The .NET Profiling API

OVERVIEW

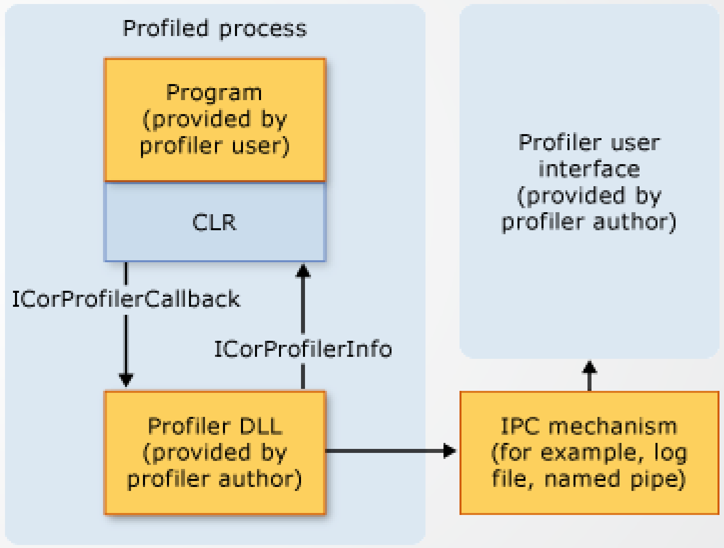
- The .NET Profiler API is available since CLR/.NET Framework 1.0
- A Profiler depends on the CLR – and not on the .NET Framework

Notable Features

- Assembly loading and unloading events
- Just-in-time (JIT) compilation and code-pitching events
- ReJIT
- Thread creation and destruction events
- Function entry and exit events
- Exceptions
- Transitions between managed and unmanaged code execution
- Information about runtime suspensions
- …

PROFILING ARCHITECTURE

- Program
  - The .NET application to monitor
- CLR
  - Required to execute Program
  - Loads Profiler DLL
- Profiler DLL
  - Unmanaged
  - Loaded by CLR into target process
- IPC mechanism
  - Interface between Profiler DLL and UI
- Profiler user interface
  - Performs costly operations
  - May be a managed application


Profiled process
Program (provided by profiler user)
CLR
ICorProfilerCallback
ICorProfilerInfo
Profiler DLL (provided by profiler author)
Profiler user interface (provided by profiler author)
IPC mechanism (for example, log file, named pipe)

STARTUP

Startup

- Process gets created
- CLR is loaded
- CLR loads Profiler DLL
- Profiler subscribes to events

Execute

- Application executes
- Profiler receives events
- Profiler communicates with Profiler user interface

Shutdown

- CLR informs Profiler of shutdown/detach
- Profiler DLL is unloaded
- Process terminates

A (VERY) BRIEF INTRODUCTION TO COM

Common Object Model (COM)

- Platform and language independent system
- Allows components to locate and communicate with each other
- Based on classes and interfaces
- Each class and interface has a GUID (called CLID or IID)
- COM servers
  - Implemented as DLLs exporting specific functions
  - Register supported CLIDs in the windows registry
- COM clients
  - Request implementations via CLID
  - Request specific interfaces from a class via IID

USING A PROFILER

How does the CLR know if and which profiler DLL to load?

- Environment Variables
  - `COR_ENABLE_PROFILING=1`
    - Must be set to 1 to enable profiling
  - `COR_PROFILER_PATH_32=`*full path to the profiler DLL*
  - `COR_PROFILER_PATH_64=`*full path to the profiler DLL*
  - `COR_PROFILER_PATH=`*full path to the profiler DLL*
    - If present, takes precedence over `COR_PROFILER` even if invalid
  - `COR_PROFILER=`*{CLSID of profiler}*
    - The GUID of the COM class implementing `ICorProfilerCallback`
    - Must be present even if `COR_PROFILER_PATH*` is used

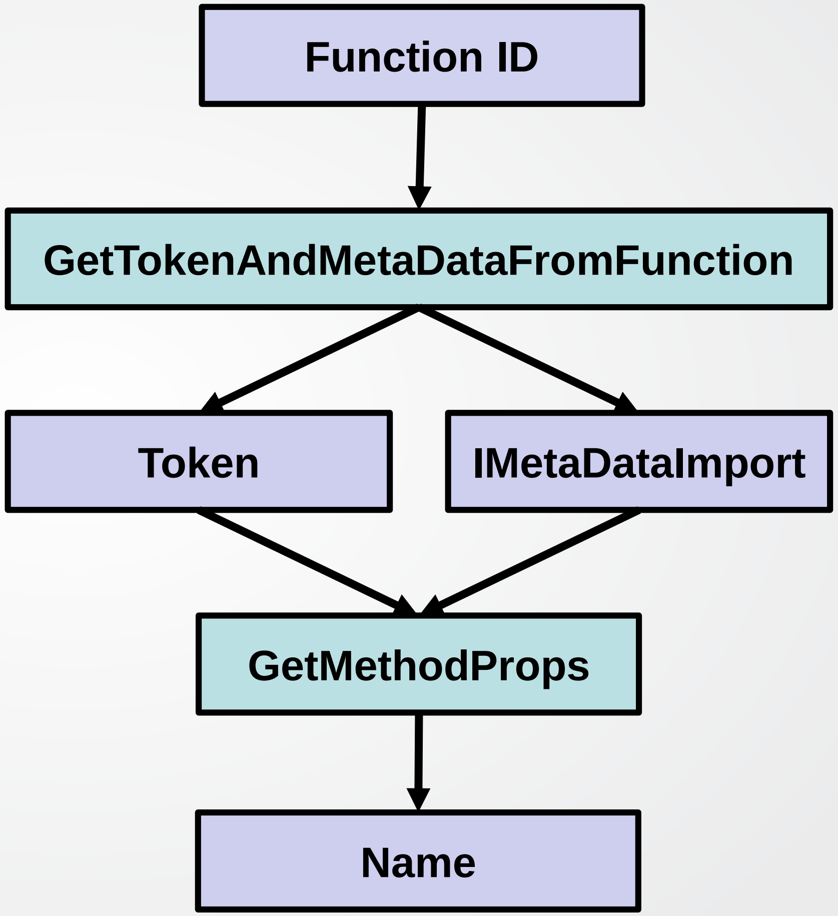
Prefix `CORECLR_` is also allowed

It’s also possible to attach a profiler after application startup (with restrictions)

IDENTIFYING TYPES AND FUNCTIONS

ID: Generated at runtime, typically passed to callbacks

Token: Generated at compile time



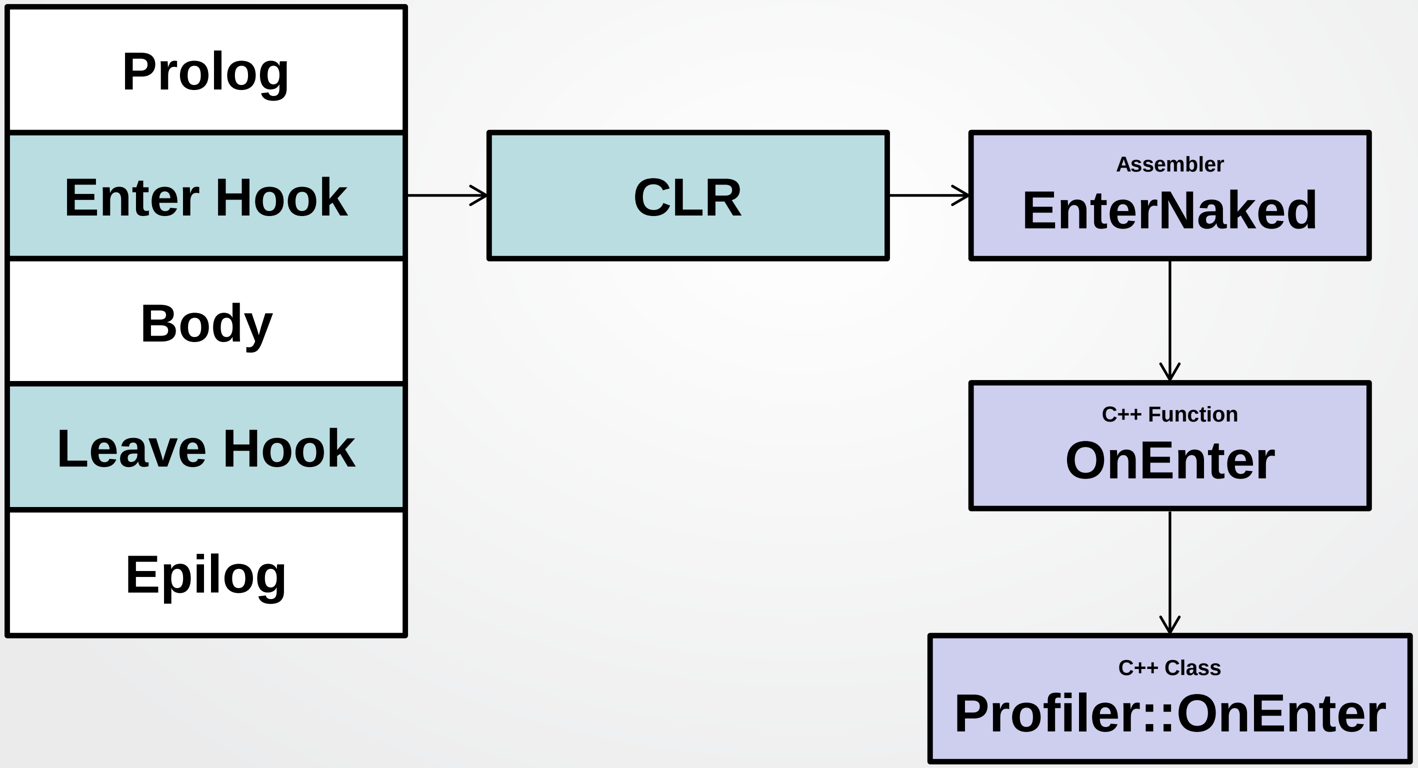
PROFILING METHOD CALLS

Different approaches possible

- Using Enter/Leave/Tailcall hooks
  - Profiler API inserts hook code when method is JITed
  - Hooks must be implemented `naked`/in assembler
  - Hooks can be installed selectively
  - Hooks can be activated/deactivated during execution
- Instrumenting methods by rewriting IL code
  - Profiler modifies IL code when method is JITed
  - ReJIT feature allows profiler to add/remove instrumentation as required
- Sampling
  - A periodic event (e.g. timer) is used to capture call stacks of threads
  - Prone to deadlocks and race conditions (as one thread suspends another)

ENTER/LEAVE/TAILCALL HOOKS

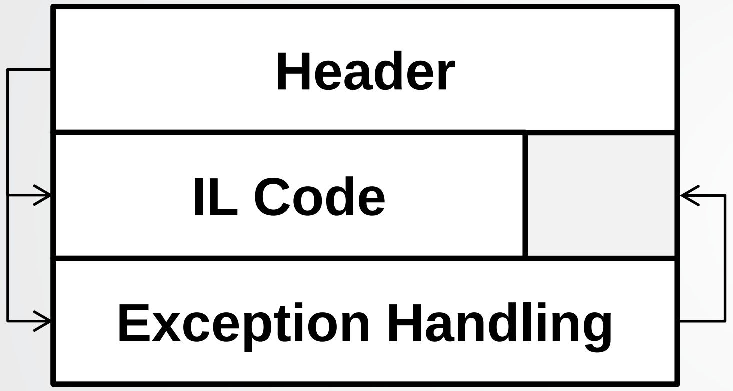
```
MyMethod
{
```



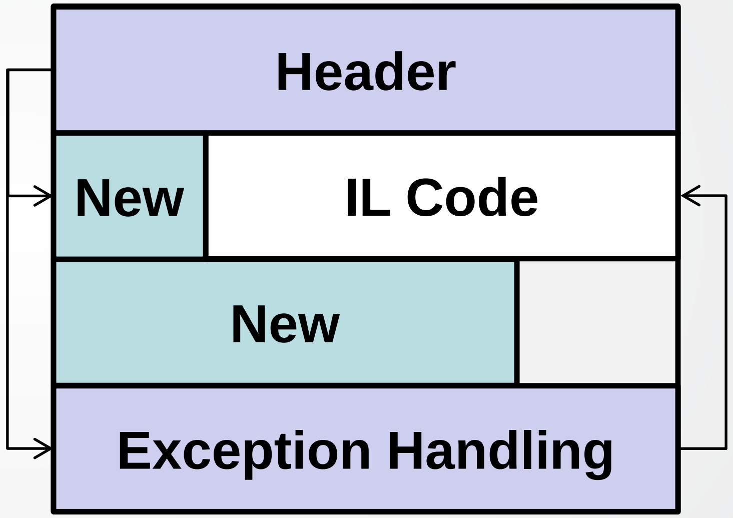
```
}
```

ANATOMY OF A (MODIFIED) FUNCTION BODY

Original Function Body



Modified Function Body

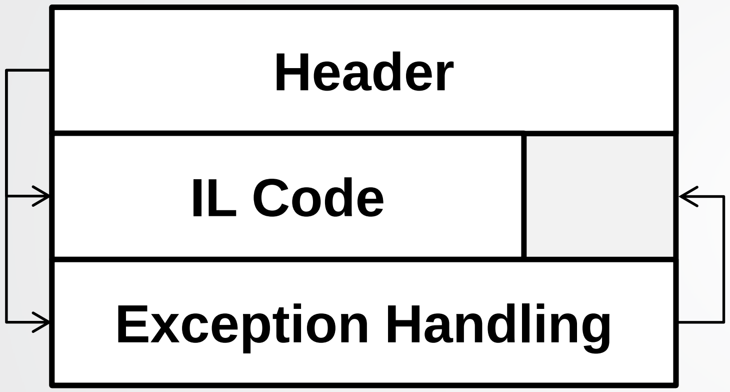


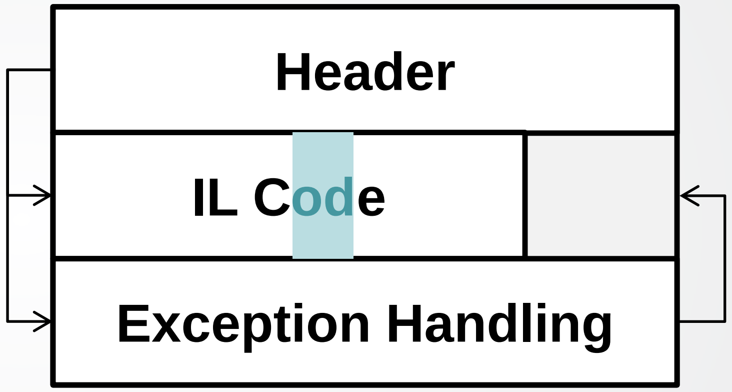
- New code is inserted
- Original IL code must be moved
- Header must be adjusted
- Exception Handling must be adjusted

ANATOMY OF A (MODIFIED) FUNCTION BODY

Original Function Body

Modified Function Body





- Replace only opcodes
- Nothing else to do ;)

REWRITING IL CODE

C# Code

```
public void MyMethod(int value)
{
  if (value == 0) // if (value != 0)
  {
    Console.WriteLine(
      "{0} == 0", value);
  }
  else
  {
    Console.WriteLine(
      "{0} != 0", value);
  }
}
```

IL Code

```
nop                 00
ldarg.1             03
ldc.i4.0            16
ceq              FE 01 <- cgt.un FE 03
stloc.0             0A
ldloc.0             06
brfalse.s           2C 15
nop                 00
ldstr               72 19 00 00 70
ldarg.1             03
box                 8C 2E 00 00 01
call                28 2A 00 00 0A
nop                 00
nop                 00
br.s                2B 13
nop                 00
ldstr               72 2B 00 00 70
ldarg.1             03
box                 8C 2E 00 00 01
call                28 2A 00 00 0A
nop                 00
nop                 00
ret                 2A
```

Fat Header

```
13 30       Flags & Size
02 00       MaxStack
32 00 00 00 CodeSize
04 00 00 11 LocalVarSigTok
```

REJIT

Allows the profiler to, well, re-JIT compile method bodys

- Profiler may request to re-JIT a method during execution of the application
- In the callback the profiler modifies the IL body
- New body is used next time when method is executed
- Profiler may request to revert the IL body to its original state

Comes with limitations

- No managed Debugging
- Can not be used with NGEN images
- Not that easy when methods are inlined
- Profiler must be attached at startup

LINKS

- Profiling (Unmanaged API Reference)
  https://docs.microsoft.com/en-us/dotnet/framework/unmanaged-api/profiling/
- David Broman's CLR Profiling API Blog
  https://blogs.msdn.microsoft.com/davbr/
- .NET Core runtime GitHub project (CoreCLR)
  https://github.com/dotnet/coreclr/blob/master/src/vm/profilinghelper.cpp
- Rewrite MSIL Code on the Fly with the .NET Framework Profiling API
  MSDN Magazine September 2003, Aleksandr Mikunov
- CLR Profiler
  https://clrprofiler.codeplex.com/

Images:

- Profiling architecture (Slide 3): https://docs.microsoft.com/en-us/dotnet/framework/unmanaged-api/profiling/profiling-overview