IL Assembler Today and Tomorrow

Serge Lidin (Microsoft)

Agenda

- IL Assembler Technology Overview
  - Unique positioning of IL Assembler
  - Compilers Employing IL Assembler
  - Build Environments Employing IL Assembler
- Recent Developments
  - Generics
  - Custom Attribute encoding
  - Declarative security encoding
  - Compilation control directives
  - Reference aliasing (**.typedef** directive)
  - Targeting 64 bit platforms
  - Type forwarding
  - IL Disassembler new features
- Future Work
  - Componentization
  - Nautilus Project
  - Phoenix Project

IL Assembler Technology Overview

- Unique positioning of IL Assembler
  - Platform-driven paradigm
  - Own language of .NET CLR
  - More than full functionality
  - “Official language” of ECMA/ISO standard
  - Popular back-end for compilers and tools

IL Assembler Technology Overview

- How can a compiler produce an executable?
  - Compile into IL Assembler source code and let IL Assembler take care of everything
  - Use System.Reflection.Emit
  - Build a PE file “manually” using IMetaDataEmit and ICeeFileGen
  - Build a PE file even more “manually” using own tools

IL Assembler Technology Overview

- Compilers Employing IL Assembler
  - Ada# (USAF Academy, Colorado)
  - Alice.NET (Saarland University, Saarbrücken)
  - Boo (codehaus.org)
  - COBOL
    - NetCOBOL (Fujitsu)
    - COBOL2002 for .NET Framework (NEC/Hitachi)
    - NetExpress (Microfocus)
  - CommonLarceny.NET (Northeastern University, Boston)
  - CULE.NET (CULEPlace.com)
  - Component Pascal (Queensland University of Technology, Australia)
  - Fortran (Lahey/Fujitsu)
  - Hotdog Scheme (Northwestern University, Chicago)

IL Assembler Technology Overview

- Compilers Employing IL Assembler (continued)
  - Lagoona.NET (University of California, Irvine)
  - LCC (ANSI C) (Microsoft Research, Redmond)
  - Mercury (University of Melbourne, Australia)
  - Modula-2 (Queensland University of Technology, Australia)
  - Moscow ML.NET (Royal Veterinary and Agricultural University, Denmark)
  - Oberon.NET (Swiss Federal Institute of Technology, Zürich)
  - S# (Smallscript.com)
  - SML.NET (Microsoft Research, Cambridge, UK)
  - …did I miss someone?

IL Assembler Technology Overview

- Build Environments Employing IL Assembler
  - ASMMETA: Resolving Circular Dependencies
  - ILLINK: Linking managed modules
  - Mike Stall's IL inlining in C# and VB
  - Preemptive's DotFuscator

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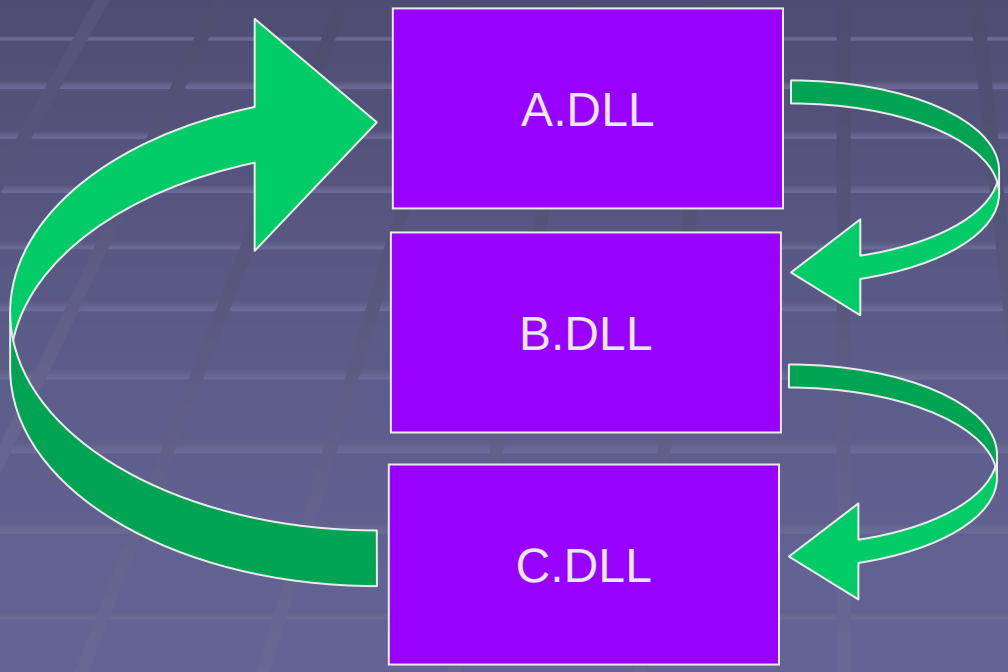
ASMMETA: Resolving Circular Dependencies

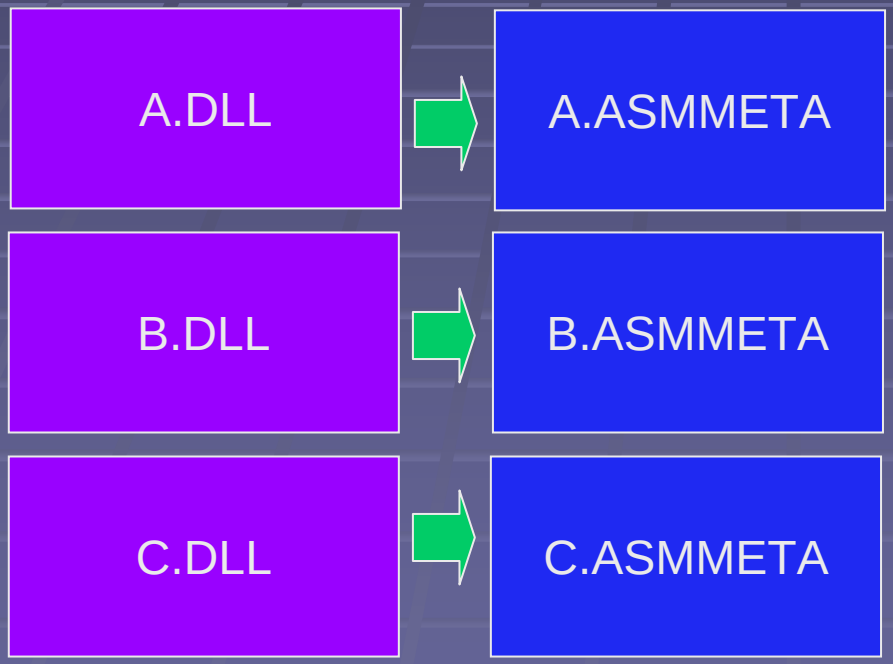
Circular dependency – How to compile?



C# and VB compilers require all referenced assemblies to be present at compile time.

ASMMETA: Resolving Circular Dependencies

Step 1: Create .asmmeta files



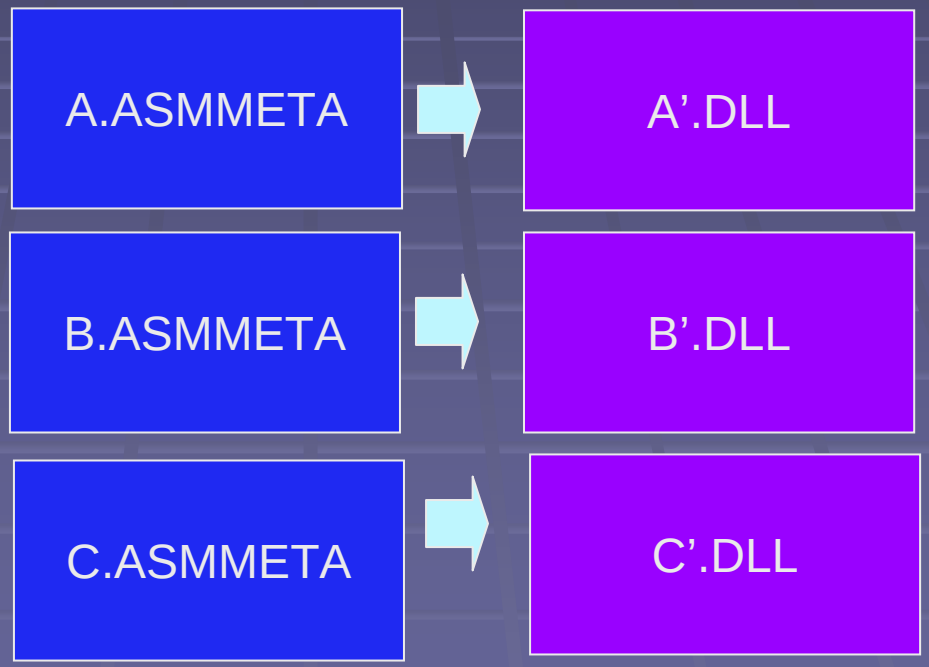
.asmmeta files are in fact IL Assembler files without method bodies and without private class members

ASMMETA: Resolving Circular Dependencies

Step 2: Create “dummy” assemblies

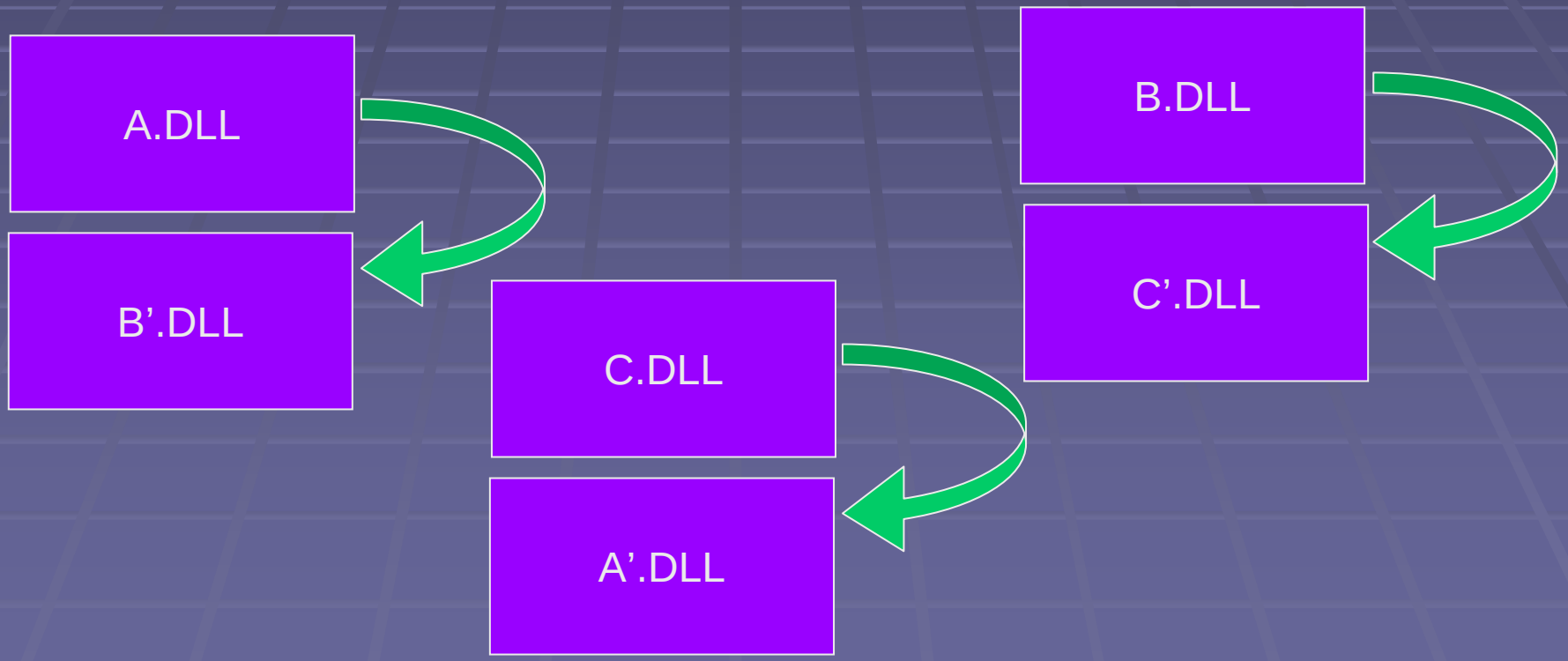
IL Assembler does not require the referenced assemblies to be present at compile time.

“Dummy” assemblies look exactly like “real” assemblies to C# or VB compiler



ASMMETA: Resolving Circular Dependencies

Step 3: No more circular dependencies. Build "real" assemblies



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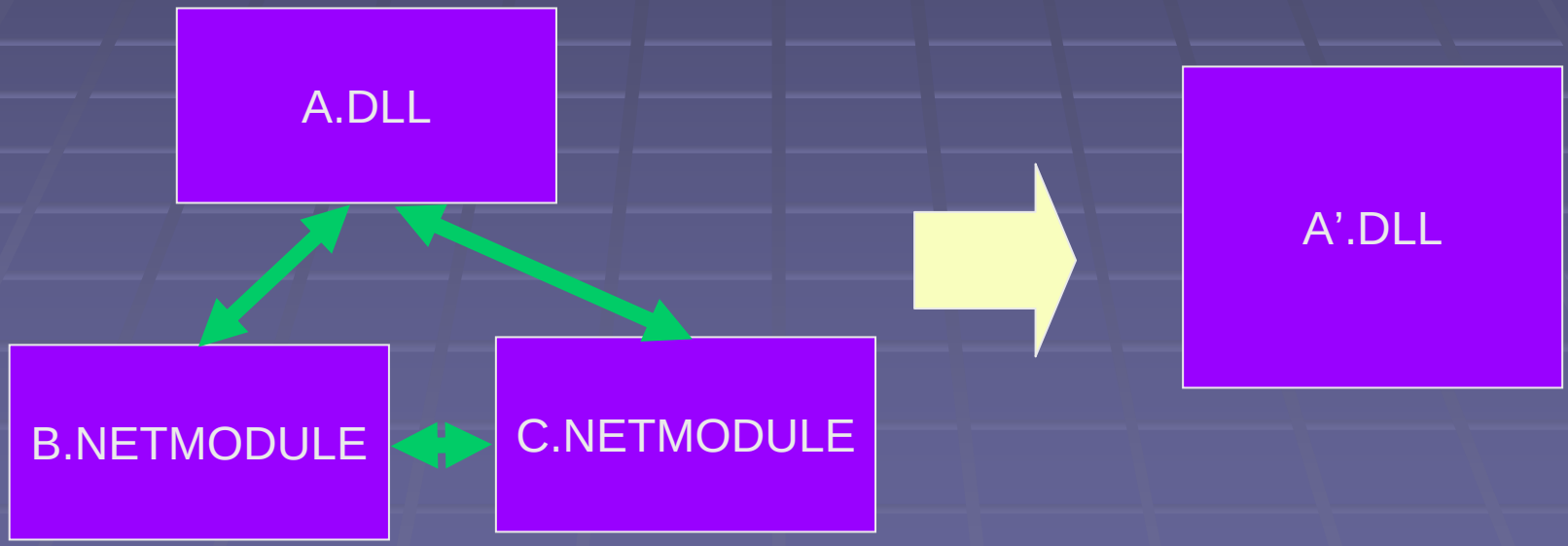
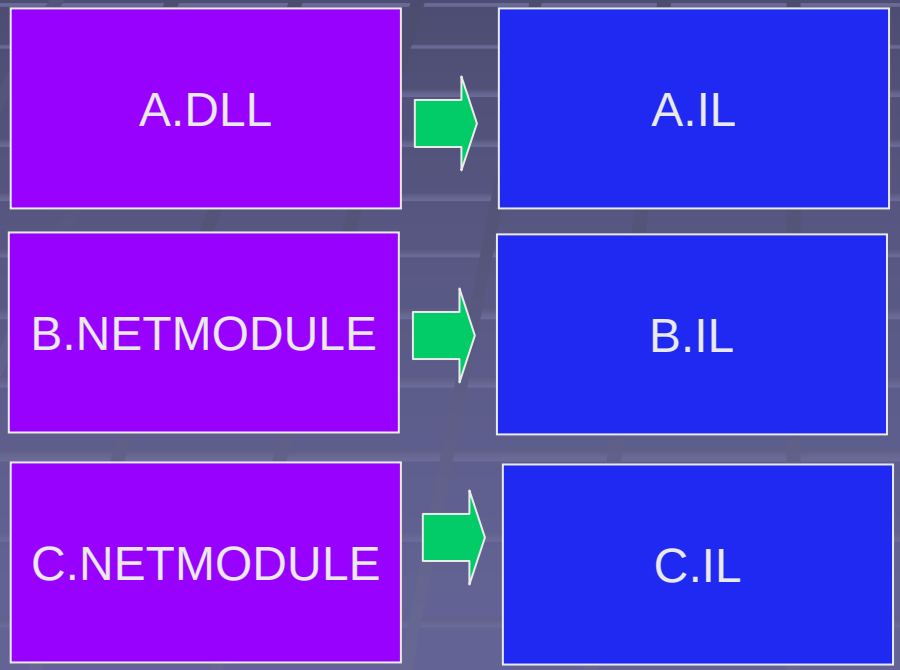
ILLINK: Linking managed modules

I have a multi-module assembly. How do I make a single-module assembly out of it?



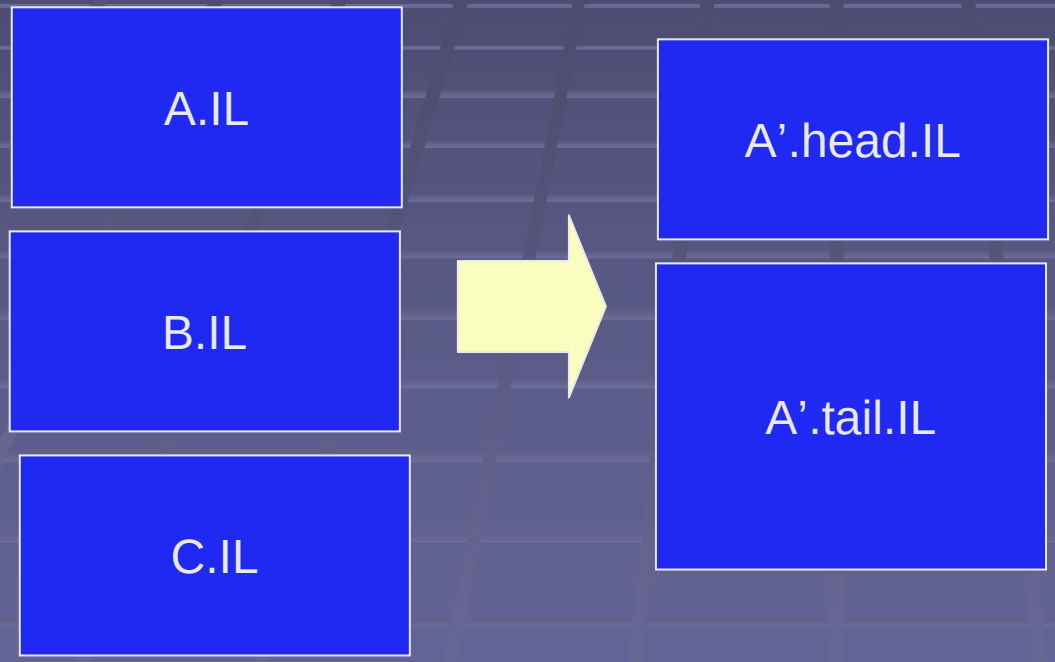
ILLINK: Linking managed modules

Step 1: Disassemble the modules



ILLINK: Linking managed modules

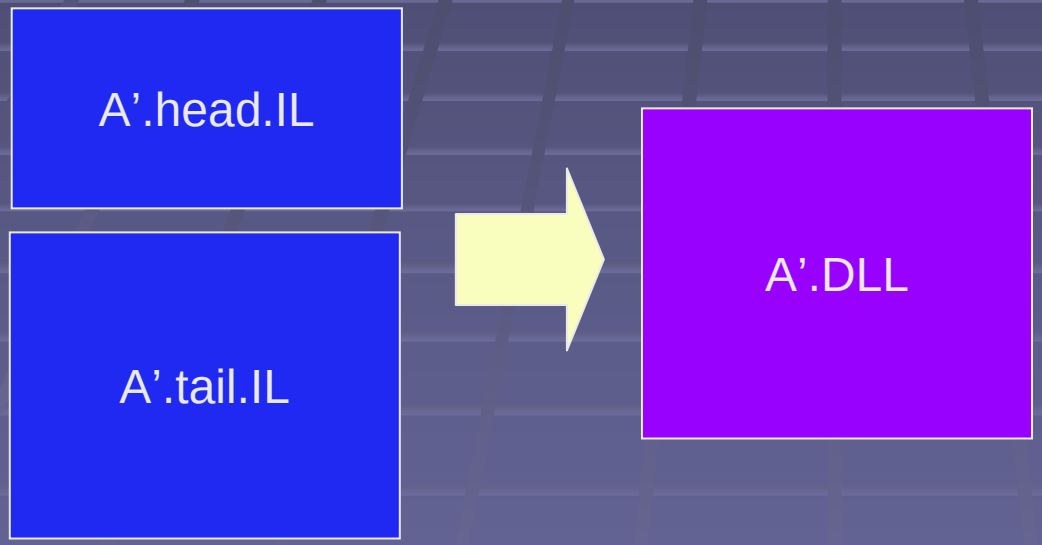
Step 2: Process the text



Text processing includes line reshuffling (all external references and manifest declarations go to "head", all the rest goes to "tail") and elimination of internal cross-references

ILLINK: Linking managed modules

Step 3: Assemble A'.DLL



ILLINK: Linking managed modules

ILLINK: 523 lines in C, including comments

http://www.gotdotnet.com/community/usersamples/Default.aspx?query=ILLINK

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Mike Stall's IL inlining in C# and VB

C# sample

```
using System;
class Program
{
    static void Main()
    {
        int x = 3;
        int y = 4;
        int z = 5;
        // Inline IL: “x=x+y+z”
#if IL
        ldloc x
        ldloc y
        add
        ldloc z
        add
        stloc x
#endif
        Console.WriteLine(x);
    }
}
```

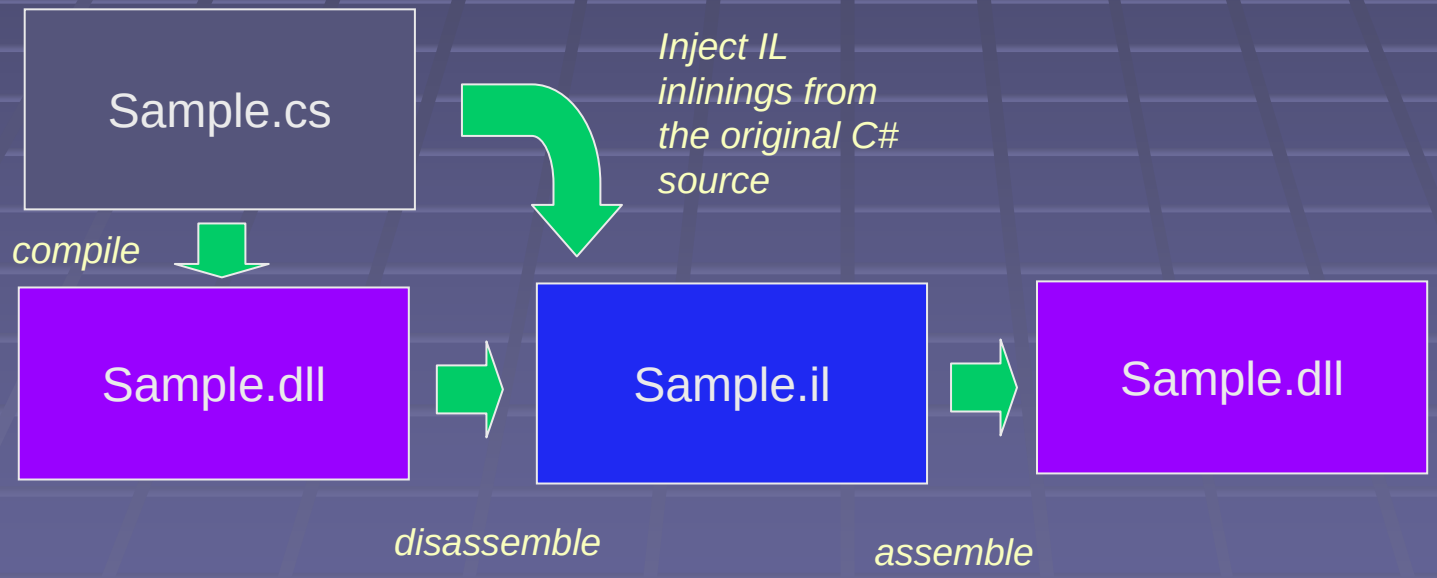
VB sample

```
' VB demo with inline IL
module m1


sub Main()
        Console.WriteLine("Hi!")
        Dim x As Integer
        x = 3
#If IL Then
        // Here's some inline IL
        ldloc x
        dup
        add
        stloc x
#End If
        Console.WriteLine(x)
    End Sub
end module
```

Mike Stall's IL inlining in C# and VB

How does it work?



Mike Stall's IL inlining in C# and VB

InlineIL: about 600 lines in C#, including comments

http://blogs.msdn.com/jmstall/archive/2005/02/21/377806.aspx

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Preemptive's DotFuscator

What is obfuscation?

```
.class TelemetricData
{
  .field private int16 ChannelID
  .field private float32 AirSpeed
  .field private int64 Azimuth
  .field private int32 Altitude
  ...
  .method private bool TimeToTarget(
              int32 targetX,
              int32 targetY)
  {
    ...
```

```
.class A
{
  .field private int16 A
  .field private float32 A
  .field private int64 A
  .field private int32 A
  ...
  .method private bool A(
        int32 A1,
        int32 A2)
  {
    ...
```

Preemptive's DotFuscator

DotFuscator features:

- Types and members renaming;
- Control flow obfuscation;
- Unused types and members removal;
- String encryption;
- Software watermarking

http://www.preemptive.com/products/dotfuscator/Features.html

Preemptive's DotFuscator

How is it done?

- Disassemble the original assembly;
- Analyze the disassembly text;
- Alter the disassembly text;
- Re-assemble.

Sounds familiar?

Recent Developments

- Generics
- Custom Attribute encoding
- Declarative Security encoding
- Compilation control directives
- Reference aliasing (**.typedef** directive)
- Targeting 64 bit platforms
- Type forwarding
- IL Disassembler new features

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Generics

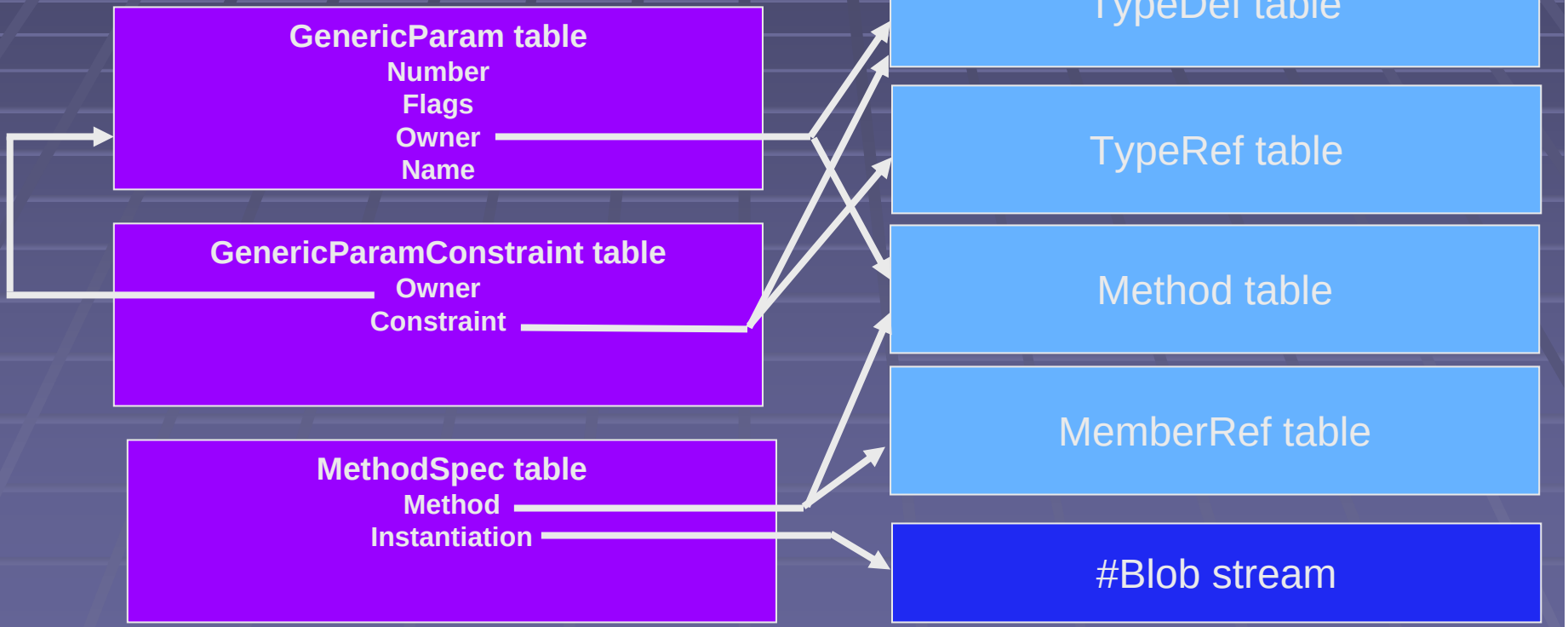
- What is it?
  - Type or method that has type parameter(s)
    For example, stack of some type, sorter of some type, etc.
    stack<T>; void sort<U>(U array[], int arraySize, ...);
  - You can constrain the type parameter(s), requiring that the prospective type argument had certain feature.
    For example, **void sort<U:IComparable>(U array[],...);**
  - Instantiation of a generic type (method) is construction of a concrete type from a generic type by specifying type arguments
    For example, **stack<string>;**
    void sort<double>(double array[],...);
  - Functionality similar to C++ templates
  - C++ templates are resolved at compile time, generics are persisted in metadata and resolved at JIT compile time. Advantage: you can define a generic in one assembly and use it in dozen others.

Generics

- Metadata tables
  - GenericParam table
    - Type parameter information
    - Constraints “must be a reference type”, “must be a value type”, “must have a default constructor”, “covariant”, “contravariant”
  - GenericParamConstraint table
    - Constraints “must extend”, “must implement”
  - MethodSpec table
    - Generic method instantiations

Generics

- Metadata tables



Generics

- IL Assembler syntax
  - Declaring generic types

```
.class public Stack<T>
{
   .field private uint32 size
   .field private uint32 top
   .field private !T[] array
   .method public void Push(!T t)
   {
        ...
   }
   .method public !T Pop()
   {
        ...
   }
   ...
}
```

Generics

- IL Assembler syntax
  - Declaring generic methods

```
.class private System.Collections.Generic.ArraySortHelper<T>
{
   ...
   .method private void QuickSort<TValue>(!T[] keys,
                                          !!TValue[] values,
                                          int32 left,
                                          int32 right,
                class System.Collections.Generic.IComparer<!T> comparer)
   {
        ...
   }
   ...
}
```

Generics

- IL Assembler syntax
  - Constraining type parameters

```
// T must be a reference type
.class public Stack<class T>
{
   ...
}
// T must be a reference type and have a default constructor
.class public Copier<class .ctor T>
{
   ...
}
// T must be a reference type and implement IComparable
.class public SortedArray<class ([mscorlib]System.IComparable)T>
{
   ...
}
```

Generics

- IL Assembler syntax
  - Referencing generic type instantiations

```
.class public Stack<class T>
{
   ...
}
.class public FloatStackUser
{
   .field private class Stack<float32> stack
   .method public specialname void .ctor()
   {
        ...
        ldarg.0
        ldc.i4.s 64
        newobj instance void class Stack<float32>::.ctor(int32)
        stfld class Stack<float32> FloatStackUser::stack
        ...
}
```

Generics

- IL Assembler syntax
  - Referencing generic method instantiations

```
.class public Stack<class T> { ... }
...
.class public A {
   .method public static class Stack<!!T>
                                StackFromArray<T>(!!T[] array) { ... }
}
.class public B {
   .method public float32[] GetFloatArray() { ... }
}
...
   call instance float32[] B::GetFloatArray()
   call class Stack<!!0> A::StackFromArray<float32>(!!0[])
...
```

Generics

- IL Assembler syntax
  - Nested generic types

```
.class public A<T>
{
   .class nested private Association<T,U>
   {
        ...
   }
   ...
}
```

Generics

- IL Assembler syntax
  - Nested generic types

```
// C#
class Tree<T> {
   class Node<T> { ... }
   ...
}

// IL
.class public Tree<T>
{
   .class nested private Node<T,T>
   {
        ...
   }
   ...
}
```

Recent Developments

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- Custom Attribute encoding
- Declarative Security encoding
- Compilation control directives
- Reference aliasing (**.typedef** directive)
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- Type forwarding
- IL Disassembler new features

Custom Attribute encoding

```
// Binary form
.custom instance void
  [System]System.ComponentModel.BrowsableAttribute::.ctor(bool,object)
        = ( 01 00 01 08 39 30 00 00 05 00 53 50 03 42 61 72
            59 57 68 6F 2E 4B 6E 6F 77 73 2E 57 68 61 74 2C
            20 53 79 73 74 65 6D 2C 20 56 65 72 73 69 6F 6E
      ...

// Verbal form
.custom instance void
  [System]System.ComponentModel.BrowsableAttribute::.ctor(bool,object)
      = {bool(true)
         object(int32(12345))
         field type 'Bar' = type([System]Who.Knows.What)
         field object 'fooBar' = object(type([System]Never.Heard.Of))
         field int32[] 'fooBaz' = int32[3](1 2 3)
         field string[] 'fooFoo' = string[2]('abc' 'def')
         property string 'Foo' = string('He\\he\\he')}
```

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Declarative security encoding

- Permission set blob encoding
  - '.' *// dot character*
  - <compressed_uint> *// number of permissions in the set*
  - { <permission> } *// set of permission encodings*
- Permission blob encoding
  - <compressed_uint> *// length of the class name (following)*
  - <class_name> *// fully qualified class name in Reflection notation*
  - <compressed_uint> *// size of initialization blob*
  - <compressed_uint> *// number of properties, can be 0*
  - [{ <property> }] *// set of properties, absent if num=0*

Declarative security encoding

- Permission property encoding
  - SERIALIZATION_TYPE_PROPERTY *// 1 byte, 0x54*
  - <type_of_the_property> *// property signature*
  - <compressed_uint> *// length of the property name (follows)*
  - <property_name>
  - <encoded_value>
- IL Assembler syntax

```
.permissionset reqmin
  = {[mscorlib]System.Security.Permissions.SecurityPermissionAttribute
        = {property bool 'SkipVerification' = bool(true)}}
```

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Compilation Control Directives

- `#include “<file name>”`
  - Include path can be specified by /INCLUDE command line option
- `#define <var_name>`
- `#define <var_name> “<string>”`
- `#ifdef <var_name>`
- `#ifndef <var_name>`
- `#else`
- `#endif`

Compilation Control Directives

```
// File AssemblyVer.il
#define VER_SYSTEM “2:0:0:0”
#define VER_MSCORLIB “2:0:0:0”
#define VER_VISUALB “8:0:0:0”
#define MS_PK_TOKEN_DCL “.publickeytoken = (B7 7A 5C 56 19 34 E0 89)”
```

```
// File MyProg.il
#include “AssemblyVer.il”
.assembly extern mscorlib {
   .ver VER_MSCORLIB
    MS_PK_TOKEN_DCL
}
.assembly extern Microsoft.VisualBasic {
   .ver VER_VISUALB
    .publickeytoken = (B0 3F 5F 7F 11 D5 0A 3A )
}
// continued ...
```

Compilation Control Directives

```
// File MyProg.il (continued)
#define ClassA_LocalDeclaration

.assembly MyProg { }
#ifdef ClassA_LocalDeclaration
.class public abstract A {
   .method public virtual abstract void a() {}
}
#else
   #include “ClassA.il”
#endif

.class public B extends A {
   .method public virtual void a() {
        ...
   }
   ...
}
```

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Reference aliasing (.typedef directive)

- Types
  - `.typedef [mscorlib]System.Console as TTY`
  - `.typedef string as str`
- Methods
  - `.typedef method void TTY::WriteLine(str) as PrintString`
- Fields
  - `.typedef field string A::hello as hithere`
- Custom Attributes
  - `.typedef .custom instance void [System]System.ComponentModel.BrowsableAttribute::.ctor(bool) = {bool(true)} as BrowsableAttr`

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Targeting 64 bit platforms

- Target classification

Target	Machine (COFF hdr)	NT Optional header type	Lower 2 bits of CLR header flags
Platform-agnostic	I386	32-bit	0x1
x86	I386	32-bit	0x0, 0x2, 0x3
Intel Itanium	IA64	64-bit	*
AMD X64	AMD64	64-bit	*

Targeting 64 bit platforms

- File structure checks for different targets
  - Headers:
    - DOS header: DOS Signature, pointer to COFF header
    - COFF header: Characteristics != SYSTEM
    - NT Optional Header:
      - NT Signature
      - Magic (32/64 bit)
      - FileAlignmement (*512)
      - SectionAlignment (*FileAlignment)
      - SizeOfImage (*SectionAlignment)
      - ImageBase (*0x10000)
      - SizeOfStackCommit <= SizeOfStackReserve
      - SizeOfHeapCommit <= SizeOfHeapReserve
      - directory entries (for IL-only images, only IMPORT, RESOURCE, SECURITY, BASERELOC, DEBUG, IAT and COMHEADER are allowed)

Targeting 64 bit platforms

- File structure checks for different targets (continued)
  - Headers:
    - Section headers:
      - Characteristics (allowed: CODE, INITIALIZED_DATA, UNITIALIZED_DATA, DISCARDABLE, NOT_CACHED, NOT_PAGED, EXECUTE, READ, WRITE, SHARED; ***not*** allowed: CODE|WRITE for all images and SHARED for IL-only images)
    - CLR header:
      - Read-only section
      - Metadata, resources and SN signature also in read-only section
      - IL-only images must not have VT Fixup table, EAT Jump table or Native Entrypoint;
    - Metadata headers:
      - Storage signature
      - on Intel Itanium, Metadata general header and storage header must be 4-byte aligned
      - storage header and streams must be contained within metadata size declared in CLR header
      - storage streams must not overlap

Targeting 64 bit platforms

- File structure checks for different targets (continued)
  - Relocations (specific to the platform: I386/Itanuim/X64)
  - Import Address Table (in IL-only images, single entry pointing to mscoree.dll is allowed)

Targeting 64 bit platforms

- Different targets in IL Assembler
  - Target options
    - /PE64 – generate a PE32+ image
    - /ITAnuim – generate image for Intel Itanium
    - /X64 – generate image for AMD X64
    - Defaults:
      - /PE64 → /PE64 /ITA
      - /ITA → /PE64 /ITA
      - /X64 → /PE64 /X64
  - Automatic generation of VT Fixups for umnanaged exports

Targeting 64 bit platforms

```
.assembly extern mscorlib { }
.assembly YDD { }
.module YDD.dll
.corflags 0x00000002
.data VT_01 = int32(0)[3]

.vtfixup [3] int32 fromunmanaged at VT_01
.method public static int32 Yabba()
{
   .vtentry 1:1
   .export [1]
   ldstr "Printing Yabba (IL)"
   call void [mscorlib]System.Console::WriteLine(string)
   ldc.i4     0xAAAA
   ret
}
...
```

Targeting 64 bit platforms

```
.assembly extern mscorlib { }
.assembly YDD { }
.module YDD.dll
// .corflags 0x00000002
// .data VT_01 = int32(0)[3]

// .vtfixup [3] int32 fromunmanaged at VT_01
.method public static int32 Yabba()
{
   // .vtentry 1:1
   .export [1]
   ldstr "Printing Yabba (IL)"
   call void [mscorlib]System.Console::WriteLine(string)
   ldc.i4     0xAAAA
   ret
}
...
```

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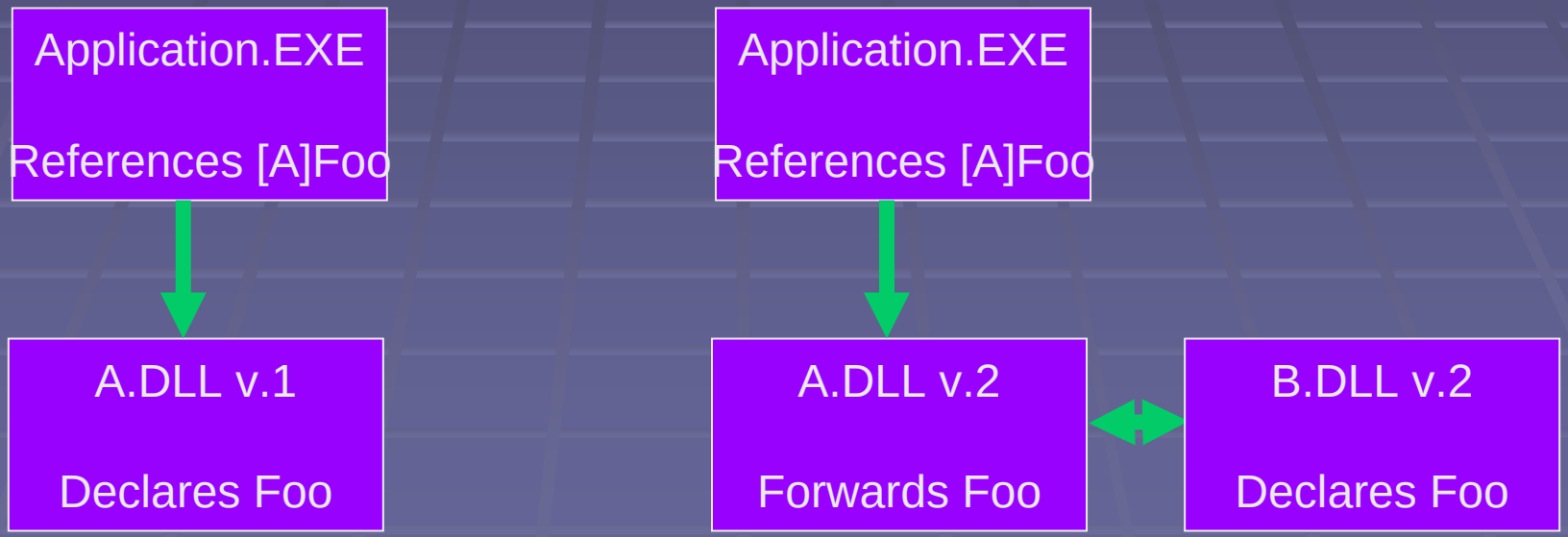
Type forwarding

- Assembly refactoring



Type forwarding

- Metadata presentation of type forwarders
  - ExportedType table
    - Flags | tdForwarder (0x00200000)
    - TypeDefId
    - TypeName
    - TypeNamespace
    - Implementation = mdAssemblyRef
- IL Assembler syntax

```
.class extern public forwarder Foo.Bar
{
    .assembly extern B
}
```

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IL Disassembler new features

- No forward type declaration by default
- Typelist: preserving order of declared types

```
.typelist { name1 name2 … nameN }
```

- References summary

```
//============ R E F E R E N C E S ============================
//    '<Module>'/*02000001*/   references
//              -   C/*02000004*/
//              -   A/*02000002*/
//              -   [mscorlib/*23000001*/]System.Console/*01000002*/
//              -   B/*02000003*/
//    A/*02000002*/   references
//              -   [mscorlib/*23000001*/]System.Object/*01000001*/
//              -   C/*02000004*/
//    B/*02000003*/   references
//              -   [mscorlib/*23000001*/]System.Object/*01000001*/
//              -   C/*02000004*/
//    C/*02000004*/   references
//              -   [mscorlib/*23000001*/]System.Object/*01000001*/
//============== END REFERENCES ============================
```

Future Work

- Componentization
  - Make IL Assembler and IL Disassembler component-based rather than stand-alone tools
- Nautilus Project
  - A group within Visual Studio experimenting with development tools and environments written entirely in managed code. We are considering incorporating IL Assembler.
- Phoenix Project
  - A group within Visual Studio experimenting with universal code generation tools (John Lefor's presentation). We are considering incorporating IL Assembler and Disassembler and expanding them on Phoenix base.

IL Assembly Language Sources:

- ECMA/ISO Standard Specification
- John Gough: Compiling for the .NET Common Language Runtime (Prentice Hall, 2001)
- S.Lidin: Inside Microsoft .NET IL Assembler (MS Press, 2002)
- J.S.Miller, S.Ragsdale: The Common Language Infrastructure Annotated Standard (Addison-Wesley, 2004)

- Questions?
- Contact: slidin@microsoft.com

Thank you!