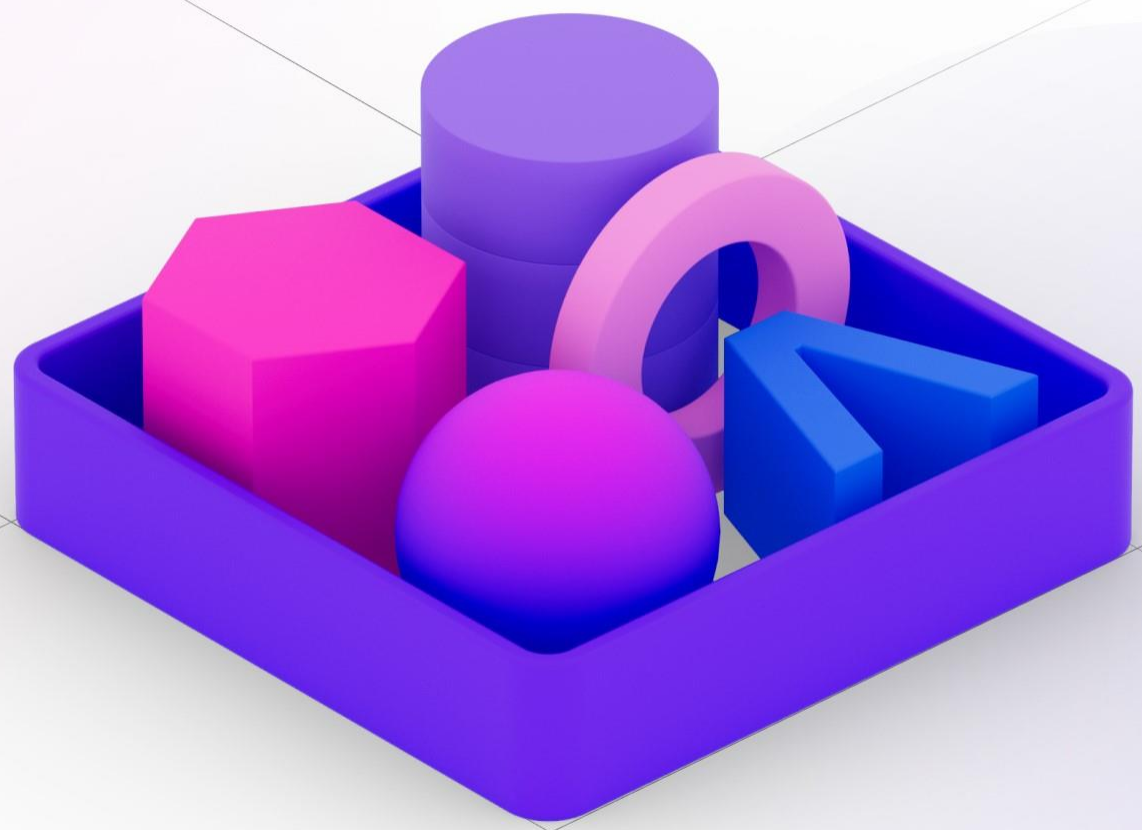
.NET Conf



ELCA
We make it work.

.NET High Performance programming

Hai Nguyen Duy
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Azure Cybersecurity Expert

Parker Solar Probe

692.000 km/h

Agenda

- How NET manage memory
- Tool to measure performance
- Optimize performance detail practices
- Q&A

1.

How .NET manage memory

Levels of optimization

Level	Description
High level design (Architectural Level)	Make the best use of the resources (images, sounds, and so on), goals, any constraints, and the expected load (e.g. microservices, data caches, load balancing, database design, denormalize column, indexing, scalability vertical – horizontal, Monitoring and Analytics Log performance, parallelism in batch job …)
Source code level (focus)	Depend on the source language, the target machine language C# 6,7,8 (changes continuously), the framework inside (e.g. EF, N+1 query) and the compiler. (e.g. dispose resource,…), Data model, Algorithms & Data structures efficiency

Levels of optimization

Level	Description
Compilation and Machine Code Optimization Level	Related to the process of compiling source code into machine code. Compilers may perform optimizations to improve execution time, efficiently use the CPU, and take advantage of specific characteristics of the computer architecture
Deployment and System Configuration Level	involves fine-tuning the deployment environment and system configuration to ensure the application operates efficiently in production conditions. This may include server configuration, database optimization, and managing system resources.

Memory Allocations

.NET is “Managed Memory Runtime”:

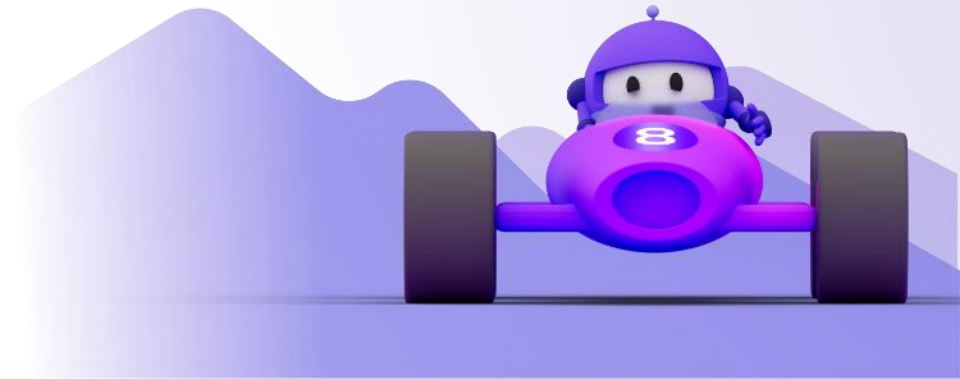
the runtime environment (Common Language Runtime - CLR) takes care of memory allocation

Stack and Heap:

The stack is used for storing value types and method call information, while the heap is used for reference types and objects.

Garbage Collection:

.NET has a garbage collector that automatically reclaims memory from objects that are no longer in use, preventing memory leaks.



Generational Collection Process

Mark Phase:	• identifies and marks objects that are still in use and reachable from the root objects.
Compact Phase (optional):	• the marked objects are compacted to reduce memory fragmentation. This phase rearranges objects in memory, moving them closer together to create contiguous blocks of free memory. • This is particularly useful in scenarios where memory fragmentation can be a problem, such as long-running applications.
Finalization Phase:	• call the finalizer methods of objects that have finalizers which used for cleaning up resources like files, database connections, etc. • The garbage collector postpones finalization until the objects are no longer accessible and marks them for finalization in the previous phase.
Completion Phase:	• the garbage collector performs a second pass to clean up objects that have been marked for finalization. These objects' finalizers are called to release unmanaged resources.
Reclamation Phase:	• the memory occupied by objects that are neither reachable nor have finalizers is reclaimed. The memory is returned to the heap, making it available for new object allocations.

Garbage Collection

.NET's heap memory is divided into three generations :

Generation 0:

1. Youngest generation.
2. Newly allocated objects.
3. Frequent garbage collection.

Generation 1:

1. Objects survived Generation 0 collections.
2. Less frequent garbage collection.
3. Objects may be promoted to Generation 2.

Generation 2:

1. Oldest generation.
2. Objects survived multiple collections.
3. Least frequent garbage collection.
4. Persistent objects for the application's lifetime.

Benefits of Generational GC

Efficiency:

Frequent collection of the Young Generation reduces overhead.

Faster Collections:

Smaller spaces are quicker to scan.

Improved Application Performance:

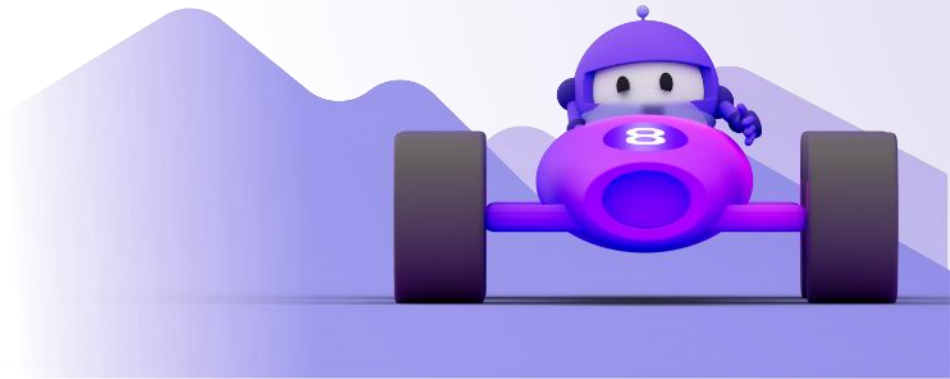
Reduced pause times for garbage collection.

Performance tips

1. Best way to reduce time taken for GC is to not allocate at all

2. Try to keep objects short-lived

3. Try to keep objects small to avoid them ending up on the LOH.



2.

NET performance tools

.NET Tools

BenchmarkDotNet
Powerful .NET library for benchmarking

Visual Studio

dotTrace

dotPeek

dotMemory

ILSpy

ANTS Performance Profiler (Redgate)

PerfView

APACHE JMeter™

Azure

Gatling

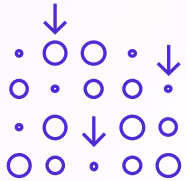
Microsoft Azure Load Testing

WinDbg

Benchmark .NET

Library for .NET benchmarking

High prevision measurements



Extra data and output available using diagnoses

Compare performance on different platform, architectures, JIT versions and GC models

BenchmarkDotNet

Transform methods into benchmarks, track their performance, and share reproducible measurement experiments

```
[SimpleJob(RuntimeMoniker.Net472, baseline: true)]
[SimpleJob(RuntimeMoniker.NetCoreApp30)]
[SimpleJob(RuntimeMoniker.NativeAot70)]
[SimpleJob(RuntimeMoniker.Mono)]
[RPlotExporter]
public class Md5VsSha256
{
    private SHA256 sha256 = SHA256.Create();
    private MD5 md5 = MD5.Create();
    private byte[] data;

    [Params(1000, 10000)]
    public int N;

    [GlobalSetup]
    public void Setup()
    {
        data = new byte[N];
        new Random(42).NextBytes(data);
    }

    [Benchmark]
    public byte[] Sha256() => sha256.ComputeHash(data);

    [Benchmark]
    public byte[] Md5() => md5.ComputeHash(data);
}
```

```
BenchmarkDotNet=v0.12.0, OS=Windows 10.0.17763.805 (1809/October2018Update/Redstone5)
Intel Core i7-7700K CPU 4.20GHz (Kaby Lake), 1 CPU, 8 logical and 4 physical cores
  [Host]       : .NET Framework 4.7.2 (4.7.3468.0), X64 RyuJIT
  Net472       : .NET Framework 4.7.2 (4.7.3468.0), X64 RyuJIT
  NetCoreApp30 : .NET Core 3.0.0 (CoreCLR 4.700.19.46205, CoreFX 4.700.19.46214), X64 RyuJIT
  NativeAot70  : .NET 7.0.0-preview.4.22172.7, X64 NativeAOT
  Mono         : Mono 6.4.0 (Visual Studio), X64
```

Method	Runtime	N	Mean	Error	StdDev	Ratio
Sha256	.NET 4.7.2	1000	7.735 us	0.1913 us	0.4034 us	1.00
Sha256	.NET Core 3.0	1000	3.989 us	0.0796 us	0.0745 us	0.50
Sha256	NativeAOT 7.0	1000	4.091 us	0.0811 us	0.1562 us	0.53
Sha256	Mono	1000	13.117 us	0.2485 us	0.5019 us	1.70
Md5	.NET 4.7.2	1000	2.872 us	0.0552 us	0.0737 us	1.00
Md5	.NET Core 3.0	1000	1.848 us	0.0348 us	0.0326 us	0.64
Md5	NativeAOT 7.0	1000	1.817 us	0.0359 us	0.0427 us	0.63
Md5	Mono	1000	3.574 us	0.0678 us	0.0753 us	1.24
Sha256	.NET 4.7.2	10000	74.509 us	1.5787 us	4.6052 us	1.00
Sha256	.NET Core 3.0	10000	36.049 us	0.7151 us	1.0025 us	0.49
Sha256	NativeAOT 7.0	10000	36.253 us	0.7076 us	0.7571 us	0.49
Sha256	Mono	10000	116.350 us	2.2555 us	3.0110 us	1.58
Md5	.NET 4.7.2	10000	17.308 us	0.3361 us	0.4250 us	1.00
Md5	.NET Core 3.0	10000	15.726 us	0.2064 us	0.1930 us	0.90
Md5	NativeAOT 7.0	10000	15.627 us	0.2631 us	0.2461 us	0.89
Md5	Mono	10000	30.205 us	0.5868 us	0.6522 us	1.74

DotNet Diagnostics tool

dumpheap -stat
dumpheap -mt 7ffee78d2e50
gcroot 023cb5011c90

dotnet-counters && dotnet-dump

```
Command Prompt - dotnet-counters  monitor --refresh-interval 1 -p 24316
Press p to pause, r to resume, q to quit.
    Status: Running

[System.Runtime]
    % Time in GC since last GC (%)                                  0
    Allocation Rate (B / 1 sec)                                 8,168
    CPU Usage (%)                                                   0
    Exception Count (Count / 1 sec)                                 0
    GC Committed Bytes (MB)                                    88.449
    GC Fragmentation (%)                                        0.771
    GC Heap Size (MB)                                          60.378
    Gen 0 GC Count (Count / 1 sec)                                  0
    Gen 0 Size (B)                                          1,507,464
    Gen 1 GC Count (Count / 1 sec)                                  0
    Gen 1 Size (B)                                         51,017,960
    Gen 2 GC Count (Count / 1 sec)                                  0
    Gen 2 Size (B)                                                  0
    IL Bytes Jitted (B)                                       209,625
    LOH Size (B)                                            4,616,800
    Monitor Lock Contention Count (Count / 1 sec)                   0
    Number of Active Timers                                         0
    Number of Assemblies Loaded                                   119
    Number of Methods Jitted                                    2,372
    POH (Pinned Object Heap) Size (B)                         171,264
    ThreadPool Completed Work Item Count (Count / 1 sec)            0
    ThreadPool Queue Length                                         0
    ThreadPool Thread Count                                         0
    Time spent in JIT (ms / 1 sec)                                  0
    Working Set (MB)                                          283.623
```

```
> gcroot 023cb5011c90
Caching GC roots, this may take a while.
Subsequent runs of this command will be faster.

HandleTable:
    0000023c9fa011f8 (strong handle)
          -> 023ca4000020     System.Object[]
          -> 023cb28188f0     testwebapi.Controllers.Processor
          -> 023cb2818908     testwebapi.Controllers.CustomerCache
          -> 023cb2818920     System.Collections.Generic.List<testw
          -> 023cba04f218     testwebapi.Controllers.Customer[]
          -> 023cb5011cf0     testwebapi.Controllers.Customer
          -> 023cb5011c90     System.String

Thread 13ac:
    baa947f610 7fff45bdca87 System.Threading.PortableThreadPool+Gat
ivate.CoreLib/src/System/Threading/PortableThreadPool.GateThread.cs
        r14:
          -> 023ca4000020     System.Object[]
          -> 023cb28188f0     testwebapi.Controllers.Processor
          -> 023cb2818908     testwebapi.Controllers.CustomerCache
          -> 023cb2818920     System.Collections.Generic.List<testw
          -> 023cba04f218     testwebapi.Controllers.Customer[]
          -> 023cb5011cf0     testwebapi.Controllers.Customer
          -> 023cb5011c90     System.String

Found 2 unique roots.
```

DotNet Diagnostics tool
dotnet-trace and perfview

```
dhn@NB30305 ~
> dotnet-trace collect -p 35536 --providers Microsoft-DotNETCore-SampleProfiler

Provider Name                           Keywords            Level               Enabled By
Microsoft-DotNETCore-SampleProfiler     0xFFFFFFFFFFFFFFFF  Verbose(5)          --providers

Process        : D:\.NET
gnosticScenarios.exe
Output File    : C:\Users

[00:00:00:36]   Recording
Press <Enter> or <Ctrl+C>
Stopping the trace. This

Trace completed.
```

Thread Time (with StartStop Activities) Stacks(330,040 metric) DiagnosticScenarios.exe_20231103_145704.nettrace in dhn (C:\Users\dhn\DiagnosticS...

File View Diff Regression Preset Help Stack View Help (F1) Understanding Perf Data Starting an Analysis Troubleshooting Tips

Update Back Forward Totals Metric: 330,040.3 Count: 165,321.0 First: 0.372 Last: 36,671.137 Last-First: 36,670.765 Metric/Interval: 9.00 TimeBucket: 1,146.0

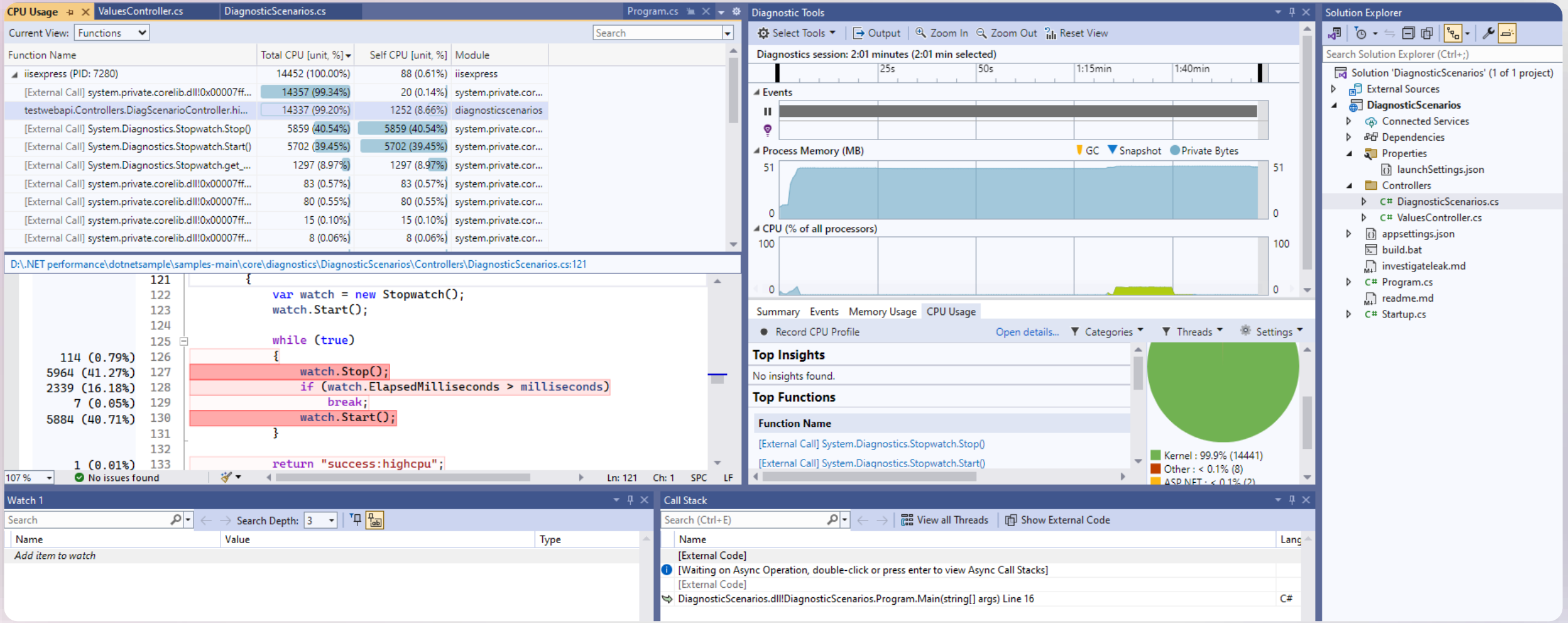
Start: 0 End: 36,671.136 Find:

GroupPats: [group module entries] {%}!=>n Fold%: FoldPats: ^STARTING TASK;UNM/ IncPats: ExcPats: LAST_BLOCK

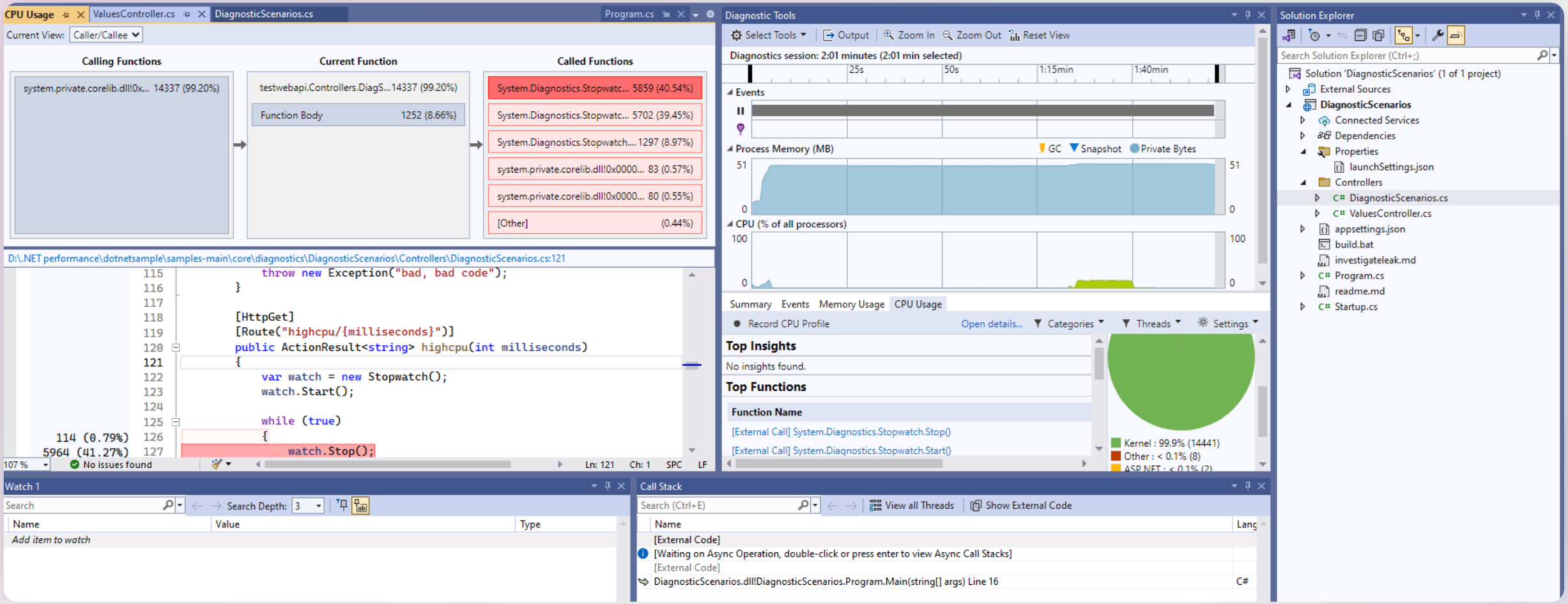
By Name ? | Caller-Callee ? | CallTree ? | Callers ? | Callees ? | Flame Graph ? | Notes ?

Name ?	Inc % ?	Inc ?	Inc Ct ?	Exc % ?	Exc ?	Exc Ct ?	Fold ?	Fold Ct ?	When ?	First ?	Last ?
ROOT	100.0	330,040.3	165,321	0.0	0	0	0	0	**********	0.372	36,671.137
+ Process64 Process(35536) (35536) Arg	100.0	330,040.3	165,321	0.0	0	0	0	0	**********	0.372	36,671.137
+ (Non-Activities)	100.0	330,040.3	165,321	0.0	0	0	0	0	**********	0.372	36,671.137
+ Threads	100.0	330,040.3	165,321	0.0	0	0	0	0	**********	0.372	36,671.137
+ Thread (34564)	11.1	36,670.9	18,369	0.0	0	0	0	0	99A99A9A9A9999AA99A9AAA9999	0.409	36,671.137
+ module System.Private.CoreLib.i	11.1	36,670.9	18,369	11.1	36,671	18,369	36,671	18,369	99A99A9A9A9999AA99A9AAA9999	0.409	36,671.137
+ Thread (35088)	11.1	36,670.8	18,369	0.0	0	0	0	0	99AA9A9AA99AAA9AAAAAA99999A	0.372	36,671.137
+ module DiagnosticScenarios <<	11.1	36,670.8	18,369	0.0	0	0	0	0	99AA9A9AA99AAA9AAAAAA99999A	0.372	36,671.137
+ module Microsoft.Extensions.H	11.1	36,670.8	18,369	0.0	0	0	0	0	99AA9A9AA99AAA9AAAAAA99999A	0.372	36,671.137
+ module System.Private.CoreL	11.1	36,670.8	18,369	11.1	36,671	18,369	36,671	18,369	99AA9A9AA99AAA9AAAAAA99999A	0.372	36,671.137

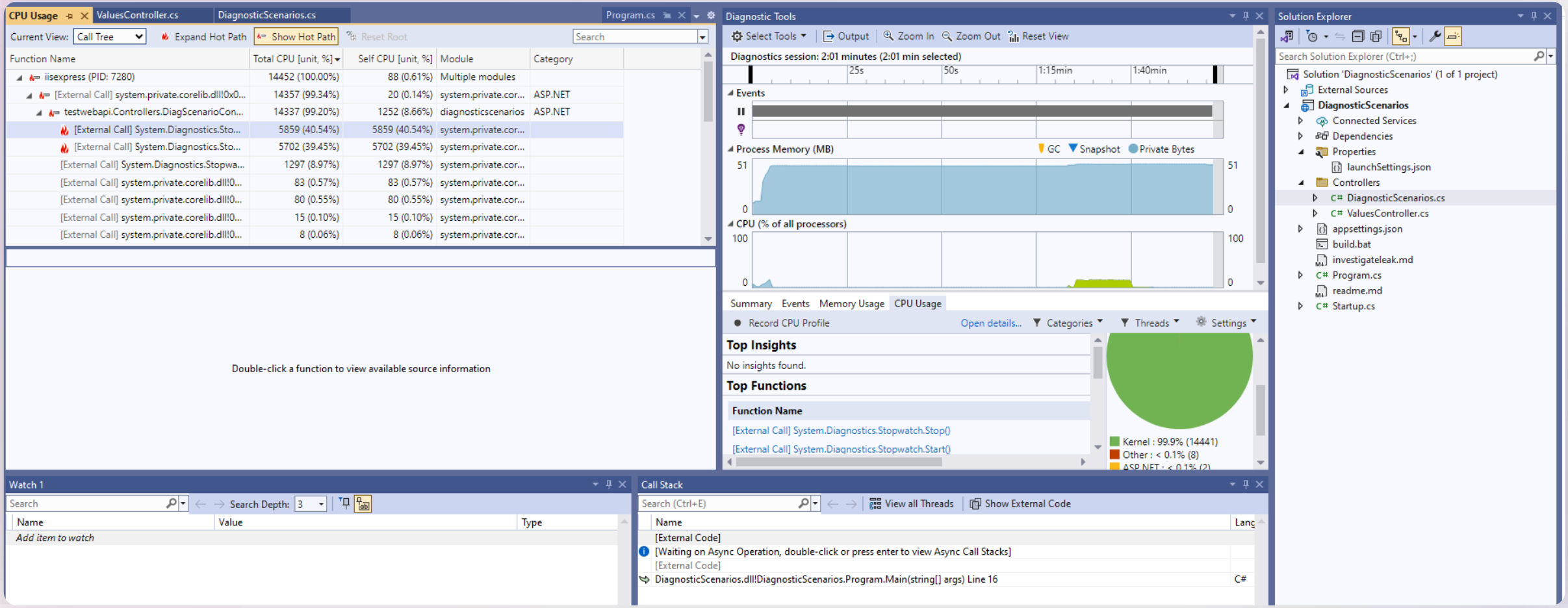
VS Profiling (CPU usage)



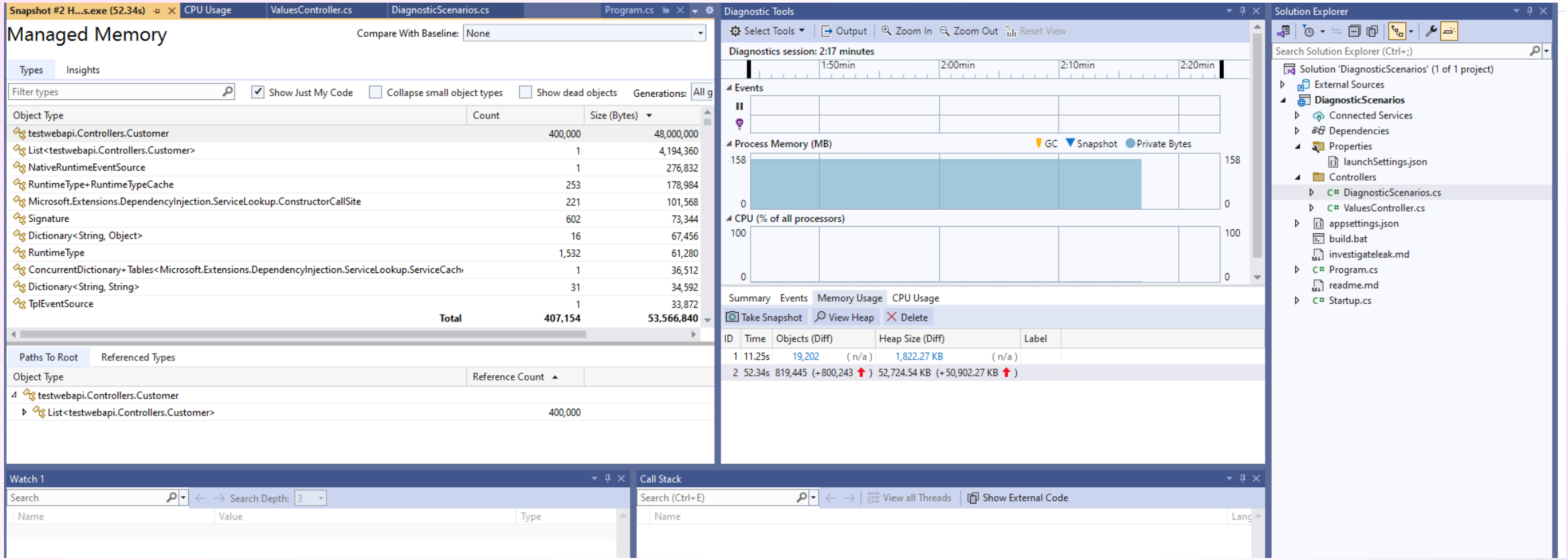
VS Profiling (CPU usage)



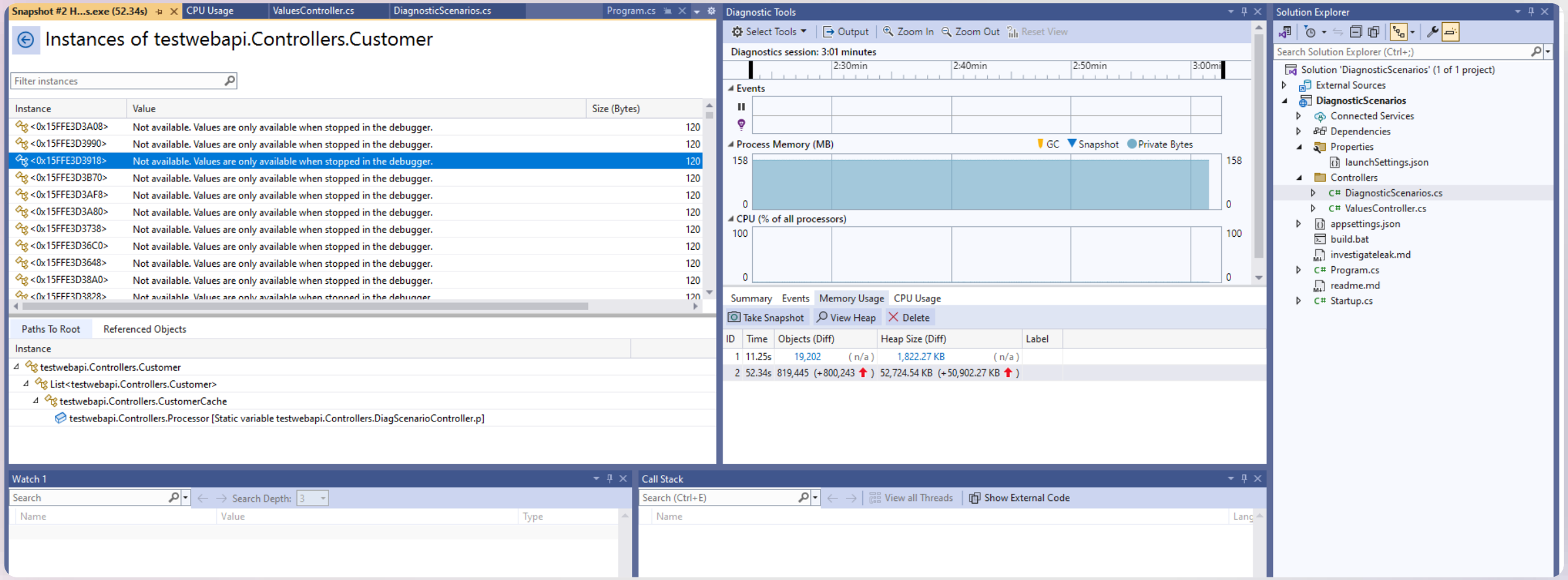
VS Profiling (CPU usage)



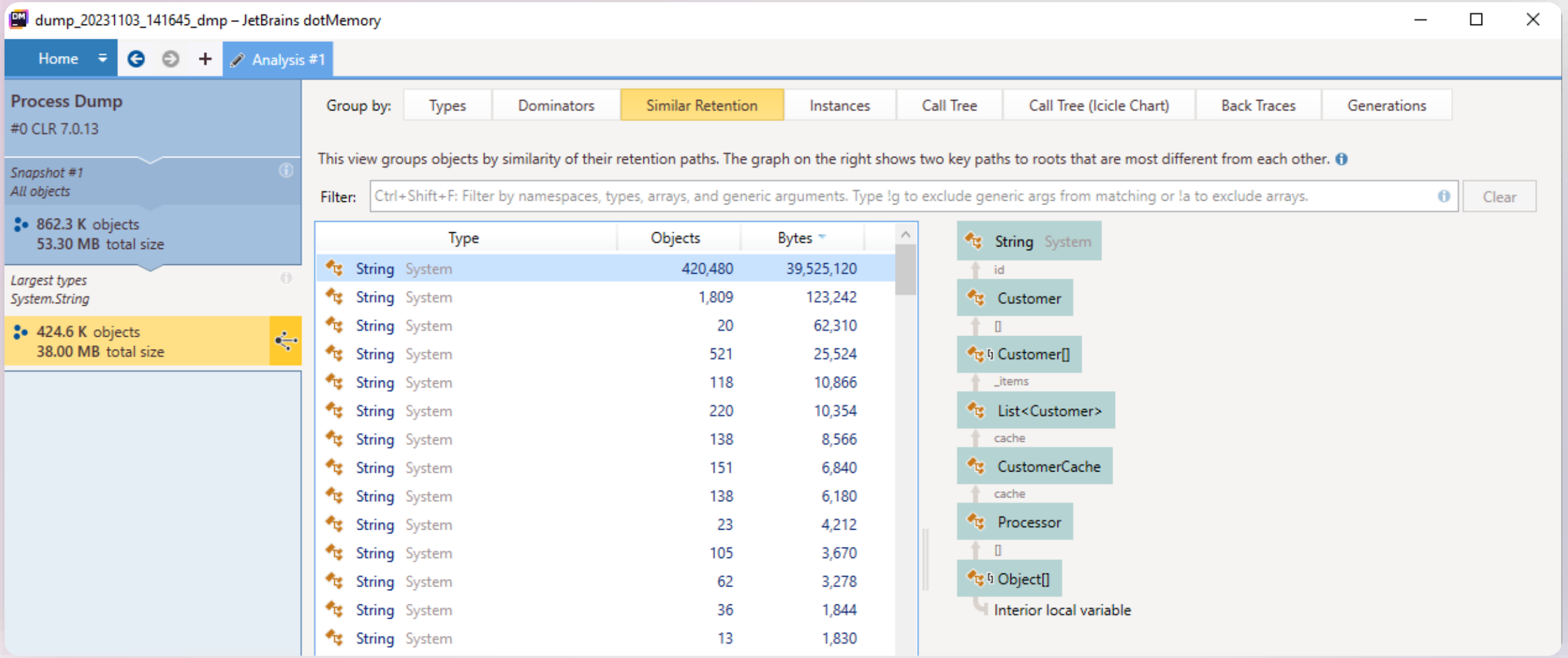
VS Profiling (memory usage)



VS Profiling (memory usage)

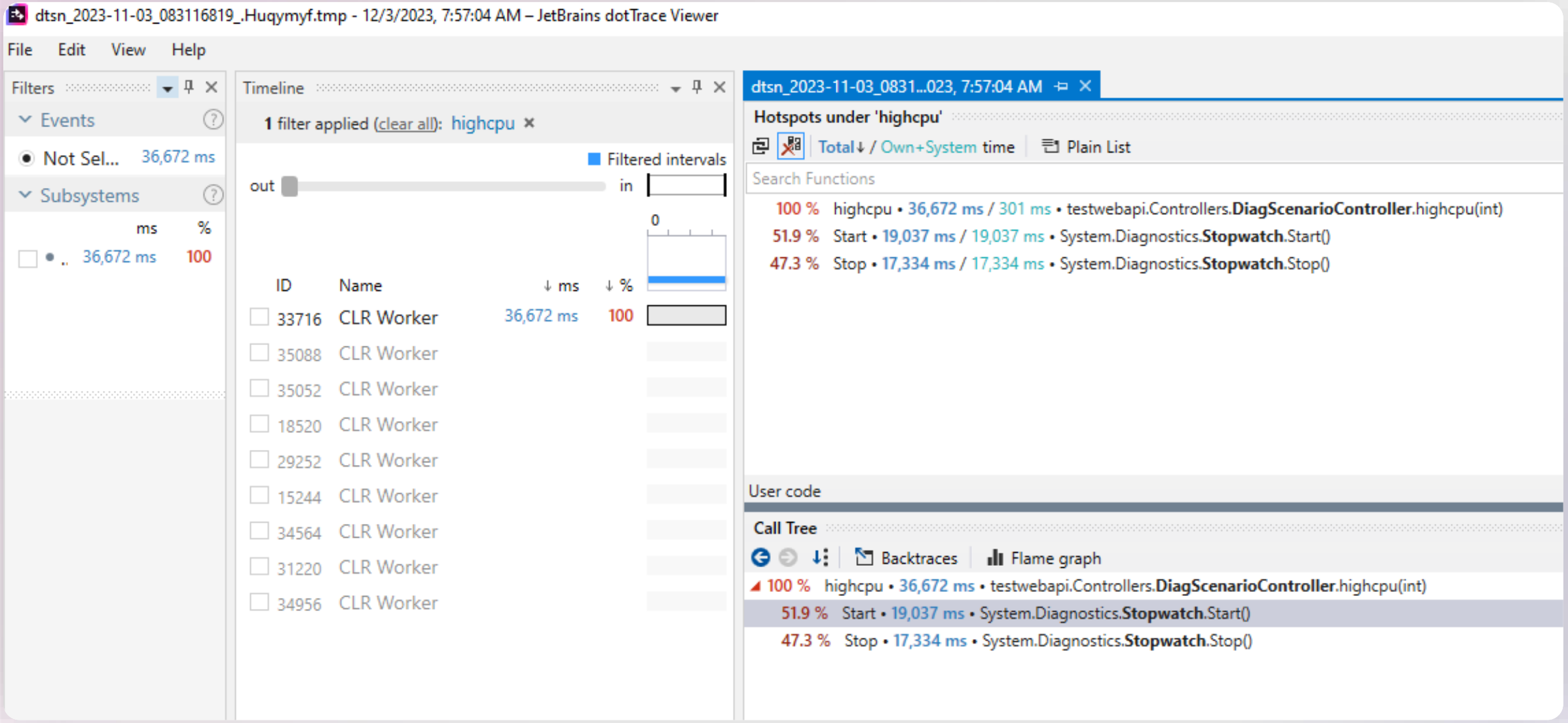


dotMemory (license)



dotTrace (license)

dotTrace



dotMemory Unit test performance

Check for objects

```
dotMemory.Check(memory =>
{
    Assert.That(memory.GetObjects(where => where.Type
                                    .Is<Foo>())
                                    .ObjectsCount,
                                    Is.EqualTo((0)));

});
```

Compare snapshots

```
var memoryCheckPoint1 = dotMemory.Check();
foo.Bar();
var memoryCheckPoint2 = dotMemory.Check(memory =>
{   Assert.That(memory.GetTrafficFrom(memoryCheckPoint1)
            .Where(obj => obj.Interface.Is<IFoo>())
            .AllocatedMemory.SizeInBytes, Is.LessThan(1000));});
bar.Foo();
dotMemory.Check(memory =>
{   Assert.That(memory.GetTrafficFrom(memoryCheckPoint2)
        .Where( obj => obj.Type.Is<Bar>())
        .AllocatedMemory.ObjectsCount, Is.LessThan(10));});
```

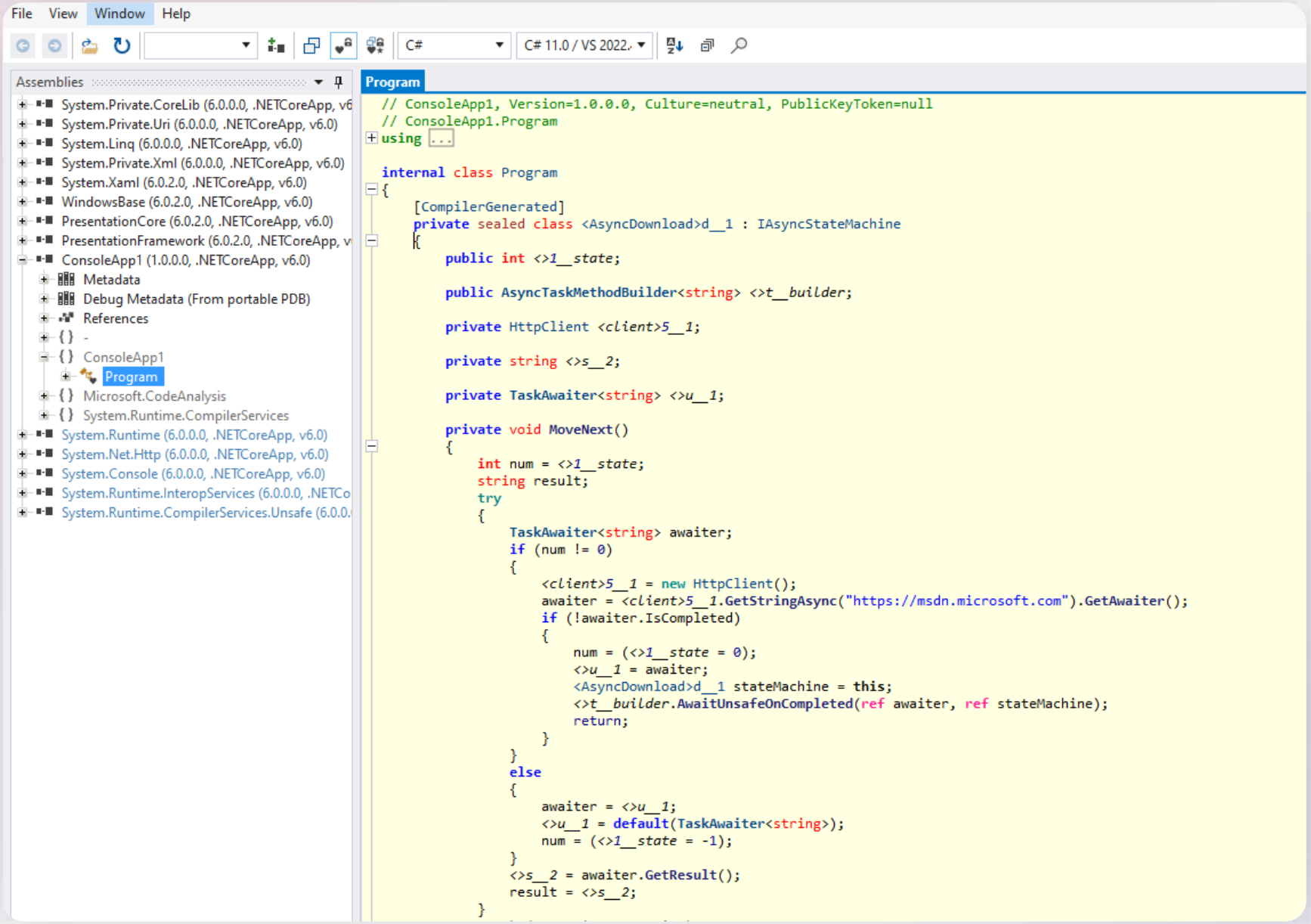
Check memory traffic

```
var memoryCheckPoint = dotMemory.Check();

foo.Bar();

dotMemory.Check(memory =>
{
    Assert.That(memory.GetDifference(memoryCheckPoint)
                            .GetSurvivedObjects()
                            .GetObjects(where => where
                            .Namespace.Like("MyApp"))
                            .ObjectsCount, Is.EqualTo(0));

});
```

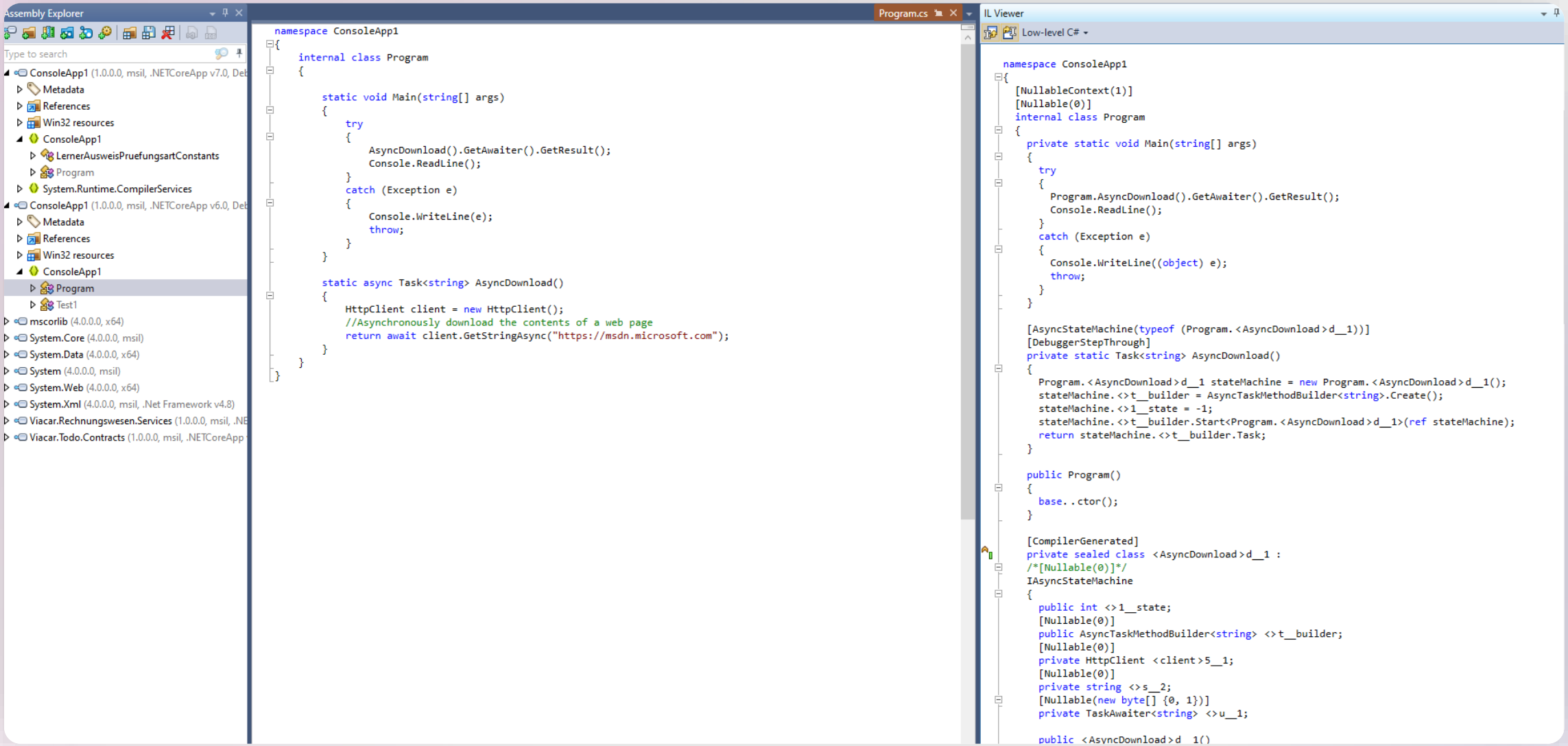
Continue analysis in dotMemory

```
[DotMemoryUnit(SavingStrategy = SavingStrategy.OnAnyFail,
                        Directory = @"C:\tmp\Class",
                        WorkspaceNumberLimit = 200,
                        DiskSpaceLimit = 104857600)]
```

ILSpy


File View Window Help
C#
C# 11.0 / VS 2022.
Assemblies
System.Private.CoreLib (6.0.0.0, .NETCoreApp, v6
System.Private.Uri (6.0.0.0, .NETCoreApp, v6.0)
System.Linq (6.0.0.0, .NETCoreApp, v6.0)
System.Private.Xml (6.0.0.0, .NETCoreApp, v6.0)
System.Xaml (6.0.2.0, .NETCoreApp, v6.0)
WindowsBase (6.0.2.0, .NETCoreApp, v6.0)
PresentationCore (6.0.2.0, .NETCoreApp, v6.0)
PresentationFramework (6.0.2.0, .NETCoreApp, v
ConsoleApp1 (1.0.0.0, .NETCoreApp, v6.0)
Metadata
Debug Metadata (From portable PDB)
References
-
ConsoleApp1
Program
Microsoft.CodeAnalysis
System.Runtime.CompilerServices
System.Runtime (6.0.0.0, .NETCoreApp, v6.0)
System.Net.Http (6.0.0.0, .NETCoreApp, v6.0)
System.Console (6.0.0.0, .NETCoreApp, v6.0)
System.Runtime.InteropServices (6.0.0.0, .NETCo
System.Runtime.CompilerServices.Unsafe (6.0.0.
Program
// ConsoleApp1, Version=1.0.0.0, Culture=neutral, PublicKeyToken=null
// ConsoleApp1.Program
using ...
internal class Program
{
[CompilerGenerated]
private sealed class <AsyncDownload>d__1 : IAsyncStateMachine
{
public int <>1__state;
public AsyncTaskMethodBuilder<string> <>t__builder;
private HttpClient <client>5__1;
private string <>s__2;
private TaskAwaiter<string> <>u__1;
private void MoveNext()
{
int num = <>1__state;
string result;
try
{
TaskAwaiter<string> awaiter;
if (num != 0)
{
<client>5__1 = new HttpClient();
awaiter = <client>5__1.GetStringAsync("https://msdn.microsoft.com").GetAwaiter();
if (!awaiter.IsCompleted)
{
num = (<>1__state = 0);
<>u__1 = awaiter;
<AsyncDownload>d__1 stateMachine = this;
<>t__builder.AwaitUnsafeOnCompleted(ref awaiter, ref stateMachine);
return;
}
}
else
{
awaiter = <>u__1;
<>u__1 = default(TaskAwaiter<string>);
num = (<>1__state = -1);
}
<>s__2 = awaiter.GetResult();
result = <>s__2;
}

dotPeek


Assembly Explorer
Type to search
ConsoleApp1 (1.0.0.0, msil, .NETCoreApp v7.0, Deb
Metadata
References
Win32 resources
ConsoleApp1
LernerAusweisPruefungsartConstants
Program
System.Runtime.CompilerServices
ConsoleApp1 (1.0.0.0, msil, .NETCoreApp v6.0, Deb
Metadata
References
Win32 resources
ConsoleApp1
Program
Test1
mscorlib (4.0.0.0, x64)
System.Core (4.0.0.0, msil)
System.Data (4.0.0.0, x64)
System (4.0.0.0, msil)
System.Web (4.0.0.0, x64)
System.Xml (4.0.0.0, msil, .Net Framework v4.8)
Viacar.Rechnungswesen.Services (1.0.0.0, msil, .NE
Viacar.Todo.Contracts (1.0.0.0, msil, .NETCoreApp
Program.cs
namespace ConsoleApp1
{
internal class Program
{
static void Main(string[] args)
{
try
{
AsyncDownload().GetAwaiter().GetResult();
Console.ReadLine();
}
catch (Exception e)
{
Console.WriteLine(e);
throw;
}
}
static async Task<string> AsyncDownload()
{
HttpClient client = new HttpClient();
//Asynchronously download the contents of a web page
return await client.GetStringAsync("https://msdn.microsoft.com");
}
}
}
IL Viewer
Low-level C#
namespace ConsoleApp1
{
[NullableContext(1)]
[Nullable(0)]
internal class Program
{
private static void Main(string[] args)
{
try
{
Program.AsyncDownload().GetAwaiter().GetResult();
Console.ReadLine();
}
catch (Exception e)
{
Console.WriteLine((object) e);
throw;
}
}
[AsyncStateMachine(typeof (Program.<AsyncDownload>d__1))]
[DebuggerStepThrough]
private static Task<string> AsyncDownload()
{
Program.<AsyncDownload>d__1 stateMachine = new Program.<AsyncDownload>d__1();
stateMachine.<>t__builder = AsyncTaskMethodBuilder<string>.Create();
stateMachine.<>1__state = -1;
stateMachine.<>t__builder.Start<Program.<AsyncDownload>d__1>(ref stateMachine);
return stateMachine.<>t__builder.Task;
}
public Program()
{
base..ctor();
}
[CompilerGenerated]
private sealed class <AsyncDownload>d__1 :
/*[Nullable(0)]*/
IAsyncStateMachine
{
public int <>1__state;
[Nullable(0)]
public AsyncTaskMethodBuilder<string> <>t__builder;
[Nullable(0)]
private HttpClient <client>5__1;
[Nullable(0)]
private string <>s__2;
[Nullable(new byte[] {0, 1})]
private TaskAwaiter<string> <>u__1;
public <AsyncDownload>d__1()

Production metrics and monitoring

- Load testing
- Stress Testing

Apache Jmeter

Gatling

Locust

NBomber

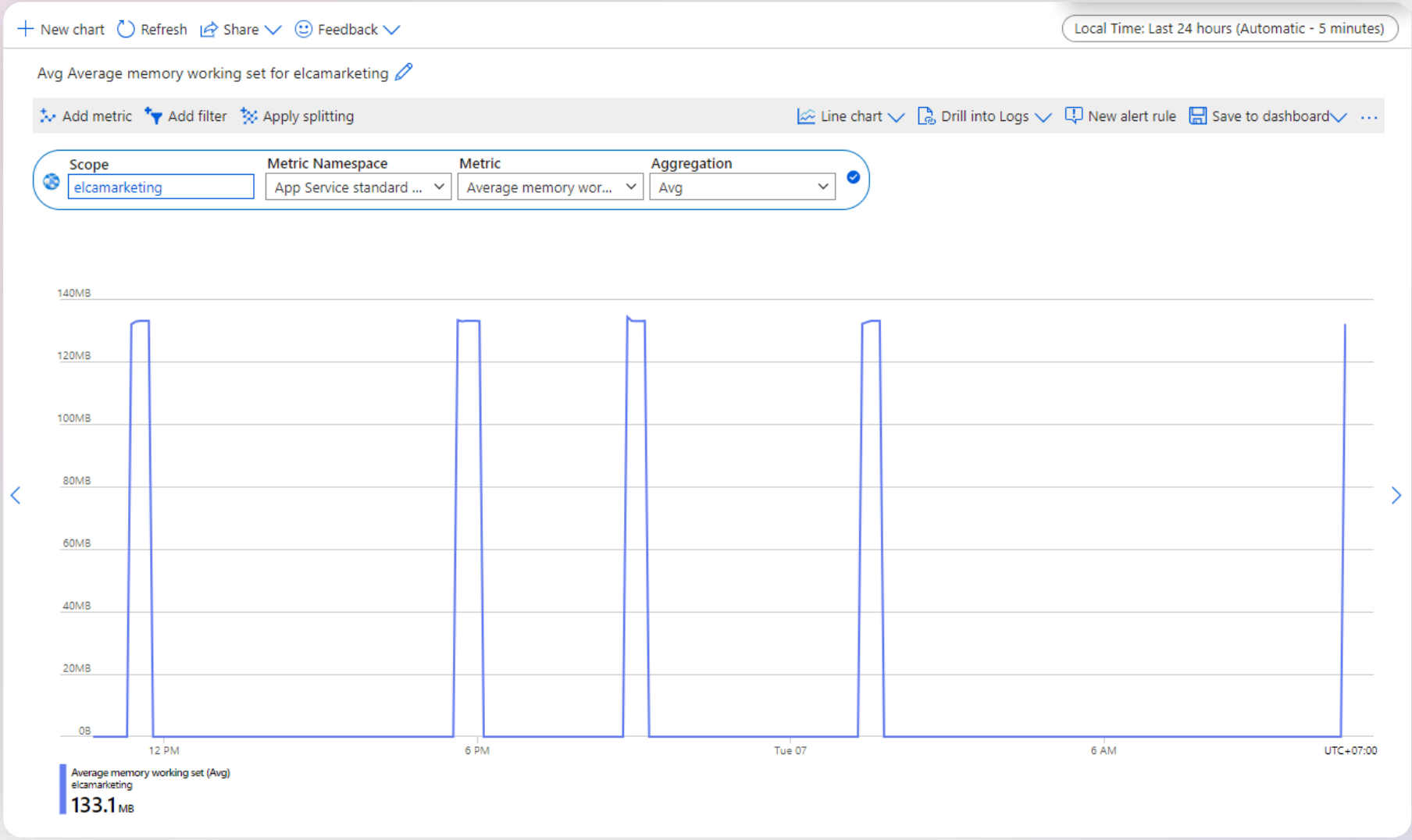
Visual Studio Load Test

Production metrics and monitoring

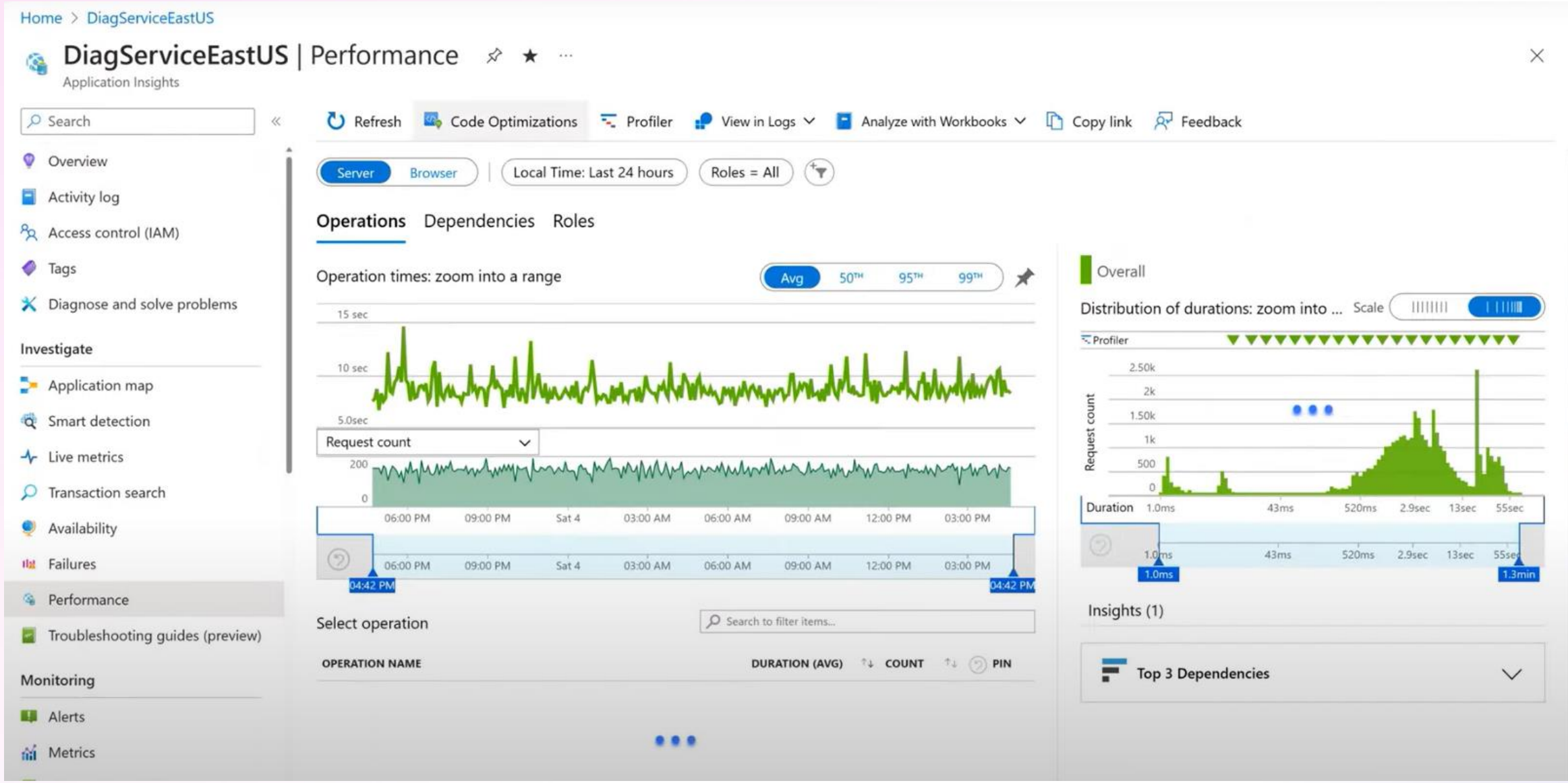
OnPremise/Cloud

- OpenTelemetry + Prometheus+ Grafana
- Elastic search + corrlationId

Azure monitoring

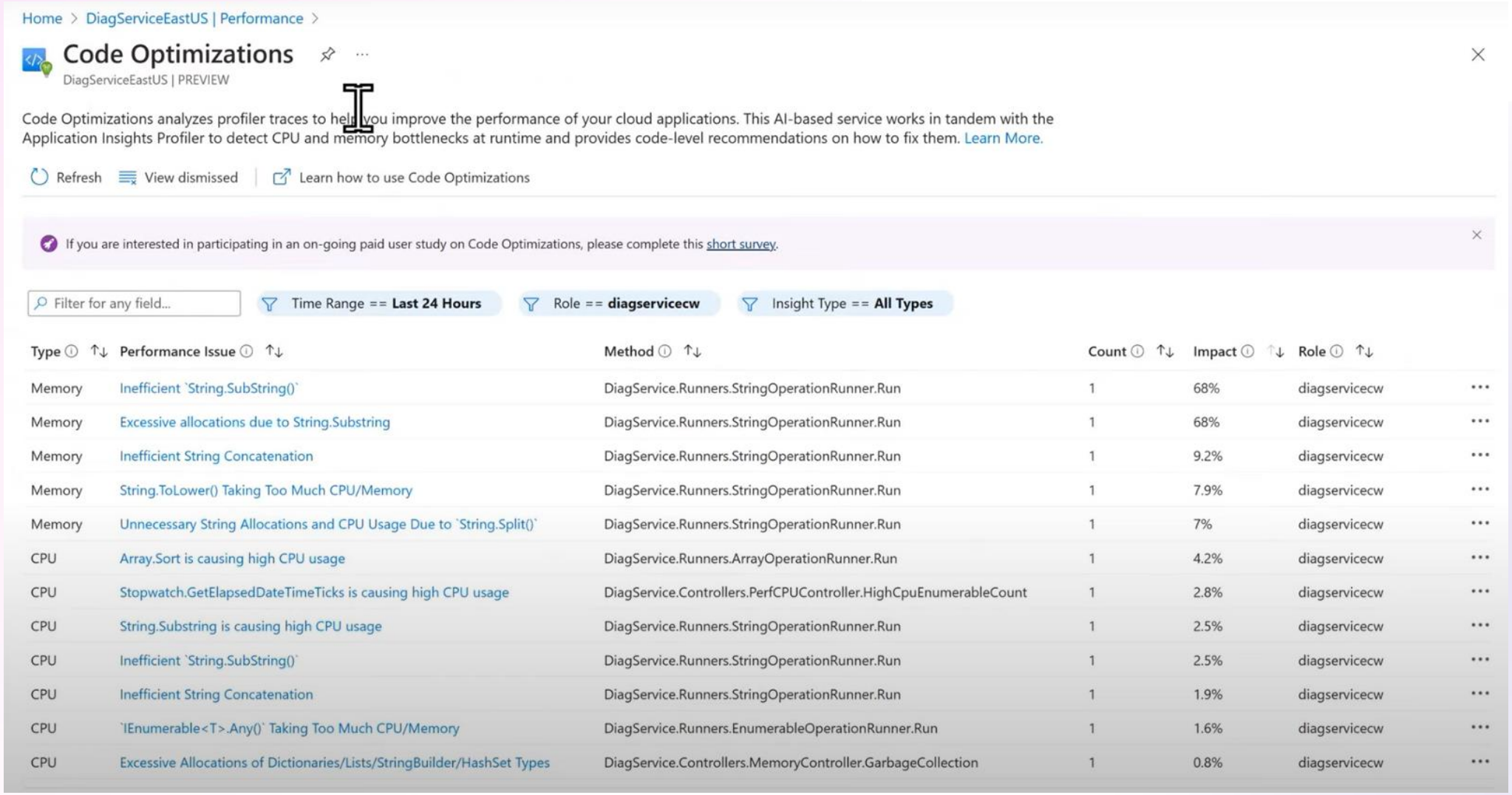


Production metrics and monitoring



Production metrics and monitoring

Github Copilot

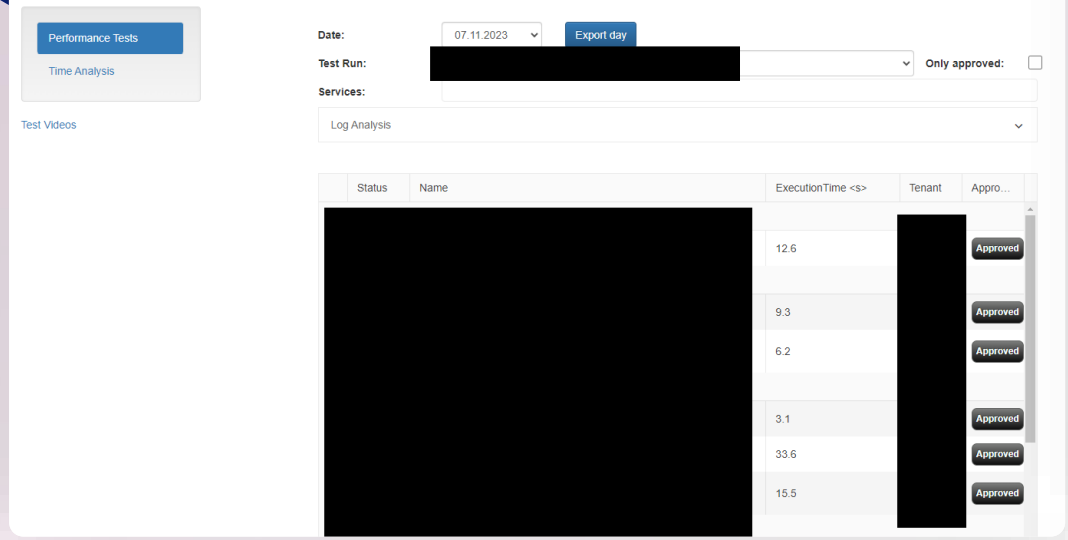


Type	Performance Issue	Method	Count	Impact	Role
Memory	Inefficient `String.SubString()`	DiagService.Runners.StringOperationRunner.Run	1	68%	diagservicecw
Memory	Excessive allocations due to String.Substring	DiagService.Runners.StringOperationRunner.Run	1	68%	diagservicecw
Memory	Inefficient String Concatenation	DiagService.Runners.StringOperationRunner.Run	1	9.2%	diagservicecw
Memory	String.ToLower() Taking Too Much CPU/Memory	DiagService.Runners.StringOperationRunner.Run	1	7.9%	diagservicecw
Memory	Unnecessary String Allocations and CPU Usage Due to `String.Split()`	DiagService.Runners.StringOperationRunner.Run	1	7%	diagservicecw
CPU	Array.Sort is causing high CPU usage	DiagService.Runners.ArrayOperationRunner.Run	1	4.2%	diagservicecw
CPU	Stopwatch.GetElapsedDateTimeTicks is causing high CPU usage	DiagService.Controllers.PerfCPUController.HighCpuEnumerableCount	1	2.8%	diagservicecw
CPU	String.Substring is causing high CPU usage	DiagService.Runners.StringOperationRunner.Run	1	2.5%	diagservicecw
CPU	Inefficient `String.SubString()`	DiagService.Runners.StringOperationRunner.Run	1	2.5%	diagservicecw
CPU	Inefficient String Concatenation	DiagService.Runners.StringOperationRunner.Run	1	1.9%	diagservicecw
CPU	`IEnumerable<T>.Any()` Taking Too Much CPU/Memory	DiagService.Runners.EnumerableOperationRunner.Run	1	1.6%	diagservicecw
CPU	Excessive Allocations of Dictionaries/Lists/StringBuilder/HashSet Types	DiagService.Controllers.MemoryController.GarbageCollection	1	0.8%	diagservicecw

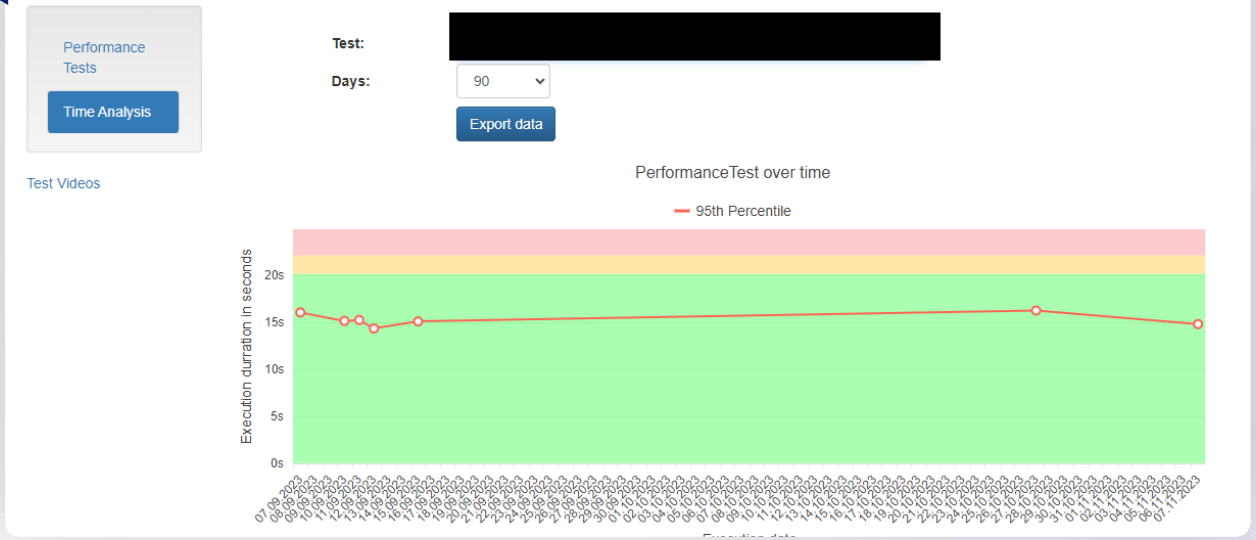
Production metrics and monitoring

Measure selenium from open to finish on UI

Performance Dashboard



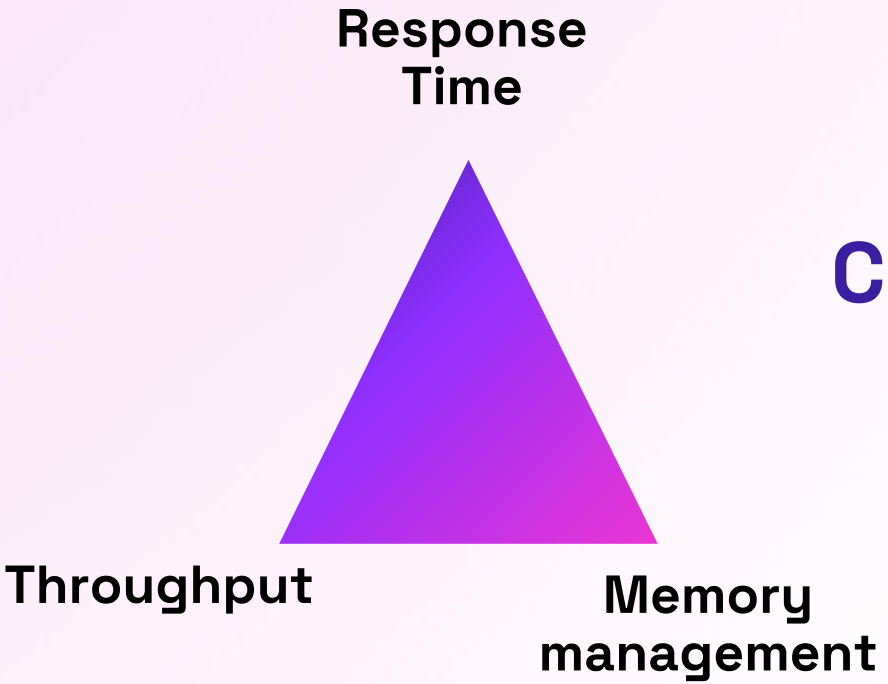
Performance Dashboard



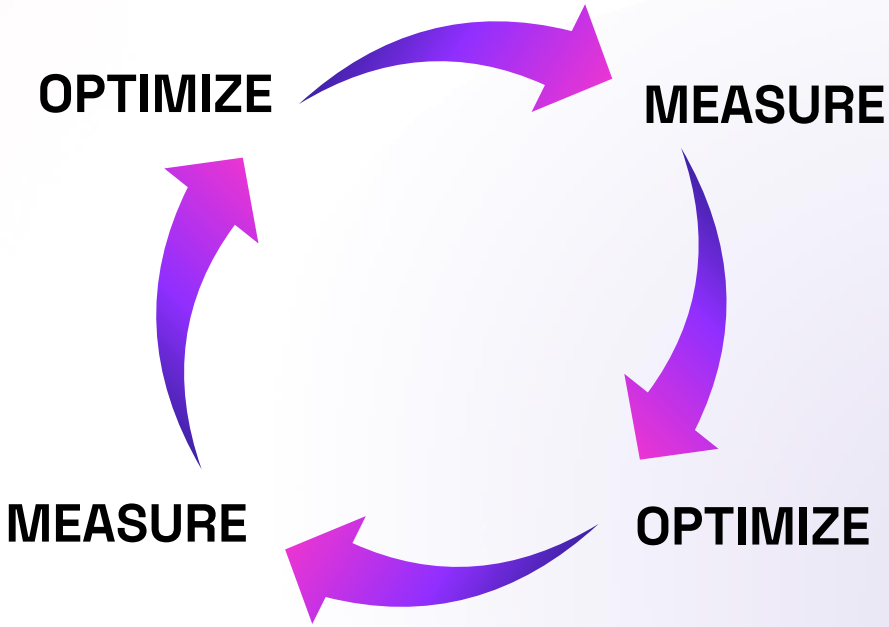
3.

Optimize detail lesson learns in C# applications

Different aspects of performance



CONTEXTUAL



Focus approach

....

#6

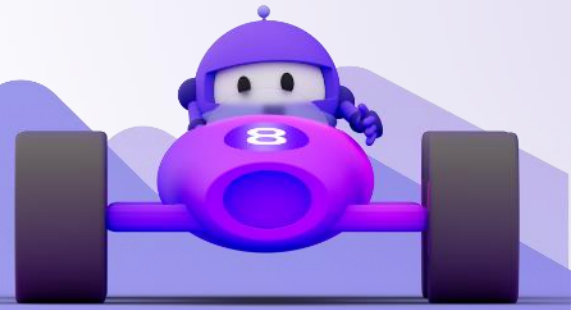
#1 Update framework to latest .NET version

Parse CSV with Span #5

#2 Deep understand framework internal

Stream techniques #4

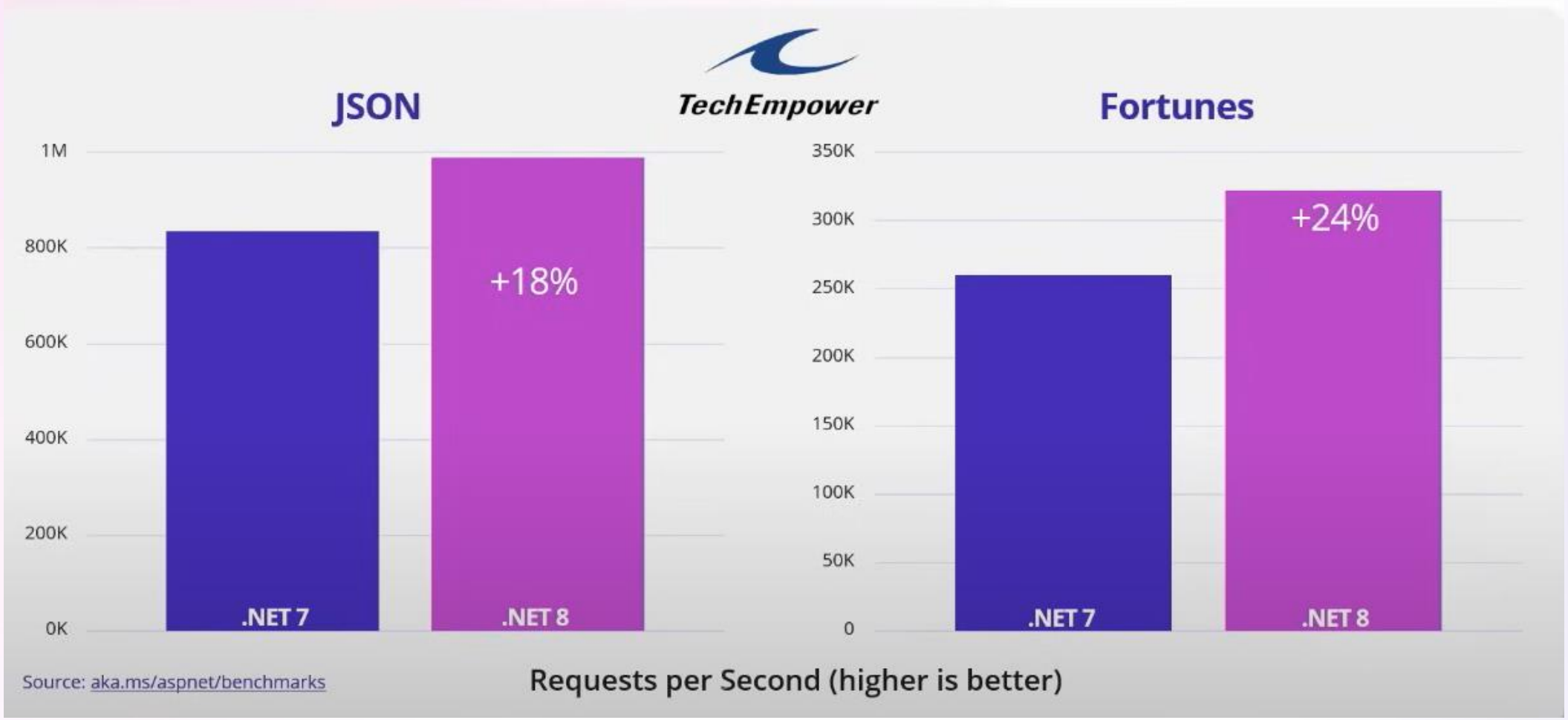
#3 Asynchronous Programming



#1 Update framework to latest .NET version

https://devblogs.microsoft.com/dotnet/performance-improvements-in-net-8/

Stephen Toub - MSFT



#1 Update framework to latest .NET version

Dynamic PGO with GDV cloning / Hoisting

```
private static int Sum(Func<int, int> func)
{
  int sum = 0;
  for (int i = 0; i < 10_000; i++)
  {
    sum += func(i);  // delegate call
  }
  return sum;
}
```

```
private static int Sum(Func<int, int> func)
{
    int sum = 0;
    if (func.Method == KnownLambda)
    {
        for (int i = 0; i < 10_000; i++)
        {
            sum += i + 1;
        }
    }
    else
    {
        for (int i = 0; i < 10_000; i++)
        {
            sum += func(i);
        }
    }
    return sum;
}
```

- Tier0+Instr
  - Tracks the method invoked at the delegate call site
- Tier1
  - Sees that just one method is invoked at the call site, and adds a GDV check
  - Inlines the call on the path where the check succeeds
  - Sees that the GDV check is a loop invariant, and clones the loop to create a check-free version

#1 Update framework to latest .NET version

```
[GlobalSetup]
0 references
public void GlobalSetup()
    => source = Enumerable.Range(

[Benchmark]
0 references
public int SumFor()
{
    var sum = 0;
    for (var index = 0; index < s
        sum += source[index];
    return sum;
}

[Benchmark]
0 references
public int SumForEach()
{
    var sum = 0;
    foreach (var item in source)
        sum += item;
    return sum;
}

[Benchmark]
0 references
public int SumLINQ()
   => source.Sum();
```

.NET 6 internal code MS

```
public static int Sum(this IEnumerable<int> source)
{
    if (source == null)
    {
        ThrowHelper.ThrowArgumentNullException(Excep
    }

    int sum = 0;
    checked
    {
        foreach (int v in source)
        {
            sum += v;
        }
    }

    return sum;
}
```

NET 8 internal code MS

```
private static TResult Sum<TSource, TResult>(this IEnumerable<TSource> source)
    where TSource : struct, INumber<TSource>
    where TResult : struct, INumber<TResult>
{
    if (source.TryGetSpan(out ReadOnlySpan<TSource> span))
    {
        return Sum<TSource, TResult>(span);
    }

    TResult sum = TResult.Zero;
    foreach (TSource value in source)
    {
        checked { sum += TResult.CreateChecked(value); }
    }

    return sum;
}
```

#1 Update framework to latest .NET version

```
// * Summary *

BenchmarkDotNet v0.13.9+228a464e8be6c580ad9408e98f18813f6407fb5a, Windows 10 (10.0.19044.3448/21H2/November2021Update)
11th Gen Intel Core i7-1165G7 2.80GHz, 1 CPU, 8 logical and 4 physical cores
.NET SDK 8.0.100-rc.2.23502.2
  [Host]   : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2
  .NET 6.0 : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2
  .NET 7.0 : .NET 7.0.13 (7.0.1323.51816), X64 RyuJIT AVX2
  .NET 8.0 : .NET 8.0.0 (8.0.23.47906), X64 RyuJIT AVX2


| Method     | Job      | Runtime  | Count | Mean         | Error        | StdDev       | Median       | Ratio | RatioSD |
|----------- |--------- |--------- |------ |-------------:|-------------:|-------------:|-------------:|------:|--------:|
| SumFor     | .NET 6.0 | .NET 6.0 | 100   |     79.89 ns |     1.672 ns |     4.850 ns |     79.72 ns |  1.00 |    0.00 |
| SumFor     | .NET 7.0 | .NET 7.0 | 100   |     84.71 ns |     2.166 ns |     5.780 ns |     84.91 ns |  1.06 |    0.10 |
| SumFor     | .NET 8.0 | .NET 8.0 | 100   |     82.28 ns |     1.819 ns |     5.305 ns |     82.65 ns |  1.03 |    0.08 |
|            |          |          |       |              |              |              |              |       |         |
| SumForEach | .NET 6.0 | .NET 6.0 | 100   |     68.10 ns |     1.873 ns |     5.493 ns |     67.11 ns |  1.00 |    0.00 |
| SumForEach | .NET 7.0 | .NET 7.0 | 100   |     81.64 ns |     3.115 ns |     9.184 ns |     79.64 ns |  1.21 |    0.18 |
| SumForEach | .NET 8.0 | .NET 8.0 | 100   |     68.05 ns |     1.482 ns |     4.275 ns |     68.25 ns |  1.01 |    0.08 |
|            |          |          |       |              |              |              |              |       |         |
| SumLINQ    | .NET 6.0 | .NET 6.0 | 100   |    547.51 ns |    10.867 ns |    26.036 ns |    548.33 ns |  1.00 |    0.00 |
| SumLINQ    | .NET 7.0 | .NET 7.0 | 100   |     88.42 ns |     2.549 ns |     7.274 ns |     88.00 ns |  0.16 |    0.02 |
| SumLINQ    | .NET 8.0 | .NET 8.0 | 100   |     24.40 ns |     0.973 ns |     2.743 ns |     23.94 ns |  0.05 |    0.01 |
|            |          |          |       |              |              |              |              |       |         |
| SumFor     | .NET 6.0 | .NET 6.0 | 10000 |  6,807.33 ns |   319.006 ns |   915.287 ns |  6,800.14 ns |  1.00 |    0.00 |
| SumFor     | .NET 7.0 | .NET 7.0 | 10000 |  7,247.09 ns |   147.534 ns |   428.024 ns |  7,289.73 ns |  1.08 |    0.15 |
| SumFor     | .NET 8.0 | .NET 8.0 | 10000 |  7,294.18 ns |   206.693 ns |   586.354 ns |  7,260.04 ns |  1.09 |    0.17 |
|            |          |          |       |              |              |              |              |       |         |
| SumForEach | .NET 6.0 | .NET 6.0 | 10000 |  6,470.56 ns |   249.755 ns |   736.410 ns |  6,558.94 ns |  1.00 |    0.00 |
| SumForEach | .NET 7.0 | .NET 7.0 | 10000 |  6,237.65 ns |   124.279 ns |   307.187 ns |  6,243.26 ns |  0.99 |    0.16 |
| SumForEach | .NET 8.0 | .NET 8.0 | 10000 |  5,431.94 ns |   185.965 ns |   548.321 ns |  5,392.62 ns |  0.85 |    0.13 |
|            |          |          |       |              |              |              |              |       |         |
| SumLINQ    | .NET 6.0 | .NET 6.0 | 10000 | 55,142.98 ns | 1,763.178 ns | 5,087.172 ns | 53,709.78 ns |  1.00 |    0.00 |
| SumLINQ    | .NET 7.0 | .NET 7.0 | 10000 |  7,727.01 ns |   167.770 ns |   481.364 ns |  7,718.31 ns |  0.14 |    0.02 |
| SumLINQ    | .NET 8.0 | .NET 8.0 | 10000 |  1,116.88 ns |    39.878 ns |   116.325 ns |  1,085.77 ns |  0.02 |    0.00 |
```

#2 Deep understand framework internal

EF core optimize performance (60% performance issues)

- **Proper Indexing**
- **Efficient Querying**
  - Where, Select, AsNoTracking, pagination with methods like Skip and Take
  - Avoid lazy loading for performance-critical scenarios
  - Consider using explicit loading, eager loading with include for related entities when needed, avoid N+1 query problem when loading related entities
  - RawSQL - For complex and performance-critical queries, bulk CRUD, cautious about SQL injection and security.
  - Projections, Batch Fetching, Compiled Queries (reduce the overhead of query compilation), denormalization

- **Database design:**
  normalized and well-structured to avoid performance bottlenecks
- **Caching:**
  caching for frequently accessed data to reduce database calls and improve response times, Use libraries like MemoryCache or Redis for caching
- **Profiling and Monitoring:**
  identify specific bottlenecks and prioritize optimizations based on real-world performance data - Entity Framework Profiler and Application Insights

#2 Deep understand framework internal

ASP.NET core optimize performance

- **Web API Response Compression:** Enable response compression to reduce the payload size and improve data transfer times.
- **Request and Response Size Limiting:** Configure limits for the size of incoming requests and outgoing responses. This can help prevent performance issues related to handling excessively large payloads.
- **Caching:** Implement caching for frequently requested data. Leverage caching mechanisms provided by ASP.NET Core. Consider using token-based authentication and caching authorization results when appropriate.
- **Use Content Delivery Networks (CDN):** Offload static content to a CDN to reduce the latency for users by serving assets from geographically distributed servers.
- **WEB MVC Compression and Minification:** Compress and minify static assets (CSS, JavaScript, images) to reduce the load time of your web pages. This can be achieved using tools like Gzip and Brotli, and by configuring bundling and minification

#3 Asynchronous Programming

Asynchronous Programming

Advantages:

- Non-blocking code.
- Allows the program to perform other tasks during slow I/O operations (e.g., file reading, network requests, database queries).

Use Cases:

- Ideal for I/O-bound tasks.

Synchronous Programming

Advantages:

- Generally, more efficient for CPU-bound tasks.
- No context-switching or task overhead.

Use Cases:

- Suitable for operations that don't involve I/O.

#3 Asynchronous Programming

```
public class TPLAsyncBetter
{
    [Benchmark]
    0 references
    public int SynchronousOperation()
    {
        int result = 0;
        for (int i = 0; i < 10; i++)
        {
            // Simulate an I/O-bound operation by reading a file synchronously.
            result += ReadFileSynchronously();
        }
        return result;
    }

    [Benchmark]
    0 references
    public async Task<int> AsynchronousOperation()
    {
        int result = 0;
        for (int i = 0; i < 10; i++)
        {
            // Simulate an I/O-bound operation by reading a file asynchronously.
            result += await ReadFileAsynchronously();
        }
        return result;
    }

    1 reference
    private int ReadFileSynchronously()
    {
        byte[] data = File.ReadAllBytes("Detail.txt");
        Thread.Sleep(100);
        return data.Length;
    }

    1 reference
    private async Task<int> ReadFileAsynchronously()
    {
        byte[] data = await File.ReadAllBytesAsync("Detail.txt");
        await Task.Delay(100);
        return data.Length;
    }
}
```

IO bound Async better

```
// * Summary *

BenchmarkDotNet v0.13.9+228a464e8be6c580ad9408e98f18813f6407
11th Gen Intel Core i7-1165G7 2.80GHz, 1 CPU, 8 logical and
.NET SDK 8.0.100
  [Host]     : .NET 8.0.0 (8.0.23.53103), X64 RyuJIT AVX2
  DefaultJob : .NET 8.0.0 (8.0.23.53103), X64 RyuJIT AVX2


| Method                | Mean    | Error     | StdDev    |
|---------------------- |--------:|----------:|----------:|
| SynchronousOperation  | 1.347 s | 0.0214 s  | 0.0190 s  |
| AsynchronousOperation | 1.319 s | 0.0258 s  | 0.0394 s  |
```

#3 Asynchronous Programming

```
[SimpleJob(RuntimeMoniker.Net80)]
1 reference
public class TPL
{
    3 references
    public static void LengthyTask()
    {
        int y = 0;
        for (int x = 0; x < 10; x++)
            y++;
    }
    [Benchmark]
    0 references
    public void SychronousMethod()
    {
        LengthyTask();
    }

    [Benchmark]
    0 references
    public void TaskMethod()
    {
        Task.Run(new Action(LengthyTask));
    }

    [Benchmark]
    0 references
    public void AsynchronousTaskMethod()
    {
        var data = async () => await Task.Run(new
            Action(LengthyTask));
        data.Invoke();
    }

}
```

Simple code sync better

```
BenchmarkDotNet v0.13.9+228a464e8be6c580ad9408e98f18813f6407fb5a, Windows 10
11th Gen Intel Core i7-1165G7 2.80GHz, 1 CPU, 8 logical and 4 physical cores
.NET SDK 8.0.100-rc.2.23502.2
  [Host]   : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2
  .NET 8.0 : .NET 8.0.0 (8.0.23.47906), X64 RyuJIT AVX2

Job=.NET 8.0  Runtime=.NET 8.0

| Method                | Mean       | Error      | StdDev     |
|---------------------- |-----------:|-----------:|-----------:|
| SychronousMethod      |   6.187 ns |  0.2425 ns |  0.6995 ns |
| TaskMethod            | 200.707 ns |  4.0488 ns |  9.8554 ns |
| AsynchronousTaskMethod | 553.373 ns | 11.0415 ns | 15.4787 ns |
```

#3 Asynchronous Programming – **Batching and parallelism with** When All

- **Issue async many independent tasks:** awaiting tasks one by one → async execution takes time.
- **Solution:** Use "WhenAll" to wait for all at once.
- **Advantage:** Boosts performance, reduces time, faster execution with "WhenAll" compared to awaiting each task separately.

```
Developer PowerShell
Developer PowerShell

// * Summary *

BenchmarkDotNet=v0.13.1, OS=Windows 10.0.19043.1415 (21H1/May2021Update)
Intel Core i5-3330 CPU 3.00GHz (Ivy Bridge), 1 CPU, 4 logical and 4 physical cores
.NET SDK=6.0.101
  [Host]     : .NET 6.0.1 (6.0.121.56705), X64 RyuJIT
  DefaultJob : .NET 6.0.1 (6.0.121.56705), X64 RyuJIT


|                  Method |     Mean |    Error |   StdDev |
|------------------------ |---------:|---------:|---------:|
|        SynchronousAwait | 624.4 ms | 6.42 ms | 5.69 ms |
| AsynchynchronousWhenAll | 311.3 ms | 2.23 ms | 1.87 ms |
```

```
public class TPLWhenAll
{
    2 references
    private async Task<int> TaskOne()
    {
        await Task.Delay(300);
        return 100;
    }
    2 references
    private async Task<string> TaskTwo()
    {
        await Task.Delay(300);
        return "TaskTwo";
    }
    [Benchmark]
    0 references
    public async Task SynchronousAwait()
    {
        int intValue = await TaskOne();
        string stringValue = await TaskTwo();
    }

    [Benchmark]
    0 references
    public async Task AsynchynchronousWhenAll()
    {
        var taskOne = TaskOne();
        var taskTwo = TaskTwo();
        await Task.WhenAll(taskOne, taskTwo);
    }
```

#3 Asynchronous Programming

Optimizing Execution:

- Use ConfigureAwait(false) to optimize context handling and avoid potential deadlocks.

CPU-Bound Tasks:

- Offload heavy CPU tasks with Task.Run.
- Ideal for large dataset processing or complex calculations.

Efficient Caching:

- Cache results for time-consuming operations.
- Avoids redundant work, improving overall performance.

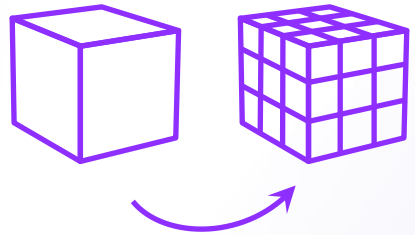
```
public async Task<List<Customer>> GetCustomersAsync()
{
    using (var context = new MyDbContext()){
        // Do some work on the current synchronization context
        var result = await context.Customers.ToListAsync().ConfigureAwait(false);
        // The following code runs without attempting to resume on the original c
        return result;
    }
}
```

```
public async Task<int> CalculateResultAsync(int input)
{
    int result = await Task.Run(() => PerformComplexCalcu
    return result;
}
```

```
private readonly ConcurrentDictionary<int, string> _cache = new Cor

public async Task<string> GetCachedDataAsync(int key)
{
    return await _cache.GetOrAddAsync(key, async k => await FetchDa
}
```

#4 Stream techniques

- Streaming processes large XML files (or other data) with minimal memory usage, enabling sequential on-the-fly data handling.



- It’s handy for very large XML files that don’t fit in memory. Instead of loading the whole file at once, you process it bit by bit as it streams, keeping memory usage low and predictable.

#4 Stream techniques

Read big XML file partially

```
using (XmlReader reader = XmlReader.Create(xmlFilePath))
{
  while (reader.Read())
  {
    if (reader.NodeType == XmlNodeType.Element)
    {
      if (reader.Name == "NodeElement")
      {
        string elementValue =
          reader.ReadElementContentAsString();
        Console.WriteLine($"NodeElement: {elementValue}");
      }
    }
  }
}
```

Download a Very Large File

```
string fileUrl = "https://verylargefile.zip";
string localFilePath = "downloadedfile.zip";

using (HttpClient httpClient = new HttpClient())
using (HttpResponseMessage response =
  await httpClient.GetAsync(fileUrl, HttpCompletionOption.ResponseHeadersRead))
using (Stream remoteStream =
  await response.Content.ReadAsStreamAsync())
using (FileStream fileStream =
  new FileStream(localFilePath, FileMode.Create,
  FileAccess.Write, FileShare.None, 8192, true))
{
    byte[] buffer = new byte[8192];
    int bytesRead;
    while ((bytesRead = await remoteStream.ReadAsync(buffer, 0, buffer.Length)) > 0)
    {
        await fileStream.WriteAsync(buffer, 0, bytesRead);
    }
    Console.WriteLine("File downloaded successfully.");
}
```

#4 Stream techniques

Event-Driven Processing	Move through the XML document element by element with a streaming reader, triggering events as needed.
Sequential Processing	Process data as you read it, avoiding storing the entire XML tree in memory. For example, extract specific data when encountering relevant elements without loading the entire document.
Low Memory Usage	Keep only a small part of the XML data in memory, ensuring a predictable and low memory footprint, regardless of file size.

#5 Parse CSV with Span

- **Problem:** Operations on ”sub-data” require a temporary object to represent it, which introduces a lot of short-living objects. Typical examples are string.Substring() or sub-arrays/sub-lists.
- **Solution:** Introduce special types that allow slicing - representing sub-regions without a memory copy.
- **Benefits:** You can operate on subset of data without overhead of memory copy - especially useful in various ”descendant” parsers.

#5 Parse CSV with Span

```
BenchmarkDotNet v0.13.9+228a464e8be6c580ad9408e98f18813f6407fb5a, Windows 10 (10.0.19
11th Gen Intel Core i7-1165G7 2.80GHz, 1 CPU, 8 logical and 4 physical cores
.NET SDK 8.0.100-rc.2.23502.2
  [Host]     : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2
  DefaultJob : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2


| Method   | Mean      | Error     | StdDev    | Ratio | RatioSD | Gen0   | Allocated |
|--------- |----------:|----------:|----------:|------:|--------:|-------:|----------:|
| Original | 139.42 ns | 2.861 ns | 6.279 ns |  1.00 |    0.00 | 0.0153 |      96 B |
| Span     |  80.31 ns | 1.655 ns | 4.122 ns |  0.58 |    0.04 |      - |         - |

// * Warnings *
```

```
private static readonly string _dateString = "31 10 2023";

[Benchmark(Baseline = true)]
0 references
public DateTime Original()
{
    var day = _dateString.Substring(0, 2);
    var month = _dateString.Substring(3, 2);
    var year = _dateString.Substring(6);
    return new DateTime(int.Parse(year), int.Parse(month), int.Parse(day));
}

[Benchmark]
0 references
public DateTime Span()
{
    ReadOnlySpan<char> dateSpan = _dateString;
    var day = dateSpan.Slice(0, 2);
    var month = dateSpan.Slice(3, 2);
    var year = dateSpan.Slice(6);
    return new DateTime(int.Parse(year), int.Parse(month), int.Parse(day));
}
```

#6 TPL

- Provides a higher-level abstraction for parallelism, making it easier to write code that can efficiently utilize multiple processors and handle concurrent tasks.
- Boost performance with parallel loops by distributing work among multiple CPU cores. Swap regular for and foreach loops with their parallel Parallel.For() and Parallel.ForEach() equivalents when safe and feasible
- Use the Partitioner class to smartly split work into chunks, minimizing overhead and ensuring balanced parallel tasks. This optimization enhances both performance and workload distribution in C# applications

#6 TPL

```
0 references
public class TPLParallelForEach
{
    private int[] numbers;

    [Params(100)]
    public int N;

    [GlobalSetup]
    0 references
    public void Setup()
    {
        numbers = new int[N];
        Random rand = new Random();

        for (int i = 0; i < N; i++)
        {
            numbers[i] = rand.Next(1, 100);
        }
    }

    [Benchmark]
    0 references
    public void NormalSum()
    {
        long total = 0;
        numbers.ToList().ForEach(x => total += Sum(x));
    }

    [Benchmark]
    0 references
    public void ParallelSum()
    {
        long total = 0;
        Parallel.ForEach(numbers, (number) =>
        {
            total += Sum(number);
        });
    }
```

```
    [Benchmark]
    0 references
    public void ParallelSumWithPartitioner()
    {
        long total = 0;
        var partitioner = Partitioner.Create(numbers);
        Parallel.ForEach(numbers, (number) =>
        {
            total += Sum(number);
        });
    }

    5 references
    private int Sum(int number)
    {
        Thread.Sleep(1);
        return number;
    }

    [Benchmark]
    0 references
    public void ParallelSum4Core()
    {
        long total = 0;
        int maxParallelism = 4; // Number of cores

        var semaphore = new SemaphoreSlim(maxParallelism);

        Parallel.ForEach(numbers, new ParallelOptions { MaxDegreeOfParallelism = maxParallelism }, (number) =>
        {
            semaphore.Wait();
            try
            {
                total += Sum(number);
            }
            finally
            {
                semaphore.Release();
            }
        });
    }
}
```

#6 TPL

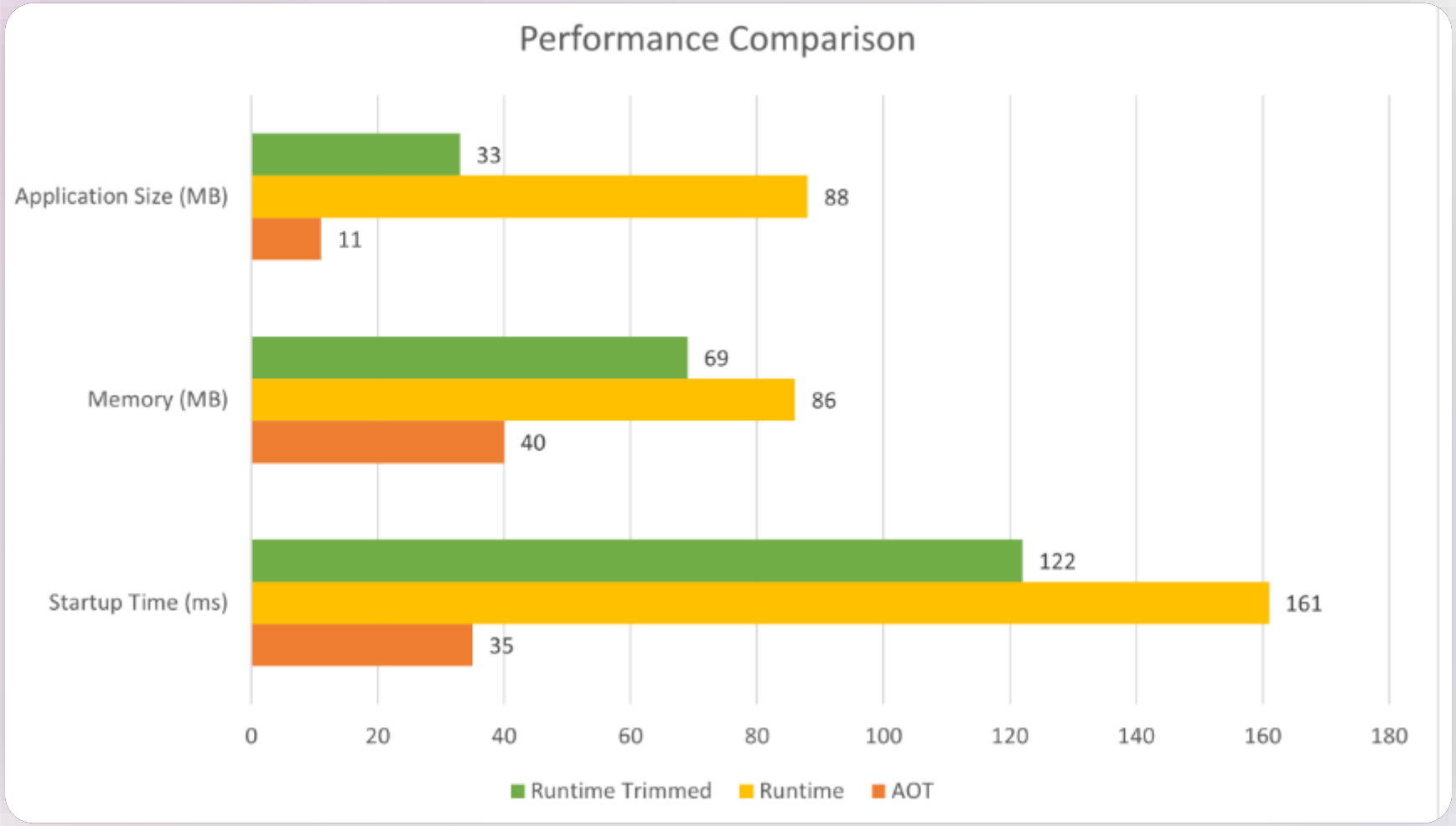
```
BenchmarkDotNet v0.13.9+228a464e8be6c580ad9408e98f18813f6407fb5a, Windows 10 (10.0.19044.3448/21H2/November2021Update)
11th Gen Intel Core i7-1165G7 2.80GHz, 1 CPU, 8 logical and 4 physical cores
.NET SDK 8.0.100-rc.2.23502.2
  [Host]     : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2
  DefaultJob : .NET 6.0.24 (6.0.2423.51814), X64 RyuJIT AVX2


| Method                      | N   | Mean         | Error      | StdDev     |
|---------------------------- |---- |------------:|----------:|----------:|
| NormalSum                   | 100 | 1,569.07 ms |  7.435 ms |  6.955 ms |
| ParallelSum                 | 100 |    93.57 ms | 11.824 ms | 32.959 ms |
| ParallelSumWithPartitioner  | 100 |   115.99 ms | 14.906 ms | 43.952 ms |
| ParallelSum4Core            | 100 |   390.79 ms |  2.969 ms |  2.777 ms |
| ParallelSum8Core            | 100 |   249.43 ms |  1.898 ms |  1.682 ms |

// * Warnings *
MultimodalDistribution
  TPLParallelForEach.ParallelSum: Default                -> It seems that the distribution is bimodal (mValue = 3.27)
  TPLParallelForEach.ParallelSumWithPartitioner: Default -> It seems that the distribution can have several modes (mVal
e = 3.17)

// * Hints *
```

#7 AOT NET 8 (not fully support)

Publishing and deploying a native AOT app provides the following benefits:

Minimized disk footprint	Produces a compact executable with only essential code from external dependencies. Benefits include smaller container images and faster deployment due to reduced executable size.
Reduced startup time	Faster start-up times in Native AOT apps mean quicker response to requests and smoother transitions in app version deployment for container orchestrators.
Reduced memory demand	Native AOT apps reduce memory usage, enhancing deployment density and scalability. CoreCRL's static PGO support enables optimizations, including performance gains based on a closed-world assumption, even without PGO.

#7 AOT NET 8 (not fully support)

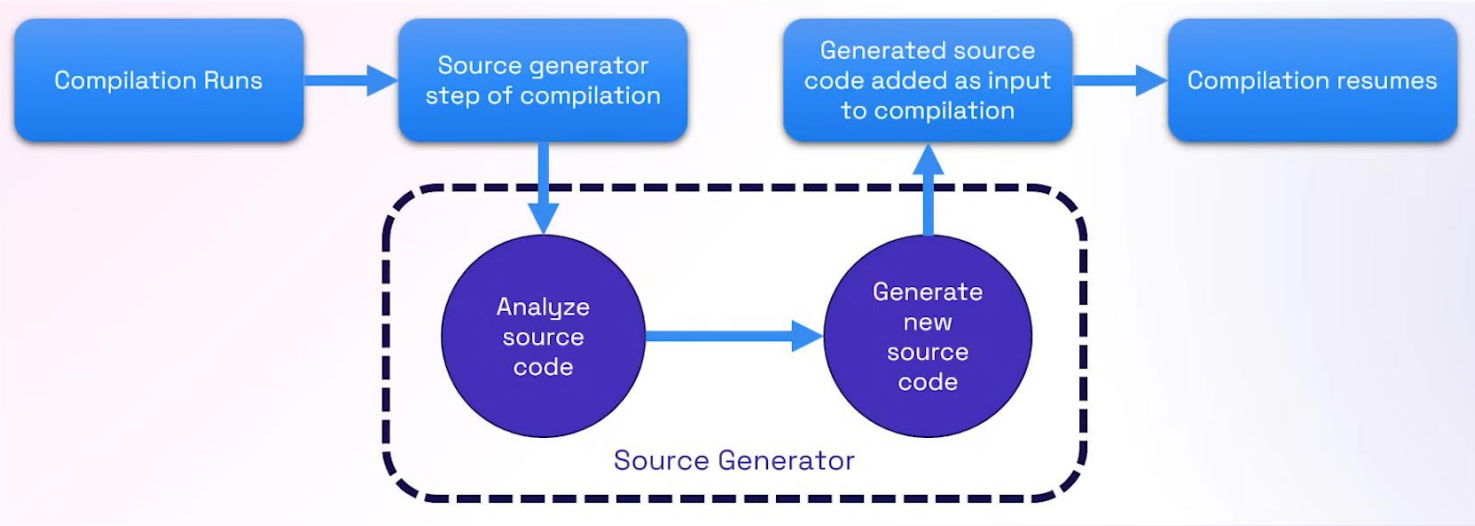


#7 AOT NET 8

Feature	Fully Supported	Partially Supported	Not Supported
gRPC	✔		
Minimal APIs		✔	
MVC			✘
Blazor Server			✘
SignalR			✘
Authentication			✘ (JWT soon)
CORS	✔		
HealthChecks	✔		
HttpLogging	✔		
Localization	✔		
OutputCaching	✔		
RateLimiting	✔		
RequestDecompression	✔		
ResponseCaching	✔		
ResponseCompression	✔		
Rewrite	✔		
Session			✘
Spa			✘
StaticFiles	✔		
WebSockets	✔		

#8 Source generators

1. **Optimized Performance**: compile-time generation for efficiency.
2. **Less Boilerplate code**: Simplified, readable, and easy to maintain.
3. **Improved code quality** by generating code that is tailored to specific needs
4. **Minimized risk of human errors**



#8 Source generators

```
[GeneratedRegex(@"[abcxyz]")]
2 references
private static partial Regex Example();
```

No issues found

enerated]

erated by the generator 'System.Text.RegularExpressions.Generator.RegexGenerator' and cannot be edited.

_2023 (net8.0) | System.Text.RegularExpressions.Generated.Utilities | s_ascii_E000007

```
file static class Utilities
{
    /// <summary>Default timeout value set in <see cref="AppContext"/>, or <see cref="Regex.InfiniteMatchTimeout"/
    internal static readonly TimeSpan s_defaultTimeout = AppContext.GetData("REGEX_DEFAULT_MATCH_TIMEOUT") is Time

    /// <summary>Whether <see cref="s_defaultTimeout"/> is non-infinite.</summary>
    internal static readonly bool s_hasTimeout = s_defaultTimeout != Regex.InfiniteMatchTimeout;

    /// <summary>Supports searching for characters in or not in "abcxyz".</summary>
    internal static readonly SearchValues<char> s_ascii_E000007 = SearchValues.Create("abcxyz");
```

Efficient search for any set of bytes or chars

```
// Before
private static readonly char[] s_values = new[] { 'a', 'b', 'c', 'x', 'y', 'z' };
...
int pos = source.IndexOfAny(s_values);
```

```
// After
private static readonly SearchValues s_values = SearchValues.Create("abcxyz");
...
int pos = source.IndexOfAny(s_values);
```

#8 Source generators

```cs
using BenchmarkDotNet.Running;

BenchmarkRunner.Run<RegexBenchmarks>();

public partial class RegexBenchmarks
{
    private const string CurrencyRegex = @"\p{Sc}+\s*\d+";
    private readonly Regex _currencyRegex = new(CurrencyRegex);
    private readonly Regex _compiledCurrencyRegex = new(CurrencyRegex, RegexOptions.Compiled);

    [GeneratedRegex(CurrencyRegex)]

    private static partial Regex NewGeneratedRegex();
    private readonly Regex _generatedCurrencyRegex = NewGeneratedRegex();


    [Params("$ 7", "7 €")]

    public string PotentialCurrency { get; set; } = default!;


    [Benchmark]

    public void Cached_Compiled_Instance()
    {
        _compiledCurrencyRegex.IsMatch(PotentialCurrency);
    }

    [Benchmark]

    public void New_Cached_Generated_Instance()
    {
        _generatedCurrencyRegex.IsMatch(PotentialCurrency);
    }
}
```

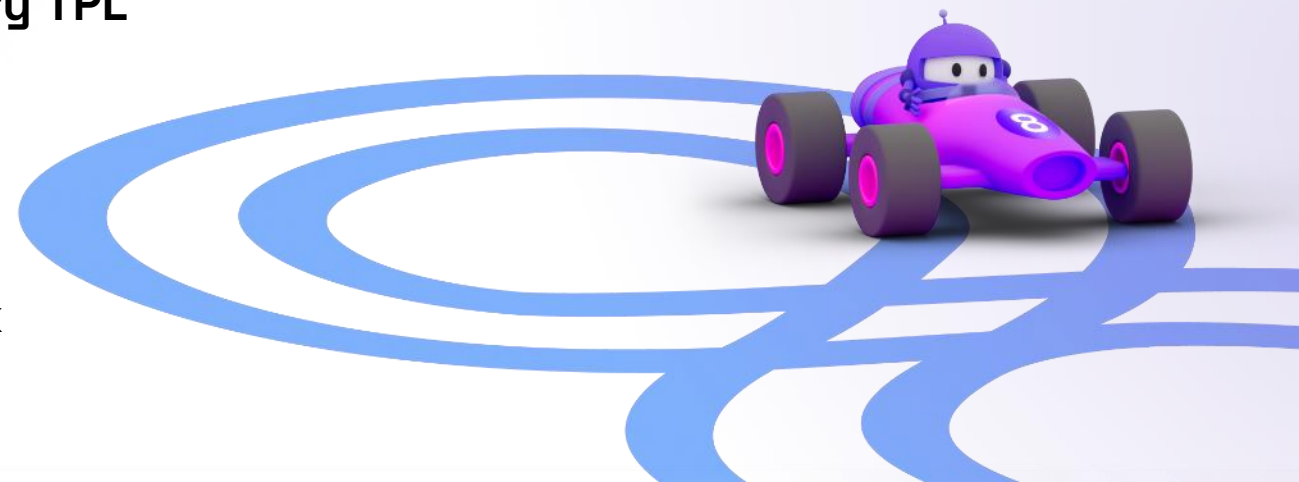
```
BenchmarkDotNet=v0.13.4, OS=Windows 10 (10.0.19044.3693/21H2/Nov
11th Gen Intel Core i7-1165G7 2.80GHz, 1 CPU, 8 logical and 4 ph
.NET SDK=8.0.100
  [Host]     : .NET 8.0.0 (8.0.23.53103), X64 RyuJIT AVX2
  DefaultJob : .NET 8.0.0 (8.0.23.53103), X64 RyuJIT AVX2


|                         Method | PotentialCurrency |      Mean |
|------------------------------- |------------------ |----------:|
|      Cached_Compiled_Instance |               $ 7 |  55.45 ns |
| New_Cached_Generated_Instance |               $ 7 |  36.25 ns |
|      Cached_Compiled_Instance |               7 ? |  51.36 ns |
| New_Cached_Generated_Instance |               7 ? |  30.62 ns |
```

#9 Avoid memory leak

1. **Unreleased Resources:** Failing to release resources properly (such as database connections, file handles, or network sockets) can cause memory leaks. Always **dispose** of resources explicitly when they are no longer needed.
2. **Prefer StringBuilder:** over string concatenation using '+' in C# to improve performance. StringBuilder is mutable and more efficient for building strings, avoiding unnecessary overhead associated with immutable strings
3. **Event Handlers:** Subscribing to events without unsubscribing can prevent objects from being garbage collected. Make sure to **unsubscribe** from events when the object is no longer in use.
4. **Static Variables:** Static variables live for the entire lifetime of the application domain. If you store large objects in static variables, they won't be garbage collected until the application shuts down. Use static variables judiciously and consider using **dependency injection** instead.
5. **Large Objects:** Creating large objects that are held in memory for a long time can cause memory leaks. Consider using **object pooling** or other techniques to manage large objects efficiently. Optimize data structures and consider using **paging** or **lazy loading**
6. **Finalizers:** Incorrectly implemented finalizers (destructors) can delay garbage collection. Avoid using finalizers unless absolutely necessary.

Summary

- Measure, Optimize, Measure, Optimize
- Performance is contextual
- Made small changes each time and measure again
- Update framework to latest NET version
- Deep understand framework internal (e.g. ORM, ...) for performance
- Asynchronous programming
- Streaming technique
- Parse CSV
- Task Parallel Library TPL
- AOT
- Source generator
- Avoid memory leak



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Questions?

THANK YOU VERY MUCH