Reflection

Leveraging the Power of Metadata

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Objectives

- **Provide an introduction to .NET Reflection**
- **Explain how applications can use Reflection to explore type information and how they can build types at runtime**

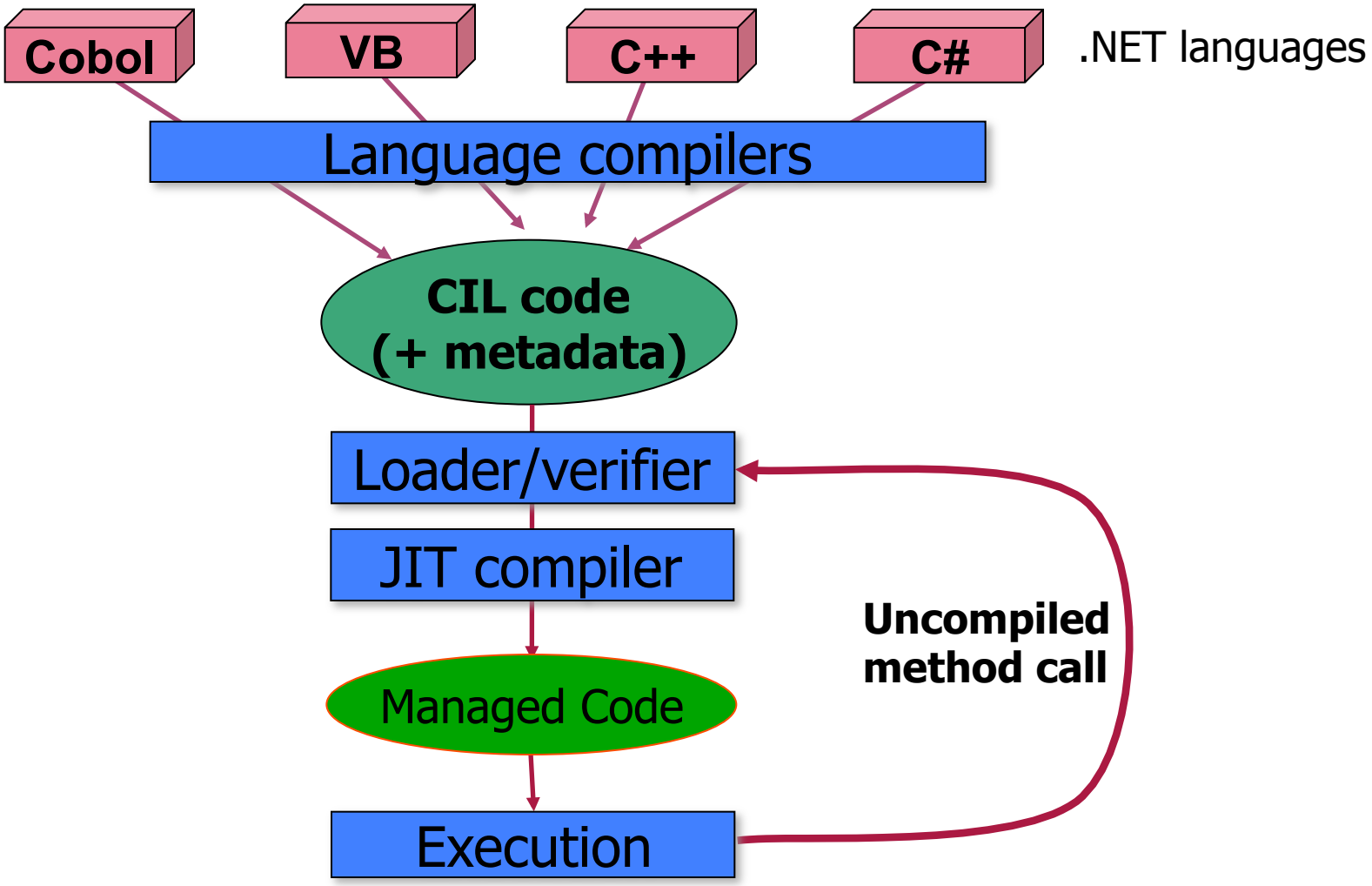
Contents

- Section 1: Overview
- Section 2: Exploring Metadata
- Section 3: Detail Information
- Section 4: Building Types at Runtime
- Section 5: Putting it together
- Summary

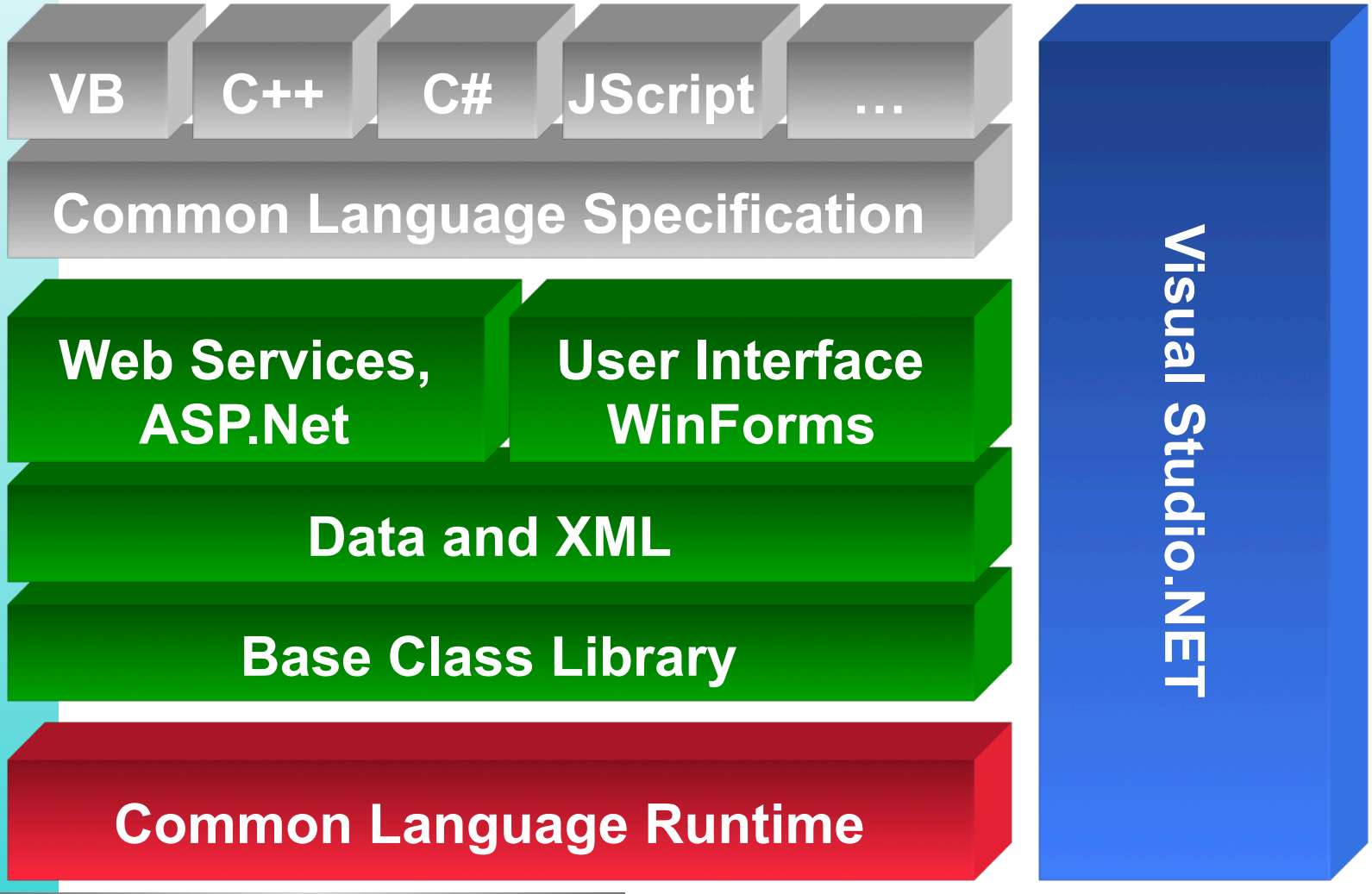
Section 1: Overview

- .NET Compile-Execution Cycle
- .NET Reflection Core Concepts

Execution model



.Net Architecture



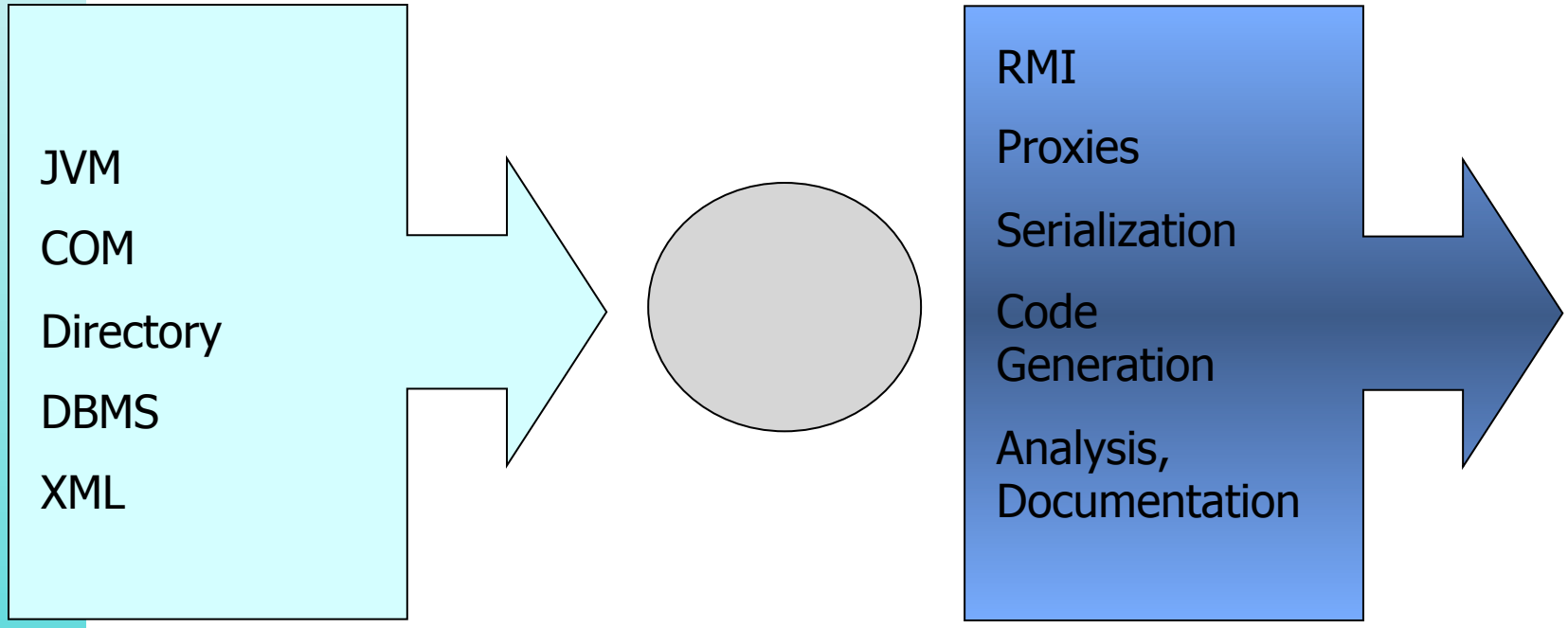
Reflection Overview

- **All types in the CLR are self-describing**
  - **CLR provides a reader and writer for type definitions**
    - **System.Reflection & System.Reflection.emit**
  - **You can ‘read’ programs**
  - **You can map between type systems**
  - **You can interrogate objects and types inside a running program**

.NET Reflection Core Concepts

- **Metadata**
  - Single location for type information and code
  - Code is literally contained within type information
  - Every .NET object can be queried for its type
  - Types' metadata can be explored with Reflection
- **Dynamic Type System**
  - Highly dynamic and language independent
  - Types may be extended and built at run-time
  - Allows on-the-fly creation of assemblies
  - .NET Compilers use .NET to emit .NET code

Reflection is fundamental to the CLR



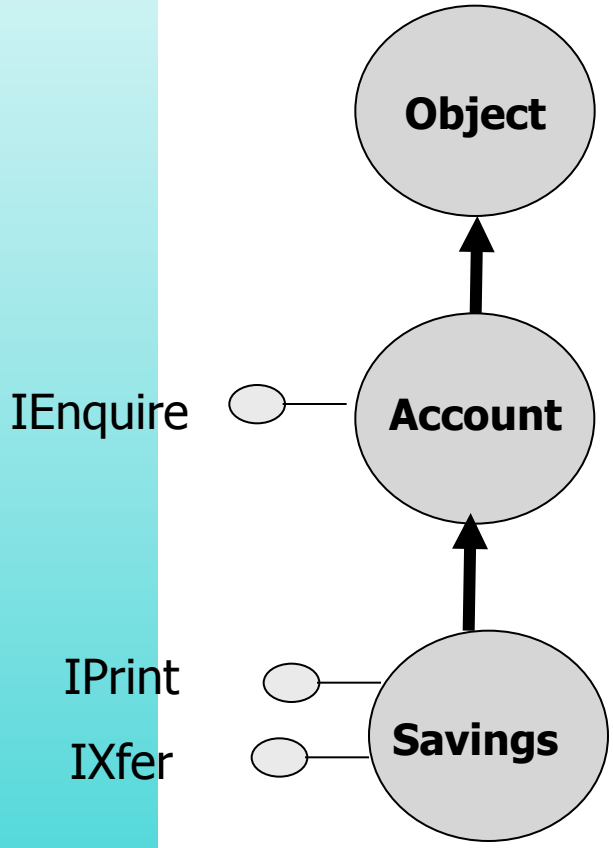
Metadata uses

- **Allows type developed in a PL to be used by code in other PL**
- **GC uses to traverse objects**
- **Serialization (essential for Web Services)**
- **IDE (e.g. IntelliSense)**

Section 2: Exploring Metadata

- **Who are you?**
- **What are you?**
- **Anything special about you?**
- **Now tell me what you have!**
- **Types and Instances**

Type Reflection



Savings.BaseType ==Account

Savings.BaseType.BaseType == Object

Ixfer.BaseType == null

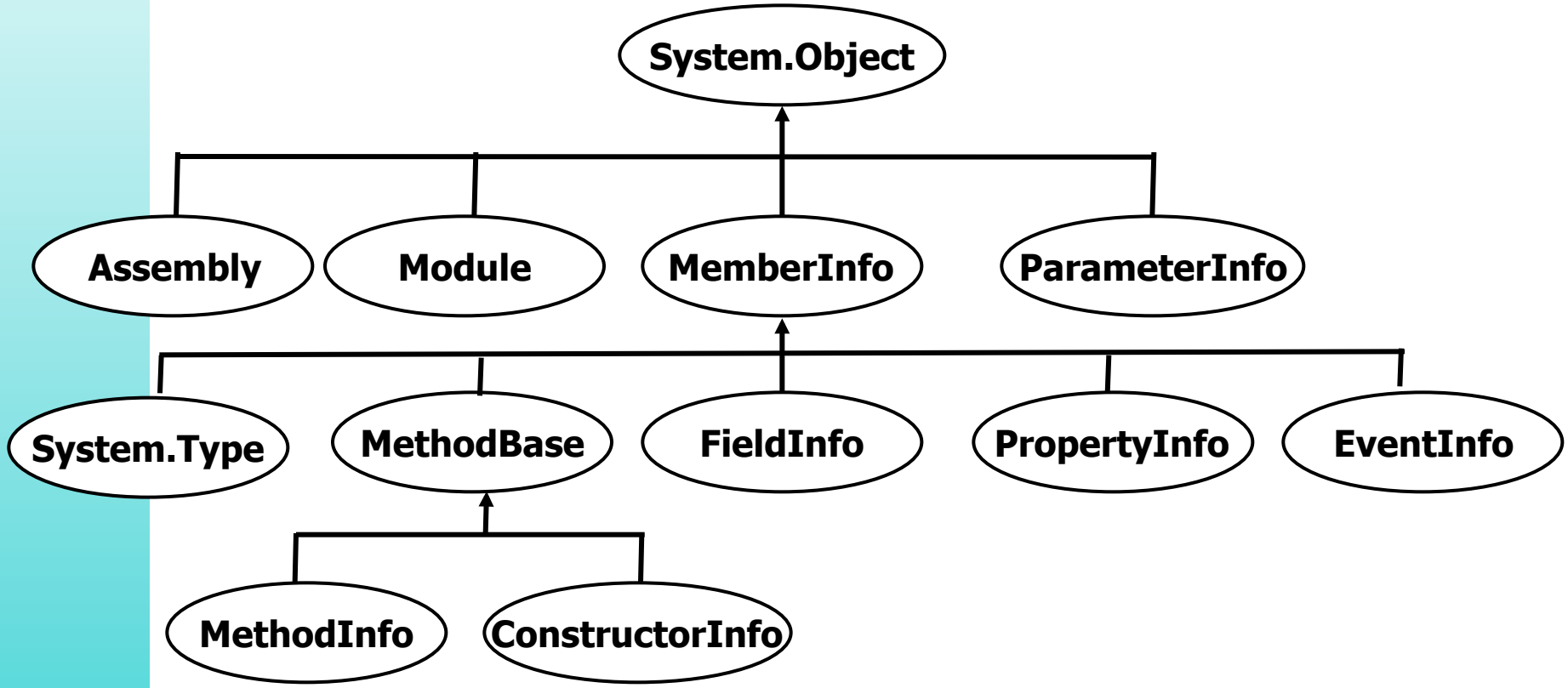
Account.IsSubClassof(IEnquire) == false

Savings.IsSubClassof(Account) == true

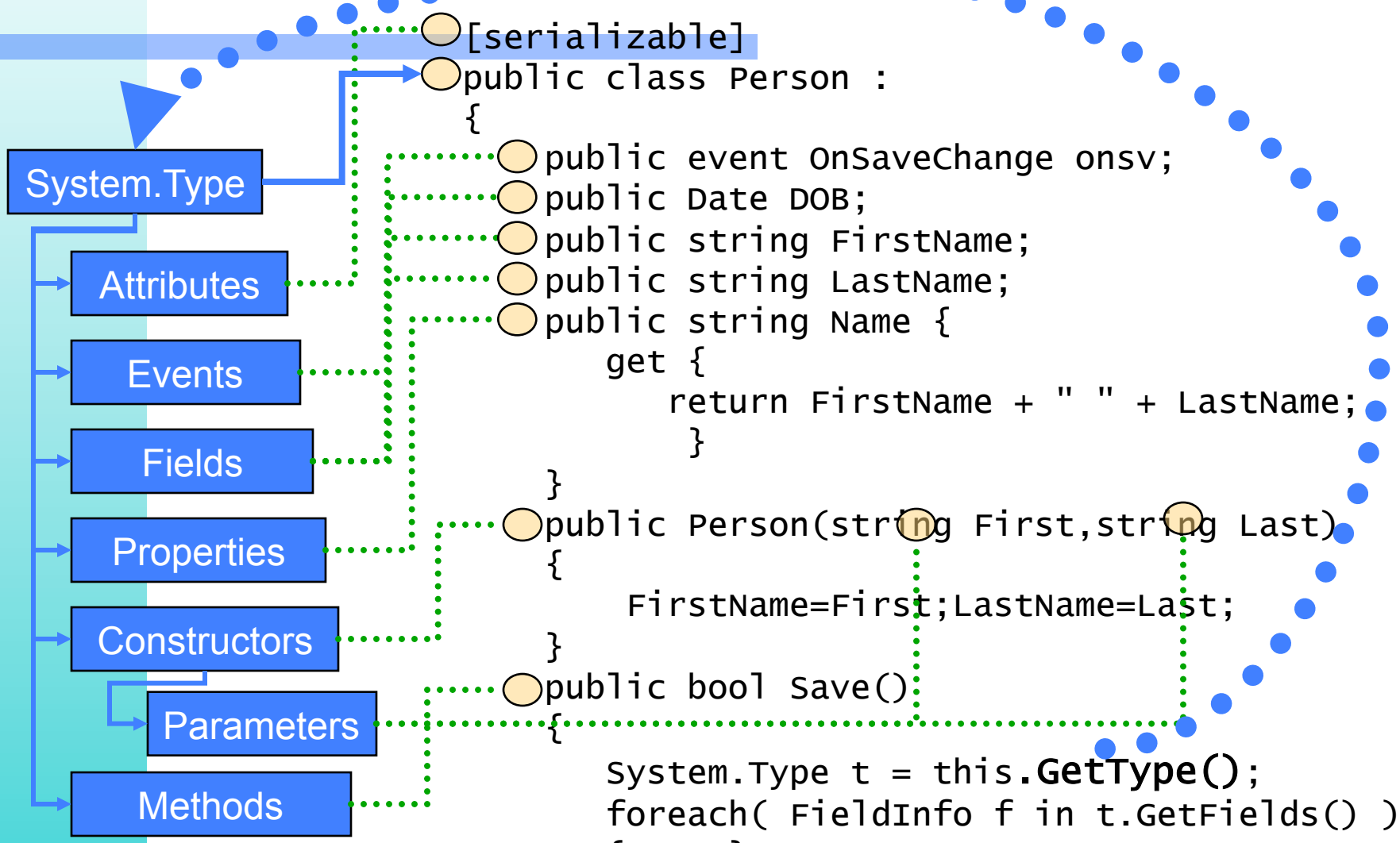
Savings.GetInterfaces() == { Iprint, Ixfer, Ienquire }

Ienquire.IsAssignableFrom(Savings) == true

Reflection and the CLR type system



MetaData: Type Info at Runtime



Traverse every element in an assembly

```
Using System.Reflection;
Public static void WalkAssembly(String assemblyName)
{
  Assembly assembly = Assembly.Load (assemblyName);
  foreach (Module module in assembly.GetModules())
     foreach (Type type in module.GetTypes())
        foreach (MemberInfo member in type.GetMembers())
           Console.WriteLine (“{0}.{1}”, type,  member.Name;
}
```

Serialization

- Save state of an object on disk or send to a stream:

```
public class Point : {
    public double x;
    public double y;
    public double length; // computed from x, y
};
```

Solutions

- **Inherit from a base type:**

  class Point : Serializable { … }

  but …

  – **base type does not know derived type**

  – **requires multiple inheritance**

- **Java solution:**

  class Point implements Serializable { … }

  but …

  – **method granularity**

  – **customization requires full rewrite of WriteObject, ReadObject**

Solution: Attributes

```
[Serializable]
public class Point : {
    public double x;
    public double y;
    [NonSerialized]
    public double length; // computed from x, y
};
```

Rotor Serialization Engine

```
protected virtual void WriteMember(String memberName, Object data) {
  if (data==null) {
    WriteObjectRef(data, memberName, typeof(Object));
    return;
  }
  Type varType = data.GetType();
  if (varType == typeof(Boolean)) {
    WriteBoolean(Convert.ToBoolean(data), memberName);
  } else if (varType == typeof(Char)) {
    WriteChar(Convert.ToChar(data), memberName);
  } else if (varType == typeof(Byte)) {
  WriteByte(Convert.ToByte(data), memberName);
  } ...
  else {
    if (varType.IsArray) {
      WriteArray(data, memberName, varType);
    } else if (varType.IsValueType) {
      WriteValueType(data, memberName, varType);
    } else {
      WriteObjectRef(data, memberName, varType);
  }
}
```

Reflection Emit

Abstractions correspond closely to the CTS that underlies the CLR:

- **Assemblybuilder**
- **ConstructorBuilder**
- **CustomAttributeBuilder**
- **EnumBuilder**
- **EventBuilder**
- **FieldBuilder**
- **ILGenerator**
- **Label**
- **LocalBuilder**
- **MethodBuilder**
- **ModuleBuilder**
- **ParameterBuilder**
- **PropertyBuilder**
- **TypeBuilder**

Who are you?

- **Accessing meta-data: System.Object.GetType()**
  - **All .NET classes (implicitly) inherit System.Object**
  - **Available on every .NET class; simple types too**
- **Explicit language support for type meta-data**
  - **C#, JScript.NET:** `typeof(…)`
  - **VB.NET:** `If TypeOf … Is … Then …`
- **Determining Type Identity**
  - **Types have unique identity across any assembly**
  - **Types can be compared for identity**
    - `if (a.GetType() == b.GetType()) { … };`

System.Type

- Access to meta-data for any .NET type
- Returned by System.Object.GetType()
- Allows drilling down into all facets of a type
  - Category: Simple, Enum, Struct or Class
  - Methods and Constructors, Parameters and Return
  - Fields and Properties, Arguments and Attributes
  - Events, Delegates and Namespaces

What are you?

- **Value, Interface or Class?**
  - `IsValueType, IsInterface, IsClass`
- **Public, Private or Sealed ?**
  - `IsNotPublic, IsSealed`
- **Abstract or Implementation?**
  - `IsAbstract`
- **Covers all possible properties of a managed type**
- **Very intuitive API, no "Parameter Hell"**

Anything special about you?

- **Special Memory Layout?**
  - `IsAutoLayout`
  - `IsExplicitLayout`
  - `IsLayoutSequential`
- **COM Objects?**
  - `IsCOMObject`
- **More…**
  - `IsUnicodeClass`
  - `IsSpecialName`, **etc.**

Now tell me what you have!

- **Finding and Exploring Members**
  - **MemberInfo: GetMembers(), FindMembers()**
- **Exploring Fields and Properties**
  - **FieldInfo: GetFields(), PropertyInfo: GetProperties()**
- **Exploring Constructors, Methods and Events**
  - **GetConstructors(), GetMethods(), GetEvents()**
- **Exploring attributes, determining implemented interfaces, enumerating nested types, …**
- **Summary: Everything you may ever want to know**

Type and Instances

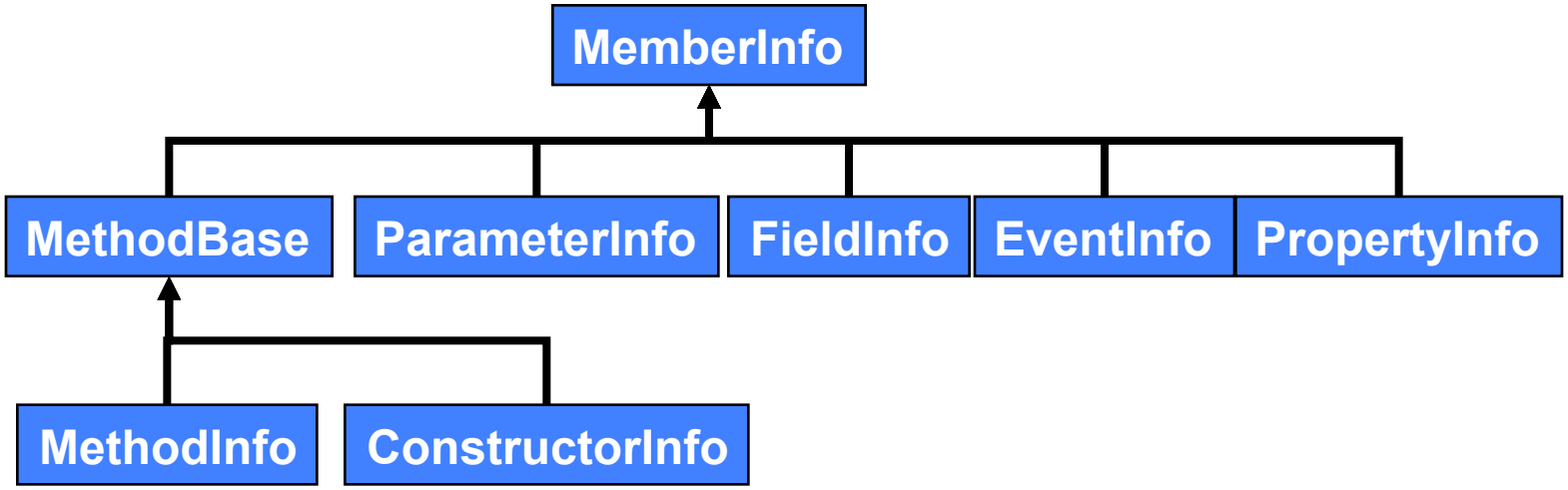
- **Type Safety First! Type checking at runtime**
  - **C#:** `if (o is Customer) { … }`
  - **VB:** `If TypeOf o Is Customer Then … End If`
- **Dynamic Invocation through Reflection**
  - **Support for late binding**
    - `MethodInfo.Invoke()`
    - `FieldInfo.SetValue()`
    - `PropertyInfo.SetValue()`

Section 3: Detail Information

- **MemberInfo**
- **FieldInfo, PropertyInfo**
- **ConstructorInfo, MethodInfo**

MemberInfo

- **Base class for all "member" element descriptions**
  - **Fields, Properties, Methods, etc.**
- **Provides member kind, name and declaring class**



FieldInfo, PropertyInfo

- **FieldInfo**
  - **Field data type and attributes**
  - **Static or Instance field, protection level**
  - **Can set value through reflection**
    - **Provides low-level, direct access with SetValueDirect()**
- **PropertyInfo**
  - **Property type and attributes**
  - **Test methods for readability, writeability**
  - **"get" and "set" MethodInfo**
  - **Indexer ParameterInfo**
  - **Can invoke "set" and "get" through Reflection**

MethodInfo, ConstructorInfo

- **MethodInfo**
  - **Return type and attributes**
  - **List of all parameters as ParameterInfo array**
  - **Detail implementation information through flag-field**
  - **Can invoke method through Reflection**
- **ConstructorInfo**
  - **Same features as MethodInfo, just for constructors**

Attributes

- Custom attributes are the killer-app for Reflection!
- Attributes enable declarative behavior
- Attributes allow data augmentation

```
[dbcolumn("Address1")] string Street;
[dbcolumn("Postcode")] string ZIP;
```

Mark class as serializable
Type.GetCustomAttributes()

Map fields to database columns with
FieldInfo.GetCustomAttributes()

```
[serializable]
class Person
{
  ...
```

Custom Attributes

```
[BugFix(121,“GA","01/03/05")]
[BugFix(107,“GA","01/04/05",
   Comment="Fixed off by one errors")]
public class MyMath {
   public double DoFunc1(double param1) {
       return param1 + DoFunc2(param1); }

   public double DoFunc2(double param1) {
       return param1 / 3; }
}
```

Definining a Custom Attribute

```
public class BugFixAttribute : System.Attribute {

  public BugFixAttribute(int bugID, string programmer,
    string date) {
    this.bugID = bugID;
    this.programmer = programmer;
    this.date = date;
  }

  //      Named parameters are implemented as properties:
  public string Comment {
    get { return comment; }
    set { comment = value; }
  } }
```

Using Attributes

```
MyMath mm = new MyMath( );
Console.WriteLine("Calling DoFunc(7). Result: {0}", mm.DoFunc1(7));
// get the member information and use it to retrieve the custom attributes

System.Reflection.MemberInfo inf = typeof(MyMath);
BugFixAttribute[] attributes =
     (BugFixAttribute[])inf.GetCustomAttributes(typeof(BugFixAttribute), false);

// iterate through the attributes, retrieving the properties
foreach(BugFixAttribute attribute in attributes) {
  Console.WriteLine("\nBugID: {0}", attribute.BugID);
  Console.WriteLine("Programmer: {0}", attribute.Programmer);
  Console.WriteLine("Date: {0}", attribute.Date);
  Console.WriteLine("Comment: {0}", attribute.Comment);
}
```

Output:

```
Calling DoFunc(7). Result: 9.33
BugID: 121 Programmer: GA Date: 01/03/05 Comment:
BugID: 107 Programmer: GA Date: 01/04/05 Comment: Fixed off by one errors
```

Dynamic Method Invocation

```
Type theMathType = Type.GetType("System.Math");
Object theObj =
    Activator.CreateInstance(theMathType);
Type[] paramTypes = new Type[]
    { Type.GetType("System.Double")};

MethodInfo CosineMeth =
    theMathType.GetMethod("Cos", paramTypes);

Object[] parameters = new Object[1];
parameters[0] = 45;
Object returnVal = CosineMeth.Invoke(theObj,
    parameters);
```

Loop unrolling

```
public int DoSumLooping(int n) {
   int result = 0;
   for(int i = 1; i <= n; i++)
       result += i;
   return result;
}
```

Loop unrolling

```
public double DoSum(int n) {
    if (adder == null)
          GenerateCode(n);
    // call the method through the interface
    return (adder.ComputeSum( ));
}
public void GenerateCode(int n) {
    Assembly theAssembly = EmitAssembly(n);
    adder = (IComputer)
    theAssembly.CreateInstance(“UnrolledSum");
}
```

Create the Assembly

```
private Assembly EmitAssembly(int n) {
assemblyName = new AssemblyName( );
    assemblyName.Name = "DoSumAssembly";
AssemblyBuilder newAssembly =
    Thread.GetDomain().DefineDynamicAssembly(
    assemblyName, AssemblyBuilderAccess.Run);
    ModuleBuilder newModule =
    newAssembly.DefineDynamicModule("Sum");
    TypeBuilder myType =
    newModule.DefineType( “UnrolledSum",
    TypeAttributes.Public);
myType.AddInterfaceImplementation( typeof(IComp
    uter));
```

Create the Assembly

```
// Define a method on the type to call. Pass an
// array that defines the types of the parameters,
// the type of the return type, the name of the
// method, and the method attributes.
Type[] paramTypes = new Type[0];
Type returnType = typeof(int);
MethodBuilder simpleMethod =
    myType.DefineMethod( "ComputeSum",
    MethodAttributes.Public |
    MethodAttributes.Virtual, returnType,
    paramTypes);
```

Generating IL code

```
ILGenerator generator = simpleMethod.GetILGenerator( );
// Emit the IL
// Push zero onto the stack. For each 'i‘ less than 'theValue',
// push 'i' onto the stack as a constant
// add the two values at the top of the stack.
// The sum is left on the stack.
generator.Emit(OpCodes.Ldc_I4, 0);
for (int i = 1; i <= theValue; i++) {
      generator.Emit(OpCodes.Ldc_I4, i);
      generator.Emit(OpCodes.Add);
    }
// return the value
generator.Emit(OpCodes.Ret);

computeSumInfo = typeof(IComputer).GetMethod("ComputeSum");
myType.DefineMethodOverride(simpleMethod, computeSumInfo);

// Create the type.
myType.CreateType( );
return newAssembly;
}
```

Generated IL Code

```
Ldc_I4 0
Ldc_I4 1
Add
Ldc_I4 2
Add
Ldc_I4 3
Add
Ldc_I4 4
Add
Ldc_I4 5
Add
Ret
```

Performance

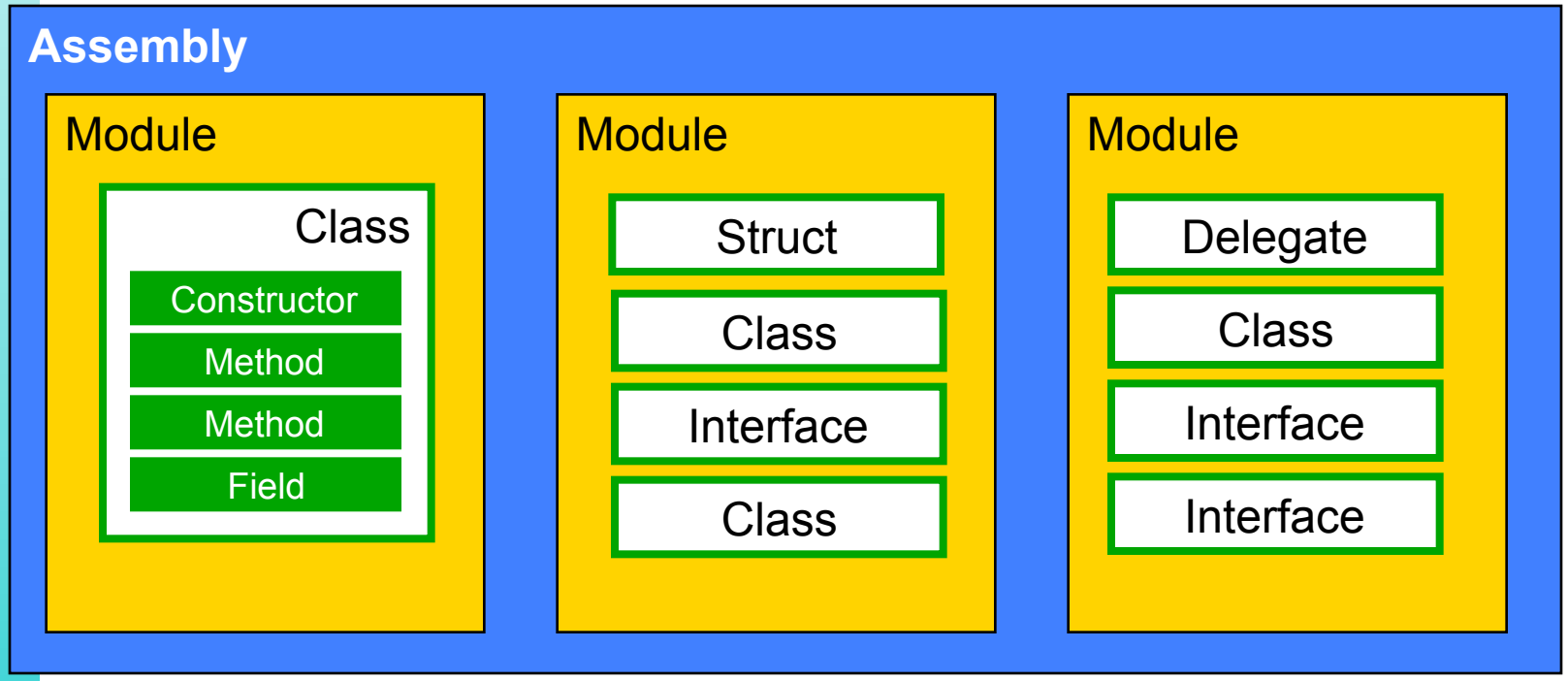
Output:

Sum of (2000) = 2001000 Looping.
Elapsed ms: 11468.75 for 1000000 iterations

Sum of (2000) = 2001000 UnrolledLoop.
Elapsed ms: 406.25 for 1000000 iterations

The Bigger picture

- **Types know their Module, Modules know their types**
- **Modules know their Assembly and vice versa**
- **Code can browse and search its entire context**



The Unmanaged Spy: Metadata API

- Unmanaged (COM) Version of Reflection
- Used by VisualStudio.NET and Compilers
- Full Access to all Reflection Information for Tools
- Fully documented in the "Tool Developer's Guide"
- Buddy: Assembly Metadata API
  - Reads/writes Assembly Manifests

Section 4: Building Types at Runtime

- **Introducing System.Reflection.Emit**
- **Why? Some scenarios**
- **Dynamic Modules and Assemblies**
- **Creating Types and Classes**
- **Writing IL**

Introducing System.Reflection.Emit

- **Full representation of physical structure**
- **Allows building modules and assemblies at runtime**
  - **Transient code only used at runtime**
  - **Persistent code for reuse**
- **Create classes, types and emit IL**
- **Used by .NET compilers to build .NET apps**

Why? Some Scenarios…

- **Build classes dynamically from script-like code**
  - **ASP.NET, Regular Expressions do just that !**
- **Generate code from visual development tools**
  - **e.g. build interfaces, base classes from UML**
- **Create dynamic wrappers for existing code**
- **Transfer code-chunks to remote machines**
  - **Distributed processing scenarios (like SETI@home)**

Building Assemblies

- System.Reflection.Emit.AssemblyBuilder
- Dynamically create new assemblies
  - Create manifest and resources
  - Add modules
  - Specify security requirements
- Can be persisted as files or held in memory
- Act and behave like any other assembly

Building Modules

- System.Reflection.Emit.ModuleBuilder
- Modules contain types, classes and code
- Allows creating fully functional modules with code
- Can associate source code
- Emit debug symbols
- Acts like any module created by any .NET compiler

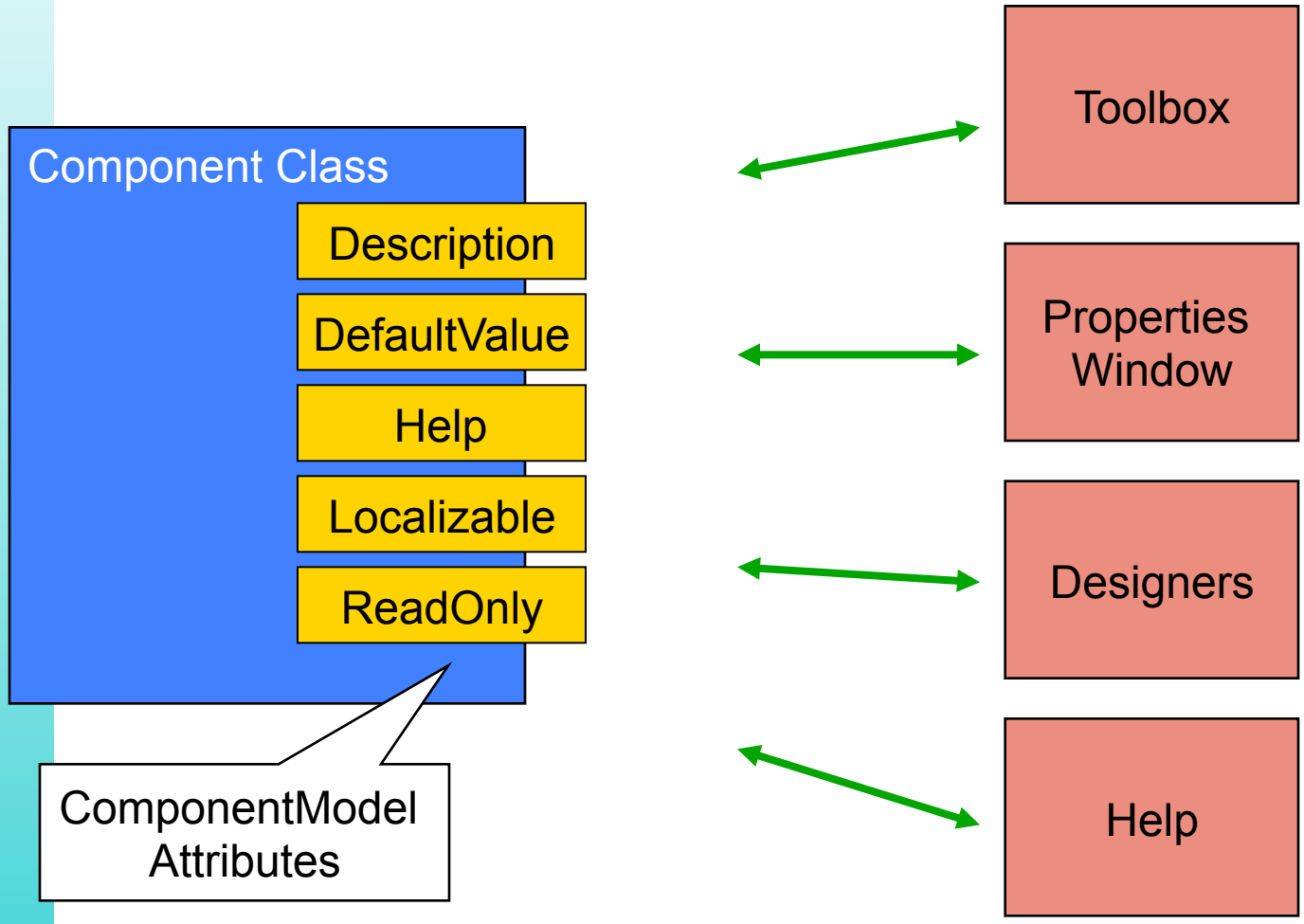
Writing IL

- Emit accepts IL (Intermediate Language) code
- Same code as emitted by C#, VB.NET, Eiffel#
- lL is optimized and translated into machine code
- Reflection.Emit puts you "on-par"
  - Same backend as .NET compilers
  - Same access to code-generation
  - Languages are mostly scanners and parsers
- For more info see System.CodeDOM

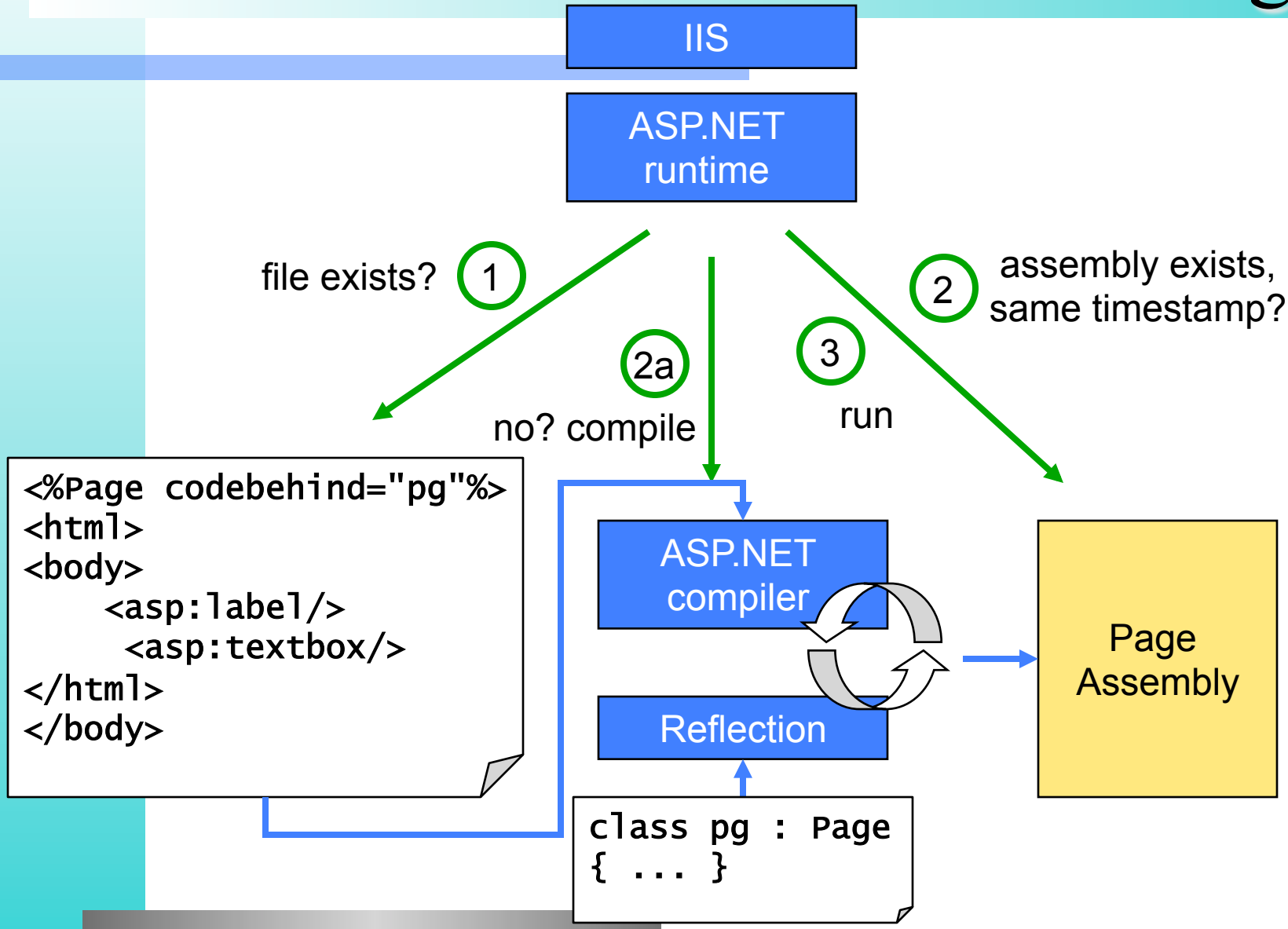
Section 5: Putting It Together

- **VisualStudio.NET and Reflection**
- **What ASP+ really does with a page**

VisualStudio.NET and Reflection



What ASP.NET does with a Page



Summary

- Reflection = System.Type + GetType()
- Explore Type Information at Runtime
- Enables Attribute-Driven Programming
- Use Emit Classes to Produce .NET Assemblies
- Bottom Line: Fully Self-Contained Structural Model