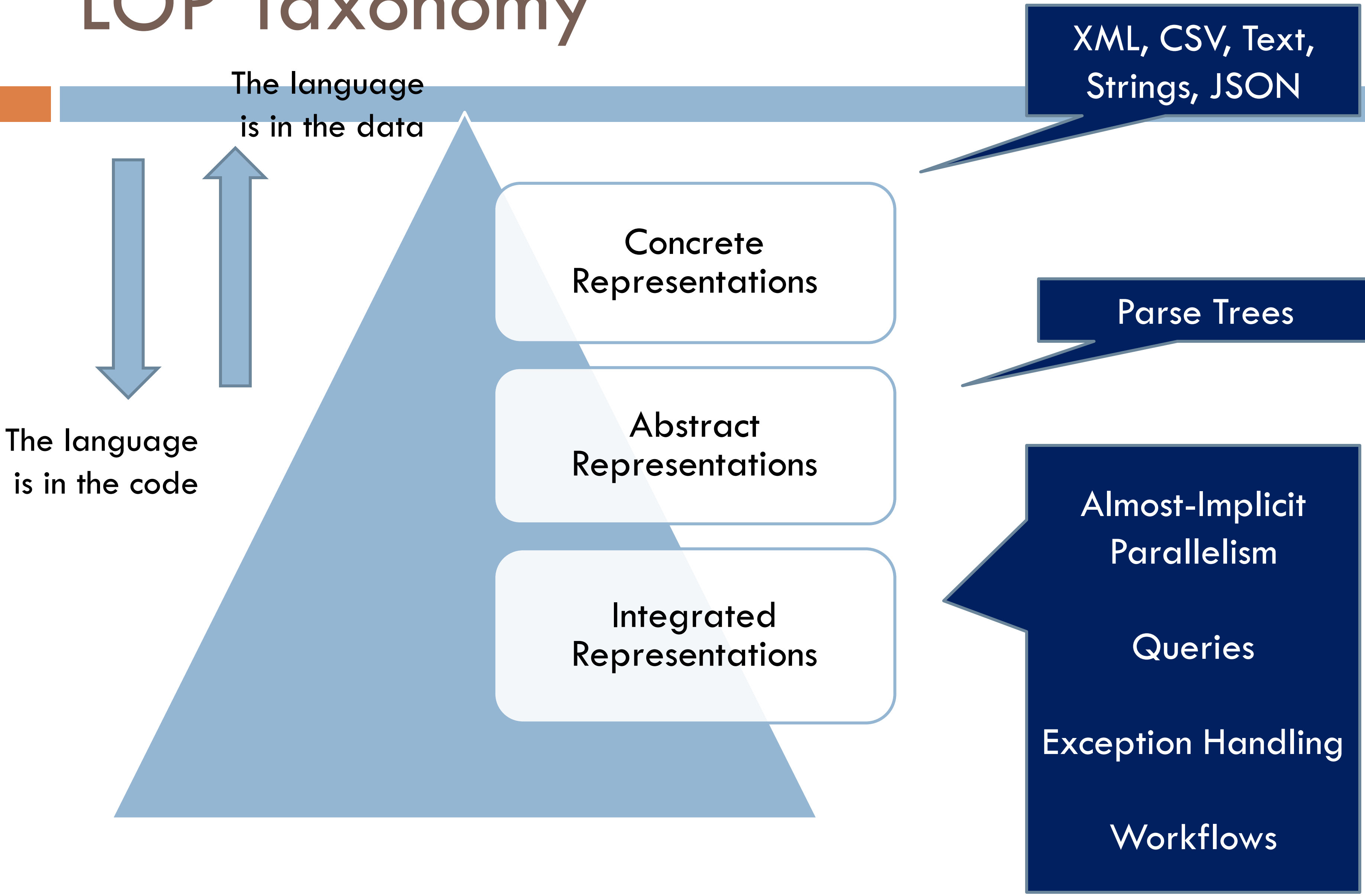
Agenda

- Intro to Functional Programming
- Intro to F#
- **What functional programming offers**
  - Functions, Records, and Discriminated Unions
  - Language Oriented Programming
  - Asynchronous workflows

Onto Visual Studio!

Language Oriented Programming

LOP Taxonomy



The language is in the data

The language is in the code

Concrete Representations

Abstract Representations

Integrated Representations

XML, CSV, Text, Strings, JSON

Parse Trees

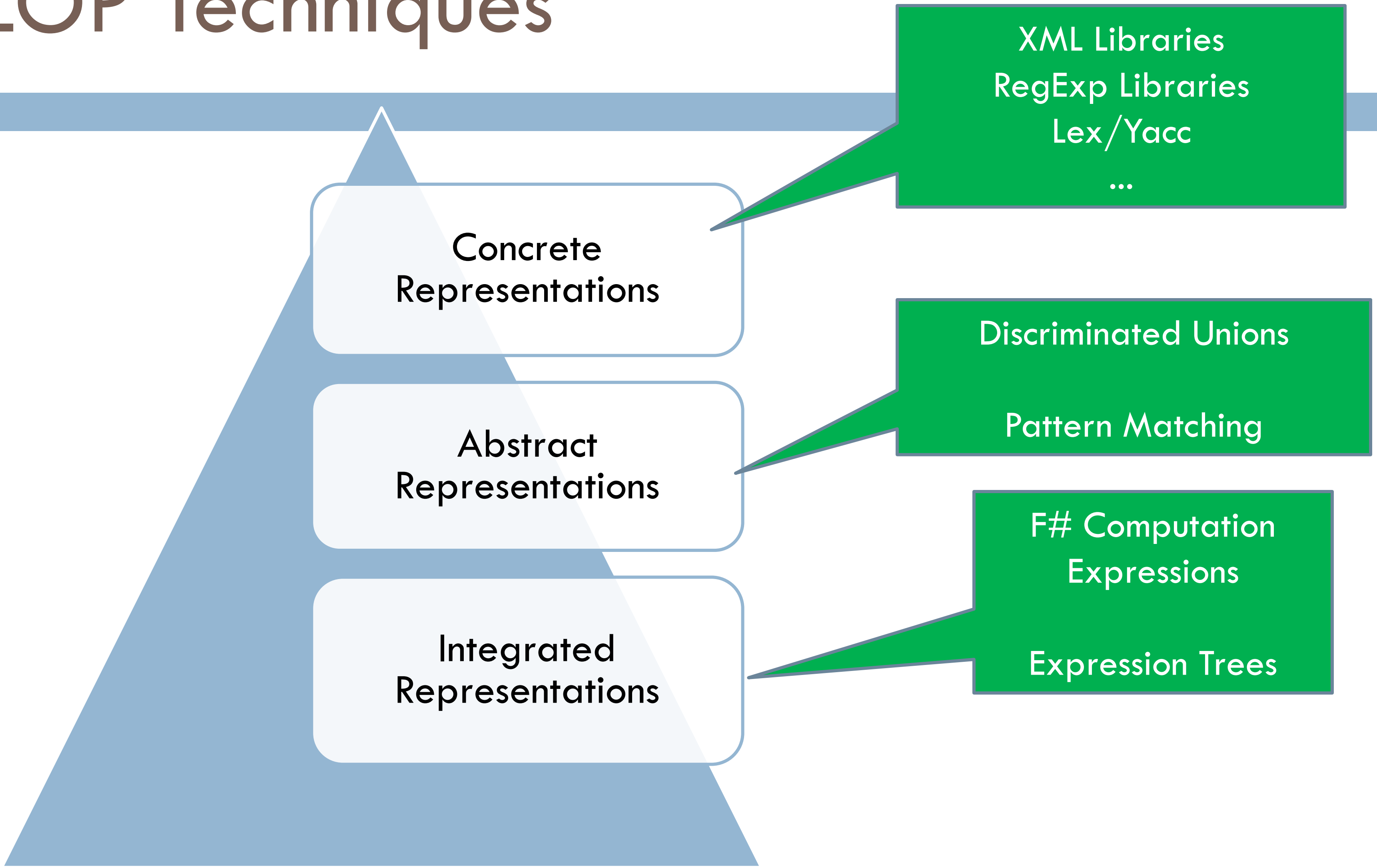
Almost-Implicit Parallelism

Queries

Exception Handling

Workflows

LOP Techniques



Concrete Representations

Abstract Representations

Integrated Representations

XML Libraries
RegExp Libraries
Lex/Yacc
...

Discriminated Unions

Pattern Matching

F# Computation Expressions

Expression Trees

Onto Visual Studio!

Async Workflows

AKA Computation Expressions

Definitions

- *Parallel* – Start doing several things at once, wait until all of them are done before continuing.
- *Asynchronous* – Start doing something in the background, it will notify you when it’s finished.
- *Reactive* – Something just sits there and when you need something from it, it will respond.

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 processImageRep

    // Threads must decrement NumImag
    // their access to it through a
    public static int NumImagesToFin
    public static Object[] NumImages
    // WaitObject is signalled when
    public static Object[] WaitObject
    public class ImageStateObject
    {
        public byte[] pixels;
        public int imageNum;
        p
        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 mustBlock
        lock (NumImagesMutex)
        {
            if (NumImagesToFinish > 0)
                mustBlock = true;
        }
        if (mustBlock)
        {
            Console.WriteLine("All worker
                " 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

Taming Asynchronous I/O

Equivalent F# code
(same perf)

Open the file, synchronously

Read from the file, asynchronously

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

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

This object coordinates

Write the result, asynchronously

Generate the tasks and queue them in parallel

“!”
= “asynchronous”

Taming Asynchronous I/O

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```
            state.imageNum = i;
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            // 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);
        }

}
```

Create 10, 000s of “asynchronous tasks”

Mostly queued, suspended and executed in the thread pool

```
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 ])
```

Exceptions can be handled properly

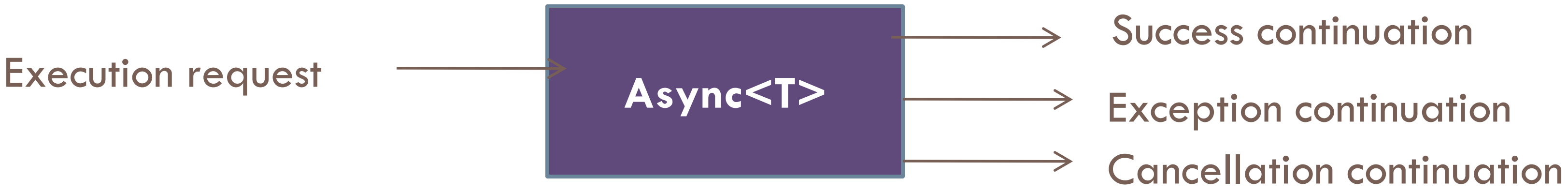
Cancellation checks inserted automatically

Resources can be disposed properly on failure

CPU threads are not blocked

How does it work?

- Uses Computational LOP to make writing continuation-passing programs simpler and compositional



Execution request

Async<T>

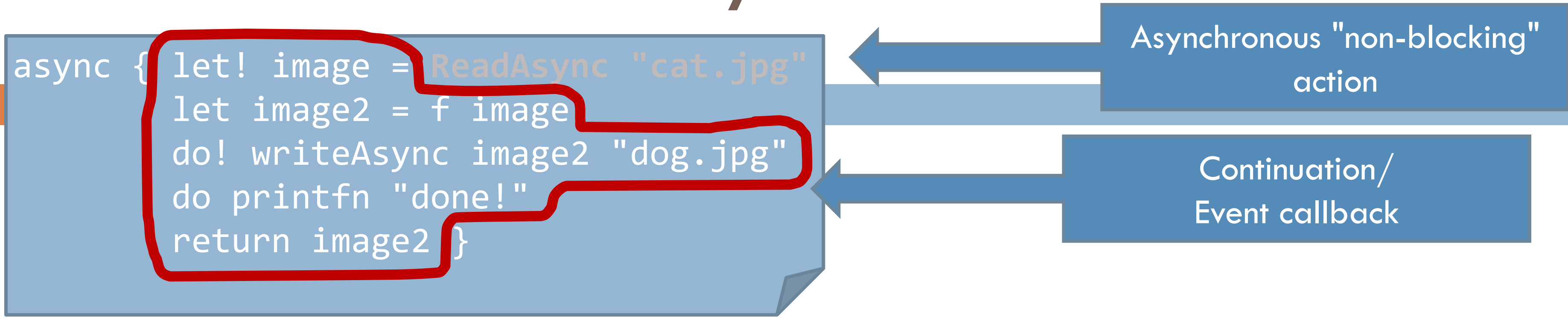
Success continuation

Exception continuation

Cancellation continuation

- Similar to techniques used in Haskell
- A wrapper over the .NET Thread Pool and .NET synchronization primitives

F# “Workflow” Syntax



```
async { let! image = ReadAsync "cat.jpg"
        let image2 = f image
        do! writeAsync image2 "dog.jpg"
        do printfn "done!"
        return image2 }
```

Asynchronous "non-blocking" action

Continuation/ Event callback

You're actually writing this (approximately):

```
async.Delay(fun () ->
    async.Bind(readAsync "cat.jpg", (fun image ->
        async.Bind(async.Return(f image),(fun image2
            async.Bind(writeAsync "dog.jpg",(fun () ->
                async.Bind(async.Return(printfn "done!"),(fun () ->
                   async.Return()))))))))
```

Onto Visual Studio!

F# Resources

- Getting F#
  - Download from http://msdn.com/fsharp
  - Installs as an Add-In for Visual Studio 2008
- Books
  - *Expert F#*
    - Don Syme, Adam Granicz, and Antonio Cisternino
  - *Foundations of F#*
    - Robert Pickering
  - F# for Scientists
    - John Harrop
- Websites
  - **http://blogs.msdn.com/chrsmith**
  - **http://cs.hubfs.net/**

Questions

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