Nowości ze świata wydajności .NET

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About myself

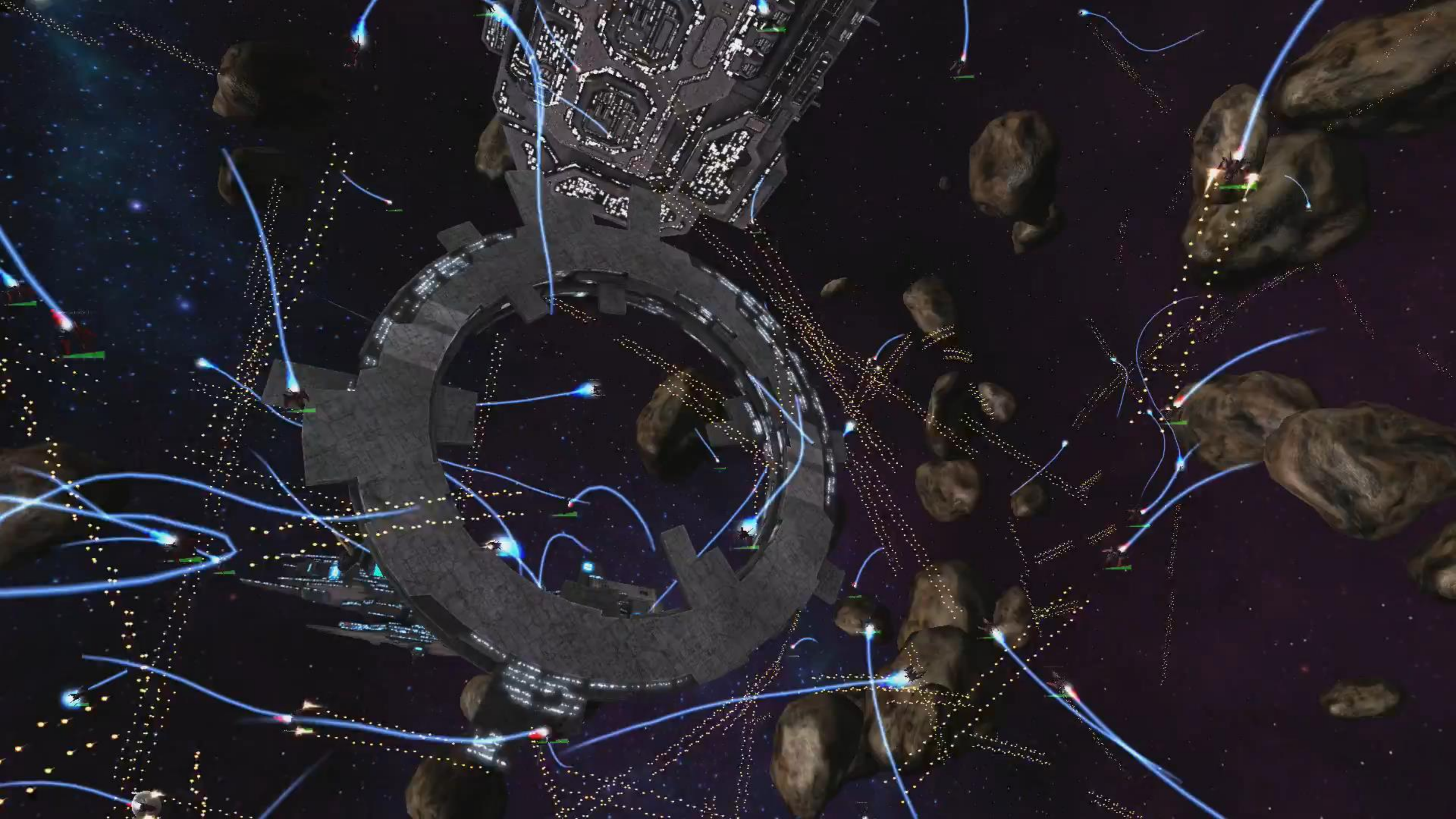
Open Source:

- BenchmarkDotNet
- Awesome .NET Performance
- Core CLR (Span<T>)
- CoreFx Lab (Span<T>)
- & more

Work:

- Energy Trading

(.NET Core running in production since July 2016)



How to get the best of GC?

- Use the right GC mode
- Reduce allocations
- Eliminate all managed allocations:
  - Use Value Types
  - Pool the managed memory
  - Use unmanaged memory

ValueTuple: sample

```
(double min, double max, double avg, double sum) GetStats(double[] numbers)
{
    double min = double.MaxValue, max = double.MinValue, sum = 0;

    for (int i = 0; i < numbers.Length; i++)
    {
        if (numbers[i] > max) max = numbers[i];
        if (numbers[i] < min) min = numbers[i];
        sum += numbers[i];
    }
    double avg = numbers.Length != 0 ? sum / numbers.Length : double.NaN;

    return (min, max, avg, sum);
}
```

Value Types: the advantages

- Better data locality
- No GC

You can learn more today at 15:00:
„**Wszystko czego (nie) wiecie o strukturach w .NET**”

Value Types: the disadvantages?!

- Can be easily boxed
- By default send to and returned from methods by **copy**.
- It’s **expensive** to copy non-primitive value types!
- It’s not obvious when the copying when it happens!

Defensive copy

```
struct Test {
    readonly int Field;
    Test(int value) => Field = value;

    void Ugly(int newValue) => this = new Test(newValue);
}

readonly Test field = new Test(1);
void DemoField() {
    WriteLine(field.Field);
    field.Ugly(2);
    WriteLine(field.Field);
}
```

```
1
2
```

```
1
1
```

C# 7.2: readonly types

```
readonly struct Test
{
    public readonly int Field;

    public Test(int value) => Field = value;

    public void Ugly(int newValue)
      => this = new Test(newValue); // compilation error!
}
```

„this” is readonly reference for readonly types

ref returns and locals: sample

```
ref int Max(
    ref int first, ref int second, ref int third)
{
    ref int max = ref first;

    if (first < second) max = second;
    if (second < third) max = third;

    return ref max;
}
```

ref locals: Benchmarks: initialization

```
struct BigStruct { public int Int1, Int2, Int3, Int4, Int5; }
```

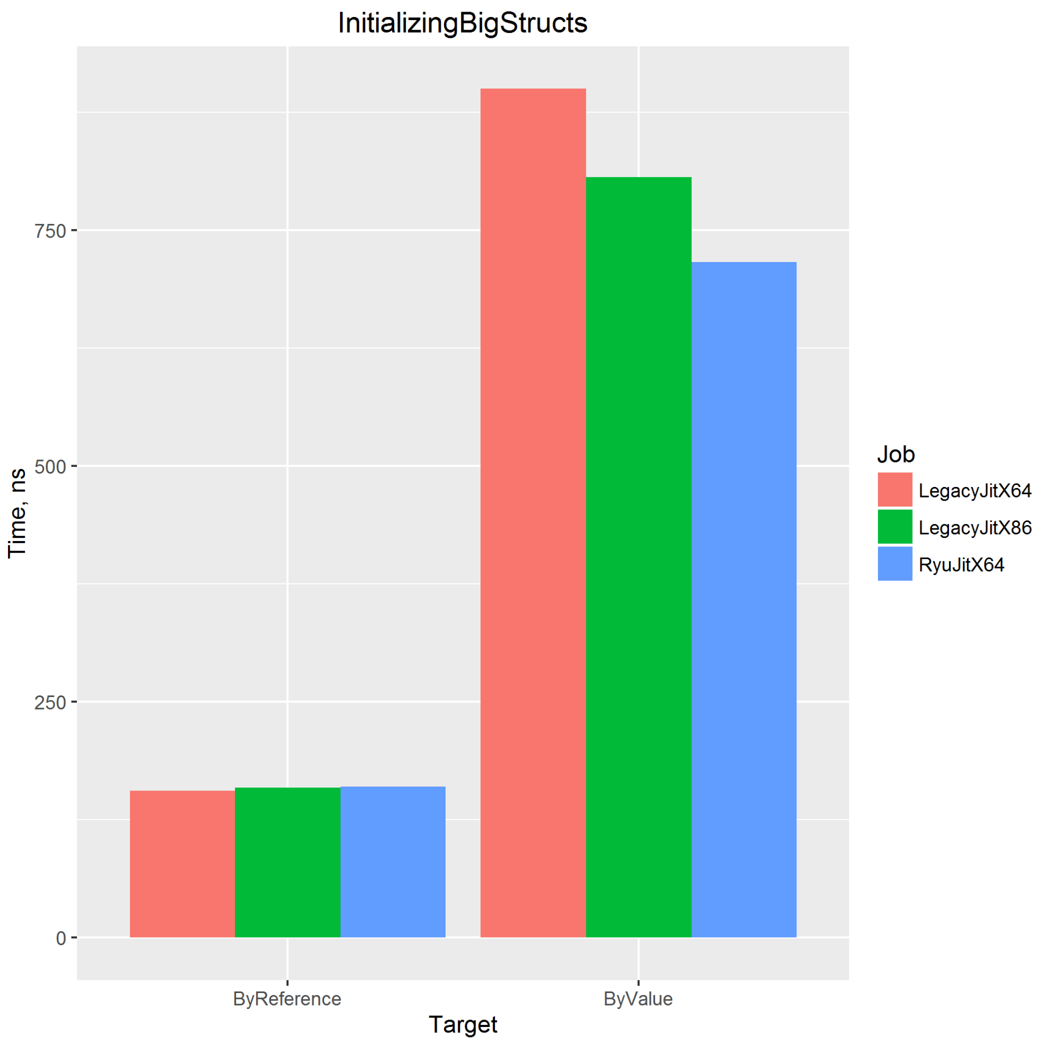
ByValue

```
for (int i = 0; i < array.Length; i++)
{
    BigStruct value = array[i];

    value.Int1 = 1;
    value.Int2 = 2;
    value.Int3 = 3;
    value.Int4 = 4;
    value.Int5 = 5;

    array[i] = value;
}
```

ByReference

```
for (int i = 0; i < array.Length; i++)
{
    ref BigStruct reference = ref array[i];

    reference.Int1 = 1;
    reference.Int2 = 2;
    reference.Int3 = 3;
    reference.Int4 = 4;
    reference.Int5 = 5;
}
```

How can old JITs support it?



BenchmarkDotNet v0.10.6.189-nightly

What about unsafe?!

```
public unsafe void ByReferenceUnsafe()
{
    fixed (BigStruct* pinned = array)
    {
        for (int i = 0;
                i < array.Length; i++)
        {
            Init(&pinned[i]);
        }
    }
}
```

```
unsafe void Init(BigStruct* pointer)
{
    (*pointer).Int1 = 1;
    (*pointer).Int2 = 2;
    (*pointer).Int3 = 3;
    (*pointer).Int4 = 4;
    (*pointer).Int5 = 5;
}
```

Safe vs Unsafe with RyuJit

Method	Jit	Mean	Scaled
ByValue	RyuJit	6.958 us	4.57
ByReference	**RyuJit**	**1.524 us**	**1.00**
ByReferenceUnsafe	RyuJit	1.540 us	1.01

No need for pinning!

Executing Unsafe code requires **full trust**. It can be a „**no go**”!

mustoverride.com

Vladimir Sadov

Engineer

Website

Twitter

Github

Posts by Tags

refs

- November 30, 2016 » Why ref locals allow only a single binding?
- November 04, 2016 » Safe to return rules for ref returns.
- October 29, 2016 » Local variables cannot be returned by reference.
- September 17, 2016 » Managed pointers.
- September 05, 2016 » ref returns are not pointers.

tuples

- February 11, 2017 » C# Tuples. Conversions.
- January 28, 2017 » C# Tuples. More about element names.
- January 16, 2017 » C# Tuples. How tuples are related to ValueTuple.
- January 07, 2017 » C# Tuples. Why mutable structs?

C# 7(.2): Performance Summary

- Value Types have better performance characteristics:
  - Data Locality
  - No GC
- Value Tuples offer clean coding and great performance
- Safe references can make your code faster than unsafe!
  - Use them only when needed to keep your code clean
- Using readonly structs can prevent from defensive copying

Async on hotpath

```
Task<T> SmallMethodExecutedVeryVeryOften()
{
    if(CanRunSynchronously()) // true most of the time
    {
        return Task.FromResult(ExecuteSynchronous());
    }
    return ExecuteAsync();
}
```

Sample ValueTask usage

```
[MethodImpl(MethodImplOptions.AggressiveInlining)]
ValueTask<int> SampleUsage()
    => IsFastSynchronousExecutionPossible()
        ? new ValueTask<int>(
            result: ExecuteSynchronous()) // INLINEABLE!!!
        : new ValueTask<int>(
            task: ExecuteAsync());

int ExecuteSynchronous() { }
Task<int> ExecuteAsync() { }
```

How **not** to consume ValueTask

```
async ValueTask<int> ConsumeWrong(int repeats)
{
    int total = 0;
    while (repeats-- > 0)
        total += await SampleUsage();

    return total;
}
```

Async Task Method Builder

```
[AsyncStateMachine(typeof(DemoInt.<ConsumeWrong>d__4))]
private Task ConsumeWrong(int repeats)
{
    DemoInt.<ConsumeWrong>d__4 <ConsumeWrong>d__;
    <ConsumeWrong>d__.<>4__this = this;
    <ConsumeWrong>d__.repeats = repeats;
    <ConsumeWrong>d__.<>t__builder = AsyncTaskMethodBuilder.Create();
    <ConsumeWrong>d__.<>1__state = -1;
    AsyncTaskMethodBuilder <>t__builder = <ConsumeWrong>d__.<>t__builder;
    <>t__builder.Start<DemoInt.<ConsumeWrong>d__4>(ref <ConsumeWrong>d__);
    return <ConsumeWrong>d__.<>t__builder.Task;
}
```

How to consume ValueTask

```
async ValueTask<int> ConsumeProperly(int repeats)
{
    int total = 0;
    while (repeats-- > 0)
    {
        ValueTask<int> valueTask = SampleUsage(); // INLINEABLE

        total += valueTask.IsCompleted
            ? valueTask.Result // hot path
            : await valueTask.AsTask();
    }

    return total;
}
```

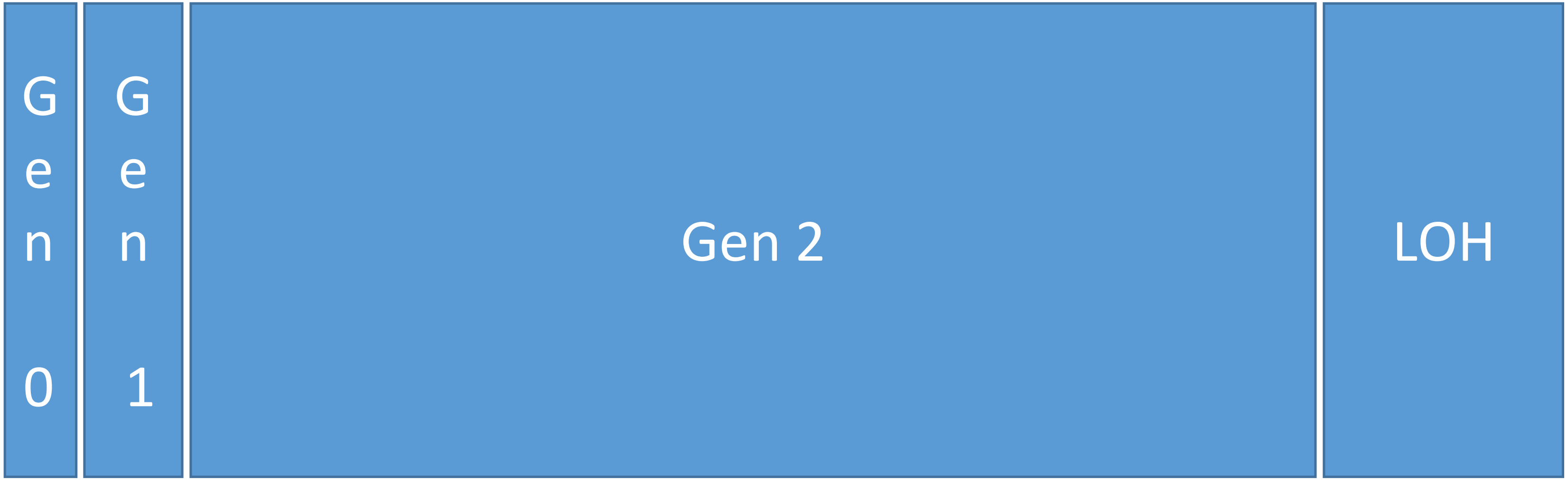
ValueTask vs Task: Overhead Only

Method	Repeats	Mean	Scaled	Gen 0	Gen 1	Allocated
Task	100	720.9 ns	1.49	3.4674	0.0001	7272 B
ValueTask_Wrong	100	1,097.4 ns	2.27	-	-	0 B
ValueTask_Properly	100	482.9 ns	1.00	-	-	0 B

Value Task: Summary

- It’s not about replacing Task
- It has a **single purpose**: reduce heap allocations in async hot path where common synchronous execution is possible
- You can benefit from inlining, but not for free
- Use the .IsCompleted and .Result for getting best performance

.NET Managed Heap*



LOH = GEN 2 = FULL GC

* - simplified, Workstation mode or view per logical processor in Server mode

ArrayPool

- **Pool of reusable managed arrays**
- The default maximum length of each array in the pool is 2^20 (1024*1024 = 1 048 576)
- System.Buffers package

ArrayPool: Sample

```
var samePool = ArrayPool<byte>.Shared;
byte[] buffer = samePool.Rent(minLength);
try
{
    Use(buffer);
}
finally
{
    samePool.Return(buffer);
}
```

Allocate? Pool?

Method	Size	Mean	StdDev	Gen 0	Gen 1	Gen 2	Allocated
Allocate	100	8.149 ns	0.0169 ns	0.0610	-	-	128 B
RentAndReturn_Shared	100	**43.446 ns**	0.0908 ns	-	-	-	**0 B**

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Allocate	1 000	41.122 ns	0.0812 ns	0.4880	0.0000	-	1024 B
RentAndReturn_Shared	1 000	**42.535 ns**	0.0621 ns	-	-	-	**0 B**

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RentAndReturn_Shared	10 000	**42.565 ns**	0.0450 ns	-	-	-	**0 B**

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Allocate	100 000	3,625.029 ns	17.2533 ns	31.2497	31.2497	31.2497	100024 B
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Allocate	1 000 000	18,769.792 ns	60.4307 ns	249.9980	249.9980	249.9980	1000024 B
RentAndReturn_Shared	1 000 000	**41.979 ns**	0.0555 ns	-	-	-	**0 B**

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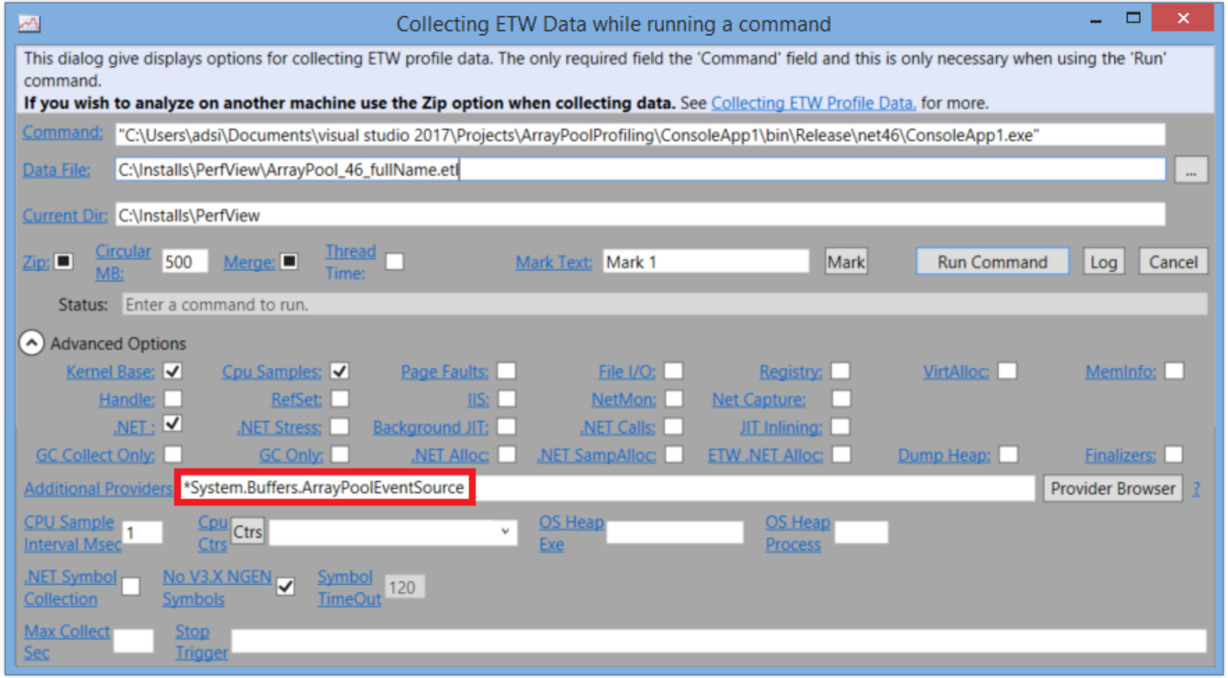
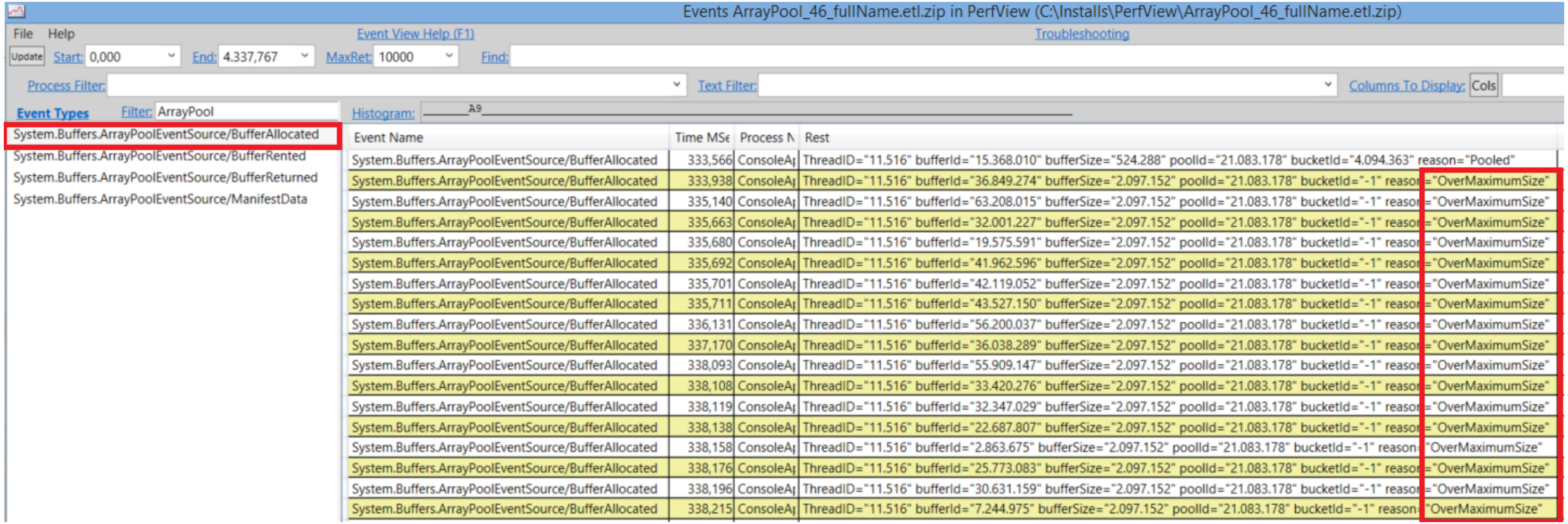
RentAndReturn_Shared	1 000 000	**41.979 ns**	0.0555 ns	-	-	-	**0 B**
Allocate	10 000 000	521,016.536 ns	55,326.9203 ns	211.2695	211.2695	211.2695	10000024 B
RentAndReturn_Shared	10 000 000	639,916.968 ns	116,288.7309 ns	206.3623	206.3623	206.3623	10000024 B
RentAndReturn_**Aware**	10 000 000	**47.200 ns**	0.0407 ns	-	-	-	**0 B**

System.Buffers.ArrayPoolEventSource



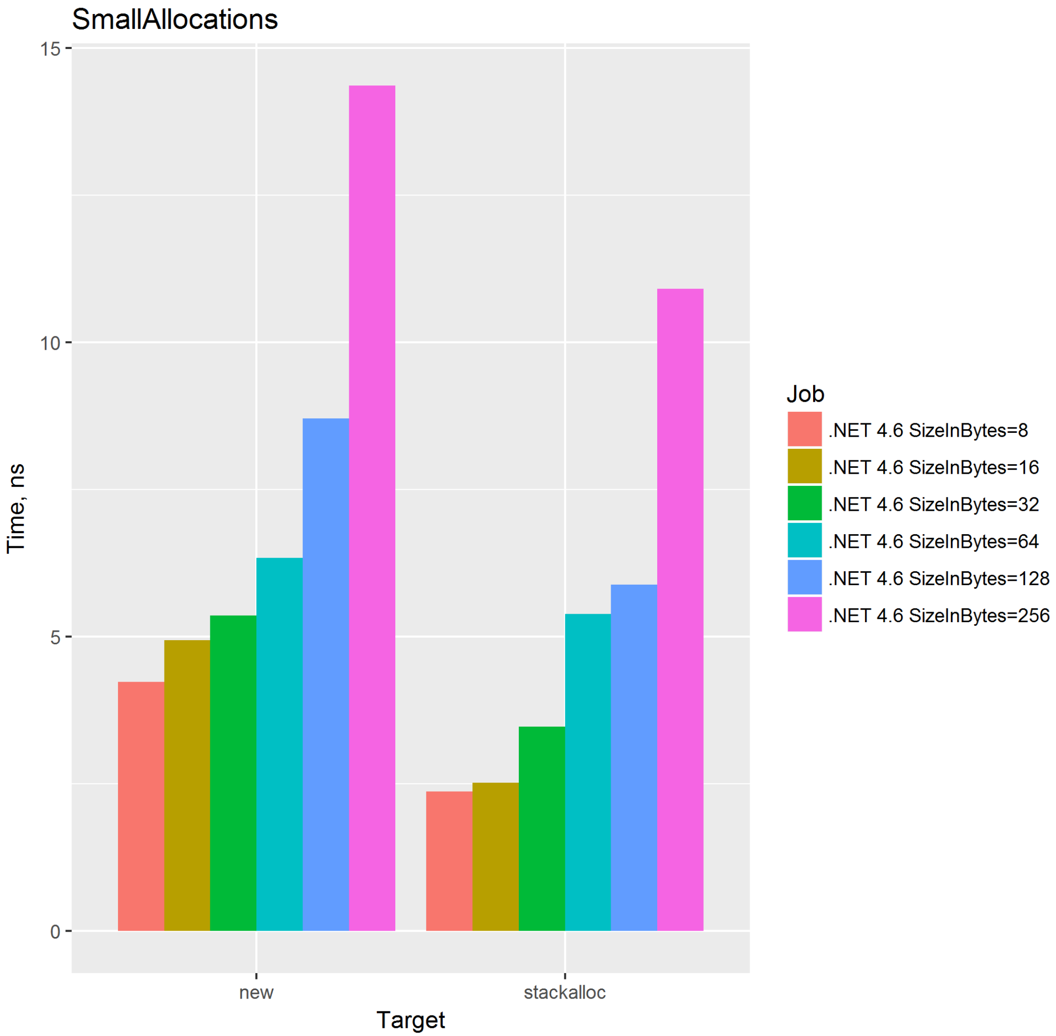
BufferAllocated event



ArrayPool: Summary

- **LOH = Gen 2 = Full GC**
- ArrayPool was designed for best possible performance
- Pool the memory if you can control the lifetime
- Use **Pool.Shared** by default
- Pool allocates the memory for buffers > maxSize
- **The fewer pools, the smaller LOH, the better!**

Stackalloc is the fastest way to allocate small chunks of memory in .NET



BenchmarkDotNet v0.10.7

	Allocation	Deallocation	Usage
Managed < 85 KB	Very fast	• Non-deterministic • Blocking • Very slow	• Very easy • Common • Safe
Managed: LOH	Fast		
Stackalloc	Super fast	• Deterministic • Super fast	• Unsafe • Not common • Limited
Marshal	Fast	• Deterministic • Fast	

APIs before Span: parsing integer

```
int Parse(string input);

int Parse(string input, int startIndex, int length);

int Parse(string input, long startIndex, int length);

unsafe int Parse(char* input, int length);

unsafe int Parse(char* input, long startIndex, int length);
```

Span<T>

It provides a uniform API for working with:

- Unmanaged memory buffers
- Arrays and subarrays
- Strings and substrings

It’s fully **type-safe** and **memory-safe**.

Almost no overhead.

It’s a **read only** and **stack only Value Type**.

Supports **any** memory

```
Span<byte> stackMemory = stackalloc byte[256]; // C# 7.2

IntPtr unmanagedHandle = Marshal.AllocHGlobal(256);
Span<byte> unmanaged = new Span<byte>(unmanagedHandle.ToPointer(), 256);

char[] array = new char[] { 'i', 'm', 'p', 'l', 'i', 'c', 'i', 't' };
Span<char> fromArray = array; // implicit cast

ReadOnlySpan<char> fromString = "State of the .NET Performance".AsSpan();
```

Simple API*

```
public int Length { get; }
public T this[int index] { get; set; }

public Span<T> Slice(int start);
public Span<T> Slice(int start, int length);

public void Clear();
public void Fill(T value);

public void CopyTo(Span<T> destination);
public bool TryCopyTo(Span<T> destination);

public ref T DangerousGetPinnableReference();
```

* It's not the full list

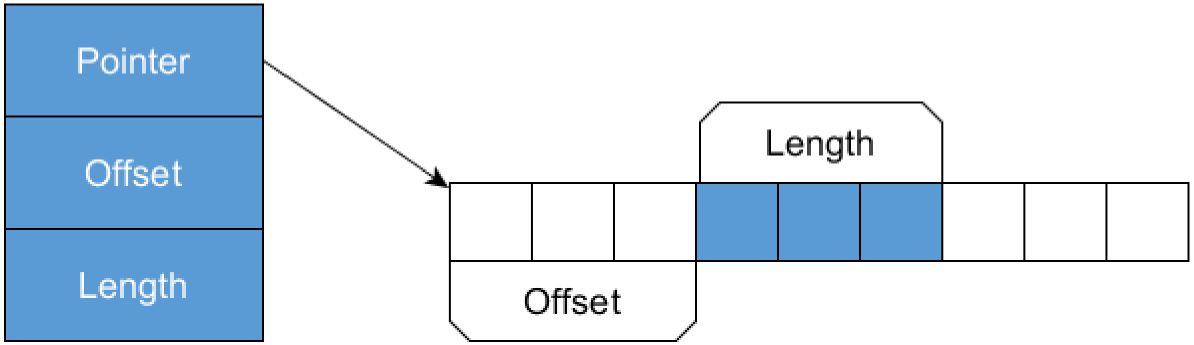
API Simplicity!

```
int Parse(Span<char> input)

void Copy<T>(Span<T> source, Span<T> destination)
```

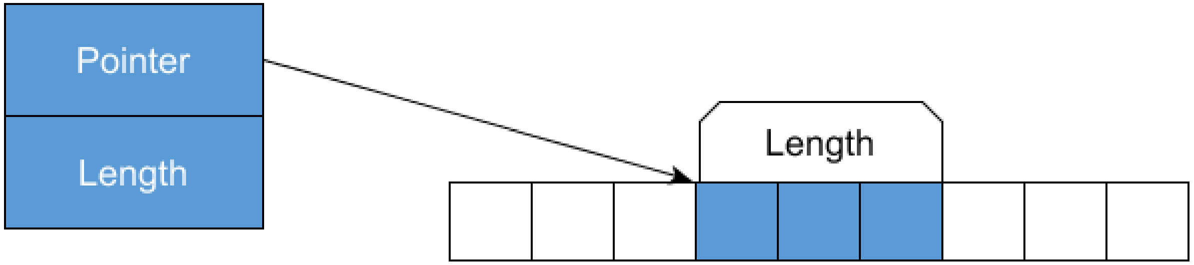
Span for existing runtimes

.NET Standard 1.0 (.NET 4.5+)



Span for new runtimes

.NET Core 2.0 and any other runtime supporting by-ref fields



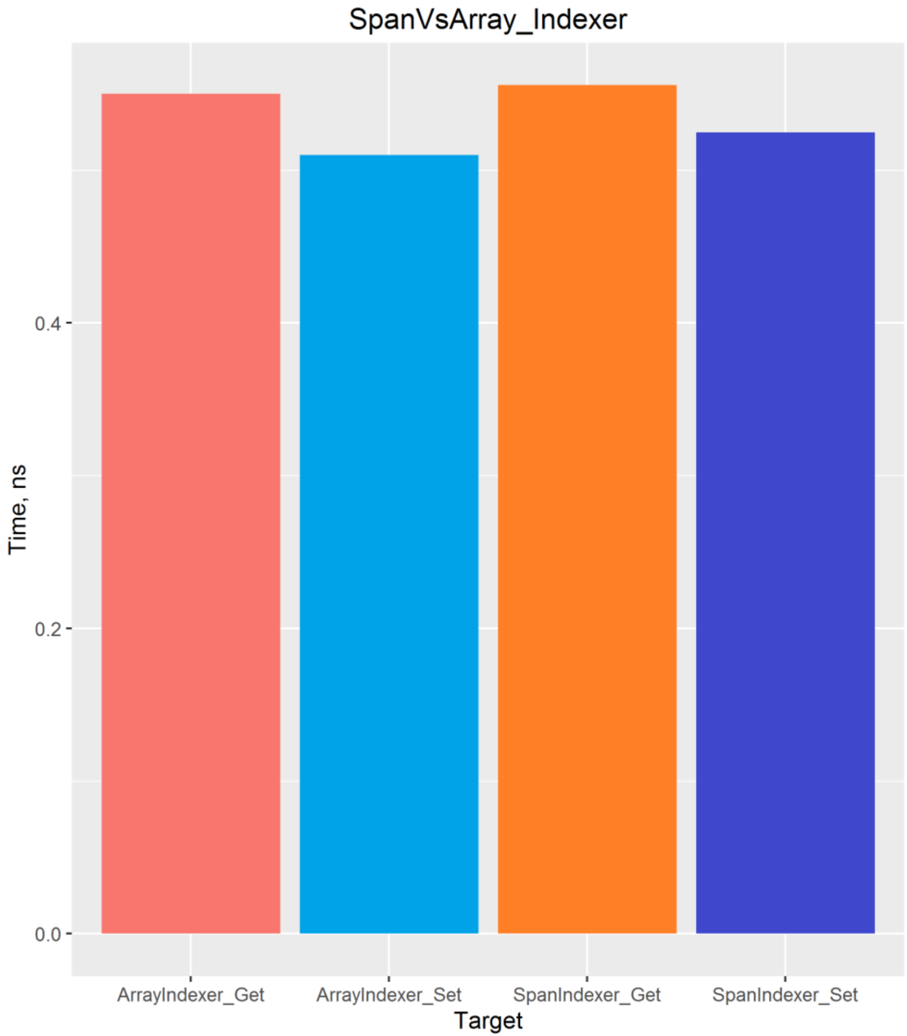
“Fast” vs “Slow” Span

Method	Job	Mean	Scaled
SpanIndexer_Get	.NET 4.6	0.6119 ns	1.14
SpanIndexer_Get	.NET Core 1.1	0.6092 ns	1.13
SpanIndexer_Get	**.NET Core 2.0**	**0.5368 ns**	**1.00**
SpanIndexer_Set	.NET 4.6	0.6117 ns	1.13
SpanIndexer_Set	.NET Core 1.1	0.6082 ns	1.12
SpanIndexer_Set	**.NET Core 2.0**	**0.5417 ns**	**1.00**

There is some place for further improvement!

Span is on par with Array*!

*.NET Core 2.0



BenchmarkDotNet v0.10.6.202-nightly

Creating substrings **before Span** (pseudocode)

```
string Substring(string text, int startIndex, int length)
{
    string result = new string(length); // ALLOCATION!

    Memory.Copy(text, result, startIndex, length); // COPYING

    return result;
}
```

Creating substrings **without allocation**! (pseudocode)

```
ReadOnlySpan<char> Slice(string text, int startIndex, int length)
    => new ReadOnlySpan<char>(
            ref text[0] + (startIndex * sizeof(char)),
            length);
```

Substring vs Slice

Method	Chars	Mean	StdDev	Scaled	Gen 0	Allocated
Substring	10	**8.277** ns	0.1938 ns	**4.54**	**0.0191**	**40 B**
Slice	10	**1.822** ns	**0.0383** ns	1.00	**-**	0 B
Substring	1000	**85.518** ns	1.3474 ns	**47.22**	**0.4919**	**1032 B**
Slice	1000	**1.811** ns	**0.0205** ns	1.00	**-**	0 B

Possible usages

- Parsing without allocations
- Formatting
- Base64/Unicode encoding
- HTTP Parsing/Writing
- Compression/Decompression
- XML/JSON parsing/writing
- Binary reading/writing
- & more!!

Stack Only

- Instances can reside only on the stack
- Which is accessed by one thread at the same time

Advantages:

- Few pointers for GC to track
- Safe Concurrency (no Struct Tearing)
- Safe lifetime. Method ends = memory can be returned to the pool or released

Stack Only: No Heap Limitations

```
void NonConstrained<T>(IEnumerable<T> collection)

struct SomeValueType<T> : IEnumerable<T> { }

void Demo()
{
    var value = new SomeValueType<int>();
    NonConstrained(value);
}
```

Boxing == Heap. Heap != Stack

```
.method private hidebysig
    instance void Demo () cil managed
{
    // Method begins at RVA 0x2054
    // Code size 21 (0x15)
    .maxstack 2
    .locals init (
        [0] valuetype Sample.SomeValueType`1<int32> 'value'
    )

    IL_0000: ldloca.s 'value'
    IL_0002: initobj valuetype Sample.SomeValueType`1<int32>
    IL_0008: ldarg.0
    IL_0009: ldloc.0
    IL_000a: box valuetype Sample.SomeValueType`1<int32>
    IL_000f: call instance void Sample.Program::NonConstrained<int32>(class
    IL_0014: ret
} // end of method Program::Demo
```

Stack Only: Even More Limitations

```
async Task Method(StackOnly<byte> bytes)

class SomeClass
{
    StackOnly<byte> field;
}

Func<StackOnly<byte>> genericArgument;
```

Memory<T>

- a type complementing Span<T>
- must not be created for stack memory

```
public Span<T> Span { get; }
```

```
public Span<T> Slice(int start);
public Span<T> Slice(int start, int length);
```

OwnedMemory<T>

```
public abstract class OwnedMemory<T> : IDisposable, IRetainable
{
    public Memory<T> AsMemory { get; }
    public abstract bool IsDisposed { get; }
    protected abstract bool IsRetained { get; }
    public abstract int Length { get; }
    public abstract Span<T> AsSpan();
    public void Dispose();
    protected abstract void Dispose(bool disposing);
    public abstract MemoryHandle Pin();
    public abstract bool Release();
    public abstract void Retain();
    protected internal abstract bool TryGetArray(out ArraySegment<T> arraySegment);
}
```

.NET Standard 2.1: Span based APIs

```
namespace System.IO
{
    public class Stream
    {
        public virtual int Read(Span<byte> destination);
        public virtual ValueTask<int> ReadAsync(Memory<byte> destination);

        public virtual void Write(ReadOnlySpan<byte> source);
        public virtual Task WriteAsync(ReadOnlyMemory<byte> source);
    }
}
```

.NET Standard 2.1: Span based APIs

- System.BitConverter, System.Convert
- System.Random
- System.Int16, System.DateTime, System.DateTimeOffset, System.TimeSpan, System.Version, System.Guid
- System.String, System.Text.StringBuilder, System.Text.Encoding
- System.IO.Stream, System.IO.TextReader, System.IO.TextWriter
- System.IO.BinaryReader, System.IO.BinaryWriter
- System.Numerics
- System.Net.IPAddress, System.Net.Sockets, System.Net.WebSockets, System.Net.Http
- System.Security.Cryptography

Span: Summary

- Allows to work with **any** type of memory.
- It makes working with native memory much easier.
- Simple abstraction over Pointer Arithmetic.
- **Avoid allocation and copying of memory with Slicing.**
- Supports .NET Standard 1.0+
- It’s perfromance is on par with Array for new runtimes.
- It’s limited due to stack only requirements.
- Use Memory/OwnedMemory to overcome Span limitations

System.Runtime.CompilerServices.Unsafe

Overcoming C# limitations:

- Managed Pointer Arithmetic
- Casting w/o constraints
- Copy/Init Block
- Read/Write w/o constraints
- SizeOf(T)

```
ref T AddByteOffset<T>(ref T source, IntPtr byteOffset)
ref T Add<T>(ref T source, int elementOffset)
ref T Add<T>(ref T source, IntPtr elementOffset)
bool AreSame<T>(ref T left, ref T right)
void* AsPointer<T>(ref T value)
ref T AsRef<T>(void* source)
T As<T>(object o) where T : class
ref TTo As<TFrom, TTo>(ref TFrom source)
IntPtr ByteOffset<T>(ref T origin, ref T target)
void CopyBlock(ref byte destination, ref byte source, uint byteCount)
void CopyBlock(void* destination, void* source, uint byteCount)
void CopyBlockUnaligned(ref byte destination, ref byte source, uint byteCount)
void CopyBlockUnaligned(void* destination, void* source, uint byteCount)
void Copy<T>(void* destination, ref T source)
void Copy<T>(ref T destination, void* source)
void InitBlock(ref byte startAddress, byte value, uint byteCount)
void InitBlock(void* startAddress, byte value, uint byteCount)
void InitBlockUnaligned(ref byte startAddress, byte value, uint byteCount)
void InitBlockUnaligned(void* startAddress, byte value, uint byteCount)
T Read<T>(void* source)
T ReadUnaligned<T>(void* source)
T ReadUnaligned<T>(ref byte source)
int SizeOf<T>()
ref T SubtractByteOffset<T>(ref T source, IntPtr byteOffset)
ref T Subtract<T>(ref T source, int elementOffset)
ref T Subtract<T>(ref T source, IntPtr elementOffset)
void Write<T>(void* destination, T value)
void WriteUnaligned<T>(void* destination, T value)
void WriteUnaligned<T>(ref byte destination, T value)
```

.NET Standard

Package name	.NET Standard	.NET Framework
System.Memory	1.0	4.5
System.Buffers	1.1	4.5.1
System.Threading.Tasks.Extensions	1.0	4.5
System.Runtime.CompilerServices.Unsafe	1.0	4.5

Summary

- Start using Value Types today!
- Use references to avoid copying of Value Types.
- Forget about unsafe, use “ref returns and locals” instead
- Use ValueTask only if it can help you!
- Pool the memory with ArrayPool
- Use Span and slicing to avoid allocations
- Use Span to take advantage of the native memory
- Use Memory/OwnedMemory to overcome Span limitations
- Use the “Unsafe” API to use C# only

Sources

- Series of Great Blog Posts by Vladimir Sadov
- Span<T> design document
- Compile time enforcement of safety for ref-like types
- Add initial Span/Buffer-based APIs across corefx
- ValueTask doesn't inline well- GitHub issue

Dziękuję!

Slides: http://adamsitnik.com/files/Gdansk.pdf

Code: https://github.com/adamsitnik/StateOfTheDotNetPerformance

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