Common Language Infrastructure (CLI)

Partition I:
Concepts and Architecture

Foreword

This sixth edition cancels and replaces the fifth edition which has been technically revised

This Standard is fully aligned with ISO/IEC 23271:2012.

The following features have been added, extended or clarified in the Standard:

- The presentation of the rules for assignment compatibility (§I.8.7, §III.1.8.1.2.3) has been extensively revised to a more precise and clearer relation-based format.
- The presentation of the verification rules for many IL instructions has been revised to be more precise and clearer by building upon the revisions to the presentation of assignment compatibility.
- The presentation of delegate signature compatibility has been revised along the same lines as assignment compatibility.
- The verification rules for the IL newobj instruction have been extended to cover general delegate creation.
- The dispatch rules for variance (§II.12.2) have been extended to define resolutions for the ambiguities that can arise.
- Type forwarders have been added to support the relocation of types between libraries (§II.6.8)

The following changes of behavior have been made to the Standard:

- The semantics of variance has been redefined making it a core feature of the CLI. In the previous edition of the Standard variance could be ignored by languages not wishing to support it (§I.1.8); as exact type matches always took precedence over matches-by-variance. In this edition the dispatch rules for interfaces (§II.12.2) allow a match-by-variance to take precedence over an exact match, so all language implementation targeting the CLI must be aware of the behavior even if it is not supported in the language (§I.1.8).
- Additional requirements on ilasm to metadata conversion. The left-to-right order of interfaces listed in a type header (§II.10.2) must now be preserved as a top-to-bottom order in the InterfaceImpl table (§II.22.23); and the top-to-bottom of method definitions (§II.10.2, §II.25) must now be preserved as a top-to-bottom order in the MethodDef table (§II.22.26). Both these additional requirements are required to support the revised variance semantics.
- System.Math and System.Double have been modified to better conform to IEEE (see Partition IV and IEC 60559:1989)

The following types have been added to the Standard or have been significantly updated (* represents an update).

Type	Library
System.Action	BCL
System.Action`1<-T>* … System.Action`8<-T1..-T8>	BCL
System.Comparison`1<-T>*	BCL

System.Converter`2<-T,+U>*	BCL
System.IComparable`1<-T>*	BCL
System.Predicate`1<-T>*	BCL
System.Collections.Generic.IComparer`1<-T>*	BCL
System.Collections.Generic.IEnumerable`1<+T>*	BCL
System.Collections.Generic.IEqualityComparer`1<-T>*	BCL
System.Guid	BCL
System.MulticastDelegate	BCL
System.Reflection.CallingConventions	Runtime Infrastructure
System.Runtime.InteropServices.GuidAttribute	Runtime Infrastructure
System.Func`1<+TResult>…System.Func`9<-T1..-T8, +TResult>	BCL
System.Collections.Generic.Comparer`1<T>	BCL
System.Collections.Generic.EqualityComparer`1<T>	BCL
System.Collections.Generic.ISet`1<T>	BCL
System.Collections.Generic.LinkedList`1<T>	BCL
System.Collections.Generic.LinkedList`1<T>.Enumerator	BCL
System.Collections.Generic.LinkedListNode`1<T>	BCL
System.Collections.Generic.Queue`1<T>	BCL
System.Collections.Generic.Stack`1<T>	BCL
System.Collections.Generic.Stack`1<T>.Enumerator	BCL
System.Collections.Stack	BCL
System.DBNull	BCL
System.Runtime.InteropServices.Marshal	Runtime Infrastructure
System.Runtime.InteropServices.SafeBuffer	Runtime Infrastructure
System.Runtime.InteropServices.SafeHandle	Runtime Infrastructure
System.Threading.AutoResetEvent	BCL
System.Threading.EventWaitHandle	BCL
System.Threading.ManualResetEvent	BCL
System.WeakReference	BCL
System.Runtime.CompilerServices.TypeForwardedToAttribute	BCL
System.Runtime.CompilerServices.TypeForwardedFromAttribute	BCL
System.Threading.EventResetMode	BCL
System.Runtime.InteropServices.DllAttribute*	Runtime Infrastructure
System.Math*	BCL

One type, INullableValue, has been removed from the Standard. INullableValue is incompatible with the semantics of boxing as defined in the previous edition of the Standard. The references to it were included in error from an earlier draft and no implementations are known to have ever included it.

Technical Report 89 (TR89), which was submitted during the third edition of this Ecma standard, will no longer be part of the submission. TR89 specified a collection of generic types, to help enhance inter-language interoperability, under consideration for inclusion in a future version of the standard. That consideration has now occurred and TR89 has fulfilled its role. A selection of the types covered in TR89 has been introduced into this edition of the standard. An archive version of TR89 will continue to be available from Ecma.

The following companies and organizations have participated in the development of this standard, and their contributions are gratefully acknowledged: Eiffel Software, Kahu Research, Microsoft Corporation, Novell Corporation, Twin Roots. For previous editions, the following companies and organizations are also acknowledged: Borland, Fujitsu Software Corporation, Hewlett-Packard, Intel Corporation, IBM Corporation, IT University of Copenhagen, Jagger Software Ltd., Monash University, Netscape, Phone.Com, Plum Hall, and Sun Microsystems.

I.1 Scope

This International Standard defines the Common Language Infrastructure (CLI) in which applications written in multiple high-level languages can be executed in different system environments without the need to rewrite those applications to take into consideration the unique characteristics of those environments. This International Standard consists of the following parts:

- Partition I: Concepts and Architecture – Describes the overall architecture of the CLI, and provides the normative description of the Common Type System (CTS), the Virtual Execution System (VES), and the Common Language Specification (CLS). It also provides an informative description of the metadata.
- Partition II: Metadata Definition and Semantics – Provides the normative description of the metadata: its physical layout (as a file format), its logical contents (as a set of tables and their relationships), and its semantics (as seen from a hypothetical assembler, *ilasm*).
- Partition III: CIL Instruction Set – Describes the Common Intermediate Language (CIL) instruction set.
- Partition IV: Profiles and Libraries – Provides an overview of the CLI Libraries, and a specification of their factoring into Profiles and Libraries. A companion file, CLILibrary.xml, considered to be part of this Partition, but distributed in XML format, provides details of each class, value type, and interface in the CLI Libraries.
- Partition V: Debug Interchange Format – Describes a standard way to interchange debugging information between CLI producers and consumers.
- Partition VI: Annexes – Contains some sample programs written in CIL Assembly Language (ILAsm), information about a particular implementation of an assembler, a machine-readable description of the CIL instruction set which can be used to derive parts of the grammar used by this assembler as well as other tools that manipulate CIL, a set of guidelines used in the design of the libraries of Partition IV, and portability considerations.

I.2 Conformance

A system claiming conformance to this International Standard shall implement all the normative requirements of this standard, and shall specify the profile (see Partition IV Library – Profiles) that it implements. The minimal implementation is the Kernel Profile. A conforming implementation can also include additional functionality provided that functionality does not prevent running code written to rely solely on the profile as specified in this standard. For example, a conforming implementation can provide additional classes, new methods on existing classes, or a new interface on a standardized class, but it shall not add methods or properties to interfaces specified in this standard.

A compiler that generates Common Intermediate Language (CIL, see Partition III) and claims conformance to this International Standard shall produce output files in the format specified in this standard, and the CIL it generates shall be correct CIL as specified in this standard. Such a compiler can also claim that it generates *verifiable* code, in which case, the CIL it generates shall be verifiable as specified in this standard.

I.3 Normative references

[Note that many of these references are cited in the XML description of the class libraries.]

Extensible Markup Language (XML) 1.0 (Third Edition), 2004 February 4, http://www.w3.org/TR/2004/REC-xml-20040204/

Federal Information Processing Standard (FIPS 180-1*), Secure Hash Standard (SHA-1)*, 1995, April.

IEC 60559:1989, *Binary Floating-point Arithmetic for Microprocessor Systems* (previously designated IEC 559:1989).

ISO 639, *Codes for the representation of names of languages*.

ISO 3166-1:2006, *Codes for the representation of names of countries*.

ISO/IEC 646:1991, *Information Technology — ISO 7-bit coded character set for information interchange*

ISO/IEC 9899:1999, *Programming languages — C*.

ISO/IEC 10646, *Information Technology — Universal Coded Character Set (UCS).*

ISO/IEC 11578:1996, *Information Technology — Open Systems Interconnection - Remote Procedure Call (RPC).*

ISO/IEC 14882:2011, *Programming languages — C++*.

ISO/IEC 23270:2006, *Programming languages — C#.*

RFC-768, *User Datagram Protocol*. J. Postel. 1980, August.

RFC-791, *Darpa Internet Program Protocol Specification*. 1981, September.

RFC-792, *Internet Control Message Protocol*. Network Working Group. J. Postel. 1981, September.

RFC-793, *Transmission Control Protocol*. J. Postel. 1981, September.

RFC-919, *Broadcasting Internet Datagrams*. Network Working Group. J. Mogul. 1984, October.

RFC-922, *Broadcasting Internet Datagrams in the presence of Subnets*. Network Working Group. J. Mogul. 1984, October.

RFC-1035, *Domain Names - Implementation and Specification*. Network Working Group. P. Mockapetris. 1987, November.

RFC-1036, *Standard for Interchange of USENET Messages*, Network Working Group. M. Horton and R. Adams. 1987, December.

RFC-1112. *Host Extensions for IP Multicasting*. Network Working Group. S. Deering 1989, August.

RFC-1222. *Advancing the NSFNET Routing Architecture.* Network Working Group. H-W Braun, Y. Rekhter. 1991 May. http://tools.ietf.org/html/rfc1222

RFC-1510, *The Kerberos Network Authentication Service (V5)*. Network Working Group. J. Kohl and C. Neuman. 1993, September.

RFC-1741, *MIME Content Type for BinHex Encoded Files: Format*. Network Working Group. P. Faltstrom, D. Crocker, and E. Fair. 1994, December.

RFC-1764. *The PPP XNS IDP Control Protocol (XNSCP).* Network Working Group. S. Senum. 1995, March.

RFC-1766, *Tags for the Identification of Languages*. Network Working Group. H. Alvestrand. 1995, March.

RFC-1792. *TCP/IPX Connection Mib Specification*. Network Working Group. T. Sung. 1995, April.

RFC-2236. *Internet Group Management Protocol, Version 2*. Network Working Group. W. Fenner. 1997, November.

RFC-2045, *Multipurpose Internet Mail Extensions (MIME) Part One: Format of Internet Message Bodies*. Network Working Group. N. Freed. 1996, November.

RFC-2616, *Hypertext Transfer Protocol -- HTTP/1.1.* Network Working Group. R. Fielding, J. Gettys, J. Mogul, H. Frystyk, L. Masinter, P. Leach, and T. Berners-Lee. 1999 June. http://www.ietf.org/rfc/rfc2616.txt

RFC-2617, *HTTP Authentication: Basic and Digest Access Authentication.* Network Working Group. J. Franks, P. Hallam-Baker, J. Hostetler, S. Lawrence, P. Leach, A. Luotonen, and L. Stewart. 1999 June, http://www.ietf.org/rfc/rfc2617.txt

The Unicode Consortium. The Unicode Standard, Version 4.0, defined by: *The Unicode Standard, Version 4.0* (Boston, MA, Addison-Wesley, 2003. ISBN 0-321-18578-1).

I.4 Conventions

I.4.1 Organization

The divisions of this International Standard are organized using a hierarchy. At the top level is the *Partition.* The next level is the *clause*, followed by *subclause*. Divisions within a subclause are also referred to as subclauses. Partitions are numbered using Roman numerals. All other divisions are numbered using Arabic digits with their place in the hierarchy indicated by nested numbers. For example, Partition II, 14.4.3.2 refers to subclause 2 in subclause 3 in subclause 4 in clause 14 in Partition II.

I.4.2 Informative text

This International Standard is intended to be used by implementers, academics, and application programmers. As such, it contains explanatory material that, strictly speaking, is not necessary in a formal specification.

Examples are provided to illustrate possible forms of the constructions described. References are used to refer to related clauses or subclauses. Notes are provided to give advice or guidance to implementers or programmers. Annexes provide additional information.

Except for whole clauses or subclauses that are identified as being informative, informative text that is contained within normative clauses and subclauses is identified as follows:

- The beginning and end of a block of informative text is marked using rectangular boxes.
- As some informative passages span pages, informative text also contains a bold set of vertical black stripes in the right margin.
- By the use of the following pairs of markers: [*Example*: … *end example*], [*Note*: … *end note*], and [*Rationale*: … *end rationale*].

Unless text is identified as being informative, it is normative.

I.5 Terms and definitions

For the purposes of this International Standard, the following definitions apply. Other terms are defined where they appear in *italic* type.

ANSI character: A character from an implementation-defined 8-bit character set whose first 128 code points correspond exactly to those of ISO/IEC 10646.

ANSI string: A string of ANSI characters, of which the final character has the value all-bits-zero.

argument: The expression supplied for a parameter at the point of the call to a method.

assembly: A configured set of loadable code modules and other resources that together implement a unit of functionality.

attribute: A characteristic of a type and/or its members that contains descriptive information. While the most common attributes are predefined, and have a specific encoding in the metadata associated with them, user-defined attributes can also be added to the metadata.

behavior, implementation-specific: Unspecified behavior, for which each implementation is required to document the choice it makes.

behavior, unspecified: Behavior, for a well-formed program construct and correct data, that depends on the implementation. The implementation is not required to document which behavior occurs.

behavior, undefined: Behavior, such as might arise upon use of an erroneous program construct or erroneous data, for which this International Standard imposes no requirements. Undefined behavior can also be expected in cases when this International Standard omits the description of any explicit definition of behavior.

boxing: The conversion of a value having some value type, to a newly allocated instance of the reference type `System.Object`.

Common Intermediate Language (CIL): The instruction set understood by the VES.

Common Language Infrastructure (CLI): A specification for the format of executable code, and the run-time environment that can execute that code.

Common Language Specification (CLS): An agreement between language designers and framework (class library) designers. It specifies a subset of the CTS and a set of usage conventions.

Common Type System (CTS): A unified type system that is shared by compilers, tools, and the CLI itself. It is the model that defines the rules the CLI follows when declaring, using, and managing types. The CTS establishes a framework that enables cross-language integration, type safety, and high performance code execution.

delegate: A reference type such that an instance of it can encapsulate one or more methods in an invocation list. Given a delegate instance and an appropriate set of arguments, one can invoke all of the methods in a delegate's invocation list with that set of arguments.

event: A member that enables an object or class to provide notifications.

Execution Engine: See **Virtual Execution System**.

field: A member that designates a typed memory location that stores some data in a program.

garbage collection : The process by which memory for managed data is allocated and released.

generic argument: The actual type used to instantiate a particular generic type or generic method. For example, in `List<string>`, `string` is the generic argument corresponding to the generic parameter `T` in the generic type definition `List<T>`.

generic parameter: A parameter within the definition of a generic type or generic method that acts as a place holder for a generic argument. For example, in the generic type definition `List<T>`, `T` is a generic parameter.

generics : The feature that allows types and methods to be defined such that they are parameterized with one or more generic parameters.

library: A repository for a set of types, which are grouped into one or more assemblies. A library can also contain modifications to types defined in other libraries. For example, a library can include additional methods, interfaces, and exceptions for types defined in other libraries.

managed code: Code that contains enough information to allow the CLI to provide a set of core services. For example, given an address for a method inside the code, the CLI must be able to locate the metadata describing that method. It must also be able to walk the stack, handle exceptions, and store and retrieve security information.

managed data: Data that is allocated and released automatically by the CLI, through a process called garbage collection.

manifest: That part of an assembly that specifies the following information about that assembly: its version, name, culture, and security requirements; which other files, if any, belong to that assembly, along with a cryptographic hash of each file; which of the types defined in other files of that assembly are to be exported from that assembly; and, optionally, a digital signature for the manifest itself, and the public key used to compute it.

member: Any of the fields, array elements, methods, properties, and events of a type.

metadata: Data that describes and references the types defined by the CTS. Metadata is stored in a way that is independent of any particular programming language. Thus, metadata provides a common interchange mechanism for use between tools that manipulate programs (such as compilers and debuggers) as well as between these tools and the VES.

method: A member that describes an operation that can be performed on values of an exact type.

method, generic: A method (be it static, instance, or virtual), defined within a type, whose signature includes one or more generic parameters, not present in the type definition itself. The enclosing type itself might, or might not, be generic. For example, within the generic type `List<T>`, the generic method `S ConvertTo<S>()` is generic.

method, non-generic: A method that is not generic.

module: A single file containing content that can be executed by the VES.

object: An instance of a reference type. An object has more to it than a value. An object is self-typing; its type is explicitly stored in its representation. It has an identity that distinguishes it from all other objects, and it has slots that store other entities (which can be either objects or values). While the contents of its slots can be changed, the identity of an object never changes.

parameter: The name used in the header and body of a method to refer to an argument value supplied at the point of call.

profile: A set of libraries, grouped together to form a consistent whole that provides a fixed level of functionality.

property: A member that defines a named value and the methods that access that value. A property definition defines the accessing contracts on that value. Hence, the property definition specifies which accessing methods exist and their respective method contracts.

signature: The part of a contract that can be checked and automatically enforced. Signatures are formed by adding constraints to types and other signatures. A constraint is a limitation on the use of or allowed operations on a value or location.

type, generic: A type whose definition is parameterized by one or more other types; for example, `List<T>`, where `T` is a generic parameter. The CLI supports the creation and use of instances of generic types. For example, `List<int32>` or `List<string>`.

type, reference: A type such that an instance of it contains a reference to its data.

type, value: A type such that an instance of it directly contains all its data.

unboxing: The conversion of a value having type `System.Object`, whose run-time type is a value type, to a value type instance.

unmanaged code: Code that is not managed.

unmanaged data: Data that is not managed.

value: A simple bit pattern for something like an integer or a float. Each value has a type that describes both the storage that it occupies and the meanings of the bits in its representation, and also the operations that can be performed on that representation. Values are intended for representing the simple types and non-objects in programming languages.

verification: The checking of both CIL and its related metadata to ensure that the CIL code sequences do not permit any access to memory outside the program's logical address space. In conjunction with the validation tests, verification ensures that the program cannot access memory or other resources to which it is not granted access.

Virtual Execution System (VES): This system implements and enforces the CTS model. The VES is responsible for loading and running programs written for the CLI. It provides the services needed to execute managed code and data using the metadata to connect separately generated modules together at runtime. The VES is also known as the **Execution Engine**.

I.6 Overview of the Common Language Infrastructure

The Common Language Infrastructure (CLI) provides a specification for executable code and the execution environment (the Virtual Execution System) in which it runs. Executable code is presented to the VES as modules. A **module** is a single file containing executable content in the format specified in Partition II.

The remainder of this clause and its subclauses contain only informative text

At the center of the CLI is a unified type system, the Common Type System that is shared by compilers, tools, and the CLI itself. It is the model that defines the rules the CLI follows when declaring, using, and managing types. The CTS establishes a framework that enables cross-language integration, type safety, and high performance code execution. This clause describes the architecture of the CLI by describing the CTS.

The following four areas are covered in this clause:

- **The Common Type System (CTS)—**The CTS provides a rich type system that supports the types and operations found in many programming languages. The CTS is intended to support the complete implementation of a wide range of programming languages. See §I.8
- **Metadata—**The CLI uses metadata to describe and reference the types defined by the CTS. Metadata is stored (that is, persisted) in a way that is independent of any particular programming language. Thus, metadata provides a common interchange mechanism for use between tools (such as compilers and debuggers) that manipulate programs, as well as between these tools and the VES. See §I.9.
- **The Common Language Specification (CLS)—**The CLS is an agreement between language designers and framework (that is, class library) designers. It specifies a subset of the CTS and a set of usage conventions. Languages provide their users the greatest ability to access frameworks by implementing at least those parts of the CTS that are part of the CLS. Similarly, frameworks will be most widely used if their publicly exported aspects (e.g., classes, interfaces, methods, and fields) use only types that are part of the CLS and that adhere to the CLS conventions. See §I.10.
- **The Virtual Execution System (VES)—**The VES implements and enforces the CTS model. The VES is responsible for loading and running programs written for the CLI. It provides the services needed to execute managed code and data, using the metadata to connect separately generated modules together at runtime (late binding). See §I.12.

Together, these aspects of the CLI form a unifying infrastructure for designing, developing, deploying, and executing distributed components and applications. The appropriate subset of the CTS is available from each programming language that targets the CLI. Language-based tools communicate with each other and with the VES using metadata to define and reference the types used to construct the application. The VES uses the metadata to create instances of the types as needed and to provide data type information to other parts of the infrastructure (such as remoting services, assembly downloading, and security).

I.6.1 Relationship to type safety

Type safety is usually discussed in terms of what it does (e.g., guaranteeing encapsulation between different objects) or in terms of what it prevents (e.g., memory corruption by writing where one shouldn't). However, from the point of view of the CTS, type safety guarantees that:

- **References are what they say they are –** Every reference is typed, the object or value referenced also has a type, and these types are assignment compatible (see §I.8.7).
- **Identities are who they say they are –** There is no way to corrupt or spoof an object, and, by implication, a user or security domain. Access to an object is through accessible functions and fields. An object can still be designed in such a way that security is compromised. However, a local analysis of the class, its methods, and the

things it uses, as opposed to a global analysis of all uses of a class, is sufficient to assess the vulnerabilities.

- **Only appropriate operations can be invoked –** The reference type defines the accessible functions and fields. This includes limiting visibility based on where the reference is (e.g., protected fields only visible in derived classes).

The CTS promotes type safety (e.g., everything is typed). Type safety can optionally be enforced. The hard problem is determining if an implementation conforms to a type-safe declaration. Since the declarations are carried along as metadata with the compiled form of the program, a compiler from the Common Intermediate Language (CIL) to native code (see §I.8.8) can type-check the implementations.

I.6.2 Relationship to managed metadata-driven execution

Metadata describes code by describing the types that the code defines and the types that it references externally. The compiler produces the metadata when the code is produced. Enough information is stored in the metadata to:

- **Manage code execution –** not just load and execute, but also memory management and execution state inspection.
- **Administer the code –** Installation, resolution, and other services.
- **Reference types in the code –** Importing into other languages and tools as well as scripting and automation support.

The CTS assumes that the execution environment is metadata-driven. Using metadata allows the CLI to support:

- **Multiple execution models –** The metadata allows the execution environment to deal with a mixture of interpreted, JIT-compiled, native, and legacy code, and still present uniform services to tools like debuggers and profilers, consistent exception handling and unwinding, reliable code access security, and efficient memory management.
- **Auto support for services –** Since the metadata is available at execution time, the execution environment and the base libraries can automatically supply support for reflection, automation, serialization, remote objects, and inter-operability with existing unmanaged native code with little or no effort on the part of the programmer.
- **Better optimization –** Using metadata references instead of physical offsets, layouts, and sizes allows the CLI to optimize the physical layouts of members and dispatch tables. In addition, this allows the generated code to be optimized to match the particular CPU or environment.
- **Reduced binding brittleness –** Using metadata references reduces version-to-version brittleness by replacing compile-time object layout with load-time layout and binding by name.
- **Flexible deployment resolution –** Since we can have metadata for both the reference and the definition of a type, more robust and flexible deployment and resolution mechanisms are possible. Resolution means that by looking in the appropriate set of places it is possible to find the implementation that best satisfies these requirements for use in this context. There are five elements of information in the foregoing: requirements and context are made available via metadata; where to look, how to find an implementation, and how to decide the best match all come from application packaging and deployment.

I.6.2.1 Managed code

Managed code is code that provides enough information to allow the CLI to provide a set of core services, including

- Given an address inside the code for a method, locate the metadata describing the method
- Walk the stack

- Handle exceptions
- Store and retrieve security information

This standard specifies a particular instruction set, the CIL (see Partition III), and a file format (see Partition II) for storing and transmitting managed code.

I.6.2.2 Managed data

Managed data is data that is allocated and released automatically by the CLI, through a process called **garbage collection**.

I.6.2.3 Summary

The CTS is about integration between languages: using another language's objects as if they were one's own.

The objective of the CLI is to make it easier to write components and applications in any language. It does this by defining a standard set of types, by making all components fully self-describing, and by providing a high performance common execution environment. This ensures that all CLI-compliant system services and components will be accessible to all CLI-aware languages and tools. In addition, this simplifies deployment of components and applications that use them, all in a way that allows compilers and other tools to leverage the high performance execution environment. The CTS covers, at a high level, the concepts and interactions that make all of this possible.

The discussion is broken down into four areas:

- Type System – What types are and how to define them.
- Metadata – How types are described and how those descriptions are stored.
- Common Language Specification – Restrictions required for language interoperability.
- Virtual Execution System – How code is executed and how types are instantiated, interact, and die.

End informative text

I.7 Common Language Specification

I.7.1 Introduction

The CLS is a set of rules intended to promote language interoperability. These rules shall be followed in order to conform to the CLS. They are described in greater detail in subsequent clauses and are summarized in §I.11. CLS conformance is a characteristic of types that are generated for execution on a CLI implementation. Such types must conform to the CLI standard, in addition to the CLS rules. These additional rules apply only to types that are visible in assemblies other than those in which they are defined, and to the members that are accessible outside the assembly; that is, those that have an accessibility of **public**, **family** (but not on sealed types), or **family-or-assembly** (but not on sealed types).

[*Note*: A library consisting of CLS-compliant code is herein referred to as a *framework*. Compilers that generate code for the CLI can be designed to make use of such libraries, but not to be able to produce or extend such library code. These compilers are referred to as *consumers*. Compilers that are designed to both produce and extend frameworks are referred to as *extenders*. In the description of each CLS rule, additional informative text is provided to assist the reader in understanding the rule's implication for each of these situations. *end note*]

I.7.2 Views of CLS compliance

This block contains only informative text.

The CLS is a set of rules that apply to generated assemblies. Because the CLS is designed to support interoperability for libraries and the high-level programming languages used to write them, it is often useful to think of the CLS rules from the perspective of the high-level source code and tools, such as compilers, that are used in the process of generating assemblies. For this reason, informative notes are added to the description of CLS rules to assist the reader in understanding the rule's implications for several different classes of tools and users. The different viewpoints used in the description are called **framework, consumer**, and **extender**, and are described here.

I.7.2.1 CLS framework

A library consisting of CLS-compliant code is herein referred to as a *framework*. Frameworks are designed for use by a wide range of programming languages and tools, including both CLS consumer and extender languages. By adhering to the rules of the CLS, authors of libraries ensure that the libraries will be usable by a larger class of tools than if they chose not to adhere to the CLS rules. The following are some additional guidelines that CLS-compliant frameworks should follow:

- Avoid the use of names commonly used as keywords in programming languages.
- Not expect users of the framework to be able to author nested types.
- Assume that implementations of methods of the same name and signature on different interfaces are independent.
- Not rely on initialization of value types to be performed automatically based on specified initializer values.
- Assume users can instantiate and use generic types and methods, but do not require them to define new generic types or methods, or deal with partially constructed generic types.

Frameworks shall not:

- Require users to define new generic types/methods, override existing generic methods, or deal with partially constructed generics in any way.

A CLS Rule applies to this topic; see the normative text at the end of §7.2.

I.7.2.2 CLS consumer

A CLS consumer is a language or tool that is designed to allow access to all of the features supplied by CLS-compliant frameworks, but not necessarily be able to produce them. The following is a partial list of things CLS consumer tools are expected to be able to do:

- Support calling any CLS-compliant method or delegate.
- Have a mechanism for calling methods whose names are keywords in the language.
- Support calling distinct methods supported by a type that have the same name and signature, but implement different interfaces.
- Create an instance of any CLS-compliant type.
- Read and modify any CLS-compliant field.
- Access nested types.
- Access any CLS-compliant property. This does not require any special support other than the ability to call the getter and setter methods of the property.
- Access any CLS-compliant event. This does not require any special support other than the ability to call methods defined for the event.
- Have a mechanism to import, instantiate, and use generic types and methods.

[*Note*: Consumers should consider supporting:

- Type inferencing over generic methods with language-defined rules for matching.
- Casting syntax to clarify ambiguous casts to a common supertype.

end note]

The following is a list of things CLS consumer tools need not support:

- Creation of new types or interfaces.
- Initialization metadata (see Partition II) on fields and parameters other than static literal fields. Note that consumers can choose to use initialization metadata, but can also safely ignore such metadata on anything other than static literal fields.

I.7.2.3 CLS extender

A CLS extender is a language or tool that is designed to allow programmers to both use and extend CLS-compliant frameworks. CLS extenders support a superset of the behavior supported by a CLS consumer (i.e., everything that applies to a CLS consumer also applies to CLS extenders). In addition to the requirements of a consumer, extenders are expected to be able to:

- Define new CLS-compliant types that extend any (non-sealed) CLS-compliant base class.
- Have some mechanism for defining types whose names are keywords in the language.
- Provide independent implementations for all methods of all interfaces supported by a type. That is, it is not sufficient for an extender to require a single code body to implement all interface methods of the same name and signature.
- Implement any CLS-compliant interface.
- Place any CLS-compliant custom attribute on all appropriate elements of metadata.
- Define new CLS-compliant (non-generic) types that extend any (non-sealed) CLS-compliant base type. Valid base types include normal (non-generic) types and also fully constructed generic types.

[*Note*: Extenders should consider supporting:

- Type inferencing over generic methods with language-defined rules for matching.
- Casting syntax to clarify ambiguous casts to a common supertype.

- *end note*]
- Extenders need not support the following:
- Definition of new CLS-compliant interfaces.
- Definition of nested types.
- Definition of generic types and methods.
- Overriding existing virtual generic methods.

The CLS is designed to be large enough that it is properly expressive yet small enough that all languages can reasonably accommodate it.

End informative text

CLS Rule 48: If two or more CLS-compliant methods declared in a type have the same name and, for a specific set of type instantiations, they have the same parameter and return types, then all these methods shall be semantically equivalent at those type instantiations.

[*Note*:

CLS (consumer): May select any one of the methods.

CLS (extender): Same as consumer.

CLS (framework): Shall not expose methods that violate this rule. *end note*]

[*Note*: To avoid confusion, the CLS rules follow historical numbering from the previous version of this Standard, despite removal/addition of rules in this version. As such, the first rule shown in this partition is Rule 48. *end note*]

I.7.3 CLS compliance

As these rules are introduced in detail, they are described in a common format. For an example, see the first rule below. The first paragraph specifies the rule itself. This is then followed by an informative description of the implications of the rule from the three different viewpoints as described above.

The CLS defines language interoperability rules, which apply only to "externally visible" items. The CLS unit of that language interoperability is the assembly—that is, within a single assembly there are no restrictions as to the programming techniques that can be used. Thus, the CLS rules apply only to items that are visible (see §I.8.5.3) outside of their defining assembly and have **public**, **family**, or **family-or-assembly** accessibility (see §I.8.5.3.2).

CLS Rule 1: CLS rules apply only to those parts of a type that are accessible or visible outside of the defining assembly.

[*Note*:

CLS (consumer): no impact.

CLS (extender): when checking CLS compliance at compile time, be sure to apply the rules only to information that will be exported outside the assembly.

CLS (framework): CLS rules do not apply to internal implementation within an assembly. A type is *CLS-compliant* if all its publicly accessible parts (those classes, interfaces, methods, fields, properties, and events that are available to code executing in another assembly) either
- have signatures composed only of CLS-compliant types, or
- are specifically marked as not CLS-compliant. *end note*]

Any construct that would make it impossible to rapidly verify code is excluded from the CLS. This allows all CLS-compliant language translators to produce verifiable code if they so choose.

I.7.3.1 Marking items as CLS-compliant

The CLS specifies how to mark externally visible parts of an assembly to indicate whether or not they comply with the CLS requirements. (Implementers are discouraged from marking extensions to this standard as CLS-compliant.) This is done using the custom attribute

mechanism (see §I.9.7 and Partition II). The class `System.CLSCompliantAttribute` (see Partition IV) indicates which types and type members are CLS-compliant. It also can be attached to an assembly, to specify the default level of compliance for all top-level types that assembly contains.

The constructor for `System.CLSCompliantAttribute` takes a Boolean argument indicating whether the item with which it is associated is CLS-compliant. This allows any item (assembly, type, or type member) to be explicitly marked as CLS-compliant or not.

The rules for determining CLS compliance are:

- When an assembly does not carry an explicit `System.CLSCompliantAttribute`, it shall be assumed to carry `System.CLSCompliantAttribute(false)`.
- By default, a type inherits the CLS-compliance attribute of its enclosing type (for nested types) or acquires the level of compliance attached to its assembly (for top-level types). A type can be marked as either CLS-compliant or not CLS-compliant by attaching the `System.CLSCompliantAttribute` attribute.
- By default, other members (methods, fields, properties, and events) inherit the CLS-compliance of their type. They can be marked as not CLS-compliant by attaching the attribute `System.CLSCompliantAttribute(false)`.

CLS Rule 2: Members of non-CLS compliant types shall not be marked CLS-compliant.

[*Note*:

CLS (consumer): Can ignore any member that is not CLS-compliant using the above rules.

CLS (extender): Should encourage correct labeling of newly authored assemblies and publicly exported types and members. Compile-time enforcement of the CLS rules is strongly encouraged.

CLS (framework): Shall correctly label all publicly exported members as to their CLS compliance. The rules specified here can be used to minimize the number of markers required (for example, label the entire assembly if all types and members are compliant or if there are only a few exceptions that need to be marked). *end note*]

I.8 Common Type System

Types describe values and specify a contract (see §I.8.6) that all values of that type shall support. Because the CTS supports Object-Oriented Programming (OOP) as well as functional and procedural programming languages, it deals with two kinds of entities: objects and values. **Values** are simple bit patterns for things like integers and floats; each value has a type that describes both the storage that it occupies and the meanings of the bits in its representation, and also the operations that can be performed on that representation. Values are intended for representing the corresponding simple types in programming languages like C, and also for representing non-objects in languages like C++ and Java™.

Objects have rather more to them than do values. Each object is self-typing, that is, its type is explicitly stored in its representation. It has an identity that distinguishes it from all other objects, and it has slots that store other entities (which can be either objects or values). While the contents of its slots can be changed, the identity of an object never changes.

There are several kinds of objects and values, as shown in the (informative) diagram below.

The generics feature allows a whole family of types and methods to be defined using a pattern, which includes placeholders called *generic parameters*. These generic parameters are replaced, as required, by specific types, to instantiate whichever member of the family is actually required. The design of generics meets the following goals:

- Orthogonality: Where possible, generic types can occur in any context where existing CLI types can occur.
- Language independence: No assumptions about the source language are made. But CLI-generics attempts to support existing generics-like features of as many languages as possible. Furthermore, the design permits clean extensions of languages currently lacking generics.
- Implementation independence: An implementation of the CLI is allowed to specialize representations and code on a case-by-case basis, or to share all representations and code, perhaps boxing and unboxing values to achieve this.
- Implementation efficiency: Performance of generics is no worse than the use of `Object` to simulate generics; a good implementation can do much better, avoiding casts on reference type instantiations, and producing specialized code for value type instantiations.
- Statically checkable at point of definition: A generic type definition can be validated and verified independently of its instantiations. Thus, a generic type is statically verifiable, and its methods are guaranteed to JIT-compile for all valid instantiations.
- Uniform behavior with respect to generic parameters: In general, the behavior of parameterized types and generic methods is “the same” at all type instantiations.

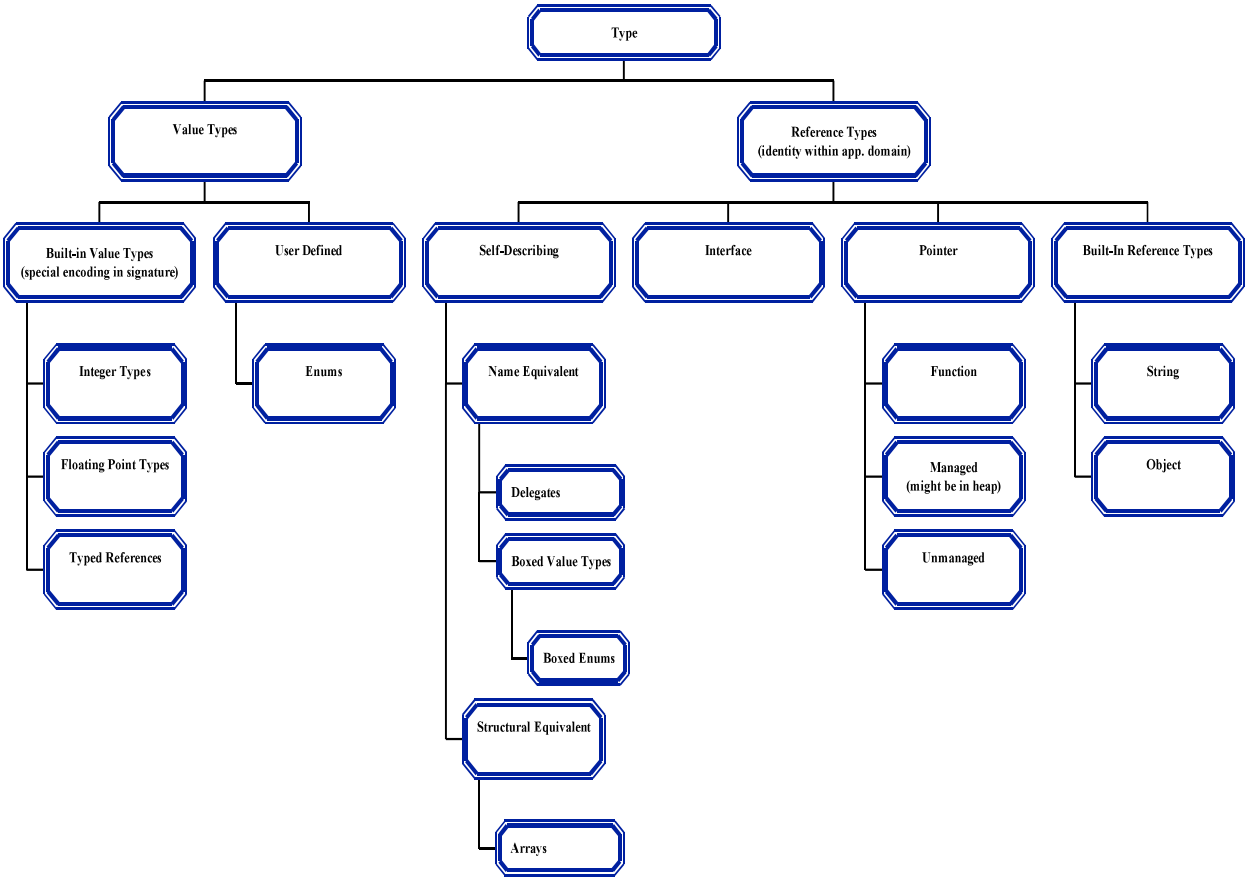
In addition, CLI supports covariant and contravariant generic parameters, with the following characteristics:

- It is type-safe (based on purely static checking)
- Simplicity: in particular, variance is only permitted on generic interfaces and generic delegates (not classes or value-types)
- Variance affects call instructions that invoke a method from a variant interface. For non-variant interfaces, a method of the exact type specified in the call instruction must exist, and is invoked. For variant interfaces, a method of the exact type specified in the call instruction need not exist; only one that is a variant match for the type. Furthermore, if multiple matches exist, the declaration order and derivation of the methods determine which one is called, and a variant match may be invoked even if an exact match exists (II.12.2). All language systems targeting the CLI must take into account variance whether or not the source language supports the feature.

- Enable implementation of more complex covariance scheme as used in some languages, e.g. Eiffel.

This figure is informative

Figure 1: Type System



[*Note*: A managed pointer might point into the heap. *end note*]

End informative figure

I.8.1 Relationship to object-oriented programming

This subclause contains only informative text

The term **type** is often used in the world of value-oriented programming to mean data representation. In the object-oriented world it usually refers to behavior rather than to representation. In the CTS, type is used to mean both of these things: two entities have compatible types if and only if they have compatible representations and compatible behaviors. Thus, in the CTS, if one type is derived from a base type, then instances of the derived type can be substituted for instances of the base type because both the representation and the behavior are compatible.

Unlike in some OOP languages, in the CTS, two objects that have fundamentally different representations have different types. Some OOP languages use a different notion of type. They consider two objects to have the same type if they respond in the same way to the same set of messages. This notion is captured in the CTS by saying that the objects implement the same interface.

Similarly, some OOP languages (e.g., Smalltalk) consider message passing to be the fundamental model of computation. In the CTS, this corresponds to calling virtual methods (see §I.8.4.4), where the signature of the virtual method plays the role of the message.

The CTS itself does not directly capture the notion of "typeless programming." That is, there is no way to call a non-static method without knowing the type of the object. Nevertheless, typeless programming can be implemented based on the facilities provided by the reflection package (see Partition IV - Reflection) if it is implemented.

End informative text

I.8.2 Values and types

Types describe *values*. Any value described by a type is called an *instance* of that type. Any use of a value—storing it, passing it as an argument, operating on it—requires a type. This applies in particular to all variables, arguments, evaluation stack locations, and method results. The type defines the allowable values and the allowable operations supported by the values of the type. All operators and functions have expected types for each of the values accessed or used.

Every value has an *exact type* that fully describes its type properties.

Every value is an instance of its exact type, and can be an instance of other types as well. In particular, if a value is an instance of a type that inherits from another type, it is also an instance of that other type.

I.8.2.1 Value types and reference types

There are two kinds of types: **value types** and **reference types**.

- Value types – The values described by a value type are self-contained (each can be understood without reference to other values).
- Reference types –A value described by a reference type denotes the location of another value. There are four kinds of reference type:
    - An **object type** is a reference type of a self-describing value (see §I.8.2.3). Some object types (e.g., abstract classes) are only a partial description of a value.
    - An **interface type** is always a partial description of a value, potentially supported by many object types.
    - A **pointer type** is a compile-time description of a value whose representation is a machine address of a location. Pointers are divided into managed (§I.8.2.1.1, §I.12.1.1.2) and unmanaged (§I.8.9.2).
    - Built-in reference types.

I.8.2.1.1 Managed pointers and related types

A **managed pointer** (§I.12.1.1.2), or **byref** (§I.8.6.1.3, §I.12.4.1.5.2), can point to a local variable, parameter, field of a compound type, or element of an array. However, when a call crosses a remoting boundary (see §I.12.5) a conforming implementation can use a copy-in/copy-out mechanism instead of a managed pointer. Thus programs shall not rely on the aliasing behavior of true pointers. Managed pointer types are only allowed for local variable (§I.8.6.1.3) and parameter signatures (§I.8.6.1.4); they cannot be used for field signatures (§I.8.6.1.2), as the element type of an array (§I.8.9.1), and boxing a value of managed pointer type is disallowed (§I.8.2.4). Using a managed pointer type for the return type of methods (§I.8.6.1.5) is not verifiable (§I.8.8).

[*Rationale*: For performance reasons items on the GC heap may not contain references to the interior of other GC objects, this motivates the restrictions on fields and boxing. Further returning a managed pointer which references a local or parameter variable may cause the reference to outlive the variable, hence it is not verifiable . *end rationale*]

There are three value types in the Base Class Library (see Partition IV - BCL): **System.TypedReference**, **System.RuntimeArgumentHandle**, and **System.ArgIterator**; which are treated specially by the CLI.

The value type **System.TypedReference**, or **typed reference** or **typedref** , (§I.8.2.2, §I.8.6.1.3, §I.12.4.1.5.3) contains both a managed pointer to a location and a runtime representation of the type that can be stored at that location. Typed references have the same restrictions as byrefs. Typed references are created by the CIL instruction `mkrefany` (see Partition III).

The value types **System.RuntimeArgumentHandle** and **System.ArgIterator** (see Partition IV and CIL instruction `arglist` in Partition III), contain pointers into the VES stack. They can be used for local variable and parameter signatures. The use of these types for fields, method return types, the element type of an array, or in boxing is not verifiable (§I.8.8). These two types are referred to as **byref-like** types.

I.8.2.2 Built-in value and reference types

The following data types are an integral part of the CTS and are supported directly by the VES. They have special encoding in the persisted metadata:

Table I.1: Special Encoding

Name in CIL assembler (see Partition II)	CLS Type?	Name in class library (see Partition IV)	Description
`bool`[1]	Yes	`System.Boolean`	True/false value
`char`[1]	Yes	`System.Char`	Unicode 16-bit char.
`object`	Yes	`System.Object`	Object or boxed value type
`string`	Yes	`System.String`	Unicode string
`float32`	Yes	`System.Single`	IEC 60559:1989 32-bit float
`float64`	Yes	`System.Double`	IEC 60559:1989 64-bit float
`int8`	No	`System.SByte`	Signed 8-bit integer
`int16`	Yes	`System.Int16`	Signed 16-bit integer
`int32`	Yes	`System.Int32`	Signed 32-bit integer
`int64`	Yes	`System.Int64`	Signed 64-bit integer
`native int`	Yes	`System.IntPtr`	Signed integer, native size
`native unsigned int`	No	`System.UIntPtr`	Unsigned integer, native size
`typedref`	No	`System.TypedReference`	Pointer plus exact type
`unsigned int8`	Yes	`System.Byte`	Unsigned 8-bit integer

`unsigned int16`	No	`System.UInt16`	Unsigned 16-bit integer
`unsigned int32`	No	`System.UInt32`	Unsigned 32-bit integer
`unsigned int64`	No	`System.UInt64`	Unsigned 64-bit integer

[1] `bool` and `char` are integer types in the categorization shown in the figure above.

I.8.2.3 Classes, interfaces, and objects

A type fully describes a value if it unambiguously defines the value's representation and the operations defined on that value.

For a value type, defining the representation entails describing the sequence of bits that make up the value's representation. For a reference type, defining the representation entails describing the location and the sequence of bits that make up the value's representation.

A **method** describes an operation that can be performed on values of an exact type. Defining the set of operations allowed on values of an exact type entails specifying named methods for each operation.

Some types are only a partial description; for example, **interface types**. These types describe a subset of the operations and none of the representation, and hence, cannot be an exact type of any value. Hence, while a value has only one exact type, it can also be a value of many other types as well. Furthermore, since the exact type fully describes the value, it also fully specifies all of the other types that a value of the exact type can have.

While it is true that every value has an exact type, it is not always possible to determine the exact type by inspecting the representation of the value. In particular, it is *never* possible to determine the exact type of a value of a value type. Consider two of the built-in value types, 32-bit signed and unsigned integers. While each type is a full specification of their respective values (i.e., an exact type) there is no way to derive that exact type from a value's particular 32-bit sequence.

For some values, called **objects**, it *is* always possible to determine the exact type from the value. Exact types of objects are also called **object types**. Objects are values of reference types, but not all reference types describe objects. Consider a value that is a pointer to a 32-bit integer, a kind of reference type. There is no way to discover the type of the value by examining the pointer bits; hence it is not an object. Now consider the built-in CTS reference type `System.String` (see Partition IV). The exact type of a value of this type is always determinable by examining the value, hence values of type `System.String` are objects, and `System.String` is an object type.

I.8.2.4 Boxing and unboxing of values

For every value type, the CTS defines a corresponding reference type called the **boxed type**. The reverse is not true: In general, reference types do not have a corresponding value type. The representation of a value of a boxed type (a **boxed value**) is a location where a value of the value type can be stored. A boxed type is an object type and a boxed value is an object.

A boxed type cannot be directly referred to by name, therefore no field or local variable can be given a boxed type. The closest named base class to a boxed enumerated value type is `System.Enum`; for all other value types it is `System.ValueType`. Fields typed `System.ValueType` can only contain the null value or an instance of a boxed value type. Locals typed `System.Enum` can only contain the null value or an instance of a boxed enumeration type.

All value types have an operation called box. Boxing a value of any value type produces its boxed value; i.e., a value of the corresponding boxed type containing a bitwise copy of the original value. If the value type is a nullable type—defined as an instantiation of the value type System.Nullable<*T*>—the result is a null reference or bitwise copy of its `Value` property of type *T*, depending on its `HasValue` property (false and true, respectively). All boxed types have an operation called unbox, which results in a managed pointer to the bit representation of the value.

The box instruction can be applied to more than just value types; such types are called *boxable* types. A type is boxable if it is one of the following:

- A value type (including instantiations of generic value types) excluding typed references (§I.8.2.1.1). Boxing a byref-like type is not verifiable (§I.8.2.1.1).

[*Rationale:* Typed references are excluded so that objects in the GC heap cannot contain references to the interior of other GC objects (§I.8.2.1.1). Byref-like types contain embedded pointers to entries in the VES stack. If byref-like types are boxed these embedded pointers could outlive the entries to which they point, so this operation is unverifiable. *end rationale*]

- A reference type (including classes, arrays, delegates, and instantiations of generic classes) excluding managed pointers/byrefs (§I.8.2.1.1)
- A generic parameter (to a generic type definition, or a generic method definition) [*Note*: Boxing and unboxing of generic arguments adds performance overhead to a CLI implementation. The constrained. prefix can improve performance during virtual dispatch to a method defined by a value type, by avoiding boxing the value type. *end note*]

The type `System.Void` is never boxable.

Interfaces and inheritance are defined only on reference types. Thus, while a value type definition (§I.8.9.7) can specify both interfaces that shall be implemented by the value type and the class (`System.ValueType` or `System.Enum`) from which it inherits, these apply only to boxed values.

CLS Rule 3: Boxed value types are not CLS-compliant.

[*Note*:

In lieu of boxed types, use `System.Object`, `System.ValueType`, or `System.Enum`, as appropriate.

CLS (consumer): Need not import boxed value types.

CLS (extender): Need not provide syntax for defining or using boxed value types.

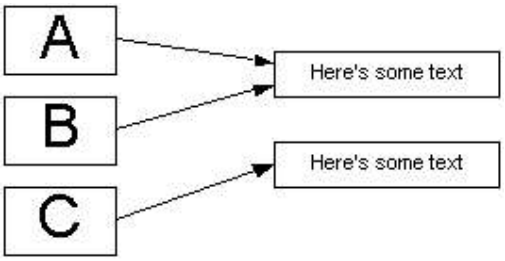
CLS (framework): Shall not use boxed value types in its publicly exported aspects. *end note*]

I.8.2.5 Identity and equality of values

There are two binary operators defined on all pairs of values: **identity** and **equality**. They return a Boolean result, and are mathematical **equivalence** operators; that is, they are:

- Reflexive – `a op a` is true.
- Symmetric – `a op b` is true if and only if `b op a` is true.
- Transitive – if `a op b` is true and `b op c` is true, then `a op c` is true.

In addition, while identity always implies equality, the reverse is not true. To understand the difference between these operations, consider three variables, A, B, and C, whose type is `System.String`, where the arrow is intended to mean "is a reference to":



The values of the variables are **identical** if the locations of the sequences of characters are the same (i.e., there is, in fact, only one string in memory). The values stored in the variables are **equal** if the sequences of characters are the same. Thus, the values of variables A and B are identical, the values of variables A and C as well as B and C are not identical, and the values of all three of A, B, and C are equal.

I.8.2.5.1 Identity

The identity operator is defined by the CTS as follows.

- If the values have different exact types, then they are not identical.

- Otherwise, if their exact type is a value type, then they are identical if and only if the bit sequences of the values are the same, bit by bit.
- Otherwise, if their exact type is a reference type, then they are identical if and only if the locations of the values are the same.

Identity is implemented on `System.Object` via the `ReferenceEquals` method.

I.8.2.5.2 Equality

For value types, the equality operator is part of the definition of the exact type. Definitions of equality should obey the following rules:

- Equality should be an equivalence operator, as defined above.
- Identity should imply equality, as stated earlier.
- If either (or both) operand is a boxed value, equality should be computed by
    - first unboxing any boxed operand(s), and then
    - applying the usual rules for equality on the resulting values.

Equality is implemented on `System.Object` via the `Equals` method.

[*Note:* Although two floating point NaNs are defined by IEC 60559:1989 to always compare as unequal, the contract for `System.Object.Equals` requires that overrides must satisfy the requirements for an equivalence operator. Therefore, `System.Double.Equals` and `System.Single.Equals` return True when comparing two NaNs, while the equality operator returns False in that case, as required by the IEC standard. *end note*]

I.8.3 Locations

Values are stored in **locations**. A location can hold only one value at a time. All locations are typed. The type of the location embodies the requirements that shall be met by values that are stored in the location. Examples of locations are local variables and parameters.

More importantly, the type of the location specifies the restrictions on usage of any value that is loaded from that location. For example, a location can hold values of potentially many exact types as long as all of the types are *assignable-to* the type of the location (see below). All values loaded from a location are treated as if they are of the type of the location. Only operations valid for the type of the location can be invoked even if the exact type of the value stored in the location is capable of additional operations.

I.8.3.1 Assignment-compatible locations

A value can be stored in a location only if one of the types of the value is **assignment compatible** with the type of the location. A type is always *assignable-to* itself. Assignment compatibility can often be determined at compile time, in which case, there is no need for testing at run time. Assignment compatibility is described in detail in §I.8.7.

I.8.3.2 Coercion

Sometimes it is desirable to take a value of a type that is *not assignable-to* a location, and convert the value to a type that *is assignable-to* the type of the location. This is accomplished through **coercion** of the value. Coercion takes a value of a particular type and a desired type and attempts to create a value of the desired type that has equivalent meaning to the original value. Coercion can result in representation change as well as type change; hence coercion does not necessarily preserve object identity.

There are two kinds of coercion: **widening**, which never loses information, and **narrowing**, in which information might be lost. An example of a widening coercion would be coercing a value that is a 32-bit signed integer to a value that is a 64-bit signed integer. An example of a narrowing coercion is the reverse: coercing a 64-bit signed integer to a 32-bit signed integer. Programming languages often implement widening coercions as **implicit conversions**, whereas narrowing coercions usually require an **explicit conversion**.

Some coercion is built directly into the VES operations on the built-in types (see §I.12.1). All other coercion shall be explicitly requested. For the built-in types, the CTS provides operations

to perform widening coercions with no runtime checks and narrowing coercions with runtime checks or truncation, according to the operation semantics.

I.8.3.3 Casting

Since a value can be of more than one type, a use of the value needs to clearly identify which of its types is being used. Since values are read from locations that are typed, the type of the value which is used is the type of the location from which the value was read. If a different type is to be used, the value is **cast** to one of its other types. Casting is usually a compile time operation, but if the compiler cannot statically know that the value is of the target type, a runtime cast check is done. Unlike coercion, a cast never changes the actual type of an object nor does it change the representation. Casting preserves the identity of objects.

For example, a runtime check might be needed when casting a value read from a location that is typed as holding a value of a particular interface. Since an interface is an incomplete description of the value, casting that value to be of a different interface type will usually result in a runtime cast check.

I.8.4 Type members

As stated above, the type defines the allowable values and the allowable operations supported by the values of the type. If the allowable values of the type have a substructure, that substructure is described via fields or array elements of the type. If there are operations that are part of the type, those operations are described via methods on the type. Fields, array elements, and methods are called **members** of the type. Properties and events are also members of the type.

I.8.4.1 Fields, array elements, and values

The representation of a value (except for those of built-in types) can be subdivided into sub-values. These sub-values are either named, in which case, they are called **fields**, or they are accessed by an indexing expression, in which case, they are called **array elements**. Types that describe values composed of array elements are **array types**. Types that describe values composed of fields are **compound types**. A value cannot contain both fields and array elements, although a field of a compound type can be an array type and an array element can be a compound type.

Array elements and fields are typed, and these types never change. All of the elements in an array shall have the same type. Each field of a compound type can have a different type.

I.8.4.2 Methods

A type can associate operations with that type or with each instance of that type. Such operations are called methods. A method is named, and has a signature (see §I.8.6.1) that specifies the allowable types for all of its arguments and for its return value, if any.

A method that is associated only with the type itself (as opposed to a particular instance of the type) is called a static method (see §I.8.4.3).

A method that is associated with an instance of the type is either an instance method or a virtual method (see §I.8.4.4). When they are invoked, instance and virtual methods are passed the instance on which this invocation is to operate (known as **this** or a **this pointer**).

The fundamental difference between an instance method and a virtual method is in how the implementation is located. An instance method is invoked by specifying a class and the instance method within that class. Except in the case of instance methods of generic types, the object passed as **this** can be **null** (a special value indicating that no instance is being specified) or an instance of any type that inherits (see §I.8.9.8) from the class that defines the method. A virtual method can also be called in this manner. This occurs, for example, when an implementation of a virtual method wishes to call the implementation supplied by its base class. The CTS allows **this** to be **null** inside the body of a virtual method.

[*Rationale:* Allowing a virtual method to be called with a non-virtual call eliminates the need for a "call super" instruction and allows version changes between virtual and non-virtual methods. It requires CIL generators to insert explicit tests for a null pointer if they don't want the null this pointer to propagate to called methods. *end rationale*]

A virtual or instance method can also be called by a different mechanism, a **virtual call**. Any type that inherits from a type that defines a virtual method can provide its own implementation of that method (this is known as **overriding**, see §I.8.10.4). It is the exact type of the object (determined at runtime) that is used to decide which of the implementations to invoke.

I.8.4.3 Static fields and static methods

Types can declare locations that are associated with the type rather than any particular value of the type. Such locations are **static fields** of the type. As such, static fields declare a location that is shared by all values of the type. Just like non-static (instance) fields, a static field is typed and that type never changes. Static fields are always restricted to a single application domain basis (see §I.12.5), but they can also be allocated on a per-thread basis.

Similarly, types can also declare methods that are associated with the type rather than with values of the type. Such methods are **static methods** of the type. Since an invocation of a static method does not have an associated value on which the static method operates, there is no **this** pointer available within a static method.

I.8.4.4 Virtual methods

An object type can declare any of its methods as **virtual**. Unlike other methods, each exact type that implements the type can provide its own implementation of a virtual method. A virtual method can be invoked through the ordinary method call mechanism that uses the static type, method name, and types of parameters to choose an implementation, in which case, the **this** pointer can be **null**. In addition, however, a virtual method can be invoked by a special mechanism (a **virtual call**) that chooses the implementation based on the dynamically detected type of the instance used to make the virtual call rather than the type statically known at compile time. Virtual methods can be marked **final** (see §I.8.10.2).

I.8.5 Naming

Names are given to entities of the type system so that they can be referred to by other parts of the type system or by the implementations of the types. Types, fields, methods, properties, and events have names. With respect to the type system, values, locals, and parameters do not have names. An entity of the type system is given a single name (e.g., there is only one name for a type).

I.8.5.1 Valid names

All name comparisons are done on a byte-by-byte (i.e., case sensitive, locale-independent, also known as code-point comparison) basis. Where names are used to access built-in VES-supplied functionality (e.g., the class initialization method) there is always an accompanying indication on the definition so as not to build in any set of reserved names.

CLS Rule 4: Assemblies shall follow Annex 7 of Technical Report 15 of the Unicode Standard 3.0 governing the set of characters permitted to start and be included in identifiers, available on-line at http://www.unicode.org/unicode/reports/tr15/tr15-18.html. Identifiers shall be in the canonical format defined by Unicode Normalization Form C. For CLS purposes, two identifiers are the same if their lowercase mappings (as specified by the Unicode locale-insensitive, one-to-one lowercase mappings) are the same. That is, for two identifiers to be considered different under the CLS they shall differ in more than simply their case. However, in order to override an inherited definition the CLI requires the precise encoding of the original declaration be used.

[*Note*:

CLS (consumer): Need not consume types that violate CLS Rule 4, but shall have a mechanism to allow access to named items that use one of its own keywords as the name.

CLS (extender): Need not create types that violate CLS Rule 4. Shall provide a mechanism for defining new names that obey these rules, but are the same as a keyword in the language.

CLS (framework): Shall not export types that violate CLS Rule 4. Should avoid the use of names that are commonly used as keywords in programming languages (see Partition VI - Annex D) *end note*]

I.8.5.2 Assemblies and scoping

Generally, names are not unique. Names are collected into groupings called **scopes**. Within a scope, a name can refer to multiple entities as long as they are of different **kinds** (methods, fields, nested types, properties, and events) or have different signatures.

CLS Rule 5: All names introduced in a CLS-compliant scope shall be distinct independent of kind, except where the names are identical and resolved via overloading. That is, while the CTS allows a single type to use the same name for a method and a field, the CLS does not.

CLS Rule 6: Fields and nested types shall be distinct by identifier comparison alone, even though the CTS allows distinct signatures to be distinguished. Methods, properties, and events that have the same name (by identifier comparison) shall differ by more than just the return type, except as specified in CLS Rule 39.

[*Note*:

CLS (consumer): Need not consume types that violate these rules after ignoring any members that are marked as not CLS-compliant.

CLS (extender): Need not provide syntax for defining types that violate these rules.

CLS (framework): Shall not mark types as CLS-compliant if they violate these rules unless they mark sufficient offending items within the type as not CLS-compliant so that the remaining members do not conflict with one another. *end note*]

A named entity has its name in exactly one scope. Hence, to identify a named entity, both a scope and a name need to be supplied. The scope is said to **qualify** the name. Types provide a scope for the names in the type; hence types qualify the names in the type. For example, consider a compound type `Point` that has a field named `x`. The name "field `x`" by itself does not uniquely identify the named field, but the **qualified name** "field `x` in type `Point`" does.

Since types are named, the names of types are also grouped into scopes. To fully identify a type, the type name shall be qualified by the scope that includes the type name. A type name is scoped by the **assembly** that contains the implementation of the type. An assembly is a configured set of loadable code modules and other resources that together implement a unit of functionality. The type name is said to be in the **assembly scope** of the assembly that implements the type. Assemblies themselves have names that form the basis of the CTS naming hierarchy.

The **type definition:**

- Defines a name for the type being defined (i.e., the **type name**) and specifies a scope in which that name will be found.
- Defines a **member scope** in which the names of the different kinds of members (fields, methods, events, and properties) are bound. The tuple of (member name, member kind, and member signature) is unique within a member scope of a type.
- Implicitly assigns the type to the assembly scope of the assembly that contains the type definition.

The CTS supports an **enum** (also known as an **enumeration type**), an alternate name for an existing type. For the purposes of matching signatures, an enum shall not be the same as the underlying type. Instances of an enum, however, shall be *assignable-to* the underlying type, and vice versa. That is, no cast (see §I.8.3.3) or coercion (see §I.8.3.2) is required to convert from the enum to the underlying type, nor are they required from the underlying type to the enum. An enum is considerably more restricted than a true type, as follows:

- It shall have exactly one instance field, and the type of that field defines the underlying type of the enumeration.
- It shall not have any methods of its own.
- It shall derive from `System.Enum` (see Partition IV Library – Kernel Profile).
- It shall not implement any interfaces of its own.
- It shall not have any properties or events of its own.

- It shall not have any static fields unless they are literal. (see §I.8.6.1.2)

The underlying type shall be a built-in integer type. Enums shall derive from `System.Enum`, hence they are value types. Like all value types, they shall be sealed (see §I.8.9.9).

CLS Rule 7: The underlying type of an enum shall be a built-in CLS integer type, the name of the field shall be "value__", and that field shall be marked `RTSpecialName`.

CLS Rule 8: There are two distinct kinds of enums, indicated by the presence or absence of the `System.FlagsAttribute` (see Partition IV Library) custom attribute. One represents named integer values; the other represents named bit flags that can be combined to generate an unnamed value. The value of an enum is not limited to the specified values.

CLS Rule 9: Literal static fields (see §I.8.6.1) of an enum shall have the type of the enum itself.

[*Note*:

CLS (consumer): Shall accept the definition of enums that follow these rules, but need not distinguish flags from named values.

CLS (extender): Same as consumer. Extender languages are encouraged to allow the authoring of enums, but need not do so.

CLS (framework): Shall not expose enums that violate these rules, and shall not assume that enums have only the specified values (even for enums that are named values). *end note*]

I.8.5.3 Visibility, accessibility, and security

To refer to a named entity in a scope, both the scope and the name in the scope shall be **visible** (see §I.8.5.3.1). Visibility is determined by the relationship between the entity that contains the reference (the **referent**) and the entity that contains the name being referenced. Consider the following pseudo-code:

```
class A
{ int32 IntInsideA;
}
class B inherits from A
{ method X(int32, int32)
  { IntInsideA := 15;
  }
}
```

If we consider the reference to the field `IntInsideA` in class `A`:

- We call class B the **referent** because it has a method that refers to that field,
- We call `IntInsideA` in class `A` the **referenced entity**.

There are two fundamental questions that need to be answered in order to decide whether the referent is allowed to access the referenced entity. The first is whether the name of the referenced entity is **visible** to the referent. If it is visible, then there is a separate question of whether the referent is **accessible** (see §I.8.5.3.2) .

Access to a member of a type is permitted only if all three of the following conditions are met:

1. The type is visible and, in the case of a nested type, accessible.
2. The member is accessible.
3. All relevant security demands (see §I.8.5.3.3) have been granted.

An instantiated generic type is visible from some assembly if and only if the generic type itself and each of its component parts (generic type definition and generic arguments) are visible. For example, if *List* is exported from assembly A (i.e., declared “public”) and *MyClass* is defined in assembly B but not exported, then *List<MyClass>* is visible only from within assembly B.

Accessibility of members of instantiated generic types is independent of instantiation.

Access to a member *C<T1, ... Tn>.m* is therefore permitted if the following conditions are met:

- *C<T1, ... Tn>* is visible.

- Member *m* within generic type *C* (i.e., *C.m*) is accessible.
- Security permissions have been granted.

I.8.5.3.1 Visibility of types

Only type names, not member names, have controlled visibility. Type names fall into one of the following three categories

- **Exported** from the assembly in which they are defined. While a type can be marked to *allow* it to be exported from the assembly, it is the configuration of the assembly that decides whether the type name *is* made available.
- **Not exported** outside the assembly in which they are defined.
- Nested within another type. In this case, the type itself has the visibility of the type inside of which it is nested (its **enclosing type**). See §I.8.5.3.4.

A top-level named type is *exported* if and only if it has public visibility. A type generated by a type definer is exported if and only if it is made from exported types.

A type generated by a type definer is visible if all types from which it was generated are visible.

I.8.5.3.2 Accessibility of members and nested types

A type scopes all of its members, and it also specifies the accessibility rules for its members. Except where noted, accessibility is decided based only on the statically visible type of the member being referenced and the type and assembly that is making the reference. The CTS supports seven different rules for accessibility:

- **compiler-controlled** – accessible only through the use of a definition, not a reference, hence only accessible from within a single compilation unit and under the control of the compiler.
- **private** – accessible only to referents in the implementation of the exact type that defines the member.
- **family** – accessible to referents that support the same type (i.e., an exact type and all of the types that inherit from it). For verifiable code (see §I.8.8), there is an additional requirement that can require a runtime check: the reference shall be made through an item whose exact type supports the exact type of the referent. That is, the item whose member is being accessed shall inherit from the type performing the access.
- **assembly** – accessible only to referents in the same assembly that contains the implementation of the type.
- **family-and-assembly** – accessible only to referents that qualify for both family and assembly access.
- **family-or-assembly** – accessible only to referents that qualify for either family or assembly access.
- **public** – accessible to all referents.

A member or nested type is exported if and only if it has public, family-or-assembly, or family accessibility, and its defining type (in the case of members) or its enclosing type (in the case of nested types) is exported.

The accessibility of a type definer is the same as that for the type from which it was generated.

In general, a member of a type can have any one of the accessibility rules assigned to it. There are three exceptions, however:

1. Members (other than nested types) defined by an interface shall be public.
2. When a type defines a virtual method that overrides an inherited definition, the accessibility shall either be identical in the two definitions or the overriding definition shall permit more access than the original definition. For example, it is possible to override an **assembly virtual** method with a new implementation that is **public virtual**, but not with one that is **family virtual**. In the case of overriding a

definition derived from another assembly, it is not considered restricting access if the base definition has **family-or-assembly** access and the override has only **family** access.

3. A member defined by a nested type, or a nested type enclosed by a nested type, shall not have greater accessibility than the nested type that defines it (in the case of a member) or the nested type that encloses it (in the case of a nested type).

[*Rationale:* Languages including C++ allow this "widening" of access. Restricting access would provide an incorrect illusion of security since simply casting an object to the base class (which occurs implicitly on method call) would allow the method to be called despite the restricted accessibility. To prevent overriding a virtual method use **final** (see §I.8.10.2) rather than relying on limited accessibility. *end rationale*]

CLS Rule 10: Accessibility shall not be changed when overriding inherited methods, except when overriding a method inherited from a different assembly with accessibility **family-or-assembly**. In this case, the override shall have accessibility **family**.

[*Note*:

CLS (consumer): Need not accept types that widen access to inherited virtual methods.

CLS (extender): Need not provide syntax to widen access to inherited virtual methods.

CLS (frameworks): Shall not rely on the ability to widen access to a virtual method, either in the exported portion of the framework or by users of the framework. *end note*]

I.8.5.3.3 Security permissions

Access to members is also controlled by security demands that can be attached to an assembly, type, method, property, or event. Security demands are not part of a type contract (see §I.8.6), and hence are not inherited. There are two kinds of demands:

- An **inheritance demand**. When attached to a type, it requires that any type that wishes to inherit from this type shall have the specified security permission. When attached to a non-final virtual method, it requires that any type that wishes to override this method shall have the specified permission. It shall not be attached to any other member.
- A **reference demand**. Any attempt to resolve a reference to the marked item shall have specified security permission.

Only one demand of each kind can be attached to any item. Attaching a security demand to an assembly implies that it is attached to all types in the assembly unless another demand of the same kind is attached to the type. Similarly, a demand attached to a type implies the same demand for all members of the type unless another demand of the same kind is attached to the member. For additional information, see Declarative Security in Partition II, and the classes in the `System.Security` namespace in Partition IV.

I.8.5.3.4 Nested types

A type can be a member of an enclosing type, in which case, it is a nested type. A nested type has the same visibility as the enclosing type and has an accessibility as would any other member of the enclosing type. This accessibility determines which other types can make references to the nested type. That is, for a class to define a field or array element of a nested type, have a method that takes a nested type as a parameter or returns one as value, etc., the nested type shall be both visible and accessible to the referencing type. A nested type is part of the enclosing type so its methods have access to all members of its enclosing type, as well as family access to members of the type from which it inherits (see §I.8.9.8). The names of nested types are scoped by their enclosing type, not their assembly (only top-level types are scoped by their assembly). There is no requirement that the names of nested types be unique within an assembly.

I.8.6 Contracts

Contracts are named. They are the shared assumptions on a set of **signatures** (see §I.8.6.1) between all implementers and all users of the contract. The signatures are the part of the contract that can be checked and enforced.

Contracts are not types; rather they specify requirements on the implementation of types. Types state which contracts they abide by (i.e., which contracts all implementations of the type shall support). An implementation of a type can be verified to check that the enforceable parts of a contract—the named signatures—have been implemented. The kinds of contracts are:

- **Class contract–** A class contract is specified with a class definition. Hence, a class definition defines both the class contract and the **class type**. The name of the class contract and the name of the class type are the same. A class contract specifies the representation of the values of the class type. Additionally, a class contract specifies the other contracts that the class type supports (e.g., which interfaces, methods, properties, and events shall be implemented). A class contract, and hence the class type, can be supported by other class types as well. A class type that supports the class contract of another class type is said to **inherit** from that class type.

- **Interface contract –** An interface contract is specified with an interface definition. Hence, an interface definition defines both the interface contract and the **interface type**. The name of the interface contract and the name of the interface type are the same. Many types can support the same interface contract. Like class contracts, interface contracts specify which other contracts the interface supports (e.g., which interfaces, methods, properties, and events shall be implemented). [*Note:* An interface type can never fully describe the representation of a value. Therefore an interface type can never support a class contract, and hence can never be a class type or an exact type. *end note*]

- **Method contract –** A method contract is specified with a method definition. A method contract is a named operation that specifies the contract between the implementation(s) of the method and the callers of the method. A method contract is always part of a type contract (class, value type, or interface), and describes how a particular named operation is implemented. The method contract specifies the contracts that each parameter to the method shall support and the contracts that the return value shall support, if there is a return value.

- **Property contract –** A property contract is specified with a property definition. There is an extensible set of operations for handling a named value, which includes a standard pair for reading the value and changing the value. A property contract specifies method contracts for the subset of these operations that shall be implemented by any type that supports the property contract. A type can support many property contracts, but any given property contract can be supported by exactly one type. Hence, property definitions are a part of the type definition of the type that supports the property.

- **Event contract –** An event contract is specified with an event definition. There is an extensible set of operations for managing a named event, which includes three standard methods (register interest in an event, revoke interest in an event, fire the event). An event contract specifies method contracts for all of the operations that shall be implemented by any type that supports the event contract. A type can support many event contracts, but any given event contract can be supported by exactly one type. Hence, event definitions are a part of the type definition of the type that supports the event.

I.8.6.1 Signatures

Signatures are the part of a contract that can be checked and automatically enforced. Signatures are formed by adding constraints to types and other signatures. A constraint is a limitation on the use of or allowed operations on a value or location. Example constraints would be whether a location can be overwritten with a different value or whether a value can ever be changed.

All locations have signatures, as do all values. Assignment compatibility requires that the signature of the value, including constraints, be compatible with the signature of the location, including constraints. There are four fundamental kinds of signatures: type signatures (see §I.8.6.1.1), location signatures (see §I.8.6.1.2), parameter signatures (see §I.8.6.1.4), and method signatures (see §I.8.6.1.5). (A fifth kind, a local signature (see §I.8.6.1.3) is really a version of a location signature.)

CLS Rule 11: All types appearing in a signature shall be CLS-compliant. All types composing an instantiated generic type shall be CLS-compliant.

CLS Rule 12: The visibility and accessibility of types and members shall be such that types in the signature of any member shall be visible and accessible whenever the member itself is visible and accessible. For example, a public method that is visible outside its assembly shall not have an argument whose type is visible only within the assembly. The visibility and accessibility of types composing an instantiated generic type used in the signature of any member shall be visible and accessible whenever the member itself is visible and accessible. For example, an instantiated generic type present in the signature of a member that is visible outside its assembly shall not have a generic argument whose type is visible only within the assembly.

[*Note*:

CLS (consumer): Need not accept types whose members violate these rules.

CLS (extender): Need not provide syntax to violate these rules.

CLS (framework): Shall not violate this rule in its exported types and their members. *end note*]

The following subclauses describe the various kinds of signatures. These descriptions are cumulative: the simplest signature is a type signature; a location signature is a type signature plus (optionally) some additional attributes; and so forth.

I.8.6.1.1 Type signatures

Type signatures define the constraints on a value and its usage. A type, by itself, is a valid type signature. The type signature of a value cannot be determined by examining the value or even by knowing the class type of the value. The type signature of a value is derived from the location signature (see below) of the location from which the value is loaded or from the operation that computes it. Normally the type signature of a value is the type in the location signature from which the value is loaded.

[*Rationale:* The distinction between a Type Signature and a Location Signature (below) is made because certain constraints, such as "constant," are constraints on values not locations. Future versions of this standard, or non-standard extensions, can introduce type constraints, thus making the distinction meaningful. *end rationale*]

I.8.6.1.2 Location signatures

All locations are typed. This means that all locations have a **location signature**, which defines constraints on the location, its usage, and on the usage of the values stored in the location. Any valid type signature is a valid location signature. Hence, a location signature contains a type and can additionally contain the constant constraint. The location signature can also contain **location constraints** that give further restrictions on the uses of the location. The location constraints are:

- The **init-only constraint** promises (hence, requires) that once the location has been initialized, its contents never change. Namely, the contents are initialized before any access, and after initialization, no value can be stored in the location. The contents are always identical to the initialized value (see §I.8.2.3). This constraint, while logically applicable to any location, shall only be placed on fields (static or instance) of compound types.
- The **literal constraint** promises that the value of the location is actually a fixed value of a built-in type. The value is specified as part of the constraint. Compilers are required to replace all references to the location with its value, and the VES therefore need not allocate space for the location. This constraint, while logically applicable to any location, shall only be placed on static fields of compound types. Fields that are so marked are not permitted to be referenced from CIL (they shall be in-lined to their constant value at compile time), but are available using reflection and tools that directly deal with the metadata.

CLS Rule 13: The value of a literal static is specified through the use of field initialization metadata (see Partition II Metadata). A CLS-compliant literal must have a value specified in field initialization metadata that is of exactly the same type as the literal (or of the underlying type, if that literal is an **enum**).

[*Note*:

CLS (consumer): Must be able to read field initialization metadata for static literal fields and inline the value specified when referenced. Consumers can assume that the type of the field initialization metadata is exactly the same as the type of the literal field (i.e., a consumer tool need not implement conversions of the values).

CLS (extender): Must avoid producing field initialization metadata for static literal fields in which the type of the field initialization metadata does not exactly match the type of the field.

CLS (framework): Should avoid the use of syntax specifying a value of a literal that requires conversion of the value. Note that compilers can do the conversion themselves before persisting the field initialization metadata resulting in a CLS-compliant framework, but frameworks are encouraged not to rely on such implicit conversions. *end note*]

[*Note:* It might seem reasonable to provide a volatile constraint on a location that would require that the value stored in the location not be cached between accesses. Instead, CIL includes a **volatile.** prefix to certain instructions to specify that the value neither be cached nor computed using an existing cache. Such a constraint can be encoded using a custom attribute (see §I.9.7), although this standard does not specify such an attribute. *end note*]

I.8.6.1.3 Local signatures

A **local signature** specifies the contract on a local variable allocated during the running of a method. A local signature contains a full location signature, plus it can specify one additional constraint:

The **byref** constraint states that the content of the corresponding location is a **managed pointer**. A managed pointer can point to a local variable, parameter, field of a compound type, or element of an array. However, when a call crosses a remoting boundary (see §I.12.5) a conforming implementation can use a copy-in/copy-out mechanism instead of a managed pointer. Thus programs shall not rely on the aliasing behavior of true pointers.

In addition, there is one special local signature. The **typed reference** local variable signature states that the local will contain both a managed pointer to a location and a runtime representation of the type that can be stored at that location. A typed reference signature is similar to a byref constraint, but while the byref specifies the type as part of the byref constraint (and hence statically as part of the type description), a typed reference provides the type information dynamically. A typed reference is a full signature in itself and cannot be combined with other constraints. In particular, it is not possible to specify a **byref** whose type is **typed reference**.

The typed reference signature is actually represented as a built-in value type, like the integer and floating-point types. In the Base Class Library (see Partition IV Library) the type is known as **System.TypedReference** and in the assembly language used in Partition II it is designated by the keyword **typedref**. This type shall only be used for parameters and local variables. It shall not be boxed, nor shall it be used as the type of a field, element of an array, or return value.

CLS Rule 14: Typed references are not CLS-compliant.

[*Note*:

CLS (consumer): There is no need to accept this type.

CLS (extender): There is no need to provide syntax to define this type or to extend interfaces or classes that use this type.

CLS (framework): This type shall not appear in exported members. *end note*]

I.8.6.1.4 Parameter signatures

A **parameter signature**, defines constraints on how an individual value is passed as part of a method invocation. Parameter signatures are declared by method definitions. Any valid local signature is a valid parameter signature.

I.8.6.1.5 Method signatures

A **method signature** is composed of

- a calling convention,
- the number of generic parameters, if the method is generic,
- if the calling convention specifies this is an instance method and the owning method definition belongs to a type T then the type of the `this` pointer is:
    - given by the first parameter signature, if the calling convention is `instance explicit` (§II.15.3),
    - inferred as &T, if T is a value type and the method definition is non-virtual (§I.8.9.7),
    - inferred as "boxed" T, if T is a value type and the method definition is virtual (this includes method definitions from an interface implemented by T) (§I.8.9.7),
    - inferred as T, otherwise
- a list of zero or more parameter signatures—one for each parameter of the method—and,
- a type signature for the result value, if one is produced.

Method signatures are declared by method definitions. Only one constraint can be added to a method signature in addition to those of parameter signatures:

- The **vararg** constraint can be included to indicate that all arguments past this point are optional. When it appears, the calling convention shall be one that supports variable argument lists.

Method signatures are used in two different ways: as part of a method definition and as a description of a calling site when calling through a function pointer. In the latter case, the method signature indicates

- the calling convention (which can include platform-specific calling conventions),
- the types of all the argument values that are being passed, and
- if needed, a vararg marker indicating where the fixed parameter list ends and the variable parameter list begins.

When used as part of a method definition, the vararg constraint is represented by the choice of calling convention.

[*Note:* a single *method implementation* may be used both to satisfy a *method definition* of a type and to satisfy a *method definition* of an interface the type implements. If the type is a value type, T, then the `this` pointer in the method signature for the type's own *method definition* is a managed pointer &T, while it is "boxed" T in the method signature associated with the interface's *method definition*. *end note*]

[*Note:* the presence of a `this` pointer affects parameter signature/argument number pairing in CIL. If the parameter signature for the `this` pointer is inferred then the first parameter signature in the metadata is for argument number one. If there is no `this` pointer, as with static methods, or this is an `instance explicit` method, then the first parameter signature is for argument number zero. See the descriptions of the call and load function instructions in Partition III. *end note*]

CLS Rule 15: The vararg constraint is not part of the CLS, and the only calling convention supported by the CLS is the standard managed calling convention.

[*Note*:

CLS (consumer): There is no need to accept methods with variable argument lists or unmanaged calling convention.

CLS (extender): There is no need to provide syntax to declare vararg methods or unmanaged calling conventions.

CLS (framework): Neither vararg methods nor methods with unmanaged calling conventions shall be exported externally. *end note*]

I.8.6.1.6 Signature Matching

For signatures other than method signatures two signatures are said to *match* if and only if every component type of the signature is identical in the two signatures.

Method signature matching is used when determining *hiding* and *overriding* (§I.8.10.2, §I.8.10.4). Two method signatures are said to *match* if and only if:

- the calling conventions are identical;
- both signatures are either static or instance;
- the number of generic parameters is identical, if the method is generic;
- for instance signatures the type of the `this` pointer of the overriding/hiding signature is *assignable-to* (§I.8.7) the type of the `this` pointer of the overridden/hidden signature;
- the number and type signatures of the parameters are identical; and
- the type signatures for the result are identical. [*Note:* This includes void (§II.23.2.11) if no value is returned. *end note*]

[*Note:* when overriding/hiding the accessibility of items need not be identical (§I.8.10.2, §I.8.10.4). *end note*]

I.8.7 Assignment compatibility

Assignment compatibility refers to the ability to store a value of type T (statically described by a type signature) into a location of type U (described by a location signature), and is sometimes abbreviated U := T. Because the type signature for T is described statically, the value might not actually be of the type described by the signature, but rather something compatible with that type. No location or value shall have type `System.Void`.

The formal description of assignment compatibility is provided here, and is extended in Partition III, Verification type compatibility, with the *verifier-assignable-to* relation.

There are different rules for determining the compatibility of types, depending upon the context in which they are evaluated. The following relations are defined in this section:

- *compatible-with* – this is the relation used by `castclass` (§III.4.3) and `isinst` (§III.4.6), and in determining the validity of variant generic arguments. [*Note:* operations based on this relation do not change the representation of a value. When casting, the source type is the dynamic type of the value. *end note*]
- *assignable-to* – this is the relation used for general assignment; including load and store instructions (§III.3), implicit argument coercion (§III.1.6), and method return (§III.3.57). [*Note:* operations based on this relation may change the representation of a value. When assigning, the source type is the static type of the value. *end note*]
- *array-element-compatible-with* – this is the auxiliary relation used to determine the validity of assignments to array elements
- *pointer-element-compatible-with* – this is the auxiliary relation used to determine the compatibility of managed pointers

Informative text

These relations are defined in terms of six type subsets:

- *storage types* – these are the types that can occur as location (§I.8.6.1.2), local (§I.8.6.1.3) and parameter (§I.8.6.1.4) signatures. [*Note*: method signatures (§I.8.6.1.5) are not included here as there are no method values which can be assigned, delegate types (§I.8.9.3) are reference types (§I.8.2.1) and may occur in the above signatures. *end note*]
- *underlying types* – in the CTS enumerations are alternate names for existing types (§I.8.5.2), termed their *underlying type*. Except for signature matching (§I.8.5.2)

enumerations are treated as their underlying type. This subset is the set of storage types with the enumerations removed.

- *reduced types* – a value of value type S can be stored into, or loaded from, an array of value type T; and an array of value type S can be assigned to an array of value type T; if and only if S and T have the same *reduced type*. The reduced types are a subset of the underlying types.
- *verification types* – the verification algorithm treats certain types as interchangeable, assigning them a common *verification type*. The verification types are a subset of the reduced types.
- *intermediate types* – only a subset of the built-in value types can be represented on the evaluation stack (§I.12.1). Values of other built-in value types are translated to/from their *intermediate type* when loaded onto/stored from the evaluation stack. The intermediate types are a subset of the verification types plus the floating-point type `F` (which is not a member of the above four subsets).
- *transient types* – these are types which can only occur on the evaluation stack: boxed types, controlled-mutability managed pointer types, and the null type. Assignment compatibility for these types is defined by the *verifier-assignable-to* relation defined in §III.1.8.1.2.3.

The precise definitions of *underlying type*, *reduced type*, *verification type* and *intermediate type* are given below.

End informative text

Treatment of floating-point types

Floating-point values have two types; the nominal type, and the representation type. There are three floating-point types: `float32`, `float64` and `F`. A value of (nominal) type `float32` or `float64` may be represented by an implementation using a value of type `F`. See §I.12.1.3 for complete details.

Unless explicitly indicated any reference to floating-point types refers to the nominal type, in particular when referring to signatures (§I.8.6.1) and assignment compatibility. Consequently when the assignment compatibility rules indicate that a floating-point representation may change based on the (nominal) types the representation types may already be the same and no change is actually performed.

Notation

In the following definitions and relations:

- S, T, U, V, W represent arbitrary type expressions;
- N, M represent declared type names; and
- X, Y represent declared (formal) type parameters.

The notation:

T is of the form $N<\{X_i \leftarrow T_i\}>$

is defined to mean:

T is a possibly-instantiated object, interface, delegate or value type of the form $N<T_1,...,T_n>$, $n \geq 0$ (for $n = 0$ the empty <> are omitted), and N is declared with generic parameters $X_1,...,X_n$

Definitions

The following definitions are used in defining assignment compatibility.

The *underlying type* of a type T is the following:

1. If T is an enumeration type, then its underlying type is the underlying type declared in the enumeration's definition.
2. Otherwise, the underlying type is itself.

The *reduced type* of a type T is the following:

1. If the underlying type of T is:
   a. int8, or unsigned int8, then its reduced type is int8.
   b. int16, or unsigned int16, then its reduced type is int16.
   c. int32, or unsigned int32, then its reduced type is int32.
   d. int64, or unsigned int64, then its reduced type is int64.
   e. native int, or unsigned native int, then its reduced type is native int.
2. Otherwise, the reduced type is itself.

[*Note*: in other words the *reduced type* ignores the semantic differences between enumerations and the signed and unsigned integer types; treating these types the same if they have the same number of bits. *end note*]

The *verification type* (§III.1.8.1.2.1) of a type T is the following:

1. If the reduced type of T is:
   a. int8 or bool, then its verification type is int8.
   b. int16 or character, then its verification type is int16.
   c. int32 then its verification type is int32.
   d. int64 then its verification type is int64.
   e. native int, then its verification type is native int.
2. If T is a managed pointer type S& and the reduced type of S is:
   a. int8 or bool, then its verification type is int8&.
   b. int16 or character, then its verification type is int16&.
   c. int32, then its verification type is int32&.
   d. int64, then its verification type is int64&.
   e. native int, then its verification type is native int&.
3. Otherwise, the verification type is itself.

[*Note*: in other words the *verification type* ignores the semantic differences between enumerations, characters, booleans, the signed and unsigned integer types, and managed pointers to any of these; treating these types the same if they have the same number of bits or point to types with the same number of bits. *end note*]

The *intermediate type* of a type T is the following:

1. If the verification type of T is int8, int16, or int32, then its intermediate type is int32.
2. If the verification type of T is a floating-point type then its intermediate type is F (§III.1.1.1).
3. Otherwise, the intermediate type is the verification type of T.

[*Note*: the *intermediate type* is similar to the *verification type in stack state* according to the table in III.1.8.1.2.1, differing only for floating-point types. The *intermediate type* of a type T may have a different representation and meaning than T. *end note*]

The *direct base class* of a type T is the following:

1. If T is an array type (zero-based single-dimensional, or general) then its direct base class is `System.Array`.
2. If T is an interface type, then its direct base class is `System.Object`.

3. If T is of the form N<{X_i ← T_i}>, and N is declared to extend a type U of the form M<{Y_j ← S_j}>, then the direct base class of T is U with any occurrence of X_1,...,X_n in S_1,...,S_m replaced by the corresponding T_1,...,T_n.

4. For any other form of type T, there is no direct base class.

[*Note*: as a result of this definition, only `System.Object` itself, the unboxed form of a value type, and generic parameters have no direct base class. *end note*]

The *interfaces directly implemented* by a type T are the following:

1. If T is of the form N<{X_i ← T_i}> and is declared to implement (or require implementation of, if N is an interface) interfaces U_1,…,U_m of the form M_j<{$Y_{j,k}$ ← $S_{j,k}$}>, then the interfaces directly implemented by T are U_1, …,U_m with any occurrence of X_i in $S_{j,k}$ replaced by the corresponding T_i.

2. For any other form of type T, there are no directly implemented interfaces.

A type T *is a reference type* if and only if one of the following holds.

1. T is a possibly-instantiated object, delegate or interface of the form N<T_1,…,T_n> ($n \geq 0$)

2. T is an array type

[*Note*: generic parameters are not reference types. Therefore, the compatibility rules for reference types do not apply. See the definition of verification compatibility in Partition III for the special case of boxed types. *end note*]

For the purpose of type compatibility when determining a type from a signature:

i) Any byref (`&`) constraint (§I.8.6.1.3) is considered part of the type;

ii) The special signature typed reference (§I.8.6.1.3) is the type `typedref`;

iii) Any `modopt`, `modreq`, or `pinned` modifiers are ignored; and

iv) Any calling convention is considered part of the type.

[*Note*: the literal constraint is not considered as fields so marked cannot be referenced from CIL (§I.8.6.1.2). *end note*]

I.8.7.1 Assignment compatibility for signature types

A signature type T is *compatible-with* a signature type U if and only if at least one of the following holds. [Formally, the *compatible-with* relation is the smallest relation that is closed under the following rules.]

1. T is identical to U. [*Note*: this is *reflexivity*. *end note*]

2. There exists some V such that T is *compatible-with* V and V is *compatible-with* U. [*Note*: this is *transitivity*. *end note*]

3. T *is a reference type*, and U is the *direct base class* of T.

4. T *is a reference type*, and U is an *interface directly implemented* by T.

5. T is a zero-based rank-1 array V[], and U is a zero-based rank-1 array W[], and V is *array-element-compatible-with* W.

6. T is an array with rank r and element type V, and U is an array with the same rank r and element type W, and V is *array-element-compatible-with* W.

7. T is a zero-based rank-1 array V[], and U is IList<W>, and V is *array-element-compatible-with* W.

8. T is D<T_1,…,T_n> and U is D<U_1,…,U_n> for some interface or delegate type D with variance declarations *var_1* to *var_n*, and for each i from 1 to n, one of the following holds:

    a. *var_i* = none (no variance), and T_i is identical to U_i

    b. *var_i* = + (covariance), and T_i is *compatible-with* U_i

c. *var_i* = **-** (contravariance), and U_i is *compatible-with* T_i

9. T and U are method signatures and T is *method-signature compatible-with* U.

A signature type T is *array-element-compatible-with* a signature type U if and only if T has *underlying type* V and U has *underlying type* W and either:

1. V is *compatible-with* W; or
2. V and W have the same *reduced type*.

[*Note*: in other words, *array-element-compatible-with* extends *compatible-with* but is agnostic with respect to enumerations and integral signed**-**ness. *end note*]

[*Note*: When W[] is *compatible-with* V[] and V and W have the same *reduced type* then no representation change from V to W shall be performed, rather the bits of the value shall be interpreted according to the type W rather than the type V (§III.1.1.1).]

[*Note*: Variance rules do not mirror the reduced type equivalence rules of *array-element-compatible-with*. Thus, for example by rule 7 above:

```
IList<int16> := int16[]
IList<uint16> := int16[]
```

But by rule 8 above:

```
IList<int16> :≠ IList<uint16>
```

end note]

A method signature type T is *method-signature compatible-with* a method signature type U if and only if:

1. For each signature, independently, if the signature is for an instance method it carries the type of *this*. [*Note*: This is always true for the signatures of instance method pointers produced by the `ldftn` (§III.3.41) and `ldvirtftn` (§III.4.18) instructions. However, variables (as opposed to methods) whose signatures specified in the metadata have `HASTHIS` set with `EXPLICITTHIS` being set cannot be used in verified code and are unsupported by *method-signature compatible-with*. *end note*]
2. The calling conventions of T and U shall match exactly, ignoring the distinction between static and instance methods (i.e., the *this* parameter, if any, is not treated specially).
3. For each parameter type of P of T, and corresponding type Q of U, P is *assignable-to* Q.
4. For the return type P of T, and return type Q of U, Q is *assignable-to* P.

I.8.7.2 Assignment compatibility for location types

In this section the *compatible-with* relation is extended to deal with managed pointer types.

A location type T is *compatible-with* a location type U if and only if one of the following holds.

1. T and U are not managed pointer types and T is *compatible-with* U according to the definition in §I.8.7.1.
2. T and U are both managed pointer types and T is *pointer-element-compatible-with* U.

A managed pointer type T is *pointer-element-compatible-with* a managed pointer type U if and only if T has *verification type* V and U has *verification type* W and V is identical to W.

I.8.7.3 General assignment compatibility

In this section the relation *assignable-to* is defined which extends *compatible-with* to cover the primitive value type assignments supported by the semantics of the various load and store instructions (§III.3), implicit argument coercion (§III.1.6), and method return (§III.3.57).

A location type T is *assignable-to* a location type U if one of the following holds:

1. T is identical to U. [*Note*: this is *reflexivity*. *end note*]

2. There exists some V such that T is *assignable-to* V and V is *assignable-to* U. [*Note*: this is *transitivity*. *end note*]
3. T has *intermediate type* V, U has *intermediate type* W, and V is identical to W.
4. T has *intermediate type* native int and U has *intermediate type* int32, or vice-versa.
5. T is *compatible-with* U.

[*Note*: an assignment governed by *assignable-to* which involves an application of rules that use the *intermediate type* may change the representation and meaning of the assigned value as it is translated to and then from the *intermediate type*. *end note*]

I.8.8 Type safety and verification

Since types specify contracts, it is important to know whether a given implementation lives up to these contracts. An implementation that lives up to the enforceable part of the contract (the named signatures) is said to be **type-safe**. An important part of the contract deals with restrictions on the visibility and accessibility of named items as well as the mapping of names to implementations and locations in memory.

Type-safe implementations only store values described by a type signature in a location that is *assignable-to* (§I.8.7.3) the location signature of the location (see §I.8.6.1). Type-safe implementations never apply an operation to a value that is not defined by the exact type of the value. Type-safe implementations only access locations that are both visible and accessible to them. In a type-safe implementation, the exact type of a value cannot change.

Verification is a mechanical process of examining an implementation and asserting that it is type-safe. Verification is said to succeed if the process proves that an implementation is type-safe. Verification is said to fail if that process does not prove the type safety of an implementation. Verification is necessarily conservative: it can report failure for a type-safe implementation, but it never reports success for an implementation that is not type-safe. For example, most verification processes report implementations that do pointer-based arithmetic as failing verification, even if the implementation is, in fact, type-safe.

There are many different processes that can be the basis of verification. The simplest possible process simply says that all implementations are not type-safe. While correct and efficient this is clearly not particularly useful. By spending more resources (time and space) a process can correctly identify more type-safe implementations. It has been proven, however, that no mechanical process can, in finite time and with no errors, correctly identify all implementations as either type-safe or not type-safe. The choice of a particular verification process is thus a matter of engineering, based on the resources available to make the decision and the importance of detecting the type safety of different programming constructs.

I.8.9 Type definers

Type definers construct a new type from existing types. **Implicit types** (e.g., built-in types, arrays, and pointers including function pointers) are defined when they are used. The mention of an implicit type in a signature is in and of itself a complete definition of the type. Implicit types allow the VES to manufacture instances with a standard set of members, interfaces, etc. Implicit types need not have user-supplied names.

All other types shall be explicitly defined using an explicit type definition. The explicit type definers are:

- interface definitions – used to define interface types
- class definitions – used to define class types, which can be either of the following:
    - object types (including delegates)
    - value types and their associated boxed types

[*Note:* While class definitions always define class types, not all class types require a class definition. Array types and pointer types, which are implicitly defined, are also class types. See §I.8.2.3.

Similarly, not all types defined by a class definition are object types. Array types, explicitly defined object types, and boxed types are object types. Pointer types, function pointer types, and value types are not object types. See §I.8.2.3. *end note*]

Class, interface, and value type definitions can be parameterized, a feature known as *generic type definitions*. That is, the definition of a class, interface, or value type can include generic parameters. When used, a specific instantiation of the generic class, interface, or value type is made, at which point the generic parameters are bound to specific generic arguments. The generic parameters can be constrained, so that only generic arguments that match these constraints can be used for instantiations.

I.8.9.1 Array types

An **array type** shall be defined by specifying the element type of the array, the **rank** (number of dimensions) of the array, and the upper and lower bounds of each dimension of the array. Hence, no separate definition of the array type is needed. The bounds (as well as indices into the array) shall be signed integers. While the actual bounds for each dimension are known only at runtime, the signature can specify the information that is known at compile time (e.g., no bounds, a lower bound, or both an upper and a lower bound).

Array elements shall be laid out within the array object in row-major order (i.e., the elements associated with the rightmost array dimension shall be laid out contiguously from lowest to highest index). The actual storage allocated for each array element can include platform-specific padding. (The size of this storage, in bytes, is returned by the sizeof instruction when it is applied to the type of that array's elements.)

Values of an array type are objects; hence an array type is a kind of object type (see §I.8.2.3). Array objects are defined by the CTS to be a repetition of locations where values of the array element type are stored. The number of repeated values is determined by the rank and bounds of the array.

Only type signatures, not location signatures, are allowed as array element types.

Exact array types are created automatically by the VES when they are required. Hence, the operations on an array type are defined by the CTS. These generally are: allocating the array based on size and lower-bound information, indexing the array to read and write a value, computing the address of an element of the array (a managed pointer), and querying for the rank, bounds, and the total number of values stored in the array.

Additionally, a created vector with element type `T`, implements the interface `System.Collections.Generic.IList<U>`, where `U := T.` (§I.8.7)

CLS Rule 16: Arrays shall have elements with a CLS-compliant type, and all dimensions of the array shall have lower bounds of zero. Only the fact that an item is an array and the element type of the array shall be required to distinguish between overloads. When overloading is based on two or more array types the element types shall be named types.

[*Note*: So-called "jagged arrays" are CLS-compliant, but when overloading multiple array types they are one-dimensional, zero-based arrays of type `System.Array`.

CLS (consumer): There is no need to support arrays of non-CLS types, even when dealing with instances of `System.Array`. Overload resolution need not be aware of the full complexity of array types. Programmers should have access to the Get, Set, and Address methods on instances of `System.Array` if there is no language syntax for the full range of array types.

CLS (extender): There is no need to provide syntax to define non-CLS types of arrays or to extend interfaces or classes that use non-CLS array types. Shall provide access to the type `System.Array`, but can assume that all instances will have a CLS-compliant type. While the full array signature must be used to override an inherited method that has an array parameter, the full complexity of array types need not be made visible to programmers. Programmers should have access to the Get, Set, and Address methods on instances of `System.Array` if there is no language syntax for the full range of array types.

CLS (framework): Non-CLS array types shall not appear in exported members. Where possible, use only one-dimensional, zero-based arrays (vectors) of simple named types, since

these are supported in the widest range of programming languages. Overloading on array types should be avoided, and when used shall obey the restrictions. *end note*]

Array types form a hierarchy, with all array types inheriting from the type `System.Array`. This is an abstract class (see §I.8.9.6.2) that represents all arrays regardless of the type of their elements, their rank, or their upper and lower bounds. The VES creates one array type for each distinguishable array type. In general, array types are only distinguished by the type of their elements and their rank. However, the VES treats single dimensional, zero-based arrays (also known as **vectors**) specially. Vectors are also distinguished by the type of their elements, but a vector is distinct from a single-dimensional array of the same element type that has a non-zero lower bound. Zero-dimensional arrays are not supported.

Consider the following examples, using the syntax of CIL as described in Partition II Metadata:

Table I.2: Array Examples

Static specification of type	Actual type constructed	Allowed in CLS?
`int32[]`	vector of `int32`	Yes
`int32[0...5]`	vector of `int32`	Yes
`int32[1...5]`	array, rank 1, of `int32`	No
`int32[,]`	array, rank 2, of `int32`	Yes
`int32[0...3, 0...5]`	array, rank 2, of `int32`	Yes
`int32[0..., 0...]`	array, rank 2, of `int32`	Yes
`int32[1..., 0...]`	array, rank 2, of `int32`	No

I.8.9.2 Unmanaged pointer types

An **unmanaged pointer type** (also known simply as a "pointer type") is defined by specifying a location signature for the location the pointer references. Any signature of a pointer type includes this location signature. Hence, no separate definition of the pointer type is needed.

While pointer types are reference types, values of a pointer type are not objects (see §I.8.2.3), and hence it is not possible, given a value of a pointer type, to determine its exact type. The CTS provides two type-safe operations on pointer types: one to load the value from the location referenced by the pointer and the other to store a value whose type is *assignable-to* (§I.8.7.3) the type referenced by the pointer into that location. The CTS also provides three operations on pointer types (byte-based address arithmetic): adding to and subtracting integers from pointers, and subtracting one pointer from another. The results of the first two operations are pointers to the same type signature as the original pointer. See Partition III – Base Instructions for details.

CLS Rule 17: Unmanaged pointer types are not CLS-compliant.

[*Note*:

CLS (consumer): There is no need to support unmanaged pointer types.

CLS (extender): There is no need to provide syntax to define or access unmanaged pointer types.

CLS (framework): Unmanaged pointer types shall not be externally exported. *end note*]

I.8.9.3 Delegates

Delegates are the object-oriented equivalent of function pointers. Unlike function pointers, delegates are object-oriented, type-safe, and secure. Delegates are created by defining a class that derives from the base type `System.Delegate` (see Partition IV). Each delegate type shall provide a method named **Invoke** with appropriate parameters, and each instance of a delegate forwards calls to its **Invoke** method to one or more static or instance methods on particular objects that are *delegate-assignable-to* (§II.14.6.1) the signature of the delegate. The objects and methods to which it delegates are chosen when the delegate instance is created.

In addition to an instance constructor and an **Invoke** method, delegates can optionally have two additional methods: **BeginInvoke** and **EndInvoke**. These are used for asynchronous calls.

While, for the most part, delegates appear to be simply another kind of user-defined class, they are tightly controlled. The implementations of the methods are provided by the VES, not user code. The only additional members that can be defined on delegate types are static or instance methods.

I.8.9.4 Interface type definition

An **interface definition** defines an interface type. An interface type is a named group of methods, locations, and other contracts that shall be implemented by any object type that supports the interface contract of the same name. An interface definition is always an incomplete description of a value, and, as such, can never define a class type or an exact type, nor can it be an object type.

Zero or more object types can support an interface type, and only object types can support an interface type. An interface type can require that objects that support it shall also support other (specified) interface types. An object type that supports the named interface contract shall provide a complete implementation of the methods, locations, and other contracts specified (but not implemented by) the interface type. Hence, a value of an object type is also a value of all of the interface types the object type supports. Support for an interface contract is declared, never inferred; i.e., the existence of implementations of the methods, locations, and other contracts required by the interface type does not imply support of the interface contract.

CLS Rule 18: CLS-compliant interfaces shall not require the definition of non-CLS compliant methods in order to implement them.

[*Note*:

CLS (consumer): There is no need to deal with such interfaces.

CLS (extender): Need not provide a mechanism for defining such interfaces.

CLS (framework): Shall not expose any non-CLS compliant methods on interfaces it defines for external use. *end note*]

Interface types are necessarily incomplete since they say nothing about the representation of the values of the interface type. For this reason, an interface type definition shall not provide field definitions for values of the interface type (i.e., instance fields), although it can declare static fields (see §I.8.4.3).

Similarly, an interface type definition shall not provide implementations for any methods on the values of its type. However, an interface type definition can—and usually does—define method contracts (method name and method signature) that shall be implemented by supporting types. An interface type definition can define and implement static methods (see §I.8.4.3) since static methods are associated with the interface type itself rather than with any value of the type.

Interfaces can have static or virtual methods, but shall not have instance methods.

CLS Rule 19: CLS-compliant interfaces shall not define static methods, nor shall they define fields.

[*Note*:

CLS-compliant interfaces can define properties, events, and virtual methods.

CLS (consumer): Need not accept interfaces that violate these rules.

CLS (extender): Need not provide syntax to author interfaces that violate these rules.

CLS (framework): Shall not externally expose interfaces that violate these rules. Where static methods, instance methods, or fields are required, a separate class can be defined that provides them. *end note*]

Interface types can also define event and property contracts that shall be implemented by object types that support the interface. Since event and property contracts reduce to sets of method contracts (§I.8.6), the above rules for method definitions apply. For more information, see §I.8.11.4 and §I.8.11.3.

Interface type definitions can specify other interface contracts that implementations of the interface type are required to support. See §I.8.9.11 for specifics.

An interface type is given a visibility attribute, as described in §I.8.5.3, that controls from where the interface type can be referenced. An interface type definition is separate from any object type definition that supports the interface type. Hence, it is possible, and often desirable, to have a different visibility for the interface type and the implementing object type. However, since accessibility attributes are relative to the implementing type rather than the interface itself, all members of an interface shall have public accessibility, and no security permissions can be attached to members or to the interface itself.

I.8.9.5 Class type definition

All types other than interfaces and those types for which a definition is automatically supplied by the CTS, are defined by **class definitions**. A **class type** is a complete specification of the representation of the values of the class type and all of the contracts (class, interface, method, property, and event) that are supported by the class type. Hence, a class type is an exact type. Unless it specifies that the class is an **abstract object type**, a class definition not only defines the class type, it also provides implementations for all of the contracts supported by the class type.

A class definition, and hence the implementation of the class type, always resides in some assembly. (An assembly is a configured set of loadable code modules and other resources that together implement a unit of functionality.)

[*Note:* While class definitions always define class types, not all class types require a class definition. Array types and pointer types, which are implicitly defined, are also class types. See §I.8.2.3. *end note*]

An explicit class definition is used to define:

- An object type (see §I.8.2.3).
- A value type and its associated boxed type (see §I.8.2.4).

An explicit class definition:

- Names the class type.
- Implicitly assigns the class type name to a scope, i.e., the assembly that contains the class definition, (see §I.8.5.2).
- Defines the class contract of the same name (see §I.8.6).
- Defines the representations and valid operations of all values of the class type using member definitions for the fields, methods, properties, and events (see §I.8.11).
- Defines the static members of the class type (see §I.8.11).
- Specifies any other interface and class contracts also supported by the class type.
- Supplies implementations for member and interface contracts supported by the class type.
- Explicitly declares a visibility for the type, either public or assembly (see §I.8.5.3).
- Can optionally specify a method (called `.cctor`) to be called to initialize the type.

The semantics of when and what triggers execution of such type initialization methods, is as follows:

1. A type can have a type-initializer method, or not.
2. A type can be specified as having a relaxed semantic for its type-initializer method (for convenience below, we call this relaxed semantic **BeforeFieldInit**).
3. If marked **BeforeFieldInit** then the type's initializer method is executed at, or sometime before, first access to any static field defined for that type.
4. If *not* marked **BeforeFieldInit** then that type's initializer method is executed at (i.e., is triggered by):

a. first access to any static field of that type, or

b. first invocation of any static method of that type, or

c. first invocation of any instance or virtual method of that type if it is a value type or

d. first invocation of any constructor for that type.

5. Execution of any type's initializer method will *not* trigger automatic execution of any initializer methods defined by its base type, nor of any interfaces that the type implements.

For reference types, a constructor has to be called to create a non-null instance. Thus, for reference types, the .cctor will be called before instance fields can be accessed and methods can be called on non-null instances. For value types, an "all-zero" instance can be created without a constructor (but only this value can be created without a constructor). Thus for value types, the .cctor is only guaranteed to be called for instances of the value type that are not "all-zero". [*Note*: This changes the semantics slightly in the reference class case from the first edition of this standard, in that the .cctor might not be called before an instance method is invoked if the 'this' argument is null. The added performance of avoiding class constructors warrants this change. *end note*]

[*Note:* **BeforeFieldInit** behavior is intended for initialization code with no interesting side-effects, where exact timing does not matter. Also, under **BeforeFieldInit** semantics, type initializers are allowed to be executed *at or before* first access to any static field of that type, at the discretion of the CLI.

If a language wishes to provide more rigid behavior—e.g., type initialization automatically triggers execution of base class's initializers, in a top-to-bottom order—then it can do so by either:

- defining hidden static fields and code in each class constructor that touches the hidden static field of its base class and/or interfaces it implements, or
- by making explicit calls to `System.Runtime.CompilerServices.RuntimeHelpers.RunClassConstructor` (see Partition IV Library).

end note]

I.8.9.6 Object type definitions

All objects are instances of an **object type**. The object type of an object is set when the object is created and it is immutable. The object type describes the physical structure of the instance and the operations that are allowed on it. All instances of the same object type have the same structure and the same allowable operations. Object types are explicitly declared by a class type definition, with the exception of array types, which are intrinsically provided by the VES.

I.8.9.6.1 Scope and visibility

Since object type definitions are class type definitions, object type definitions implicitly specify the scope of the name of object type to be the assembly that contains the object type definition, see §I.8.5.2. Similarly, object type definitions shall also explicitly state the visibility attribute of the object type (either **public**or **assembly**); see §I.8.5.3.

I.8.9.6.2 Concreteness

An object type can be marked as **abstract** by the object type definition. An object type that is not marked **abstract** is, by definition, **concrete**. Only object types can be declared as abstract. Only an abstract object type is allowed to define method contracts for which the type or the VES does not also provide the implementation. Such method contracts are called **abstract methods** (see §I.8.11). Methods on an abstract class need not be abstract.

It is an error to attempt to create an instance of an abstract object type, whether or not the type has abstract methods. An object type that derives from an abstract object type can be concrete if it provides implementations for all abstract methods in the base object type and is not itself marked as abstract. Instances can be made of such a concrete derived class. Locations can have

an abstract type, and instances of a concrete type that derives from the abstract type can be stored in them.

I.8.9.6.3 Type members

Object type definitions include member definitions for all of the members of the type. Briefly, members of a type include fields into which values are stored, methods that can be invoked, properties that are available, and events that can be raised. Each member of a type can have attributes as described in §I.8.4.

- Fields of an object type specify the representation of values of the object type by specifying the component pieces from which it is composed (see I.8.4.1). Static fields specify fields associated with the object type itself (see §I.8.4.3). The fields of an object type are named and they are typed via location signatures. The names of the members of the type are scoped to the type (see §I.8.5.2). Fields are declared using a field definition (see §I.8.11.2).
- Methods of an object type specify operations on values of the type (see §I.8.4.2). Static methods specify operations on the type itself (see §I.8.4.3). Methods are named and they have a method signature. The names of methods are scoped to the type (see §I.8.5.2). Methods are declared using a method definition (see §I.8.11.1).
- Properties of an object type specify named values that are accessible via methods that read and write the value. The name of the property is the grouping of the methods; the methods themselves are also named and typed via method signatures. The names of properties are scoped to the type (see §I.8.5.2). Properties are declared using a property definition (see §I.8.11.3).
- Events of an object type specify named state transitions in which subscribers can register/unregister interest via accessor methods. When the state changes, the subscribers are notified of the state transition. The name of the event is the grouping of the accessor methods; the methods themselves are also named and typed via method signatures. The names of events are scoped to the type (see §I.8.5.2). Events are declared using an event definition (see §I.8.11.4).

I.8.9.6.4 Supporting interface contracts

Object type definitions can declare that they support zero or more interface contracts. Declaring support for an interface contract places a requirement on the implementation of the object type to fully implement that interface contract. Implementing an interface contract always reduces to implementing the required set of methods, i.e., the methods required by the interface type.

The different types that the object type implements (i.e., the object type and any implemented interface types), are each a separate logical grouping of named members. If a class `Foo` implements an interface `IFoo`, and `IFoo` declares a member method `int a()`, and `Foo` also declares a member method `int a()`, there are two members, one in the `IFoo` interface type and one in the `Foo` class type. An implementation of `Foo` will provide an implementation for both, potentially shared.

Similarly, if a class implements two interfaces `IFoo` and `IBar`, each of which defines a method `int a()`, the class will supply two method implementations, one for each interface, although they can share the actual code of the implementation.

CLS Rule 20: CLS-compliant classes, value types, and interfaces shall not require the implementation of non-CLS-compliant members.

[*Note*:

CLS (consumer): Need not accept classes, value types or interfaces that violate this rule.

CLS (extender): Need not provide syntax to author classes, value types, or interfaces that violate this rule.

CLS (framework): Shall not externally expose classes, value types, or interfaces that violate this rule. If a CLS-compliant framework exposes a class implementing a non-CLS-compliant interface, the framework shall provide concrete implementations of all non-CLS-compliant

members. This ensures that CLS extenders do not need syntax for implementing non-CLS-compliant members. *end note*]

I.8.9.6.5 Supporting class contracts

Object type definitions can declare support for one other class contract. Declaring support for another class contract is synonymous with object type inheritance (see §I.8.9.9).

I.8.9.6.6 Constructors

New values of an object type are created via **constructors**. Constructors shall be instance methods, defined via a special form of method contract, which defines the method contract as a constructor for a particular object type. The constructors for an object type are part of the object type definition. While the CTS and VES ensure that only a properly defined constructor is used to make new values of an object type, the ultimate correctness of a newly constructed object is dependent on the implementation of the constructor itself.

Object types shall define at least one constructor method, but that method need not be public. Creating a new value of an object type by invoking a constructor involves the following steps, in order:

1. Space for the new value is allocated in managed memory.
2. VES data structures of the new value are initialized and user-visible memory is zeroed.
3. The specified constructor for the object type is invoked.

Inside the constructor, the object type can do any initialization it chooses (possibly none).

CLS Rule 21: An object constructor shall call some instance constructor of its base class before any access occurs to inherited instance data. (This does not apply to value types, which need not have constructors.)

CLS Rule 22: An object constructor shall not be called except as part of the creation of an object, and an object shall not be initialized twice.

[*Note*:

CLS (consumer): Shall provide syntax for choosing the constructor to be called when an object is created.

CLS (extender): Shall provide syntax for defining constructor methods with different signatures. It can issue a compiler error if the constructor does not obey these rules.

CLS (framework): Can assume that object creation includes a call to one of the constructors, and that no object is initialized twice. `System.Object.MemberwiseClone` (see Partition IV Library) and deserialization (including object remoting) shall not run constructors. *end note*]

I.8.9.6.7 Finalizers

A class definition that creates an object type can supply an instance method (called a *finalizer*) to be called when an instance of the class is no longer reachable. The class `System.GC` (see Partition IV) provides limited control over the behavior of finalizers through the methods `SuppressFinalize` and `ReRegisterForFinalize`. Conforming implementations of the CLI can specify and provide additional mechanisms that affect the behavior of finalizers.

A conforming implementation of the CLI shall not automatically call a finalizer twice for the same object unless

- there has been an intervening call to `ReRegisterForFinalize` (not followed by a call to `SuppressFinalize`), or
- the program has invoked an implementation-specific mechanism that is clearly specified to produce an alteration to this behavior.

[*Rationale:* Programmers expect that finalizers are run precisely once on any given object unless they take an explicit action to cause the finalizer to be run multiple times. *end rationale*]

It is valid to define a finalizer for a value type. However, that finalizer will only be run for *boxed* instances of that value type.

[*Note:* Since programmers might depend on finalizers to be called, the CLI should make every effort, before it shuts down, to ensure that finalizers are called for all objects that have not been exempted from finalization by a call to `SuppressFinalize`. The implementation should specify any conditions under which this behavior cannot be guaranteed. *end note*]

[*Note:* Since resources might become exhausted if finalizers are not called expeditiously, the CLI should ensure that finalizers are called soon after the instance becomes inaccessible. While relying on memory pressure to trigger finalization is acceptable, implementers should consider the use of additional metrics. *end note*]

I.8.9.7 Value type definition

Not all types defined by a class definition are object types (see §I.8.2.3); in particular, value types are not object types, but they are defined using a class definition. A class definition for a value type defines both the (unboxed) value type and the associated boxed type (see §I.8.2.4). The members of the class definition define the representation of both:

1. When a non-static method (i.e., an instance or virtual method) is called on the value type, its **this** pointer is a managed reference to the instance, whereas when the method is called on the associated boxed type, the **this** pointer is an object reference.

   Instance methods on value types receive a **this** pointer that is a managed pointer to the unboxed type whereas virtual methods (including those on interfaces implemented by the value type) receive an instance of the boxed type.

2. Value types do not support interface contracts, but their associated boxed types do.

3. A value type does not inherit; rather the base type specified in the class definition defines the base type of the boxed type.

4. The base type of a boxed type shall not have any fields.

5. Unlike object types, instances of value types do not require a constructor to be called when an instance is created. Instead, the verification rules require that verifiable code initialize instances to zero (null for object fields).

I.8.9.8 Type inheritance

Inheritance of types is another way of saying that the derived type guarantees support for all of the type contracts of the base type. In addition, the derived type usually provides additional functionality or specialized behavior. A type inherits from a base type by implementing the type contract of the base type. An interface type implements zero or more other interfaces. Value types do not inherit, although the associated boxed type is an object type and hence inherits from other types.

The derived class type shall support all of the supported interfaces contracts, class contracts, event contracts, method contracts, and property contracts of its base type. In addition, all of the locations defined by the base type are also defined in the derived type. The inheritance rules guarantee that code that was compiled to work with a value of a base type will still work when passed a value of the derived type. Because of this, a derived type also inherits the implementations of the base type. The derived type can extend, override, and/or hide these implementations.

I.8.9.9 Object type inheritance

With the sole exception of `System.Object`, which does not inherit from any other object type, all object types shall either explicitly or implicitly declare support for (i.e., inherit from) exactly one other object type. The graph of the inherits-relation shall form a singly rooted tree with `System.Object` at the base; i.e., all object types eventually inherit from the type `System.Object`. The introduction of generic types makes it more difficult to give a precise definition; see Partition II Metadata - Security.

An object type declares that it shall not be used as a base type (be inherited from) by declaring that it is a **sealed** type.

CLS Rule 23: `System.Object` is CLS-compliant. Any other CLS-compliant class shall inherit from a CLS-compliant class.

Arrays are object types and, as such, inherit from other object types. Since array object types are manufactured by the VES, the inheritance of arrays is fixed. See §I.8.9.1.

I.8.9.10 Value type inheritance

In their unboxed form value types do not inherit from any type. Boxed value types shall inherit directly from `System.ValueType` unless they are enumerations, in which case, they shall inherit from `System.Enum`. Boxed value types shall be sealed.

Logically, the boxed type corresponding to a value type

- Is an object type.
- Will specify which object type is its base type (i.e., the object type from which it inherits).
- Will have a base type that has no fields defined.
- Will be **sealed** to avoid dealing with the complications of value slicing.

The more restrictive rules specified here allow for more efficient implementation without severely compromising functionality.

I.8.9.11 Interface type derivation

Interface types can require the implementation of one or more other interfaces. Any type that implements support for an interface type shall also implement support for any required interfaces specified by that interface. This is different from object type inheritance in two ways:

- Object types form a single inheritance tree; interface types do not.
- Object type inheritance specifies how implementations are inherited; required interfaces do not, since interfaces do not define implementation. Required interfaces specify additional contracts that an implementing object type shall support.

To highlight the last difference, consider an interface, `IFoo`, that has a single method. An interface, `IBar`, which derives from it, is requiring that any object type that supports `IBar` also support `IFoo`. It does not say anything about which methods `IBar` itself will have.

I.8.10 Member inheritance

Only object types can inherit implementations, hence only object types can inherit members (see §I.8.9.8). While interface types can be derived from other interface types, they only "inherit" the requirement to implement method contracts, never fields or method implementations.

I.8.10.1 Field inheritance

A derived object type inherits all of the non-static fields of its base object type. This allows instances of the derived type to be used wherever instances of the base type are expected (the shapes, or layouts, of the instances will be the same). Static fields are not inherited. Just because a field exists does not mean that it can be read or written. The type visibility, field accessibility, and security attributes of the field definition (see §I.8.5.3) determine if a field is accessible to the derived object type.

I.8.10.2 Method inheritance

A derived object type inherits all of the instance and virtual methods of its base object type. It does not inherit constructors or static methods. Just because a method exists does not mean that it can be invoked. It shall be accessible via the typed reference that is being used by the referencing code. The type visibility, method accessibility, and security attributes of the method definition (see §I.8.5.3) determine if a method is accessible to the derived object type.

A derived object type can hide a non-virtual (i.e., static or instance) method of its base type by providing a new method definition with the same name or same name and signature. Either

method can still be invoked, subject to method accessibility rules, since the type that contains the method always qualifies a method reference.

Virtual methods can be marked as **final**, in which case, they shall not be overridden in a derived object type. This ensures that the implementation of the method is available, by a virtual call, on any object that supports the contract of the base class that supplied the final implementation. If a virtual method is not final it is possible to demand a security permission in order to override the virtual method, so that the ability to provide an implementation can be limited to classes that have particular permissions. When a derived type overrides a virtual method, it can specify a new accessibility for the virtual method, but the accessibility in the derived class shall permit at least as much access as the access granted to the method it is overriding. See §I.8.5.3.

I.8.10.3 Property and event inheritance

Fundamentally, properties and events are constructs of the metadata intended for use by tools that target the CLI and are not directly supported by the VES itself. Therefore, it is the job of the source language compiler and the reflection library (see Partition IV – Kernel Package) to determine rules for name hiding, inheritance, and so forth. The source compiler shall generate CIL that directly accesses the methods named by the events and properties, not the events or properties themselves.

I.8.10.4 Hiding, overriding, and layout

There are two separate issues involved in inheritance. The first is which contracts a type shall implement and hence which member names and signatures it shall provide. The second is the layout of the instance so that an instance of a derived type can be substituted for an instance of any of its base types. Only the non-static fields and the virtual methods that are part of the derived type affect the layout of an object.

The CTS provides independent control over both the names that are visible from a base type (**hiding**) and the sharing of layout slots in the derived class (**overriding**). Hiding is controlled by marking a member in the derived class as either **hide by name** or **hide by name-and-signature**. Hiding is always performed based on the kind of member, that is, derived field names can hide base field names, but not method names, property names, or event names. If a derived member is marked **hide by name**, then members of the same kind in the base class with the same name are not visible in the derived class; if the member is marked **hide by name-and-signature** then only a member of the same kind with exactly the same name and type (for fields) or method signature (for methods) is hidden from the derived class. Implementation of the distinction between these two forms of hiding is provided entirely by source language compilers and the reflection library; it has no direct impact on the VES itself.

[*Example*: For example:

```
class Base
{ field  int32         A;
  field  System.String A;
  method int32         A();
  method int32         A(int32);
}
class Derived inherits from Base
{ field  int32 A;
  hidebysig method int32 A();
}
```

The member names available in type `Derived` are:

Table I.3: Member names

Kind of member	Type / Signature of member	Name of member
`Field`	`int32`	`A`
`Method`	`() -> int32`	`A`
`Method`	`(int32) -> int32`	`A`

end example]

While hiding applies to all members of a type, overriding deals with object layout and is applicable only to instance fields and virtual methods. The CTS provides two forms of member overriding, **new slot** and **expect existing slot**. A member of a derived type that is marked as a new slot will always get a new slot in the object's layout, guaranteeing that the base field or method is available in the object by using a qualified reference that combines the name of the base type with the name of the member and its type or signature. A member of a derived type that is marked as expect existing slot will re-use (i.e., share or override) a slot that corresponds to a member of the same kind (field or method), name, and type if one already exists from the base type; if no such slot exists, a new slot is allocated and used.

The general algorithm that is used for determining the names in a type and the layout of objects of the type is roughly as follows:

- Flatten the inherited names (using the **hide by name** or **hide by name-and-signature** rule) *ignoring* accessibility rules.
- For each new member that is marked "expect existing slot", look to see if an exact match on kind (i.e., field or method), name, and signature exists and use that slot if it is found, otherwise allocate a new slot.
- After doing this for all new members, add these new member-kind/name/signatures to the list of members of this type
- Finally, remove any inherited names that match the new members based on the **hide by name** or **hide by name-and-signature** rules.

I.8.11 Member definitions

Object type definitions, interface type definitions, and value type definitions can include member definitions. Field definitions define the representation of values of the type by specifying the substructure of the value. Method definitions define operations on values of the type and operations on the type itself (static methods). Property and event definitions shall only be defined on object types. Properties and events define named groups of accessor method definitions that implement the named event or property behavior. Nested type declarations define types whose names are scoped by the enclosing type and whose instances have full access to all members of the enclosing class.

Depending on the kind of type definition, there are restrictions on the member definitions allowed.

I.8.11.1 Method definitions

Method definitions are composed of a name, a method signature, and optionally an implementation of the method. The method signature defines the calling convention, type of the parameters to the method, and the return type of the method (see §I.8.6.1). The implementation is the code to execute when the method is invoked. A value type or object type shall define only one method of a given name and signature. However, a derived object type can have methods that are of the same name and signature as its base object type. See §I.8.10.2 and §I.8.10.4.

The name of the method is scoped to the type (see §I.8.5.2). Methods can be given accessibility attributes (see §I.8.5.3). Methods shall only be invoked with arguments whose types are *assignable-to* (§I.8.7.3) the parameter types of the method signature. The type of the return value of the method shall also be *assignable-to* (§I.8.7.3) the location in which it is stored.

Methods can be marked as **static**, indicating that the method is not an operation on values of the type but rather an operation associated with the type as a whole. Methods not marked as static define the valid operations on a value of a type. When a non-static method is invoked, a particular value of the type, referred to as **this** or the **this pointer**, is passed as the first parameter.

A method definition that does not include a method implementation shall be marked as **abstract.** All non-static methods of an interface definition are abstract. Abstract method definitions are only allowed in object types that are marked as abstract.

A non-static method definition in an object type can be marked as **virtual**, indicating that an alternate implementation can be provided in derived types. All non-static method definitions in

interface definitions shall be virtual methods. Virtual method can be marked as **final**, indicating that derived object types are not allowed to override the method implementation.

Method definitions can be parameterized, a feature known as *generic method definitions*. When used, a specific instantiation of the generic method is made, at which point the generic parameters are bound to specific generic arguments. Generic methods can be defined as members of a non-generic type; or can be defined as members of a generic type, but parameterized by different generic parameter (or parameters) than its owner type. For example, the `Stack<T>` class might include a generic method `S ConvertTo<S> ()`, where the `S` generic parameter is distinct from the `T` generic parameter in `Stack<T>`.

I.8.11.2 Field definitions

Field definitions are composed of a name and a location signature. The location signature defines the type of the field and the accessing constraints, see §I.8.6.1. A value type or object type shall define only one field of a given name and type. However, a derived object type can have fields that are of the same name and type as its base object type. See §I.8.10.1 and §I.8.10.4.

The name of the field is scoped to the type (see §I.8.5.2). Fields can be given accessibility attributes, see §I.8.5.3. Fields shall only store values whose types are *assignable-to* (§I.8.7.3)the type of the field (see §I.8.3.1).

Fields can be marked as **static**, indicating that the field is not part of values of the type but rather a location associated with the type as a whole. Locations for the static fields are created when the type is loaded and initialized when the type is initialized.

Fields not marked as static define the representation of a value of a type by defining the substructure of the value (see §I.8.4.1). Locations for such fields are created within every value of the type whenever a new value is constructed. They are initialized during construction of the new value. A non-static field of a given name is always located at the same place within every value of the type.

A field that is marked **serializable** is to be serialized as part of the persistent state of a value of the type. This standard does not require that a conforming implementation provide support for serialization (or its counterpart, deserialization), not does it specify the mechanism by which these operations might be accomplished.

I.8.11.3 Property definitions

A property definition defines a named value and the methods that access the value. A property definition defines the accessing contracts on that value. Hence, the property definition specifies which accessing methods exist and their respective method contracts. An implementation of a type that declares support for a property contract shall implement the accessing methods required by the property contract. The implementation of the accessing methods defines how the value is retrieved and stored.

A property definition is always part of either an interface definition or a class definition. The name and value of a property definition is scoped to the type that includes the property definition. The CTS requires that the method contracts that comprise the property shall match the method implementations, as with any other method contract. There are no CIL instructions associated with properties, just metadata.

By convention, properties define a **getter** method (for accessing the current value of the property) and optionally a **setter** method (for modifying the current value of the property). The CTS places no restrictions on the set of methods associated with a property, their names, or their usage.

CLS Rule 24: The methods that implement the `getter` and `setter` methods of a property shall be marked `SpecialName` in the metadata.

CLS Rule 25: No longer used. [*Note*: In an earlier version of this standard, this rule stated "The accessibility of a property and of its accessors shall be identical." The removal of this rule allows, for example, public access to a getter while restricting access to the setter. *end note*]

CLS Rule 26: A property's accessors shall all be static, all be virtual, or all be instance.

CLS Rule 27: The type of a property shall be the return type of the getter and the type of the last argument of the **setter**. The types of the parameters of the property shall be the types of the parameters to the getter and the types of all but the final parameter of the setter. All of these types shall be CLS-compliant, and shall not be managed pointers (i.e., shall not be passed by reference).

CLS Rule 28: Properties shall adhere to a specific naming pattern. See §I.10.4. The `SpecialName` attribute referred to in CLS rule 24 shall be ignored in appropriate name comparisons and shall adhere to identifier rules. A property shall have a getter method, a setter method, or both.

[*Note*:

CLS (consumer): Shall ignore the `SpecialName` bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the property.

CLS (extender): Shall ignore the `SpecialName` bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the property. In particular, an extender need not be able to define properties.

CLS (framework): Shall design understanding that not all CLS languages will access the property using special syntax. *end note*]

I.8.11.4 Event definitions

The CTS supports events in precisely the same way that it supports properties (see §I.8.11.3). The conventional methods, however, are different and include means for subscribing and unsubscribing to events as well as for firing the event.

CLS Rule 29: The methods that implement an event shall be marked `SpecialName` in the metadata.

CLS Rule 30: The accessibility of an event and of its accessors shall be identical.

CLS Rule 31: The `add` and `remove` methods for an event shall both either be present or absent.

CLS Rule 32: The `add` and `remove` methods for an event shall each take one parameter whose type defines the type of the event and that shall be derived from `System.Delegate`.

CLS Rule 33: Events shall adhere to a specific naming pattern. See §I.10.4. The `SpecialName` attribute referred to in CLS rule 29 shall be ignored in appropriate name comparisons and shall adhere to identifier rules.

[*Note*:

CLS (consumer): Shall ignore the `SpecialName` bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the event.

CLS (extender): Shall ignore the `SpecialName` bit in appropriate name comparisons and shall adhere to identifier rules. Otherwise, no direct support other than the usual access to the methods that define the event. In particular, an extender need not be able to define events.

CLS (framework): Shall design based on the understanding that not all CLS languages will access the event using special syntax. *end note*]

I.8.11.5 Nested type definitions

A nested type definition is identical to a top-level type definition, with one exception: a top-level type has a visibility attribute, while the visibility of a nested type is the same as the visibility of the enclosing type. See §I.8.5.3.

I.9 Metadata

This clause and its subclauses contain only informative text, with the exception of the CLS rules introduced here and repeated in §I.11. The metadata format is specified in Partition II Metdata – File Format

New types—value types and reference types—are introduced into the CTS via type declarations expressed in **metadata**. In addition, metadata is a structured way to represent all information that the CLI uses to locate and load classes, lay out instances in memory, resolve method invocations, translate CIL to native code, enforce security, and set up runtime context boundaries. Every CLI PE/COFF module (see Partition II Metadata – File Format) carries a compact metadata binary that is emitted into the module by the CLI-enabled development tool or compiler.

Each CLI-enabled language will expose a language-appropriate syntax for declaring types and members and for annotating them with attributes that express which services they require of the infrastructure. Type imports are also handled in a language-appropriate way, and it is the development tool or compiler that consumes the metadata to expose the types that the developer sees.

Note that the typical component or application developer will not need to be aware of the rules for emitting and consuming CLI metadata. While it can help a developer to understand the structure of metadata, the rules outlined in this clause are primarily of interest to tool builders and compiler writers.

I.9.1 Components and assemblies

Each CLI component carries the metadata for declarations, implementations, and references specific to that component. Therefore, the component-specific metadata is referred to as **component metadata**, and the resulting component is said to be **self-describing**. In object models such as COM or CORBA, this information is represented by a combination of typelibs, IDL files, DLLRegisterServer, and a myriad of custom files in disparate formats and separate from the actual executable file. In contrast, the metadata is a fundamental part of a CLI component.

Collections of CLI components and other files are packaged together for deployment into **assemblies**, discussed in more detail in a later subclause. An assembly is a logical unit of functionality that serves as the primary unit of reuse in the CLI. Assemblies establish a name scope for types.

Types declared and implemented in individual components are exported for use by other implementations via the assembly in which the component participates. All references to a type are scoped by the identity of the assembly in whose context the type is being used. The CLI provides services to locate a referenced assembly and request resolution of the type reference. It is this mechanism that provides an isolation scope for applications: the assembly alone controls its composition.

I.9.2 Accessing metadata

Metadata is emitted into and read from a CLI module using either direct access to the file format as described in Partition II Metadata – File Format or through the Reflection library. It is possible to create a tool that verifies a CLI module, including the metadata, during development, based on the specifications supplied in Partition II and Partition III.

When a class is loaded at runtime, the CLI loader imports the metadata into its own in-memory data structures, which can be browsed via the CLI Reflection services. The Reflection services should be considered as similar to a compiler; they automatically walk the inheritance hierarchy to obtain information about inherited methods and fields, they have rules about hiding by name or name-and-signature, rules about inheritance of methods and properties, and so forth.

I.9.2.1 Metadata tokens

A metadata token is an implementation-dependent encoding mechanism. Partition II describes the manner in which metadata tokens are embedded in various sections of a CLI PE/COFF module. Metadata tokens are embedded in CIL and native code to encode method invocations and field accesses at call sites; the token is used by various infrastructure services to retrieve information from metadata about the reference and the type on which it was scoped in order to resolve the reference.

A metadata token is a typed identifier of a metadata object (such as type declaration and member declaration). Given a token, its type can be determined and it is possible to retrieve the specific metadata attributes for that metadata object. However, a metadata token is not a persistent identifier. Rather it is scoped to a specific metadata binary. A metadata token is represented as an index into a metadata data structure, so access is fast and direct.

I.9.2.2 Member signatures in metadata

Every location—including fields, parameters, method return values, and properties—has a type, and a specification for its type is carried in metadata.

A value type describes values that are represented as a sequence of bits. A reference type describes values that are represented as the location of a sequence of bits. The CLI provides an explicit set of built-in types, each of which has a default runtime form as either a value type or a reference type. The metadata APIs can be used to declare additional types, and part of the type specification of a variable encodes the identity of the type as well as which form (value or reference) the type is to take at runtime.

Metadata tokens representing encoded types are passed to CIL instructions that accept a type (newobj, newarray, ldtoken). (See the CIL instruction set specification in Partition III.)

These encoded type metadata tokens are also embedded in member signatures. To optimize runtime binding of field accesses and method invocations, the type and location signatures associated with fields and methods are encoded into member signatures in metadata. A member signature embodies all of the contract information that is used to decide whether a reference to a member succeeds or fails.

I.9.3 Unmanaged code

It is possible to pass data from CLI managed code to unmanaged code. This always involves a transition from managed to unmanaged code, which has some runtime cost, but data can often be transferred without copying. When data must be reformatted the VES provides a reasonable specification of default behavior, but it is possible to use metadata to explicitly require other forms of **marshalling** (i.e., reformatted copying). The metadata also allows access to unmanaged methods through implementation-specific pre-existing mechanisms.

I.9.4 Method implementation metadata

For each method for which an implementation is supplied in the current CLI module, the tool or compiler will emit information used by the CIL-to-native code compilers, the CLI loader, and other infrastructure services. This information includes:

- Whether the code is managed or unmanaged.
- Whether the implementation is in native code or CIL (note that all CIL code is managed).
- The location of the method body in the current module, as an address relative to the start of the module file in which it is located (a **Relative Virtual Address**, or **RVA**). Or, alternatively, the RVA is encoded as 0 and other metadata is used to tell the infrastructure where the method implementation will be found, including:
    - A method implementation to be located by implementation-specific means described outside this Standard.
    - Forwarding calls through an imported global static method.

I.9.5 Class layout

In the general case, the CLI loader is free to lay out the instances of a class in any way it chooses, consistent with the rules of the CTS. However, there are times when a tool or compiler needs more control over the layout. In the metadata, a class is marked with an attribute indicating whether its layout rule is:

- **autolayout**: A class marked `autolayout` indicates that the loader is free to lay out the class in any way it sees fit; any layout information that might have been specified is ignored. This is the default.
- **sequentiallayout**: A class marked `sequentiallayout` guides the loader to preserve field order as emitted, but otherwise the specific offsets are calculated based on the CLI type of the field; these can be shifted by explicit offset, padding, and/or alignment information.
- **explicitlayout**: A class marked `explicitlayout` causes the loader to ignore field sequence and to use the explicit layout rules provided, in the form of field offsets and/or overall class size or alignment. There are restrictions on valid layouts, specified in Partition II.

It is also possible to specify an overall size for a class. This enables a tool or compiler to emit a value type specification where only the size of the type is supplied. This is useful in declaring CLI built-in types (such as 32-bit integer). It is also useful in situations where the data type of a member of a structured value type does not have a representation in CLI metadata (e.g., C++ bit fields). In the latter case, as long as the tool or compiler controls the layout, and CLI doesn't need to know the details or play a role in the layout, this is sufficient. Note that this means that the VES can move bits around but can't marshal across machines – the emitting tool or compiler will need to handle the marshaling.

Optionally, a developer can specify a packing size for a class. This is layout information that is not often used, but it allows a developer to control the alignment of the fields. It is not an alignment specification, per se, but rather serves as a modifier that places a ceiling on all alignments. Typical values are 1, 2, 4, 8, or 16. Generic types shall not be marked `explicitlayout`.

For the full specification of class layout attributes, see the classes in `System.Runtime.InteropServices` in Partition IV.

I.9.6 Assemblies: name scopes for types

An assembly is a collection of resources that are built to work together to deliver a cohesive set of functionality. An assembly carries all of the rules necessary to ensure that cohesion. It is the unit of access to resources in the CLI.

Externally, an assembly is a collection of exported resources, including types. Resources are exported by name. Internally, an assembly is a collection of public (exported) and private (internal to the assembly) resources. It is the assembly that determines which resources are to be exported outside of the assembly and which resources are accessible only within the current assembly scope. It is the assembly that controls how a reference to a resource, public or private, is mapped onto the bits that implement the resource. For types in particular, the assembly can also supply runtime configuration information. A CLI module can be thought of as a packaging of type declarations and implementations, where the packaging decisions can change under the covers without affecting clients of the assembly.

The identity of a type is its assembly scope and its declared name. A type defined identically in two different assemblies is considered two different types.

Assembly Dependencies: An assembly can depend on other assemblies. This happens when implementations in the scope of one assembly reference resources that are scoped in or owned by another assembly.

- All references to other assemblies are resolved under the control of the current assembly scope. This gives an assembly an opportunity to control how a reference to another assembly is mapped onto a particular version (or other characteristic) of that

referenced assembly (although that target assembly has sole control over how the referenced resource is resolved to an implementation).

- It is always possible to determine which assembly scope a particular implementation is running in. All requests originating from that assembly scope are resolved relative to that scope.

From a deployment perspective, an assembly can be deployed by itself, with the assumption that any other referenced assemblies will be available in the deployed environment. Or, it can be deployed with its dependent assemblies.

Manifests: Every assembly has a manifest that declares which files make up the assembly, what types are exported, and what other assemblies are required to resolve type references within the assembly. Just as CLI components are self-describing via metadata in the CLI component, so are assemblies self-describing via their manifests. When a single file makes up an assembly it contains both the metadata describing the types defined in the assembly and the metadata describing the assembly itself. When an assembly contains more than one file with metadata, each of the files describes the types defined in the file, if any, and one of these files also contains the metadata describing the assembly (including the names of the other files, their cryptographic hashes, and the types they export outside of the assembly).

Applications: Assemblies introduce isolation semantics for applications. An application is simply an assembly that has an external entry point that triggers (or causes a hosting environment such as a browser to trigger) the creation of a new **application domain**. This entry point is effectively the root of a tree of request invocations and resolutions. Some applications are a single, self-contained assembly. Others require the availability of other assemblies to provide needed resources. In either case, when a request is resolved to a module to load, the module is loaded into the same application domain from which the request originated. It is possible to monitor or stop an application via the application domain.

References: A reference to a type always qualifies a type name with the assembly scope within which the reference is to be resolved; that is, an assembly establishes the name scope of available resources. However, rather than establishing relationships between individual modules and referenced assemblies, every reference is resolved through the current assembly. This allows each assembly to have absolute control over how references are resolved. See Partition II.

I.9.7 Metadata extensibility

CLI metadata is extensible. There are three reasons this is important:

- The CLS is a specification for conventions that languages and tools agree to support in a uniform way for better language integration. The CLS constrains parts of the CTS model, and the CLS introduces higher-level abstractions that are layered over the CTS. It is important that the metadata be able to capture these sorts of development-time abstractions that are used by tools even though they are not recognized or supported explicitly by the CLI.
- It should be possible to represent language-specific abstractions in metadata that are neither CLI nor CLS language abstractions. For example, it should be possible, over time, to enable languages like C++ to not require separate headers or IDL files in order to use types, methods, and data members exported by compiled modules.
- It should be possible, in member signatures, to encode types and type modifiers that are used in language-specific overloading. For example, to allow C++ to distinguish **int** from **long** even on 32-bit machines where both map to the underlying type **int32**.

This extensibility comes in the following forms:

- Every metadata object can carry custom attributes, and the metadata APIs provide a way to declare, enumerate, and retrieve custom attributes. Custom attributes can be identified by a simple name, where the value encoding is opaque and known only to the specific tool, language, or service that defined it. Or, custom attributes can be identified by a type reference, where the structure of the attribute is self-describing (via data members declared on the type) and any tool including the CLI reflection services can browse the value encoding.

CLS Rule 34: The CLS only allows a subset of the encodings of custom attributes. The only types that shall appear in these encodings are (see Partition IV): `System.Type`, `System.String`, `System.Char`, `System.Boolean`, `System.Byte`, `System.Int16`, `System.Int32`, `System.Int64`, `System.Single`, `System.Double`, and any enumeration type based on a CLS-compliant base integer type.

[*Note*:

CLS (consumer): Shall be able to read attributes encoded using the restricted scheme.

CLS (extender): Must meet all requirements for CLS consumer and be able to author new classes and new attributes. Shall be able to attach attributes based on existing attribute classes to any metadata that is emitted. Shall implement the rules for the `System.AttributeUsageAttribute` (see Partition IV).

CLS (framework): Shall externally expose only attributes that are encoded within the CLS rules and following the conventions specified for `System.AttributeUsageAttribute` *end note*]

- In addition to CTS type extensibility, it is possible to emit custom modifiers into member signatures (see Types in Partition II). The CLI will honor these modifiers for purposes of method overloading and hiding, as well as for binding, but will not enforce any of the language-specific semantics. These modifiers can reference the return type or any parameter of a method, or the type of a field. They come in two kinds: **required modifiers** that anyone using the member must understand in order to correctly use it, and **optional modifiers** that can be ignored if the modifier is not understood.

CLS Rule 35: The CLS does not allow publicly visible required modifiers (**modreq**, see Partition II), but does allow optional modifiers (**modopt**, see Partition II) it does not understand.

[*Note*:

CLS (consumer): Shall be able to read metadata containing optional modifiers and correctly copy signatures that include them. Can ignore these modifiers in type matching and overload resolution. Can ignore types that become ambiguous when the optional modifiers are ignored, or that use required modifiers.

CLS (extender): Shall be able to author overrides for inherited methods with signatures that include optional modifiers. Consequently, an extender must be able to copy such modifiers from metadata that it imports. There is no requirement to support required modifiers, nor to author new methods that have any kind of modifier in their signature.

CLS (framework): Shall not use required modifiers in externally visible signatures unless they are marked as not CLS-compliant. Shall not expose two members on a class that differ only by the use of optional modifiers in their signature, unless only one is marked CLS-compliant. *end note*]

I.9.8 Globals, imports, and exports

The CTS does not have the notion of **global statics**: all statics are associated with a particular class. Nonetheless, the metadata is designed to support languages that rely on static data that is stored directly in a PE/COFF file and accessed by its relative virtual address. In addition, while access to managed data and managed functions is mediated entirely through the metadata itself, the metadata provides a mechanism for accessing unmanaged data and unmanaged code.

CLS Rule 36: Global static fields and methods are not CLS-compliant.

[*Note*:

CLS (consumer): Need not support global static fields or methods.

CLS (extender): Need not author global static fields or methods.

CLS (framework): Shall not define global static fields or methods. *end note*]

I.9.9 Scoped statics

The CTS does not include a model for file- or function-scoped static functions or data members. However, there are times when a compiler needs a metadata token to emit into CIL for a scoped function or data member. The metadata allows members to be marked so that they are never visible or accessible outside of the PE/COFF file in which they are declared and for which the compiler guarantees to enforce all access rules.

End informative text

I.10 Name and type rules for the Common Language Specification

I.10.1 Identifiers

Languages that are either case-sensitive or case-insensitive can support the CLS. Since its rules apply only to items exported to other languages, **private** members or types that aren't exported from an assembly can use any names they choose. For interoperation, however, there are some restrictions.

In order to make tools work well with a case-sensitive language it is important that the exact case of identifiers be maintained. At the same time, when dealing with non-English languages encoded in Unicode, there might be more than one way to represent precisely the same identifier that includes combining characters. The CLS requires that identifiers obey the restrictions of the appropriate Unicode standard and they are persisted in Canonical form C, which preserves case but forces combining characters into a standard representation. See CLS Rule 4, in §I.8.5.1.

At the same time, it is important that externally visible names not conflict with one another when used from a case-insensitive programming language. As a result, all identifier comparisons shall be done internally to CLS-compliant tools using the Canonical form KC, which first transforms characters to their case-canonical representation. See CLS Rule 4, in §I.8.5.1.

When a compiler for a CLS-compliant language supports interoperability with a non-CLS-compliant language it must be aware that the CTS and VES perform all comparisons using code-point (i.e., byte-by-byte) comparison. Thus, even though the CLS requires that persisted identifiers be in Canonical form C, references to non-CLS identifiers will have to be persisted using whatever encoding the non-CLS language chose to use. It is a language design issue, not covered by the CTS or the CLS, precisely how this should be handled.

I.10.2 Overloading

[*Note:* Although the CTS describes inheritance, object layout, name hiding, and overriding of virtual methods, it does not discuss overloading at all. While this is surprising, it arises from the fact that overloading is entirely handled by compilers that target the CTS and not the type system itself. In the metadata, all references to types and type members are fully resolved and include the precise signature that is intended. This choice was made since every programming language has its own set of rules for coercing types and the VES does not provide a means for expressing those rules. *end note*]

Following the rules of the CTS, it is possible for duplicate names to be defined in the same scope as long as they differ in either kind (field, method, etc.) or signature. The CLS imposes a stronger restriction for overloading methods. Within a single scope, a given name can refer to any number of methods provided they differ in any of the following:

- Number of parameters
- Type of any parameter

Notice that the signature includes more information, but CLS-compliant languages need not produce or consume classes that differ only by that additional information (see Partition II for the complete list of information carried in a signature):

- Calling convention
- Custom modifiers
- Return type
- Whether a parameter is passed by value or by reference

There is one exception to this rule. For the special names `op_Implicit` and `op_Explicit`, described in §I.10.3.3, methods can be provided that differ only by their return type. These are marked specially and can be ignored by compilers that don't support operator overloading.

Properties shall not be overloaded by type (that is, by the return type of their `getter` method), but they can be overloaded with different number or types of indices (that is, by the number and types of the parameters of their **getter** methods). The overloading rules for properties are identical to the method overloading rules.

CLS Rule 37: Only properties and methods can be overloaded.

CLS Rule 38: Properties and methods can be overloaded based only on the number and types of their parameters, except the conversion operators named `op_Implicit` and `op_Explicit`, which can also be overloaded based on their return type.

[*Note*:

CLS (consumer): Can assume that only properties and methods are overloaded, and need not support overloading based on return type unless providing special syntax for operator overloading. If return type overloading isn't supported, then the `op_Implicit` and `op_Explicit` can be ignored since the functionality shall be provided in some other way by a CLS-compliant framework. Consumers must first apply the hide-by-name and hide-by-signature-and-name rules (§I.8.10.4) to avoid any ambiguity.

CLS (extender): Should not permit the authoring of overloads other than those specified here. It is not necessary to support operator overloading at all, hence it is possible to entirely avoid support for overloading on return type.

CLS (framework): Shall not publicly expose overloading except as specified here. Frameworks authors should bear in mind that many programming languages, including object-oriented languages, do not support overloading and will expose overloaded methods or properties through mangled names. Most languages support neither operator overloading nor overloading based on return type, so `op_Implicit` and `op_Explicit` shall always be augmented with some alternative way to gain the same functionality. *end note*]

[*Note*: The names visible on any class `C`, are the names visible in that class and its base classes. As a consequence, the names of methods on interfaces implemented by `C` that are only implemented via MethodImpls (see Partition II) are not visible on class `C`. The names visible on an interface `I`, consist only of the names directly defined on this interface. As a consequence, the names of methods from other interfaces (which `I` requires be implemented) are not visible on `I` itself. *end note*]

I.10.3 Operator overloading

CLS-compliant consumer and extender tools are under no obligation to allow defining of operator overloading. CLS-compliant consumer and extender tools do not have to provide a special mechanism to call these methods.

[*Note:* This topic is addressed by the CLS so that

- languages that do provide operator overloading can describe their rules in a way that other languages can understand, and
- languages that do not provide operator overloading can still access the underlying functionality without the addition of special syntax.

end note]

Operator overloading is described by using the names specified below, and by setting a special bit in the metadata (**SpecialName**) so that they do not collide with the user's name space. A CLS-compliant producer tool shall provide some means for setting this bit. If these names are used, they shall have precisely the semantics described here.

I.10.3.1 Unary operators

Unary operators take one operand, perform some operation on it, and return the result. They are represented as static methods on the class that defines the type of their one operand. Table I.4: Unary Operator Names shows the names that are defined.

Table I.4: Unary Operator Names

Name	**ISO/IEC 14882:2003 C++ Operator Symbol** (This column is informative.)
`op_Decrement`	`Similar to --`[1]
`op_Increment`	`Similar to ++`[1]
`op_UnaryNegation`	`- (unary)`

op_UnaryPlus	+ (unary)
op_LogicalNot	!
op_True[2]	Not defined
op_False[2]	Not defined
op_AddressOf	& (unary)
op_OnesComplement	~
op_PointerDereference	* (unary)

[1] From a pure C++ point of view, the way one must write these functions for the CLI differs in one very important aspect. In C++, these methods must increment or decrement their operand directly, whereas, in CLI, they must not; instead, they simply return the value of their operand +/- 1, as appropriate, without modifying their operand. The operand must be incremented or decremented by the compiler that generates the code for the ++/-- operator, separate from the call to these methods.

[2] The op_True and op_False operators do not exist in C++. They are provided to support tri-state Boolean types, such as those used in database languages.

I.10.3.2 Binary operators

Binary operators take two operands, perform some operation on them, and return a value. They are represented as static methods on the class that defines the type of one of their two operands. Table I.5: Binary Operator Names shows the names that are defined.

Table I.5: Binary Operator Names

Name	**ISO/IEC 14882:2003 C++ Operator Symbol** (This column is informative.)
op_Addition	+ (binary)
op_Subtraction	- (binary)
op_Multiply	* (binary)
op_Division	/
op_Modulus	%
op_ExclusiveOr	^
op_BitwiseAnd	& (binary)
op_BitwiseOr	|
op_LogicalAnd	&&
op_LogicalOr	||
op_Assign	Not defined (= is not the same)
op_LeftShift	<<
op_RightShift	>>
op_SignedRightShift	Not defined
op_UnsignedRightShift	Not defined
op_Equality	==
op_GreaterThan	>
op_LessThan	<
op_Inequality	!=
op_GreaterThanOrEqual	>=
op_LessThanOrEqual	<=
op_UnsignedRightShiftAssignment	Not defined
op_MemberSelection	->
op_RightShiftAssignment	>>=

op_MultiplicationAssignment	*=
op_PointerToMemberSelection	->*
op_SubtractionAssignment	-=
op_ExclusiveOrAssignment	^=
op_LeftShiftAssignment	<<=
op_ModulusAssignment	%=
op_AdditionAssignment	+=
op_BitwiseAndAssignment	&=
op_BitwiseOrAssignment	|=
op_Comma	,
op_DivisionAssignment	/=

I.10.3.3 Conversion operators

Conversion operators are unary operations that allow conversion from one type to another. The operator method shall be defined as a static method on either the operand or return type. There are two types of conversions:

- An implicit (**widening**) coercion shall not lose any magnitude or precision. These should be provided using a method named `op_Implicit`.
- An explicit (**narrowing**) coercion can lose magnitude or precision. These should be provided using a method named `op_Explicit`.

[*Note:* Conversions provide functionality that can't be generated in other ways, and many languages do not support the use of the conversion operators through special syntax. Therefore, CLS rules require that the same functionality be made available through an alternate mechanism. It is recommended that the more common ToXxx (where Xxx is the target type) and FromYyy (where Yyy is the name of the source type) naming pattern be used. *end note*]

Because these operations can exist on the class of their operand type (so-called "from" conversions) and would therefore differ on their return type only, the CLS specifically allows that these two operators be overloaded based on their return type. The CLS, however, also requires that if this form of overloading is used then the language shall provide an alternate means for providing the same functionality since not all CLS languages will implement operators with special syntax.

CLS Rule 39: If either `op_Implicit` or `op_Explicit` is provided, an alternate means of providing the coercion shall be provided.

[*Note*:

CLS (consumer): Where appropriate to the language design, use the existence of `op_Implicit` and/or `op_Explicit` in choosing method overloads and generating automatic coercions.

CLS (extender): Where appropriate to the language design, implement user-defined implicit or explicit coercion operators using the corresponding `op_Implicit`, `op_Explicit`, `ToXxx`, and/or `FromXxx` methods.

CLS (framework): If coercion operations are supported, they shall be provided as `FromXxx` and `ToXxx`, and optionally `op_Implicit` and `op_Explicit` as well. CLS frameworks are encouraged to provide such coercion operations. *end note*]

I.10.4 Naming patterns

See also Partition VI.

While the CTS does not dictate the naming of properties or events, the CLS does specify a pattern to be observed.

For Events:

An individual event is created by choosing or defining a delegate type that is used to indicate the event. Then, three methods are created with names based on the name of the event and with a fixed signature. For the examples below we define an event named `Click` that uses a delegate type named `EventHandler`.

```
EventAdd, used to add a handler for an event
        Pattern: void add_<EventName> (<DelegateType> handler)
        Example: void add_Click (EventHandler handler);

EventRemove, used to remove a handler for an event
        Pattern: void remove_<EventName> (<DelegateType> handler)
        Example: void remove_Click (EventHandler handler);

EventRaise, used to indicate that an event has occurred
        Pattern: void family raise_<EventName> (Event e)
```

For Properties:

An individual property is created by deciding on the type returned by its getter method and the types of the getter's parameters (if any). Then, two methods are created with names based on the name of the property and these types. For the examples below we define two properties: `Name` takes no parameters and returns a `System.String`, while `Item` takes a `System.Object` parameter and returns a `System.Object`. `Item` is referred to as an indexed property, meaning that it takes parameters and thus can appear to the user as through it were an array with indices.

```
PropertyGet, used to read the value of the property
        Pattern: <PropType> get_<PropName> (<Indices>)
        Example: System.String get_Name ();
        Example: System.Object get_Item (System.Object key);

PropertySet, used to modify the value of the property
        Pattern: void set_<PropName> (<Indices>, <PropType>)
        Example: void set_Name (System.String name);
        Example: void set_Item (System.Object key, System.Object
value);
```

I.10.5 Exceptions

The CLI supports an exception handling model, which is introduced in §I.12.4.2. CLS-compliant frameworks can define and throw externally visible exceptions, but there are restrictions on the type of objects thrown:

CLS Rule 40: Objects that are thrown shall be of type `System.Exception` or a type inheriting from it. Nonetheless, CLS-compliant methods are not required to block the propagation of other types of exceptions.

[*Note*:

CLS (consumer): Need not support throwing or catching of objects that are not of the specified type.

CLS (extender): Must support throwing of objects of type `System.Exception` or a type inheriting from it. Need not support the throwing of objects having other types.

CLS (framework): Shall not publicly expose thrown objects that are not of type `System.Exception` or a type inheriting from it. *end note*]

I.10.6 Custom attributes

In order to allow languages to provide a consistent view of custom attributes across language boundaries, the Base Class Library provides support for the following rule defined by the CLS:

CLS Rule 41: Attributes shall be of type `System.Attribute`, or a type inheriting from it.

[*Note*:

CLS (consumer): Need not support attributes that are not of the specified type.

CLS (extender): Must support the authoring of custom attributes.

CLS (framework): Shall not publicly expose attributes that are not of type `System.Attribute` or a type inheriting from it. *end note*]

The use of a particular attribute class can be restricted in various ways by placing an attribute on the attribute class. The `System.AttributeUsageAttribute` is used to specify these restrictions. The restrictions supported by the `System.AttributeUsageAttribute` are:

- What kinds of constructs (types, methods, assemblies, etc.) can have the attribute applied to them. By default, instances of an attribute class can be applied to any construct. This is specified by setting the value of the `ValidOn` property of `System.AttributeUsageAttribute`. Several constructs can be combined.
- Multiple instances of the attribute class can be applied to a given piece of metadata. By default, only one instance of any given attribute class can be applied to a single metadata item. The `AllowMultiple` property of the attribute is used to specify the desired value.
- Do not inherit the attribute when applied to a type. By default, any attribute attached to a type should be inherited to types that derive from it. If multiple instances of the attribute class are allowed, the inheritance performs a union of the attributes inherited from the base class and those explicitly applied to the derived class type. If multiple instances are not allowed, then an attribute of that type applied directly to the derived class overrides the attribute supplied by the base class. This is specified by setting the `Inherited` property of `System.AttributeUsageAttribute` to the desired value.

[*Note:* Since these are CLS rules and not part of the CTS itself, tools are required to specify explicitly the custom attributes they intend to apply to any given metadata item. That is, compilers or other tools that generate metadata must implement the `AllowMultiple` and `Inherit` rules. The CLI does not supply attributes automatically. The usage of attributes in the CLI is further described in Partition II. *end note*]

I.10.7 Generic types and methods

The following subclauses describe the CLS rules for generic types and methods.

I.10.7.1 Nested type parameter re-declaration

Any type exported by a CLS-compliant framework, that is nested in a generic type, itself declares, by position, all the generic parameters of that enclosing type. (The nested type can also introduce new generic parameters.) As such, any CLS-compliant type nested inside a generic type is itself generic. Such redeclared generic parameters shall precede any newly introduced generic parameters. [*Example:* Consider the following C# source code:

```
public class A<T> {
  public class B {}
  public class C<U,V> {
    public class D<W> {}
  }
}
public class X {
  public class Y<T> {}
}
```

The relevant corresponding ILAsm code is:

```
.class … A`1<T> … {                          // T is introduced
  .class … nested … B<T> … { }               // T is redeclared
  .class … nested … C`2<T,U,V> … {           // T is redeclared; U and V are
introduced
    .class … nested … D`1<T,U,V,W> … { }     // T, U, and V are redeclared; W
is introduced
  }
}

.class … X … {
  .class … nested Y`1<T> … { }               // Nothing is redeclared; T is
introduced
}
```

As generic parameter re-declaration is based on parameter position matching, not on parameter name matching, the name of a redeclared generic parameter need not be the same as the one it re-declares. For example:

```
.class … A`1<T> … {                                  // T is introduced
  .class … nested … B<Q> … { }                       // T is redeclared (as Q)
  .class … nested … C`2<T1,U,V> … {                  // T is redeclared (as T1); U and
V
                                                     // are introduced
    .class … nested … D`1<R1,R2,R3,W> … { }          // T1, U, and V are redeclared (as
R1, R2,
                                                     // and R3); W is introduced
  }
}
```

A CLS-compliant Framework should therefore expose the following types:

Lexical Name	Total Generic Parameters	Redeclared Generic Parameters	Introduced Generic Parameters
A<T>	1 (T)	0	1 T
A<T>.B	1 (T)	1 T	0
A<T>.C<U,V>	3 (T,U,V)	1 T	2 U,V
A<T>.C<U,V>.D<W>	4 (T,U,V,W)	3 T,U,V	1 W
X	0	0	0
X.Y<T>	1 (T)	0	1 T

end example]

CLS Rule 42: Nested types shall have at least as many generic parameters as the enclosing type. Generic parameters in a nested type correspond by position to the generic parameters in its enclosing type.

[*Note*:

CLS (consumer): Need not consume types that violate this rule.

CLS (extender): Same as consumers. Extenders choosing to support definition of types nested in generic types shall follow this rule for externally visible types.

CLS (framework): Shall not expose types that violate this rule. *end note*]

I.10.7.2 Type names and arity encoding

CLS-compliant generic type names are encoded using the format "*name*[**`***arity*]" , where **[**…**]** indicates that the grave accent character "`" and *arity* together are optional. The encoded name shall follow these rules:

1. *name* shall be an *ID* (see Partition II) that does not contain the "`" character.

2. *arity* is specified as an unsigned decimal number without leading zeros or spaces.

3. For a normal generic type, *arity* is the number of type parameters declared on the type.

4. For a nested generic type, *arity* is the number of newly introduced type parameters.

[*Example:* Consider the following C# source code:

```
public class A<T> {
  public class B {}
  public class C<U,V> {
    public class D<W> {}
  }
}

public class X {
  public class Y<T> {}
}
```

The relevant corresponding ILAsm code is:

```
.class … A`1<T> … {                              // T is introduced
  .class … nested … B<T> … { }                   // T is redeclared
  .class … nested … C`2<T,U,V> … {               // T is redeclared; U and V are
introduced
    .class … nested … D`1<T,U,V,W> … { }         // T, U, and V are redeclared; W
is introduced
  }
}

.class … X … {
  .class … nested Y`1<T> … { }                   // Nothing is redeclared; T is
introduced
}
```

A CLS-compliant Framework should expose the following types:

Lexical Name	Total Generic Parameters	Redeclared Generic Parameters	Introduced Generic Parameters	Metadata Encoding
A<T>	1 (T)	0	1 T	A`1
A<T>.B	1 (T)	1 T	0	B
A<T>.C<U,V>	3 (T,U,V)	1 T	2 U,V	C`2
A<T>.C<U,V>.D<W>	4 (T,U,V,W)	3 T,U,V	1 W	D`1
X	0	0	0	X
X.Y<T>	1 (T)	0	1 T	Y`1

While a type name encoded in metadata does not explicitly mention its enclosing type, the CIL and Reflection type name grammars do include this detail:

Lexical Name	Metadata Encoding	CIL	Reflection
A<T>	A`1	A`1	A`1[T]
A<T>.B	B	A`1/B	A`1+B[T]
A<T>.C<U,V>	C`2	A`1/C`2	A`1+C`2[T,U,V]
A<T>.C<U,V>.D<W>	D`1	A`1/C`2/D`1	A`1+C`2+D`1[T,U,V,W]
X	X	X	X
X.Y<T>	Y`1	X/Y`1	X+Y`1[T]

end example]

CLS Rule 43: The name of a generic type shall encode the number of type parameters declared on the non-nested type, or newly introduced to the type if nested, according to the rules defined above.

[*Note*:

CLS (consumer): Need not consume types that violate this rule.

CLS (extender): Same as consumers. Extenders choosing to support definition of generic types shall follow this rule for externally visible types.

CLS (framework): Shall not expose types that violate this rule. *end note*]

I.10.7.3 Type constraint re-declaration

CLS Frameworks shall ensure that a generic type explicitly re-declares any constraints present on generic parameters in its base class and all implemented interfaces. Put another way, CLS Extenders and Consumers should be able to examine just the specific type in question, to determine the set of constraints that need to be satisfied.

CLS Rule 44: A generic type shall redeclare sufficient constraints to guarantee that any constraints on the base type, or interfaces would be satisfied by the generic type constraints.

[*Note*:

CLS (consumer): Need not consume types that violate this rule. Consumers who check constraints need only look at the type being instantiated to determine the applicable constraints.

CLS (extender): Same as consumers. Extenders choosing to support definition of generic types shall follow this rule.

CLS (framework): Shall not expose types that violate this rule. *end note*]

I.10.7.4 Constraint type restrictions

CLS Rule 45: Types used as constraints on generic parameters shall themselves be CLS-compliant.

[*Note*:

CLS (consumer): Need not consume types that violate this rule.

CLS (extender): Same as consumers. Extenders choosing to support definition of generic types shall follow this rule when checking for CLS compliance, and need not provide syntax to violate this rule.

CLS (framework): Shall not expose types that violate this rule. *end note*]

I.10.7.5 Frameworks and accessibility of nested types

CLI generics treat the generic type declaration and all instantiations of that generic type as having the same accessibility scope. However, language accessibility rules may differ in this regard, with some choosing to follow the CLI accessibility model, while others use a more restrictive, per-instantiation model. To enable consumption by all CLS languages, CLS frameworks shall be designed with a conservative per-instantiation model of accessibility in mind, and not expose nested types or require access to protected members based on specific, alternate instantiations of a generic type.

This has implications for signatures containing nested types with **family** accessibility. Open generic types shall not expose fields or members with signatures containing a specific instantiation of a nested generic type with family accessibility. Non-generic types extending a specific instantiation of a generic base class or interface, shall not expose fields or members with signatures containing a different instantiation of a nested generic type with family accessibility. [*Example:* Consider the following C# source code:

```
public class C<T> {
  protected class N {…}
  protected void M1(C<int>.N n) {…}   // Not CLS-compliant - C<int>.N not
                                      // accessible from within C<T> in all
languages
  protected void M2(C<T>.N n) {…}     // CLS-compliant – C<T>.N accessible
inside C<T>
}

public class D : C<long> {
  protected void M3(C<int>.N n) {…}   // Not CLS-compliant – C<int>.N is not
                                      // accessible in D (extends C<long>)
  protected void M4(C<long>.N n) {…}  // CLS-compliant, C<long>.N is
                                      // accessible in D (extends C<long>)
}
```

The relevant corresponding ILASM code is:

```
.class public … C`1<T> … {
  .class … nested … N<T> … {}
  .method family hidebysig instance void  M1(class C`1/N<int32> n) … {}
  // Not CLS-compliant - C<int>.N is not accessible from within C<T> in all
languages

  .method family hidebysig instance void  M2(class C`1/N<!0> n) … {}
  // CLS-compliant – C<T>.N is accessible inside C<T>
}
```

```
.class public … D extends class C`1<int64> {
  .method family hidebysig instance void  M3(class C`1/N<int32> n) … {}
  // Not CLS-compliant – C<int>.N is not accessible in D (extends C<long>)

  .method family hidebysig instance void  M4(class C`1/N<int64> n) … {}
  // CLS-compliant, C<long>.N is accessible in D (extends C<long>)
}
```

end example]

CLS Rule 46: The visibility and accessibility of members (including nested types) in an instantiated generic type shall be considered to be scoped to the specific instantiation rather than the generic type declaration as a whole. Assuming this, the visibility and accessibility rules of CLS rule 12 still apply.

[*Note*:

CLS (consumer): Need not consume types that violate this rule.

CLS (extender): Shall use this more restrictive notion of accessibility when determining CLS compliance.

CLS (framework): Shall not expose members that violate this rule. *end note*]

I.10.7.6 Frameworks and abstract or virtual methods

CLS Frameworks shall not expose libraries that require CLS Extenders to override or implement generic methods to use the framework. This does not imply that virtual or abstract generic methods are non-compliant; rather, the framework shall also provide concrete implementations with appropriate default behavior.

CLS Rule 47: For each abstract or virtual generic method, there shall be a default concrete (non-abstract) implementation.

[*Note*:

CLS (consumer): No impact.

CLS (extender): Need not provide syntax for overriding generic methods.

CLS (framework): Shall not expose generic methods that violate this rule without also providing appropriate concrete implementations. *end note*]

I.11 Collected Common Language Specification rules

The complete set of CLS rules are collected here for reference. Recall that these rules apply only to "externally visible" items—types that are visible outside of their own assembly and members of those types that have `public`, `family`, or `family-or-assembly` accessibility. Furthermore, items can be explicitly marked as CLS-compliant or not using the `System.CLSCompliantAttribute`. The CLS rules apply only to items that are marked as CLS-compliant.

CLS Rule 1: CLS rules apply only to those parts of a type that are accessible or visible outside of the defining assembly. (§I.7.3)

CLS Rule 2: Members of non-CLS compliant types shall not be marked CLS-compliant. (§I.7.3.1)

CLS Rule 3: Boxed value types are not CLS-compliant. (§I.8.2.4.)

CLS Rule 4: Assemblies shall follow Annex 7 of Technical Report 15 of the Unicode Standard 3.0 governing the set of characters permitted to start and be included in identifiers, available on-line at http://www.unicode.org/unicode/reports/tr15/tr15-18.html. Identifiers shall be in the canonical format defined by Unicode Normalization Form C. For CLS purposes, two identifiers are the same if their lowercase mappings (as specified by the Unicode locale-insensitive, one-to-one lowercase mappings) are the same. That is, for two identifiers to be considered different under the CLS they shall differ in more than simply their case. However, in order to override an inherited definition the CLI requires the precise encoding of the original declaration be used. (§I.8.5.1)

CLS Rule 5: All names introduced in a CLS-compliant scope shall be distinct independent of kind, except where the names are identical and resolved via overloading. That is, while the CTS allows a single type to use the same name for a method and a field, the CLS does not. (§I.8.5.2)

CLS Rule 6: Fields and nested types shall be distinct by identifier comparison alone, even though the CTS allows distinct signatures to be distinguished. Methods, properties, and events that have the same name (by identifier comparison) shall differ by more than just the return type, except as specified in CLS Rule 39. (§I.8.5.2)

CLS Rule 7: The underlying type of an enum shall be a built-in CLS integer type, the name of the field shall be "value__", and that field shall be marked RTSpecialName. (§I.8.5.2)

CLS Rule 8: There are two distinct kinds of enums, indicated by the presence or absence of the System.FlagsAttribute (see Partition IV Library) custom attribute. One represents named integer values; the other represents named bit flags that can be combined to generate an unnamed value. The value of an enum is not limited to the specified values. (§I.8.5.2)

CLS Rule 9: Literal static fields (see §I.8.6.1) of an enum shall have the type of the enum itself. (§I.8.5.2)

CLS Rule 10: Accessibility shall not be changed when overriding inherited methods, except when overriding a method inherited from a different assembly with accessibility family-or-assembly. In this case, the override shall have accessibility family. (§I.8.5.3.2)

CLS Rule 11: All types appearing in a signature shall be CLS-compliant. All types composing an instantiated generic type shall be CLS-compliant. (§I.8.6.1)

CLS Rule 12: The visibility and accessibility of types and members shall be such that types in the signature of any member shall be visible and accessible whenever the member itself is visible and accessible. For example, a public method that is visible outside its assembly shall not have an argument whose type is visible only within the assembly. The visibility and accessibility of types composing an instantiated generic type used in the signature of any member shall be visible and accessible whenever the member itself is visible and accessible. For example, an instantiated generic type present in the signature of a member that is visible outside its assembly shall not have a generic argument whose type is visible only within the assembly. (§I.8.6.1)

CLS Rule 13: The value of a literal static is specified through the use of field initialization metadata (see Partition II Metadata). A CLS-compliant literal must have a value specified in field initialization metadata that is of exactly the same type as the literal (or of the underlying type, if that literal is an enum). (§I.8.6.1.2)

CLS Rule 14: Typed references are not CLS-compliant. (§I.8.6.1.3)

CLS Rule 15: The vararg constraint is not part of the CLS, and the only calling convention supported by the CLS is the standard managed calling convention. (§I.8.6.1.5)

CLS Rule 16: Arrays shall have elements with a CLS-compliant type, and all dimensions of the array shall have lower bounds of zero. Only the fact that an item is an array and the element type of the array shall be required to distinguish between overloads. When overloading is based on two or more array types the element types shall be named types. (§I.8.9.1)

CLS Rule 17: Unmanaged pointer types are not CLS-compliant. (§I.8.9.2)

CLS Rule 18: CLS-compliant interfaces shall not require the definition of non-CLS compliant methods in order to implement them. (§I.8.9.4)

CLS Rule 19: CLS-compliant interfaces shall not define static methods, nor shall they define fields. (§I.8.9.4)

CLS Rule 20: CLS-compliant classes, value types, and interfaces shall not require the implementation of non-CLS-compliant members. (§I.8.9.6.4)

CLS Rule 21: An object constructor shall call some instance constructor of its base class before any access occurs to inherited instance data. (This does not apply to value types, which need not have constructors.) (§I.8.9.6.6)

CLS Rule 22: An object constructor shall not be called except as part of the creation of an object, and an object shall not be initialized twice. (§I.8.9.6.6)

CLS Rule 23: System.Object is CLS-compliant. Any other CLS-compliant class shall inherit from a CLS-compliant class. (§I.8.9.9)

CLS Rule 24: The methods that implement the getter and setter methods of a property shall be marked SpecialName in the metadata. (§I.8.11.3)

CLS Rule 25: No longer used. [*Note*: In an earlier version of this standard, this rule stated "The accessibility of a property and of its accessors shall be identical." The removal of this rule allows, for example, public access to a getter while restricting access to the setter. *end note*] (§I.8.11.3)

CLS Rule 26: A property's accessors shall all be static, all be virtual, or all be instance. (§I.8.11.3)

CLS Rule 27: The type of a property shall be the return type of the getter and the type of the last argument of the setter. The types of the parameters of the property shall be the types of the parameters to the getter and the types of all but the final parameter of the setter. All of these types shall be CLS-compliant, and shall not be managed pointers (i.e., shall not be passed by reference). (§I.8.11.3)

CLS Rule 28: Properties shall adhere to a specific naming pattern. See §I.10.4. The SpecialName attribute referred to in CLS rule 24 shall be ignored in appropriate name comparisons and shall adhere to identifier rules. A property shall have a getter method, a setter method, or both. (§I.8.11.3)

CLS Rule 29: The methods that implement an event shall be marked SpecialName in the metadata. (§I.8.11.4)

CLS Rule 30: The accessibility of an event and of its accessors shall be identical. (§I.8.11.4)

CLS Rule 31: The add and remove methods for an event shall both either be present or absent. (§I.8.11.4)

CLS Rule 32: The add and remove methods for an event shall each take one parameter whose type defines the type of the event and that shall be derived from System.Delegate. (§I.8.11.4)

CLS Rule 33: Events shall adhere to a specific naming pattern. See §I.10.4. The SpecialName attribute referred to in CLS rule 29 shall be ignored in appropriate name comparisons and shall adhere to identifier rules. (§I.8.11.4)

CLS Rule 34: The CLS only allows a subset of the encodings of custom attributes. The only types that shall appear in these encodings are (see Partition IV): System.Type, System.String, System.Char, System.Boolean, System.Byte, System.Int16, System.Int32, System.Int64, System.Single, System.Double, and any enumeration type based on a CLS-compliant base integer type. (§I.9.7)

CLS Rule 35: The CLS does not allow publicly visible required modifiers (modreq, see Partition II), but does allow optional modifiers (modopt, see Partition II) it does not understand. (§I.9.7)

CLS Rule 36: Global static fields and methods are not CLS-compliant. (§I.9.8)

CLS Rule 37: Only properties and methods can be overloaded. (§I.10.2)

CLS Rule 38: Properties and methods can be overloaded based only on the number and types of their parameters, except the conversion operators named op_Implicit and op_Explicit, which can also be overloaded based on their return type. (§I.10.2)

CLS Rule 39: If either op_Implicit or op_Explicit is provided, an alternate means of providing the coercion shall be provided. (§I.10.3.3)

CLS Rule 40: Objects that are thrown shall be of type System.Exception or a type inheriting from it. Nonetheless, CLS-compliant methods are not required to block the propagation of other types of exceptions. (§I.10.5)

CLS Rule 41: Attributes shall be of type System.Attribute, or a type inheriting from it. (§I.10.6)

CLS Rule 42: Nested types shall have at least as many generic parameters as the enclosing type. Generic parameters in a nested type correspond by position to the generic parameters in its enclosing type. (§I.10.7.1)

CLS Rule 43: The name of a generic type shall encode the number of type parameters declared on the non-nested type, or newly introduced to the type if nested, according to the rules defined above. (§I.10.7.2)

CLS Rule 44: A generic type shall redeclare sufficient constraints to guarantee that any constraints on the base type, or interfaces would be satisfied by the generic type constraints. (§I.10.7.3)

CLS Rule 45: Types used as constraints on generic parameters shall themselves be CLS-compliant. (§I.10.7.4)

CLS Rule 46: The visibility and accessibility of members (including nested types) in an instantiated generic type shall be considered to be scoped to the specific instantiation rather than the generic type declaration as a whole. Assuming this, the visibility and accessibility rules of CLS rule 12 still apply. (§I.10.7.5)

CLS Rule 47: For each abstract or virtual generic method, there shall be a default concrete (non-abstract) implementation. (§I.10.7.6)

CLS Rule 48: If two or more CLS-compliant methods declared in a type have the same name and, for a specific set of type instantiations, they have the same parameter and return types, then all these methods shall be semantically equivalent at those type instantiations. (§I.7.2.1)

I.12 Virtual Execution System

The Virtual Execution System (VES) provides an environment for executing managed code. It provides direct support for a set of built-in data types, defines a hypothetical machine with an associated machine model and state, a set of control flow constructs, and an exception handling model. To a large extent, the purpose of the VES is to provide the support required to execute the CIL instruction set (see Partition III).

I.12.1 Supported data types

The CLI directly supports the data types shown in Table I.6: Data Types Directly Supported by the CLI. That is, these data types can be manipulated using the CIL instruction set (see Partition III).

Table I.6: Data Types Directly Supported by the CLI

Data Type	Description
`int8`	8-bit two's-complement signed value
`unsigned int8`	8-bit unsigned binary value
`int16`	16-bit two's-complement signed value
`unsigned int16`	16-bit unsigned binary value
`int32`	32-bit two's-complement signed value
`unsigned int32`	32-bit unsigned binary value
`int64`	64-bit two's-complement signed value
`unsigned int64`	64-bit unsigned binary value
`float32`	32-bit IEC 60559:1989 floating-point value
`float64`	64-bit IEC 60559:1989 floating-point value
`native int`	native size two's-complement signed value
`native unsigned int`	native size unsigned binary value, also unmanaged pointer
`F`	native size floating-point number (internal to VES, not user visible)
`O`	native size object reference to managed memory
`&`	native size managed pointer (can point into managed memory)

The CLI model uses an evaluation stack. Instructions that copy values from memory to the evaluation stack are "loads"; instructions that copy values from the stack back to memory are "stores". The full set of data types in Table I.6: Data Types Directly Supported by the CLI can be represented in memory. However, the CLI supports only a subset of these types in its operations upon values stored on its evaluation stack—`int32`, `int64`, and `native int`. In addition, the CLI supports an internal data type to represent floating-point values on the internal evaluation stack. The size of the internal data type is implementation-dependent. For further information on the treatment of floating-point values on the evaluation stack, see §I.12.1.3 and Partition III. Short numeric values (`int8`, `int16`, `unsigned int8`, and `unsigned int16`) are widened when loaded and narrowed when stored. This reflects a computer model that assumes, for numeric and object references, memory cells are 1, 2, 4, or 8 bytes wide, but stack locations are either 4 or 8 bytes wide. User-defined value types can appear in memory locations or on the stack and have no size limitation; the only built-in operations on them are those that compute their address and copy them between the stack and memory.

The only CIL instructions with special support for short numeric values (rather than support for simply the 4- or 8-byte integral values) are:

- Load and store instructions to/from memory: ldelem, ldind, stelem, stind
- Data conversion: conv, conv.ovf
- Array creation: newarr

The signed integer types (`int8`, `int16`, `int32`, `int64`, and `native int`) and their corresponding unsigned integer types (`unsigned int8`, `unsigned int16`, `unsigned int32`, `unsigned int64`, and `native unsigned int`) differ only in how the bits of the integer are interpreted. For those operations in which an unsigned integer is treated differently from a signed integer (e.g., in comparisons or arithmetic with overflow) there are separate instructions for treating an integer as unsigned (e.g., cgt.un and add.ovf.un).

This instruction set design simplifies CIL-to-native code (e.g., JIT) compilers and interpreters of CIL by allowing them to internally track a smaller number of data types. See §I.12.3.2.1.

As described below, CIL instructions do not specify their operand types. Instead, the CLI keeps track of operand types based on data flow and aided by a stack consistency requirement described below. For example, the single add instruction will add two integers or two floats from the stack.

I.12.1.1 Native size: native int, native unsigned int, O and &

The native-size types (`native int`, `native unsigned int`, `O`, and `&`) are a mechanism in the CLI for deferring the choice of a value's size. These data types exist as CIL types; however, the CLI maps each to the native size for a specific processor. (For example, data type I would map to `int32` on a Pentium processor, but to `int64` on an IA64 processor.) So, the choice of size is deferred until JIT compilation or runtime, when the CLI has been initialized and the architecture is known. This implies that field and stack frame offsets are also not known at compile time. For languages like Visual Basic, where field offsets are not computed early anyway, this is not a hardship. In languages like C or C++, where sizes must be known when source code is compiled, a conservative assumption that they occupy 8 bytes is sometimes acceptable (for example, when laying out compile-time storage).

I.12.1.1.1 Unmanaged pointers as type native unsigned int

[*Rationale:* For languages like C, when compiling all the way to native code, where the size of a pointer is known at compile time and there are no managed objects, the fixed-size unsigned integer types (`unsigned int32` or `unsigned int64`) can serve as pointers. However choosing pointer size at compile time has its disadvantages. If pointers were chosen to be 32- bit quantities at compile time, the code would be restricted to 4 gigabytes of address space, even if it were run on a 64-bit machine. Moreover, a 64-bit CLI would need to take special care so those pointers passed back to 32-bit code would always fit in 32 bits. If pointers were chosen at compile time to be 64 bits, the code would run on a 32-bit machine, but pointers in every data structure would be twice as large as necessary on that CLI.

For other languages, where the size of a data type need not be known at compile time, it is desirable to defer the choice of pointer size from compile time to CLI initialization time. In that way, the same CIL code can handle large address spaces for those applications that need them, while also being able to reap the size benefit of 32-bit pointers for those applications that do not need a large address space. *end rationale*]

The `native unsigned int` type is used to represent unmanaged pointers with the VES. The metadata allows unmanaged pointers to be represented in a strongly typed manner, but these types are translated into type `native unsigned int` for use by the VES.

I.12.1.1.2 Object reference and managed pointer types: O and &

The `O` data type represents an object reference that is managed by the CLI. As such, the number of specified operations is severely limited. In particular, references shall only be used on operations that indicate that they operate on reference types (e.g., ceq and ldind.ref), or on operations whose metadata indicates that references are allowed (e.g., call, ldsfld, and stfld).

The `&` data type (managed pointer) is similar to the `O` type, but points to the interior of an object. That is, a managed pointer is allowed to point to a field within an object or an element within an array, rather than to point to the 'start' of object or array.

Object references (`O`) and managed pointers (`&`) can be changed during garbage collection, since the data to which they refer might be moved.

[*Note:* In summary, object references, or `O` types, refer to the 'outside' of an object, or to an object as-a-whole. But managed pointers, or `&` types, refer to the interior of an object. The

`&` types are sometimes called "byref types" in source languages, since passing a field of an object by reference is represented in the VES by using an `&` type to represent the type of the parameter. *end note*]

In order to allow managed pointers to be used more flexibly, they are also permitted to point to areas that aren't under the control of the CLI garbage collector, such as the evaluation stack, static variables, and unmanaged memory. This allows them to be used in many of the same ways that unmanaged pointers (`U`) are used. Verification restrictions guarantee that, if all code is verifiable, a managed pointer to a value on the evaluation stack doesn't outlast the life of the location to which it points.

I.12.1.1.3 Portability: storing pointers in memory

Several instructions, including calli, cpblk, initblk, ldind.*, and stind.*, expect an address on the top of the stack. If this address is derived from a pointer stored in memory, there is an important portability consideration.

1. Code that stores pointers in a native-sized integer or pointer location (types `native int`, `O`, `native unsigned int`, or `&`) is always fully portable.
2. Code that stores pointers in an 8-byte integer (type `int64` or `unsigned int64`) *can* be portable. But this requires that a conv.ovf.un instruction be used to convert the pointer from its memory format before its use as a pointer. This might cause a runtime exception if run on a 32-bit machine.
3. Code that uses any smaller integer type to store a pointer in memory (`int8`, `unsigned int8`, `int16`, `unsigned int16`, `int32`, `unsigned int32`) is *never* portable, even though the use of an `unsigned int32` or `int32` will work correctly on a 32-bit machine.

I.12.1.2 Handling of short integer data types

The CLI defines an evaluation stack that contains either 4-byte or 8-byte integers; however, it also has a memory model that encompasses 1- and 2-byte integers. To be more precise, the following rules are part of the CLI model:

- Loading from 1- or 2-byte locations (arguments, locals, fields, statics, pointers) expands to 4-byte values. For locations with a known type (e.g., local variables) the type being accessed determines whether the load sign-extends (signed locations) or zero-extends (unsigned locations). For pointer dereference (ldind.*), the instruction itself identifies the type of the location (e.g., ldind.u1 indicates an unsigned location, while ldind.i1 indicates a signed location).
- Storing into a 1- or 2-byte location truncates to fit and will not generate an overflow error. Specific instructions (conv.ovf.*) can be used to test for overflow before storing.
- Calling a method assigns values from the evaluation stack to the arguments for the method, hence it truncates just as any other store would when the argument is larger than the parameter.
- Returning from a method assigns a value to an invisible return variable, so it also truncates as a store would when the type of the value returned is larger than the return type of the method. Since the value of this return variable is then placed on the evaluation stack, it is then sign-extended or zero-extended as would any other load. Note that this truncation followed by extending is *not* identical to simply leaving the computed value unchanged.

It is the responsibility of any translator from CIL to native machine instructions to make sure that these rules are faithfully modeled through the native conventions of the target machine. The CLI does not specify, for example, whether truncation of short integer arguments occurs at the call site or in the target method.

I.12.1.3 Handling of floating-point data types

Floating-point calculations shall be handled as described in IEC 60559:1989. This standard describes encoding of floating-point numbers, definitions of the basic operations and conversion, rounding control, and exception handling.

The standard defines special values, **NaN** (not a number), **+infinity**, and **–infinity**. These values are returned on overflow conditions. A general principle is that operations that have a value in the limit return an appropriate infinity while those that have no limiting value return **NaN** (see the standard for details).

[*Note:* The following examples show the most commonly encountered cases.

```
X rem 0 = NaN
0 *  +infinity = 0 * -infinity = NaN
(X / 0) =     +infinity, if X > 0
              NaN, if X = 0
              infinity, if X < 0
NaN op X = X op NaN = NaN for all operations
(+infinity) + (+infinity) =  (+infinity)
X / (+infinity) = 0
X mod (-infinity) = -X
(+infinity) - (+infinity) =  NaN
```

This standard does not specify the behavior of arithmetic operations on denormalized floating-point numbers, nor does it specify when or whether such representations should be created. This is in keeping with IEC 60559:1989. In addition, this standard does not specify how to access the exact bit pattern of NaNs that are created, nor the behavior when converting a NaN between 32-bit and 64-bit representation. All of this behavior is deliberately left implementation-specific. *end note*]

For purposes of comparison, infinite values act like a number of the correct sign, but with a very large magnitude when compared with finite values. For comparison purposes, **NaN** is 'unordered' (see clt, clt.un).

While the IEC 60559:1989 standard also allows for exceptions to be thrown under unusual conditions (such as overflow and invalid operand), the CLI does not generate these exceptions. Instead, the CLI uses the **NaN, +infinity**, and **–infinity** return values and provides the instruction ckfinite to allow users to generate an exception if a result is **NaN**, **+infinity**, or **–infinity**.

The rounding mode defined in IEC 60559:1989 shall be set by the CLI to "round to the nearest number," and neither the CIL nor the class library provide a mechanism for modifying this setting. Conforming implementations of the CLI need not be resilient to external interference with this setting. That is, they need not restore the mode prior to performing floating-point operations, but rather, can rely on it having been set as part of their initialization.

For conversion to integers, the default operation supplied by the CIL is "truncate towards zero". Class libraries are supplied to allow floating-point numbers to be converted to integers using any of the other three traditional operations (**round** to nearest integer, **floor** (truncate towards **–infinity**), **ceiling** (truncate towards **+infinity**)).

Storage locations for floating-point numbers (statics, array elements, and fields of classes) are of fixed size. The supported storage sizes are `float32` and `float64`. Everywhere else (on the evaluation stack, as arguments, as return types, and as local variables) floating-point numbers are represented using an internal floating-point type. In each such instance, the nominal type of the variable or expression is either `float32`or `float64`, but its value can be represented internally with additional range and/or precision. The size of the internal floating-point representation is implementation-dependent, can vary, and shall have precision at least as great as that of the variable or expression being represented. An implicit widening conversion to the internal representation from `float32` or `float64` is performed when those types are loaded from storage. The internal representation is typically the native size for the hardware, or as required for efficient implementation of an operation. The internal representation shall have the following characteristics:

- The internal representation shall have precision and range greater than or equal to the nominal type.

- Conversions to and from the internal representation shall preserve value.

[*Note:* This implies that an implicit widening conversion from `float32` (or `float64`) to the internal representation, followed by an explicit conversion from the internal representation to `float32` (or `float64`), will result in a value that is identical to the original `float32` (or `float64`) value. *end note*]

[*Rationale:* This design allows the CLI to choose a platform-specific high-performance representation for floating-point numbers until they are placed in storage locations. For example, it might be able to leave floating-point variables in hardware registers that provide more precision than a user has requested. At the same time, CIL generators can force operations to respect language-specific rules for representations through the use of conversion instructions. *end rationale*]

When a floating-point value whose internal representation has greater range and/or precision than its nominal type is put in a storage location, it is automatically coerced to the type of the storage location. This can involve a loss of precision or the creation of an out-of-range value (NaN, +infinity, or -infinity). However, the value might be retained in the internal representation for future use, if it is reloaded from the storage location without having been modified. It is the responsibility of the compiler to ensure that the retained value is still valid at the time of a subsequent load, taking into account the effects of aliasing and other execution threads (see memory model (§I.12.6)). This freedom to carry extra precision is not permitted, however, following the execution of an explicit conversion (conv.r4 or conv.r8), at which time the internal representation must be exactly representable in the associated type.

[*Note:* To detect values that cannot be converted to a particular storage type, a conversion instruction (conv.r4, or conv.r8) can be used, followed by a check for a non-finite value using ckfinite. Underflow can be detected by converting to a particular storage type, comparing to zero before and after the conversion. *end note*]

[*Note:* The use of an internal representation that is wider than `float32` or `float64` can cause differences in computational results when a developer makes seemingly unrelated modifications to their code, the result of which can be that a value is spilled from the internal representation (e.g., in a register) to a location on the stack. *end note*]

I.12.1.4 CIL instructions and numeric types

This subclause contains only informative text

Most CIL instructions that deal with numbers take their operands from the evaluation stack (see §I.12.3.2.1), and these inputs have an associated type that is known to the VES. As a result, a single operation like add can have inputs of any numeric data type, although not all instructions can deal with all combinations of operand types. Binary operations other than addition and subtraction require that both operands be of the same type. Addition and subtraction allow an integer to be added to or subtracted from a managed pointer (types `&` and `O`). Details are specified in Partition II.

Instructions fall into the following categories:

Numeric: These instructions deal with both integers and floating point numbers, and consider integers to be signed. Simple arithmetic, conditional branch, and comparison instructions fit in this category.

Integer: These instructions deal only with integers. Bit operations and unsigned integer division/remainder fit in this category.

Floating-point: These instructions deal only with floating-point numbers.

Specific: These instructions deal with integer and/or floating-point numbers, but have variants that deal specially with different sizes and unsigned integers. Integer operations with overflow detection, data conversion instructions, and operations that transfer data between the evaluation stack and other parts of memory (see §I.12.3.2) fit into this category.

Unsigned/unordered: There are special comparison and branch instructions that treat integers as unsigned and consider unordered floating-point numbers specially (as in "branch if greater than or unordered"):

Load constant: The load constant (ldc.*) instructions are used to load constants of type `int32`, `int64`, `float32`, or `float64`. Native size constants (type `native int`) shall be created by conversion from `int32` (conversion from `int64` would not be portable) using conv.i or conv.u.

Table I.7: CIL Instructions by Numeric Category shows the CIL instructions that deal with numeric values, along with the category to which they belong. Instructions that end in ".*" indicate all variants of the instruction (based on size of data and whether the data is treated as signed or unsigned). The notation "[.s]" means both the long and short forms of these instructions.

Table I.7: CIL Instructions by Numeric Category

add	Numeric	div	Numeric
add.ovf.*	Specific	div.un	Integer
and	Integer	ldc.*	Load constant
beq[.s]	Numeric	ldelem. *	Specific
bge[.s]	Numeric	ldind.*	Specific
bge.un[.s]	Unsigned/unordered	mul	Numeric
bgt[.s]	Numeric	mul.ovf.*	Specific
bgt.un[.s]	Unsigned/unordered	neg	Integer
ble[.s]	Numeric	newarr.*	Specific
ble.un[.s]	Unsigned/unordered	not	Integer
blt[.s]	Numeric	or	Integer
blt.un[.s]	Unsigned/unordered	rem	Numeric
bne.un[.s]	Unsigned/unordered	rem.un	Integer
ceq	Numeric	shl	Integer
cgt	Numeric	shr	Integer
cgt.un	Unsigned/unordered	shr.un	Specific
ckfinite	Floating point	stelem.*	Specific
clt	Numeric	stind.*	Specific
clt.un	Unsigned/unordered	sub	Numeric
conv.*	Specific	sub.ovf.*	Specific
conv.ovf.*	Specific	xor	Integer

End informative text

I.12.1.5 CIL instructions and pointer types

This subclause contains only informative text

[*Rationale:* Some implementations of the CLI will require the ability to track pointers to objects and to collect objects that are no longer reachable (thus providing memory management by "garbage collection"). This process moves objects in order to reduce the working set and thus will modify all pointers to those objects as they move. For this to work correctly, pointers to objects can only be used in certain ways. The `O` (object reference) and `&` (managed pointer) data types are the formalization of these restrictions. *end rationale*]

The use of object references is tightly restricted in the CIL. They are used almost exclusively with the "virtual object system" instructions, which are specifically designed to deal with objects. In addition, a few of the base instructions of the CIL handle object references. In particular, object references can be:

1. Loaded onto the evaluation stack to be passed as arguments to methods (ldloc, ldarg), and stored from the stack to their home locations (stloc, starg)
2. Duplicated or popped off the evaluation stack (dup, pop)
3. Tested for equality with one another, but not other data types (beq, beq.s, bne, bne.s, ceq)
4. Loaded-from / stored-into unmanaged memory, in type unmanaged code only (ldind.ref, stind.ref)
5. Created as a null reference (ldnull)
6. Returned as a value (ret)

Managed pointers have several additional base operations.

1. Addition and subtraction of integers, in units of *bytes*, returning a managed pointer (add, add.ovf.u, sub, sub.ovf.u)
2. Subtraction of two managed pointers to elements of the same array, returning the number of *bytes* between them (sub, sub.ovf.u)
3. Unsigned comparison and conditional branches based on two managed pointers (bge.un, bge.un.s, bgt.un, bgt.un.s, ble.un, ble.un.s, blt.un, blt.un.s, cgt.un, clt.un)

Arithmetic operations upon managed pointers are intended *only* for use on pointers to elements of the same array. If other uses of arithmetic on managed pointers are made, the behavior is unspecified.

[*Rationale:* Since the memory manager runs asynchronously with respect to programs and updates managed pointers, both the distance between distinct objects and their relative position can change. *end rationale*]

End informative text

I.12.1.6 Aggregate data

This subclause contains only informative text

The CLI supports *aggregate data*, that is, data items that have sub-components (arrays, structures, or object instances) but are passed by copying the value. The sub-components can include references to managed memory. Aggregate data is represented using a value type, which can be instantiated in two different ways:

- **Boxed**: as an object, carrying full type information at runtime, and typically allocated on the heap by the CLI memory manager.
- **Unboxed**: as a "value type instance" that does *not* carry type information at runtime and that is never allocated directly on the heap. It can be part of a larger structure on the heap – a field of a class, a field of a boxed value type, or an element of an array. Or it can be in the local variables or incoming arguments array (see §I.12.3.2). Or it can be allocated as a static variable or static member of a class or a static member of another value type.

Because value type instances, specified as method arguments, are copied on method call, they do not have "identity" in the sense that objects (boxed instances of classes) have.

I.12.1.6.1 Homes for values

The **home** of a data value is where it is stored for possible reuse. The CLI directly supports the following home locations:

- An incoming **argument**
- A **local variable** of a method
- An instance **field** of an object or value type

- A **static** field of a class, interface, or module
- An **array element**

For each home location, there is a means to compute (at runtime) the address of the home location and a means to determine (at JIT compile time) the type of a home location. These are summarized in Table I.8: Address and Type of Home Locations.

Table I.8: Address and Type of Home Locations

Type of Home	Runtime Address Computation	JIT compile time Type Determination
Argument	ldarga for by-value arguments or ldarg for by-reference (byref) arguments	Method signature
Local Variable	ldloca for by-value locals or ldloc for by-reference (byref) byref locals	Locals signature in method header
Field	ldflda	Type of field in the class, interface, or module
Static	ldsflda	Type of field in the class, interface, or module
Array Element	ldelema for single-dimensional zero-based arrays or call the instance method **Address**	Element type of array

In addition to homes, built-in values can exist in two additional ways (i.e., without homes):

1. as constant values (typically embedded in the CIL instruction stream using ldc.* instructions)
2. as an intermediate value on the evaluation stack, when returned by a method or CIL instruction.

I.12.1.6.2 Operations on value type instances

Value type instances can be created, passed as arguments, returned as values, and stored into and extracted from locals, fields, and elements of arrays (i.e., copied). Like classes, value types can have both static and non-static members (methods and fields). But, because they carry no type information at runtime, value type instances are not substitutable for items of type `System.Object`; in this respect, they act like the built-in types int32, int64, and so forth. There are two operations, box and unbox, that convert between value type instances and objects.

I.12.1.6.2.1 Initializing instances of value types

There are three options for initializing the home of a value type instance. You can zero it by loading the address of the home (see Table I.8: Address and Type of Home Locations) and using the initobj instruction (for local variables this is also accomplished by setting the **localsinit** bit in the method's header). You can call a user-defined constructor by loading the address of the home (see Table I.8: Address and Type of Home Locations) and then calling the constructor directly. Or you can copy an existing instance into the home, as described in §I.12.1.6.2.2.

I.12.1.6.2.2 Loading and storing instances of value types

There are two ways to load a value type onto the evaluation stack:

- Directly load the value from a home that has the appropriate type, using an ldarg, ldloc, ldfld, or ldsfld instruction.
- Compute the address of the value type, then use an ldobj instruction.

Similarly, there are two ways to store a value type from the evaluation stack:

- Directly store the value into a home of the appropriate type, using a starg, stloc, stfld, or stsfld instruction.
- Compute the address of the value type, then use a stobj instruction.

I.12.1.6.2.3 Passing and returning value types

Value types are treated just as any other value would be treated:

- **To pass a value type by value**, simply load it onto the stack as you would any other argument: use ldloc, ldarg, etc., or call a method that returns a value type. To access a value type parameter that has been passed by value use the ldarga instruction to compute its address or the ldarg instruction to load the value onto the evaluation stack.
- **To pass a value type by reference**, load the address of the value type as you normally would (see Table I.8: Address and Type of Home Locations). To access a value type parameter that has been passed by reference use the ldarg instruction to load the address of the value type and then the ldobj instruction to load the value type onto the evaluation stack.
- **To return a value type**, just load the value onto an otherwise empty evaluation stack and then issue a ret instruction.

I.12.1.6.2.4 Calling methods

Static methods on value types are handled no differently from static methods on an ordinary class: use a call instruction with a metadata token specifying the value type as the class of the method. Non-static methods (i.e., instance and virtual methods) are supported on value types, but they are given special treatment. A non-static method on a reference type (rather than a value type) expects a **this** pointer that is an instance of that class. This makes sense for reference types, since they have identity and the **this** pointer represents that identity. Value types, however, have identity only when boxed. To address this issue, the **this** pointer on a non-static method of a value type is a byref parameter of the value type rather than an ordinary by-value parameter.

A non-static method on a value type can be called in the following ways:

- For unboxed instances of a value type, the exact type is known statically. The call instruction can be used to invoke the function, passing as the first parameter (the **this** pointer) the address of the instance. The metadata token used with the call instruction shall specify the value type itself as the class of the method.
- Given a boxed instance of a value type, there are three cases to consider:
  - Instance or virtual methods introduced on the value type itself: unbox the instance and call the method directly using the value type as the class of the method.
  - Virtual methods inherited from a base class: use the callvirt instruction and specify the method on the `System.Object`, `System.ValueType` or `System.Enum` class as appropriate.
  - Virtual methods on interfaces implemented by the value type: use the callvirt instruction and specify the method on the interface type.

I.12.1.6.2.5 Boxing and unboxing

Boxing and **unboxing** are conceptually equivalent to (and can be seen in higher-level languages as) casting between a value type instance and `System.Object`. Because they change data representations, however, boxing and unboxing are like the widening and narrowing of various sizes of integers (the conv and conv.ovf instructions) rather than the casting of reference types (the isinst and castclass instructions). The box instruction is a widening (always type-safe) operation that converts a value type instance to `System.Object` by making a copy of the instance and embedding it in a newly allocated object. unbox is a narrowing (runtime exception can be generated) operation that converts a `System.Object` (whose exact type is a value type) to a value type instance. This is done by computing the address of the embedded value type instance without making a copy of the instance.

I.12.1.6.2.6 castclass and isinst on value types

Casting to and from value type instances isn't permitted (the equivalent operations are box and unbox). When boxed, however, it is possible to use the isinst instruction to see whether a value of type `System.Object` is the boxed representation of a particular class.

I.12.1.6.3 Opaque classes

Some languages provide multi-byte data structures whose contents are manipulated directly by address arithmetic and indirection operations. To support this feature, the CLI allows value types to be created with a specified size but no information about their data members. Instances of these "opaque classes" are handled in precisely the same way as instances of any other class, but the ldfld, stfld, ldflda, ldsfld, and stsfld instructions shall not be used to access their contents.

End informative text

I.12.2 Module information

Partition II provides details of the CLI PE file format. The CLI relies on the following information about each method defined in a PE file:

- The *instructions* composing the method body, including all exception handlers.
- The *signature* of the method, which specifies the return type and the number, order, parameter passing convention, and built-in data type of each of the arguments. It also specifies the native calling convention (this does *not* affect the CIL virtual calling convention, just the native code).
- The *exception handling array*. This array holds information delineating the ranges over which exceptions are filtered and caught. See Partition II and §I.12.4.2.
- The size of the evaluation stack that the method will require.
- The size of the locals array that the method will require.
- A "localsinit flag" that indicates whether the local variables and memory pool (§I.12.3.2.4) should be initialized by the CLI (see also localloc §III.3.47).
- Type of each local variable in the form of a signature of the local variable array (called the "locals signature").

In addition, the file format is capable of indicating the degree of portability of the file. There is one kind of restriction that can be described:

- Restriction to a specific 32-bit size for integers.

By stating which restrictions are placed on executing the code, the CLI class loader can prevent non-portable code from running on an architecture that it cannot support.

I.12.3 Machine state

One of the design goals of the CLI is to hide the details of a method call frame from the CIL code generator. This allows the CLI (and not the CIL code generator) to choose the most efficient calling convention and stack layout. To achieve this abstraction, the call frame is integrated into the CLI. The machine state definitions below reflect these design choices, where machine state consists primarily of global state and method state.

I.12.3.1 The global state

The CLI manages multiple concurrent threads of control (not necessarily the same as the threads provided by a host operating system), multiple managed heaps, and a shared memory address space.

[*Note:* A thread of control can be thought of, somewhat simplistically, as a singly linked list of *method states*, where a new state is created and linked back to the current state by a method call instruction – the traditional model of a stack-based calling sequence. Notice that this model of the thread of control doesn't correctly explain the operation of tail., jmp, or throw instructions. *end note*]

Figure 2: Machine State Model illustrates the machine state model, which includes threads of control, method states, and multiple heaps in a shared address space. Method state, shown separately in Figure 3: Method State, is an abstraction of the stack frame. Arguments and local variables are part of the method state, but they can contain Object References that refer to data stored in any of the managed heaps. In general, arguments and local variables are only visible to

the executing thread, while instance and static fields and array elements can be visible to multiple threads, and modification of such values is considered a side-effect.

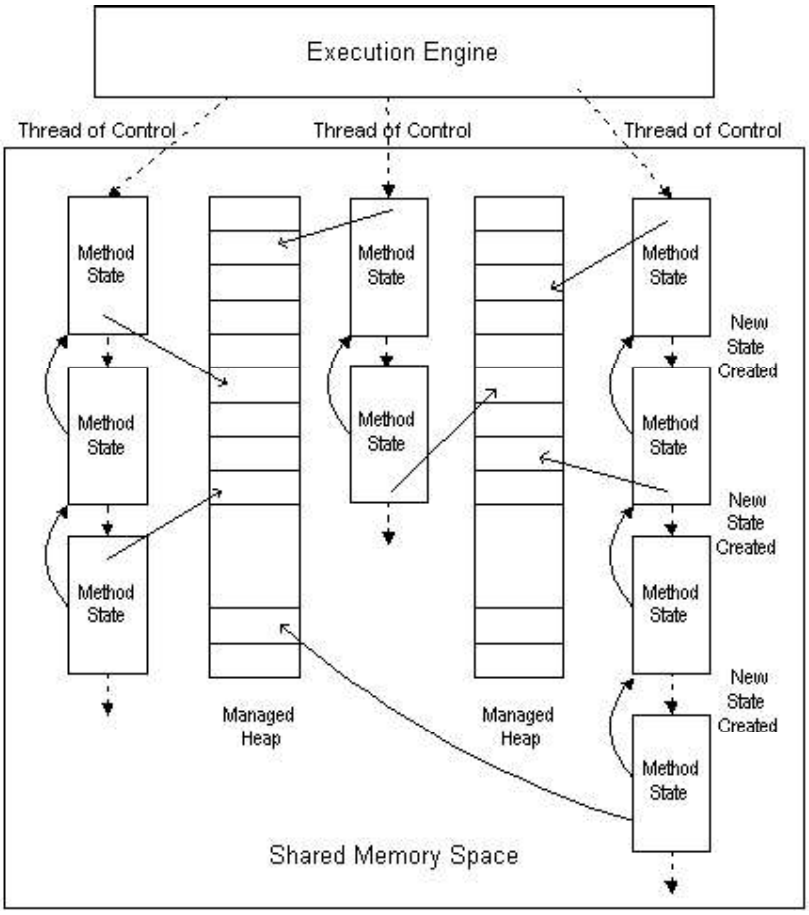


Figure 2: Machine State Model

Figure 3: Method State

I.12.3.2 Method state

Method state describes the environment within which a method executes. (In conventional compiler terminology, it corresponds to a superset of the information captured in the "invocation stack frame"). The CLI method state consists of the following items:

- An *instruction pointer* (**IP**) – This points to the next CIL instruction to be executed by the CLI in the present method.
- An *evaluation stack* – The stack is empty upon method entry. Its contents are entirely local to the method and are preserved across call instructions (that's to say, if this

method calls another, once that other method returns, our evaluation stack contents are "still there"). The evaluation stack is not addressable. At all times it is possible to deduce which one of a reduced set of types is stored in any stack location at a specific point in the CIL instruction stream (see §I.12.3.2.1).

- A *local variable array* (starting at index 0) – Values of local variables are preserved across calls (in the same sense as for the evaluation stack). A local variable can hold any data type. However, a particular slot shall be used in a type consistent way (where the type system is the one described in §I.12.3.2.1). Local variables are initialized to 0 before entry if the localsinit flag for the method is set (see §I.12.2). The address of an individual local variable can be taken using the ldloca instruction.
- An *argument array* – The values of the current method's incoming arguments (starting at index 0). These can be read and written by logical index. The address of an argument can be taken using the ldarga instruction. The address of an argument is also implicitly taken by the arglist instruction for use in conjunction with type-safe iteration through variable-length argument lists.
- A *methodInfo* handle – This contains read-only information about the method. In particular it holds the signature of the method, the types of its local variables, and data about its exception handlers.
- A *local memory pool* – The CLI includes instructions for dynamic allocation of objects from the local memory pool (localloc). Memory allocated in the local memory pool is *addressable*. The memory allocated in the local memory pool is reclaimed upon method context termination.
- A *return state* handle – This handle is used to restore the method state on return from the current method. Typically, this would be the state of the method's caller. This corresponds to what in conventional compiler terminology would be the *dynamic link*.
- A *security descriptor* – This descriptor is not directly accessible to managed code but is used by the CLI security system to record security overrides (**assert**, **permit-only**, and **deny**).

The four areas of the method state—incoming arguments array, local variables array, local memory pool and evaluation stack—are specified as if logically distinct areas. A conforming implementation of the CLI can map these areas into one contiguous array of memory, held as a conventional stack frame on the underlying target architecture, or use any other equivalent representation technique.

I.12.3.2.1 The evaluation stack

Associated with each method state is an evaluation stack. Most CLI instructions retrieve their arguments from the evaluation stack and place their return values on the stack. Arguments to other methods and their return values are also placed on the evaluation stack. When a procedure call is made the arguments to the called methods become the incoming arguments array (see §I.12.3.2.2) to the method. This can require a memory copy, or simply a sharing of these two areas by the two methods.

The evaluation stack is made up of slots that can hold any data type, including an unboxed instance of a value type. The type state of the stack (the stack depth and types of each element on the stack) at any given point in a program shall be identical for all possible control flow paths. For example, a program that loops an unknown number of times and pushes a new element on the stack at each iteration would be prohibited.

While the CLI, in general, supports the full set of types described in §I.12.1, the CLI treats the evaluation stack in a special way. While some JIT compilers might track the types on the stack in more detail, the CLI only requires that values be one of:

- `int64`, an 8-byte signed integer
- `int32`, a 4-byte signed integer
- `native int`, a signed integer of either 4 or 8 bytes, whichever is more convenient for the target architecture

- `F`, a floating point value (`float32`, `float64`, or other representation supported by the underlying hardware)
- `&`, a managed pointer
- `O`, an object reference
- *, a "transient pointer," which can be used only within the body of a single method, that points to a value known to be in unmanaged memory (see the CIL Instruction Set specification for more details. * types are generated internally within the CLI; they are not created by the user).
- A user-defined value type

The other types are synthesized through a combination of techniques:

- Shorter integer types in other memory locations are zero-extended or sign-extended when loaded onto the evaluation stack; these values are truncated when stored back to their home location.
- Special instructions perform numeric conversions, with or without overflow detection, between different sizes and between signed and unsigned integers.
- Special instructions treat an integer on the stack as though it were unsigned.
- Instructions that create pointers which are guaranteed not to point into the memory manager's heaps (e.g., ldloca, ldarga, and ldsflda) produce transient pointers (type *) that can be used wherever a managed pointer (type `&`) or unmanaged pointer (type `native unsigned int`) is expected.
- When a method is called, an unmanaged pointer (type `native unsigned int` or *) is permitted to match a parameter that requires a managed pointer (type `&`). The reverse, however, is *not* permitted since it would allow a managed pointer to be "lost" by the memory manager.
- A managed pointer (type `&`) can be explicitly converted to an unmanaged pointer (type `native unsigned int`), although this is not verifiable and might produce a runtime exception.

I.12.3.2.2 Local variables and arguments

Part of each method state is an array that holds local variables and an array that holds arguments. Like the evaluation stack, each element of these arrays can hold any single data type or an instance of a value type. Both arrays start at 0 (that is, the first argument or local variable is numbered 0). The address of a local variable can be computed using the ldloca instruction, and the address of an argument using the ldarga instruction.

Associated with each method is metadata that specifies:

- whether the local variables and memory pool memory will be initialized when the method is entered.
- the type of each argument and the length of the argument array (but see below for variable argument lists).
- the type of each local variable and the length of the local variable array.

The CLI inserts padding as appropriate for the target architecture. That is, on some 64-bit architectures all local variables can be 64-bit aligned, while on others they can be 8-, 16-, or 32-bit aligned. The CIL generator shall make no assumptions about the offsets of local variables within the array. In fact, the CLI is free to reorder the elements in the local variable array, and different implementations might choose to order them in different ways.

I.12.3.2.3 Variable argument lists

The CLI works in conjunction with the class library to implement methods that accept argument lists of unknown length and type ("vararg methods"). Access to these arguments is through a type-safe iterator in the library, called `System.ArgIterator` (see Partition IV).

The CIL includes one instruction provided specifically to support the argument iterator, arglist. This instruction shall only be used within a method that is declared to take a variable number of arguments. It returns a value that is needed by the constructor for a `System.ArgIterator` object. Basically, the value created by arglist provides access both to the address of the argument list that was passed to the method and a runtime data structure that specifies the number and type of the arguments that were provided. This is sufficient for the class library to implement the user visible iteration mechanism.

From the CLI point of view, vararg methods have an array of arguments like other methods. But only the initial portion of the array has a fixed set of types and only these can be accessed directly using the ldarg, starg, and ldarga instructions. The argument iterator allows access to both this initial segment and the remaining entries in the array.

I.12.3.2.4 Local memory pool

Part of each method state is a local memory pool. Memory can be explicitly allocated from the local memory pool using the localloc instruction. All memory in the local memory pool is reclaimed on method exit, and that is the only way local memory pool memory is reclaimed (there is no instruction provided to *free* local memory that was allocated during this method invocation). The local memory pool is used to allocate objects whose type or size is not known at compile time and which the programmer does not wish to allocate in the managed heap.

Because the local memory pool cannot be shrunk during the lifetime of the method, a language implementation cannot use the local memory pool for general-purpose memory allocation.

I.12.4 Control flow

The CIL instruction set provides a rich set of instructions to alter the normal flow of control from one CIL instruction to the next.

- **Conditional and Unconditional Branch** instructions for use within a method, provided the transfer doesn't cross a protected region boundary (see §I.12.4.2).
- **Method call** instructions to compute new arguments, transfer them and control to a known or computed destination method (see §I.12.4.1).
- **Tail call** prefix to indicate that a method should relinquish its stack frame before executing a method call (see §I.12.4.1).
- **Return** from a method, returning a value if necessary.
- **Method jump** instructions to transfer the current method's arguments to a known or computed destination method (see §I.12.4.1).
- **Exception-related** instructions (see §I.12.4.2). These include instructions to initiate an exception, transfer control out of a protected region, and end a filter, catch clause, or finally clause.

While the CLI supports control transfers within a method, there are several restrictions that shall be observed:

1. Control transfer is never permitted to enter a catch handler or finally clause (see §I.12.4.2) except through the exception handling mechanism.
2. Control transfer out of a protected region is covered in §I.12.4.2.
3. The evaluation stack shall be empty after the return value is popped by a **ret** instruction.
4. Regardless of the control flow that allows execution to arrive there, each slot on the stack shall have the same data type at any given point within the method body.
5. In order for the JIT compilers to efficiently track the data types stored on the stack, the stack shall normally be empty at the instruction following an unconditional control transfer instruction (br, br.s, ret, jmp, throw, endfilter, endfault, or endfinally). The stack shall be non-empty at such an instruction only if at some earlier location within the method there has been a forward branch to that instruction.

6. Control is not permitted to simply "fall through" the end of a method. All paths shall terminate with one of these instructions: ret, throw, jmp, or (tail. followed by call, calli, or callvirt).

I.12.4.1 Method calls

Instructions emitted by the CIL code generator contain sufficient information for different implementations of the CLI to use different native calling conventions. All method calls initialize the method state areas (see §I.12.3.2) as follows:

1. The incoming arguments array is set by the caller to the desired values.
2. The local variables array always has **null** for object types and for fields within value types that hold objects. In addition, if the localsinit flag is set in the method header, then the local variables array is initialized to 0 for all integer types and to 0.0 for all floating-point types. Value types are not initialized by the CLI, but verified code will supply a call to an initializer as part of the method's entry point code.
3. The evaluation stack is empty.

I.12.4.1.1 Call site descriptors

Call sites specify additional information that enables an interpreter or JIT compiler to synthesize any native calling convention. All CIL calling instructions (call, calli, and callvirt) include a description of the call site. This description can take one of two forms. The simpler form, used with the calli instruction, is a "call site description" (represented as a metadata token for a stand-alone call signature) that provides:

- The number of arguments being passed.
- The data type of each argument.
- The order in which they have been placed on the call stack.
- The native calling convention to be used

The more complicated form, used for the call and callvirt instructions, is a "method reference" (a metadata **methodref** token) that augments the call site description with an identifier for the target of the call instruction.

I.12.4.1.2 Calling instructions

The CIL has three call instructions that are used to transfer argument values to a destination method. Under normal circumstances, the called method will terminate and return control to the calling method.

- call is designed to be used when the destination address is fixed at the time the CIL is linked. In this case, a method reference is placed directly in the instruction. This is comparable to a direct call to a static function in C. It can be used to call static or instance methods or the (statically known) base class method within an instance method body.
- calli is designed for use when the destination address is calculated at run time. A method pointer is passed on the stack and the instruction contains only the call site description.
- callvirt, part of the CIL common type system instruction set, uses the class of an object (known only at runtime) to determine the method to be called. The instruction includes a method reference, but the particular method isn't computed until the call actually occurs. This allows an instance of a derived class to be supplied and the method appropriate for that derived class to be invoked. The callvirt instruction is used both for instance methods and methods on interfaces. For further details, see the CTS specification and the CIL instruction set specification in Partition III.

In addition, each of these instructions can be immediately preceded by a `tail.` instruction prefix. This specifies that the calling method terminates with this method call (and returns whatever value is returned by the called method). The `tail.` prefix instructs the JIT compiler to discard

the caller's method state prior to making the call (if the call is from untrusted code to trusted code the frame cannot be fully discarded for security reasons). When the called method executes a ret instruction, control returns not to the calling method but rather to wherever that method would itself have returned (typically, return to caller's caller). Notice that the `tail.` instruction shortens the lifetime of the caller's frame so it is unsafe to pass managed pointers (type `&`) as arguments.

Finally, there are two instructions that indicate an optimization of the `tail.` case:

- jmp is followed by a **methodref** or **methoddef** token and indicates that the current method's state should be discarded, its arguments should be transferred intact to the destination method, and control should be transferred to the destination. The signature of the calling method shall exactly match the signature of the destination method.

I.12.4.1.3 Computed destinations

The destination of a method call can be either encoded directly in the CIL instruction stream (the call and jmp instructions) or computed (the callvirt, and calli instructions). The destination address for a callvirt instruction is automatically computed by the CLI based on the method token and the value of the first argument (the **this** pointer). The method token shall refer to a virtual method on a class that is a direct ancestor of the class of the first argument. The CLI computes the correct destination by locating the nearest ancestor of the first argument's class that supplies an implementation of the desired method.

[*Note:* The implementation can be assumed to be more efficient than the linear search implied here. *end note*]

For the calli instruction the CIL code is responsible for computing a destination address and pushing it on the stack. This is typically done through the use of an ldftn or ldvirtfn instruction at some earlier time. The ldftn instruction includes a metadata token in the CIL stream that specifies a method, and the instruction pushes the address of that method. The ldvirtfn instruction takes a metadata token for a virtual method in the CIL stream and an object on the stack. It performs the same computation described above for the callvirt instruction but pushes the resulting destination on the stack rather than calling the method.

The calli instruction includes a call site description that includes information about the native calling convention that should be used to invoke the method. Correct CIL code shall specify a calling convention in the calli instruction that matches the calling convention for the method that is being called.

I.12.4.1.4 Virtual calling convention

The CIL provides a "virtual calling convention" that is converted by the JIT compiler into a native calling convention. The JIT compiler determines the optimal native calling convention for the target architecture. This allows the native calling convention to differ from machine to machine, including details of register usage, local variable homes, copying conventions for large call-by-value objects (as well as deciding, based on the target machine, what is considered "large"). This also allows the JIT compiler to reorder the values placed on the CIL virtual stack to match the location and order of arguments passed in the native calling convention.

The CLI uses a single uniform calling convention for all method calls. It is the responsibility of the implementation to convert this into the appropriate native calling convention. The contents of the stack at the time of a call instruction (call, calli, or callvirt any of which can be preceded by `tail.`) are as follows:

1. If the method being called is an instance method (class or interface) or a virtual method, the **this** pointer is the first object on the stack at the time of the call instruction. For methods on objects (including boxed value types), the **this** pointer is of type `O` (object reference). For methods on value types, the **this** pointer is provided as a byref parameter; that is, the value is a pointer (managed, `&`, or unmanaged, * or `native int`) to the instance.
2. The remaining arguments appear on the stack in left-to-right order (that is, the lexically leftmost argument is the lowest on the stack, immediately following the

this pointer, if any). §I.12.4.1.5 describes how each of the three parameter passing conventions (by-value, byref, and typed reference) should be implemented.

I.12.4.1.5 Parameter passing

The CLI supports three kinds of parameter passing, all indicated in metadata as part of the signature of the method. Each parameter to a method has its own passing convention (e.g., the first parameter can be passed by-value while all others are passed byref). Parameters shall be passed in one of the following ways (see detailed descriptions below):

- **By-value –** where the **value** of an object is passed from the caller to the callee.
- **By-reference –** where the **address** of the data is passed from the caller to the callee, and the type of the parameter is therefore a managed or unmanaged pointer.
- **Typed reference –** where a runtime representation of the data type is passed along with the address of the data, and the type of the parameter is therefore one specially supplied for this purpose.

It is the responsibility of the CIL generator to follow these conventions. Verification checks that the types of parameters match the types of values passed, but is otherwise unaware of the details of the calling convention.

I.12.4.1.5.1 By-value parameters

For built-in types (integers, floats, etc.) the caller copies the value onto the stack before the call. For objects the object reference (type `O`) is pushed on the stack. For managed pointers (type `&`) or unmanaged pointers (type `native unsigned int`), the address is passed from the caller to the callee. For value types, see the protocol in §I.12.1.6.2.

I.12.4.1.5.2 By-reference parameters

By-reference parameters (identified by the presence of a byref constraint) are the equivalent of C++ reference parameters or PASCAL **var** parameters: instead of passing as an argument the value of a variable, field, or array element, its address is passed instead; and any assignment to the corresponding parameter actually modifies the corresponding caller's variable, field, or array element. Much of this work is done by the higher-level language, which hides from the user the need to compute addresses to pass a value and the use of indirection to reference or update values.

Passing a value by reference requires that the value have a home (see §I.12.1.6.1) and it is the address of this home that is passed. Constants, and intermediate values on the evaluation stack, cannot be passed as byref parameters because they have no home.

The CLI provides instructions to support byref parameters:

- calculate addresses of home locations (see Table I.8: Address and Type of Home Locations)
- load and store built-in data types through these address pointers (ldind.*, stind.*, ldfld, etc.)
- copy value types (ldobj and cpobj).

Some addresses (e.g., local variables and arguments) have lifetimes tied to that method invocation. These shall not be referenced outside their lifetimes, and so they should not be stored in locations that last beyond their lifetime. The CIL does not (and cannot) enforce this restriction, so the CIL generator shall enforce this restriction or the resulting CIL will not work correctly. For code to be verifiable (see §I.8.8) byref parameters shall **only** be passed to other methods or referenced via the appropriate stind or ldind instructions.

I.12.4.1.5.3 Typed reference parameters

By-reference parameters and value types are sufficient to support statically typed languages (C++, Pascal, etc.). They also support dynamically typed languages that pay a performance penalty to box value types before passing them to polymorphic methods (Lisp, Scheme, Smalltalk, etc.). Unfortunately, they are not sufficient to support languages like Visual Basic that require byref passing of unboxed data to methods that are not statically restricted as to the type of data they accept. These languages require a way of passing *both* the address of the home of the

data *and* the static type of the home. This is exactly the information that would be provided if the data were boxed, but without the heap allocation required of a box operation.

Typed reference parameters address this requirement. A typed reference parameter is very similar to a standard byref parameter but the static data type is passed as well as the address of the data. Like byref parameters, the argument corresponding to a typed reference parameter will have a home.

[*Note:* If it were not for the fact that verification and the memory manager need to be aware of the data type and the corresponding address, a byref parameter could be implemented as a standard value type with two fields: the address of the data and the type of the data. *end note*]

Like a regular byref parameter, a typed reference parameter can refer to a home that is on the stack, and that home will have a lifetime limited by the call stack. Thus, the CIL generator shall apply appropriate checks on the lifetime of byref parameters; and verification imposes the same restrictions on the use of typed reference parameters as it does on byref parameters (see §I.12.4.1.5.2).

A typed reference is passed by either creating a new typed reference (using the mkrefany instruction) or by copying an existing typed reference. Given a typed reference argument, the address to which it refers can be extracted using the refanyval instruction; the type to which it refers can be extracted using the refanytype instruction.

I.12.4.1.5.4 Parameter interactions

A given parameter can be passed using any one of the parameter passing conventions: by-value, by-reference, or typed reference. No combination of these is allowed for a single parameter, although a method can have different parameters with different calling mechanisms.

A parameter that has been passed in as typed reference shall not be passed on as by-reference or by-value without a runtime type check and (in the case of by-value) a copy.

A byref parameter can be passed on as a typed reference by attaching the static type.

Table I.9: Parameter Passing Conventions illustrates the parameter passing convention used for each data type.

Table I.9: Parameter Passing Conventions

Type of data	Pass By	How data is sent
Built-in value type (int, float, etc.)	Value	Copied to called method, type statically known at both sides
	Reference	Address sent to called method, type statically known at both sides
	Typed reference	Address sent along with type information to called method
User-defined value type	Value	Called method receives a copy; type statically known at both sides
	Reference	Address sent to called method, type statically known at both sides
	Typed reference	Address sent along with type information to called method
Object	Value	Reference to data sent to called method, type statically known and class available from reference
	Reference	Address of reference sent to called method, type statically known and class available from reference
	Typed reference	Address of reference sent to called method along with static type information, class (i.e., dynamic type) available from reference

I.12.4.2 Exception handling

Exception handling is supported in the CLI through exception objects and protected blocks of code. When an exception occurs, an object is created to represent the exception. All exception objects are instances of some class (i.e., they can be boxed value types, but not pointers, unboxed

value types, etc.). Users can create their own exception classes, typically by deriving from `System.Exception` (see Partition IV).

There are four kinds of handlers for protected blocks. A single protected block shall have exactly one handler associated with it:

- A **finally handler** that shall be executed whenever the block exits, regardless of whether that occurs by normal control flow or by an unhandled exception.
- A **fault handler** that shall be executed if an exception occurs, but not on completion of normal control flow.
- A **catch handler** that handles any exception of a specified class or any of its sub-classes.
- A **filter handler** that runs a user-specified set of CIL instructions to determine if the exception should be handled by the associated handler, or passed on to the next protected block.

Protected regions, the type of the associated handler, and the location of the associated handler and (if needed) user-supplied filter code are described through an Exception Handler Table associated with each method. The exact format of the Exception Handler Table is specified in detail in Partition II. Details of the exception handling mechanism are also specified in Partition II.

I.12.4.2.1 Exceptions thrown by the CLI

CLI instructions can throw the following exceptions as part of executing individual instructions. The documentation for each instruction lists all the exceptions the instruction can throw (except for the general purpose `System.ExecutionEngineException` described below that can be generated by all instructions).

Base Instructions (see Partition III)

- `System.ArithmeticException`
- `System.DivideByZeroException`
- `System.ExecutionEngineException`
- `System.InvalidAddressException`
- `System.OverflowException`
- `System.SecurityException`
- `System.StackOverflowException`

Object Model Instructions (see Partition III)

- `System.TypeLoadException`
- `System.IndexOutOfRangeException`
- `System.InvalidAddressException`
- `System.InvalidCastException`
- `System.MissingFieldException`
- `System.MissingMethodException`
- `System.NullReferenceException`
- `System.OutOfMemoryException`
- `System.SecurityException`
- `System.StackOverflowException`

The `System.ExecutionEngineException` is special. It can be thrown by any instruction and indicates an unexpected inconsistency in the CLI. Running exclusively verified code can never

cause this exception to be thrown by a conforming implementation of the CLI. However, unverified code (even though that code is conforming CIL) can cause this exception to be thrown if it might corrupt memory. Any attempt to execute non-conforming CIL or non-conforming file formats can result in unspecified behavior: a conforming implementation of the CLI need not make any provision for these cases.

There are no exceptions for things like 'MetaDataTokenNotFound.' CIL verification (see Partition III) will detect this inconsistency before the instruction is executed, leading to a verification violation. If the CIL is not verified this type of inconsistency shall raise `System.ExecutionEngineException`.

Exceptions can also be thrown by the CLI, as well as by user code, using the throw instruction. The handling of an exception is identical, regardless of the source.

I.12.4.2.2 Deriving from exception classes

Certain types of exceptions thrown by the CLI can be derived from to provide more information to the user. The specification of CIL instructions in Partition III describes what types of exceptions should be thrown by the runtime environment when an abnormal situation occurs. Each of these descriptions allows a conforming implementation to throw an object of the type described or an object of a derived class of that type.

[*Note:* For instance, the specification of the ckfinite instruction requires that an exception of type `System.ArithmeticException` or a derived class of `ArithmeticException` be thrown by the CLI. A conforming implementation might simply throw an exception of type `ArithmeticException`, but it might also choose to provide more information to the programmer by throwing an exception of type `NotFiniteNumberException` with the offending number. *end note*]

I.12.4.2.3 Resolution exceptions

CIL allows types to reference, among other things, interfaces, classes, methods, and fields. Resolution errors occur when references are not found or are mismatched. Resolution exceptions can be generated by references from CIL instructions, references to base classes, to implemented interfaces, and by references from signatures of fields, methods and other class members.

To allow scalability with respect to optimization, detection of resolution exceptions is given latitude such that it might occur as early as install time and as late as execution time.

The latest opportunity to check for resolution exceptions from all references except CIL instructions is as part of initialization of the type that is doing the referencing (see Partition II). If such a resolution exception is detected the static initializer for that type, if present, shall not be executed.

The latest opportunity to check for resolution exceptions in CIL instructions is as part of the first execution of the associated CIL instruction. When an implementation chooses to perform resolution exception checking in CIL instructions as late as possible, these exceptions, if they occur, shall be thrown prior to any other non-resolution exception that the VES might throw for that CIL instruction. Once a CIL instruction has passed the point of throwing resolution errors (it has completed without exception, or has completed by throwing a non-resolution exception), subsequent executions of that instruction shall no longer throw resolution exceptions.

If an implementation chooses to detect some resolution errors, from any references, earlier than the latest opportunity for that kind of reference, it is not required to detect all resolution exceptions early.

An implementation that detects resolution errors early is allowed to prevent a class from being installed, loaded or initialized as a result of resolution exceptions detected in the class itself or in the transitive closure of types from following references of any kind.

For example, each of the following represents a permitted scenario. An installation program can throw resolution exceptions (thus failing the installation) as a result of checking CIL instructions for resolution errors in the set of items being installed. An implementation is allowed to fail to load a class as a result of checking CIL instructions in a referenced class for resolution errors. An implementation is permitted to load and initialize a class that has resolution errors in its CIL instructions.

The following exceptions are among those considered resolution exceptions:

- `BadImageFormatException`
- `EntryPointNotFoundException`
- `MissingFieldException`
- `MissingMemberException`
- `MissingMethodException`
- `NotSupportedException`
- `TypeLoadException`
- `TypeUnloadedException`

For example, when a referenced class cannot be found, a `TypeLoadException` is thrown. When a referenced method (whose class is found) cannot be found, a `MissingMethodException` is thrown. If a matching method being used consistently is accessible, but violates declared security policy, a `SecurityException` is thrown.

I.12.4.2.4 Timing and choice of exceptions

Certain types of exceptions thrown by CIL instructions might be detected before the instruction is executed. In these cases, the specific time of the throw is not precisely defined, but the exception should be thrown no later than the instruction is executed. Relaxation of the timing of exceptions is provided so that an implementation can choose to detect and throw an exception before any code is run (e.g., at the time of CIL to native code conversion).

There is a distinction between the time of detecting the error condition and throwing the associated exception. An error condition can be detected early (e.g., at JIT time), but the condition can be signaled later (e.g., at the execution time of the offending instruction) by throwing an exception.

The following exceptions are among those that can be thrown early by the runtime:

- `MissingFieldException`
- `MissingMethodException`
- `SecurityException`
- `TypeLoadException`

In addition, as to when class initialization (see Partition II) occurs is not fully specified. In particular, there is no guarantee when `System.TypeInitializationException` might be thrown.

If more than one exception's conditions are met by a method invocation, as to which exception is thrown is unspecified.

I.12.4.2.5 Overview of exception handling

See the exception handling specification in Partition II for details.

Each method in an executable has associated with it a (possibly empty) array of exception handling information. Each entry in the array describes a protected block, its filter, and its handler (which shall be a **catch** handler, a **filter** handler, a **finally** handler, or a **fault** handler). When an exception occurs, the CLI searches the array for the first protected block that

- Protects a region including the current instruction pointer *and*
- Is a catch handler block *and*
- Whose filter wishes to handle the exception

If a match is not found in the current method, the calling method is searched, and so on. If no match is found the CLI will dump a stack trace and abort the program.

[*Note:* A debugger can intervene and treat this situation like a breakpoint, before performing any stack unwinding, so that the stack is still available for inspection through the debugger. *end note*]

If a match is found, the CLI walks the stack back to the point just located, but this time calling the **finally** and **fault** handlers. It then starts the corresponding exception handler. Stack frames are discarded either as this second walk occurs or after the handler completes, depending on information in the exception handler array entry associated with the handling block.

Some things to notice are:

- The ordering of the exception clauses in the Exception Handler Table is important. If handlers are nested, the most deeply nested try blocks shall come before the try blocks that enclose them.
- Exception handlers can access the local variables and the local memory pool of the routine that catches the exception, but any intermediate results on the evaluation stack at the time the exception was thrown are lost.
- An exception object describing the exception is automatically created by the CLI and pushed onto the evaluation stack as the first item upon entry of a filter or catch clause.
- Execution cannot be resumed at the location of the exception, except with a **filter handler**.

I.12.4.2.6 CIL support for exceptions

The CIL has special instructions to:

- **Throw** and **rethrow** a user-defined exception.
- **Leave** a protected block and execute the appropriate **finally** clauses within a method, without throwing an exception. This is also used to exit a **catch** clause. Notice that leaving a protected block does *not* cause the fault clauses to be called.
- End a user-supplied filter clause (endfilter) and return a value indicating whether to handle the exception.
- End a finally clause (endfinally) and continue unwinding the stack.

I.12.4.2.7 Lexical nesting of protected blocks

A *protected region* (also called a *try block*) is described by an address and a length: the **trystart** is the address of the first instruction to be protected, and the **trylength** is the length of the protected region. (The **tryend**, the address immediately following the last instruction to be protected, can be trivially computed from these two). A *handler region* is described by an address and a length: the **handlerstart** is the address of the first instruction of the handler and the **handlerlength** is the length of the handler region. (The **handlerend**, the address immediately following the last instruction of the handler, can be trivially computed from these two.)

Every method can have associated with it a set of **exception entries**, called the **exception set**. Each **exception entry** consists of

- Optional: a type token (the type of exception to be handled) or **filterstart** (the address of the first instruction of the user-supplied filter code)
- Required: **protected block**
- Required: **handler region**. There are four kinds of handler regions: catch handlers, filtered handlers, finally handlers, and fault handlers. (A filtered handler is the code that runs if the filter evaluates to true.)

If an exception entry contains a **filterstart**, then **filterstart** strictly precedes **handlerstart**. The **filter** starts at the instruction specified by **filterstart** and contains all instructions up to (but not including) that specified by **handlerstart**. The lexically last instruction in the filter must be endfilter. If there is no **filterstart** then the filter is empty (hence it does not overlap with any region).

No two regions (protected block, filter, handler region) of a single exception entry may overlap with one another.

Each region must begin and end on an instruction boundary.

For every pair of exception entries in an exception set, one of the following must be true:

- They **nest**: all three regions of one entry shall be within a single region of the other entry, with the further restriction that the enclosing region shall not be a filter. [*Note*: Functions called from within a filter can contain exception handling. *end note*]

- They are **disjoint**: all six regions of the two entries are pairwise-disjoint (no addresses overlap).
- They **mutually protect**: the protected blocks are the same and the other regions are pairwise-disjoint. In this case, all handlers shall be either catch handlers or filtered handlers. The precedence of the handler regions is determined by their ordering in the Exception Handler Table (Partition II).

The encoding of an exception entry in the file format (see Partition II) guarantees that only a filtered handler (not a catch handler, fault handler or finally handler) can have a filter.

An *exception-handling block* is either a protected region, a filter, a catch handler, a filter handler, a fault handler, or a finally handler.

I.12.4.2.8 Control flow restrictions on protected blocks

I.12.4.2.8.1 Fall Through

An instruction I1 is capable of *fall through* if one of the following is true:

- I1 is not a control-flow instruction (i.e., the only way control flow could be altered by I1 would be if it threw an exception).
- I1 is a switch or conditional branch. [*Note*: Fall through would be the not-taken case. *end note*]
- I1 is a method call instruction.

[*Note*: For the purposes of this section, the ability of an instruction to fall through can be determined purely by the type of the instruction. *end note*]

[*Note*: Most instructions can allow control to fall through after their execution—only unconditional branches, ret, jmp, leave(.s), endfinally, endfault, endfilter, throw, and rethrow do not. Call instructions do allow control to fall through, since the next instruction to be executed in the current method is the one lexically following the call instruction, which executes after the call returns. *end note*]

[*Note*: The determination of validity with respect to fall through can be done lexically; no control-flow or data-flow analysis is required. *end note*]

Entry to filters or handlers can only be accomplished through the CLI exception system; that is, it is not valid for control to fall through into such blocks. This means filters and handlers cannot appear at the beginning of a method, or immediately following any instruction that can cause control flow to fall through.

[*Note*: Conditional branches can have multiple effects on control flow. Since one of the possible effects is to allow control flow to fall through, a filter or handler cannot appear immediately following a conditional branch. *end note*]

Entry to protected blocks can be accomplished by fall-through, at which time the evaluation stack shall be empty.

Exit from protected blocks, filters, or handlers cannot be accomplished via fall through.

I.12.4.2.8.2 Control-flow Instructions

Instructions that affect control flow have restrictions on how they are used in protected blocks, filters, and handlers. The particular rules depend on the type of instruction. This subclause describes restrictions based on the following:

- The **source** of the instruction; i.e., the address of the start of the instruction.
- The **target(s)** of the instruction; i.e., the address(es) of all instructions within the same method that might be executed following it, excluding fall through (which has been addressed above). If an instruction has a target rule, the exact definition of the target precedes that rule.

For the source and each target of an instruction, consider each protected block, filter, or handler that encloses that address. If all rules are satisfied for all enclosing protected blocks, filters, or handlers, for the source of an instruction and all targets, then the instruction is valid with respect

to exception-handling. (Obviously, the instruction shall still follow all other validity rules.) An instruction is considered to be within a block even if the source of the instruction is at the very start of that block.

I.12.4.2.8.2.1 throw (and all CIL instructions not listed below)

source

1. There are no source restrictions.

target

1. There are no target restrictions.

I.12.4.2.8.2.2 rethrow:

source

1. Shall be enclosed in a catch handler

[*Note*: The catch handler need not be the innermost enclosing exception-handling block. For example, the rethrow may be within a finally that is within a catch. In such a case, the exception to be rethrown is the one caught by the innermost enclosing catch handler. *end note*]

target

1. There are no target restrictions.

I.12.4.2.8.2.3 ret:

source

1. Shall not be enclosed in any protected block, filter, or handler.

[*Note*: To return from a protected block, filtered handler, or catch handler, a leave(.s) instruction is needed to transfer control to an address outside all exception-handling blocks, then a ret instruction is needed at that address. *end note*]

[*Note*: Since the tail. prefix on an instruction requires that that instruction be followed by ret, tail calls are not allowed from within protected blocks, filters, or handlers. *end note*]

target

1. There are no target restrictions.

I.12.4.2.8.2.4 jmp:

source

1. Shall not be enclosed in any protected block, filter, or handler

target

1. There are no target restrictions.

I.12.4.2.8.2.5 endfilter:

source

1. Shall appear as the lexically last instruction in the filter.

[*Note*: The endfilter is required even if no control-flow path reaches it. This can happen if, for example, the filter does a throw. *end note*]

[*Note*: The lexical nesting rules prohibit nesting other exception-handling entries inside a filter. Thus the innermost exception-handling block enclosing an endfilter instruction shall be a filter. *end note*]

target

1. There are no target restrictions.

I.12.4.2.8.2.6 endfinally/endfault:

source

1. The innermost enclosing protected block, filter, or handler shall be a finally or fault handler

[*Note*: endfinally and endfault are aliases for the same CIL opcode. Conventionally, CIL assemblers require that endfinally be used within a finally handler, and endfault be used within a fault handler, but the instruction emitted is exactly the same by either name. *end note*]

[*Note*: A finally or fault handler can contain more than one endfinally/endfault. The lexically last instruction in the finally or fault handler need not be endfinally/endfault. In fact, a finally or fault handler might not require an endfinally/endfault at all if all control-flow paths terminate through other means. This can happen if, for example, the finally or fault handler throws. *end note*]

target

1. There are no target restrictions.

I.12.4.2.8.2.7 Branches (br, br.s, conditional branches, switch):

source

1. If the source of the branch is within a protected block, filter, or handler, the target(s) shall be within the same protected block, filter, or handler

target

The target of br, br.s, and the conditional branches, is the address specified. The targets of switch are all of the addresses specified in the jump table.

1. If any target of the branch is within a protected block, except the first instruction of that protected block, the source shall be within the same protected block.
2. If any target of the branch is within a filter or handler, the source shall be within the same filter or handler.

[*Note*: Code can branch to the first instruction of a protected block, but not into the middle of one. *end note*]

[*Note*: Since the conditional branches and switch have a fall-through case, they shall also obey the rules for fall through. *end note*]

I.12.4.2.8.2.8 leave and leave.s:

source

1. If the source is within a filter, fault handler, or finally handler, the target shall be within the same filter, fault handler, or finally handler.

   [*Note*: This means control cannot be transferred out of a filter, fault handler, or finally handler via the leave(.s) instruction. *end note*]
2. If the source is within a protected block, the target shall be within the same protected block, within an enclosing protected block, the first instruction of a disjoint protected block, or not within any protected block.
3. If the source is within a catch handler or filtered handler, the target shall be within the same catch handler or filtered handler, within the associated protected block, within a protected block that encloses the catch handler or filtered handler, the first instruction of a disjoint protected block, or not within any protected block.

[*Note*: If the source is outside any exception-handling block, that fact implies no additional restrictions on the target. In effect, a leave from outside of exception handling acts like a branch, with the side-effect of emptying the evaluation stack. *end note*]

target

The target of leave(.s) is the address specified by leave(.s).

1. If the target is within a filter or handler, the source shall be within the same filter or handler.
2. If the target is within a protected block, except the first instruction of that protected block, the source shall be within the same protected block, or within the associated catch handler or filtered handler.

[*Note*: To be clear, if the target is the first instruction of a protected block, the source can be outside of the protected block. *end note*]

[*Note*: This means that it is possible to transfer control from a catch handler or a filtered handler to the associated protected block. *end note*]

I.12.4.2.8.2.9 Examples

[*Example*: Example 1

```
{
EX1:
        br TryStart2
        .try
        {
TryStart1:
                .try
                {
TryStart2:
                        leave End
                }
                finally
                {
                        endfinally
                }
        }
        finally
        {
                endfinally
        }
End:
        ret
}
```

Consider the `br TryStart2` instruction at `EX1`. It is not contained within any exception-handling block, so the source rules do not apply and are thus satisfied. The target is contained within two protected regions, so the target rules are applied once for each region.

Considering the outermost protected region, branch target rule 1 is satisfied since the target is the first instruction of the outermost protected region. Branch target rule 2 does not apply to protected regions and is thus satisfied.

Considering the innermost protected region, branch target rule 1 is satisfied since the target is the first instruction of the innermost protected region. Branch target rule 2 does not apply to protected regions and is thus satisfied.

Thus, the branch instruction at `EX1` is valid from the exception-handling perspective. *end example*]

[*Example*: Example 2

```
{
        ldc.i4.0
EX2:
        brtrue TryStart2
        .try
        {
TryStart1:
EX3:
                br TryStart2
                .try
                {
TryStart2:
                        leave End
                }
```

```
                finally
                {
                        endfinally
                }
        }

        finally
        {
                endfinally
        }
End:
        ret
}
```

Consider the `brtrue TryStart2` instruction at `EX2`. It is not contained within any exception-handling block, so the source rules do not apply and are thus satisfied. The target is contained within two protected regions, so the target rules are applied once for each region.

Branch target rule 1 is satisfied for the inner protected block since the target is the first instruction of the block. However, branch target rule 1 is *not* satisfied for the outer protected block since the source is not within the outer protected block and the target is not the first instruction of that block.

Thus the conditional branch instruction at `EX2` is invalid from an exception-handling perspective.

Now consider the `br TryStart2` instruction at `EX3`. It is within one protected block, so the source rules are applied considering that protected block. Branch source rule 1 is satisfied since the target is within that protected block. The target is contained within two protected regions, so the target rules are applied once for each region.

Considering the outer protected block, branch target rule 1 is satisfied since the source is also within the outer protected block. Branch target rule 2 does not apply to protected blocks, and is thus satisfied.

Considering the inner protected block, branch target rule 1 is satisfied since the target is the first instruction of the inner protected block. Branch target rule 2 does not apply to protected blocks, and is thus satisfied.

Thus, the branch instruction at `EX3` is valid from an exception-handling perspective. *end example*]

[*Example*: Example 3

```
{
        .try
        {
                newobj instance void [mscorlib]System.Exception::.ctor()
                throw
AfterThrow:
                leave End
        }

        catch [mscorlib]System.Exception
        {
                .try
                {
                        newobj instance void [mscorlib]System.Exception::.ctor()
                        throw
                }

                catch [mscorlib]System.Exception
                {
EX4:
                        leave AfterThrow
                }
                leave End
        }
End:
        ret
}
```

Consider the `leave` instruction at `EX4`. It is contained within two catch handlers, so the source rules are applied once for each region.

Considering the outer catch handler, leave source rules 1 and 2 do not apply to catch handlers and are thus satisfied. Leave source rule 3 is satisfied since the target is within the associated protected region.

Considering the inner catch handler, leave source rules 1 and 2 do not apply to catch handlers and are thus satisfied. Leave source rule 3 is not satisfied since the target is in the middle of a disjoint protected region.

Thus, the `leave` instruction at `EX4` is invalid from an exception-handling perspective. However, for illustration purposes, consider the target rules as well.

The target is within one protected region, so the target rules are applied considering that protected region. Leave target rule 1 does not apply to protected regions, and is thus satisfied. Leave target rule 2 is satisfied because the source is within a catch block associated with the protected region. *end example*]

[*Example*: Example 4

```
  {
          .try
          {
                  .try
                  {
                          newobj instance void [mscorlib]System.Exception::.ctor()
                          throw
                  }

                  catch [mscorlib] System.Exception
                  {
EX5:
                          leave EndOfOuterTry
                  }
EndOfOuterTry:
                  // …
                  leave End
          }

          catch [mscorlib]System.Exception
          {
                  leave End
          }
End:
          ret
}
```

Consider the `leave` instruction at `EX5`. It is contained within a protected region and within a catch handler, so the source rules are applied once for each.

Considering the protected region, leave source rules 1 and 3 do not apply to protected regions and are thus satisfied. Leave source rule 2 is satisfied because the target is within the same protected region.

Considering the catch handler, leave source rules 1 and 2 do not apply to catch handlers and are thus satisfied. Leave source rule 3 is satisfied because the target is within a protected block that encloses the catch handler.

The target is within one protected region, so the target rules are applied considering that protected region. Target rule 1 does not apply to protected regions and is thus satisfied. Target rule 2 is satisfied because the source is within the same protected block.

Thus the `leave` instruction at `EX5` is valid from an exception-handling perspective. *end example*]

I.12.5 Proxies and remoting

A **remoting boundary** exists if it is not possible to share the identity of an object directly across the boundary. For example, if two objects exist on physically separate machines that do not share a common address space, then a remoting boundary will exist between them. There are other administrative mechanisms for creating remoting boundaries.

The VES provides a mechanism, called the **application domain**, to isolate applications running in the same operating system process from one another. Types loaded into one application domain are distinct from the same type loaded into another application domain, and instances of

objects shall not be directly shared from one application domain to another. Hence, the application domain itself forms a remoting boundary.

The VES implements remoting boundaries based on the concept of a **proxy**. A proxy is an object that exists on one side of the boundary and represents an object on the other side. The proxy forwards references to instance fields and methods to the actual object for interpretation. Proxies do not forward references to static fields or calls to static methods.

The implementation of proxies is provided automatically for instances of types that derive from `System.MarshalByRefObject` (see Partition IV).

I.12.6 Memory model and optimizations

I.12.6.1 The memory store

By "memory store" we mean the regular process memory that the CLI operates within. Conceptually, this store is simply an array of bytes. The index into this array is the address of a data object. The CLI accesses data objects in the memory store via the ldind.* and stind.* instructions.

I.12.6.2 Alignment

Built-in data types shall be *properly aligned*, which is defined as follows:

- 1-byte, 2-byte, and 4-byte data is properly aligned when it is stored at a 1-byte, 2-byte, or 4-byte boundary, respectively.
- 8-byte data is properly aligned when it is stored on the same boundary required by the underlying hardware for atomic access to a `native int`.

Thus, `int16` and `unsigned int16` start on even address; `int32`, `unsigned int32`, and `float32` start on an address divisible by 4; and `int64`, `unsigned int64`, and `float64` start on an address divisible by 4 or 8, depending upon the target architecture. The native size types (`native int`, `native unsigned int`, and `&`) are always naturally aligned (4 bytes or 8 bytes, depending on the architecture). When generated externally, these should also be aligned to their natural size, although portable code can use 8-byte alignment to guarantee architecture independence. It is strongly recommended that `float64` be aligned on an 8-byte boundary, even when the size of `native int` is 32 bits.

There is a special prefix instruction, unaligned., that can immediately precede an ldind, stind, initblk, or cpblk instruction. This prefix indicates that the data can have arbitrary alignment; the JIT compiler is required to generate code that correctly performs the effect of the instructions regardless of the actual alignment. Otherwise, if the data is not properly aligned, and no unaligned. prefix has been specified, executing the instruction can generate unaligned memory faults or incorrect data.

I.12.6.3 Byte ordering

For data types larger than 1 byte, the byte ordering is dependent on the target CPU. Code that depends on byte ordering might not run on all platforms. The PE file format (see §I.12.2) allows the file to be marked to indicate that it depends on a particular type ordering.

I.12.6.4 Optimization

Conforming implementations of the CLI are free to execute programs using any technology that guarantees, within a single thread of execution, that side-effects and exceptions generated by a thread are visible in the order specified by the CIL. For this purpose only volatile operations (including volatile reads) constitute visible side-effects. (Note that while only volatile operations constitute visible side-effects, volatile operations also affect the visibility of non-volatile references.) Volatile operations are specified in §I.12.6.7. There are no ordering guarantees relative to exceptions injected into a thread by another thread (such exceptions are sometimes called "asynchronous exceptions" (e.g., `System.Threading.ThreadAbortException`).

[*Rationale:* An optimizing compiler is free to reorder side-effects and synchronous exceptions to the extent that this reordering does not change any observable program behavior. *end rationale*]

[*Note:* An implementation of the CLI is permitted to use an optimizing compiler, for example, to convert CIL to native machine code provided the compiler maintains (within each single thread of execution) the same order of side-effects and synchronous exceptions.

This is a stronger condition than ISO C++ (which permits reordering between a pair of sequence points) or ISO Scheme (which permits reordering of arguments to functions). *end note*]

Optimizers are granted additional latitude for relaxed exceptions in methods. A method is *E-relaxed* for a kind of exception if the innermost custom attribute `System.Runtime.CompilerServices. CompilationRelaxationsAttribute` pertaining to exceptions of kind *E* is present and specifies to relax exceptions of kind *E*. (Here, "innermost" means inspecting the method, its class, and its assembly, in that order.)

A *E-relaxed sequence* is a sequence of instructions executed by a thread, where

- Each instruction causing visible side effects or exceptions is in an *E*-relaxed method.
- The sequence does not cross the boundary of a non-trivial protected or handler region. A region is trivial if it can be optimized away under the rules for non-relaxed methods.

Below, an *E-check* is defined as a test performed by a CIL instruction that upon failure causes an exception of kind *E* to be thrown. Furthermore, the type and range tests performed by the methods that set or get an array element's value, or that get an array element's address are considered checks here.

A conforming implementation of the CLI is free to change the timing of relaxed *E*-checks in an *E*-relaxed sequence, with respect to other checks and instructions as long as the observable behavior of the program is changed only in the case that a relaxed *E*-check fails. If an *E*-check fails in an *E*-relaxed sequence:

- The rest of the associated instruction must be suppressed, in order to preserve verifiability. If the instruction was expected to push a value on the VES stack, no subsequent instruction that uses that value should visibly execute.
- It is unspecified whether or not any or all of the side effects in the *E*-relaxed sequence are made visible by the VES.
- The check's exception is thrown some time in the sequence, unless the sequence throws another exception. When multiple relaxed checks fail, it is unspecified as to which exception is thrown by the VES.

[*Note*: Relaxed checks preserve verifiability, but not necessarily security. Because a relaxed check's exception might be deferred and subsequent code allowed to execute, programmers should never rely on implicit checks to preserve security, but instead use explicit checks and throws when security is an issue. *end note*]

[*Rationale*: Different programmers have different goals. For some, trading away precise exception behavior is unacceptable. For others, optimization is more important. The programmer must specify their preference. Different kinds of exceptions may be relaxed or not relaxed separately because different programmers have different notions of which kinds of exceptions must be timed precisely. *end rationale*]

[*Note*: For background and implementation information for relaxed exception handling , plus examples, see Annex F of Partition VI. *end note*]

I.12.6.5 Locks and threads

The logical abstraction of a thread of control is captured by an instance of the `System.Threading.Thread` object in the class library. Classes beginning with the prefix "`System.Threading`" (see Partition IV) provide much of the user visible support for this abstraction.

To create consistency across threads of execution, the CLI provides the following mechanisms:

1. **Synchronized methods**. A lock that is visible across threads controls entry to the body of a synchronized method. For instance and virtual methods the lock is associated with the *this* pointer. For static methods the lock is associated with the

type to which the method belongs. The lock is taken by the logical thread (see `System.Threading.Thread` in Partition IV) and can be entered any number of times by the same thread; entry by other threads is prohibited while the first thread is still holding the lock. The CLI shall release the lock when control exits (by any means) the method invocation that first acquired the lock.

2. **Explicit locks and monitors.** These are provided in the class library, see `System.Threading.Monitor`. Many of the methods in the `System.Threading.Monitor` class accept an `Object` as argument, allowing direct access to the same lock that is used by synchronized methods. While the CLI is responsible for ensuring correct protocol when this lock is only used by synchronized methods, the user must accept this responsibility when using explicit monitors on these same objects.

3. **Volatile reads and writes.** The CIL includes a prefix, `volatile.`, that specifies that the subsequent operation is to be performed with the cross-thread visibility constraints described in §I.12.6.7. In addition, the class library provides methods to perform explicit volatile reads (`System.Thread.VolatileRead`) and writes (`System.Thread.VolatileWrite`), as well as barrier synchronization (`System.Thread.MemoryBarrier`).

4. **Built-in atomic reads and writes.** All reads and writes of certain properly aligned data types are guaranteed to occur atomically. See §I.12.6.6.

5. **Explicit atomic operations.** The class library provides a variety of atomic operations in the `System.Threading.Interlocked` class. These operations (e.g., Increment, Decrement, Exchange, and CompareExchange) perform implicit acquire/release operations.

Acquiring a lock (`System.Threading.Monitor.Enter` or entering a synchronized method) shall implicitly perform a volatile read operation, and releasing a lock (`System.Threading.Monitor.Exit` or leaving a synchronized method) shall implicitly perform a volatile write operation. See §I.12.6.7.

I.12.6.6 Atomic reads and writes

A conforming CLI shall guarantee that read and write access to *properly aligned* memory locations no larger than the native word size (the size of type `native int`) is atomic (see §I.12.6.2) when all the write accesses to a location are the same size. Atomic writes shall alter no bits other than those written. Unless explicit layout control (see Partition II (Controlling Instance Layout)) is used to alter the default behavior, data elements no larger than the natural word size (the size of a `native int`) shall be properly aligned. Object references shall be treated as though they are stored in the native word size.

[*Note:* There is no guarantee about atomic update (read-modify-write) of memory, except for methods provided for that purpose as part of the class library (see Partition IV). An atomic write of a "small data item" (an item no larger than the native word size) *is* required to do an atomic read/modify/write on hardware that does not support direct writes to small data items. *end note*]

[*Note:* There is no guaranteed atomic access to 8-byte data when the size of a `native int` is 32 bits even though some implementations might perform atomic operations when the data is aligned on an 8-byte boundary. *end note*]

I.12.6.7 Volatile reads and writes

The volatile. prefix on certain instructions shall guarantee cross-thread memory ordering rules. They do not provide atomicity, other than that guaranteed by the specification of §I.12.6.6.

A volatile read has "acquire semantics" meaning that the read is guaranteed to occur prior to any references to memory that occur after the read instruction in the CIL instruction sequence. A volatile write has "release semantics" meaning that the write is guaranteed to happen after any memory references prior to the write instruction in the CIL instruction sequence.

A conforming implementation of the CLI shall guarantee this semantics of volatile operations. This ensures that all threads will observe volatile writes performed by any other thread in the

order they were performed. But a conforming implementation is *not* required to provide a single total ordering of volatile writes as seen from all threads of execution.

An optimizing compiler that converts CIL to native code shall not remove any volatile operation, nor shall it coalesce multiple volatile operations into a single operation.

[*Rationale:* One traditional use of volatile operations is to model hardware registers that are visible through direct memory access. In these cases, removing or coalescing the operations might change the behavior of the program. *end rationale*]

[*Note:* An optimizing compiler from CIL to native code is permitted to reorder code, provided that it guarantees both the single-thread semantics described in §I.12.6 and the cross-thread semantics of volatile operations. *end note*]

I.12.6.8 Other memory model issues

All memory allocated for static variables (other than those assigned RVAs within a PE file, see Partition II) and objects shall be zeroed before they are made visible to any user code.

A conforming implementation of the CLI shall ensure that, even in a multi-threaded environment and without proper user synchronization, objects are allocated in a manner that prevents unauthorized memory access and prevents invalid operations from occurring. In particular, on multiprocessor memory systems where explicit synchronization is required to ensure that all relevant data structures are visible (for example, vtable pointers) the Execution Engine shall be responsible for either enforcing this synchronization automatically or for converting errors due to lack of synchronization into non-fatal, non-corrupting, user-visible exceptions.

It is explicitly *not* a requirement that a conforming implementation of the CLI guarantee that all state updates performed within a constructor be uniformly visible before the constructor completes. CIL generators can ensure this requirement themselves by inserting appropriate calls to the memory barrier or volatile write instructions.