

# Performance tricks I learned from contributing to open source .NET packages

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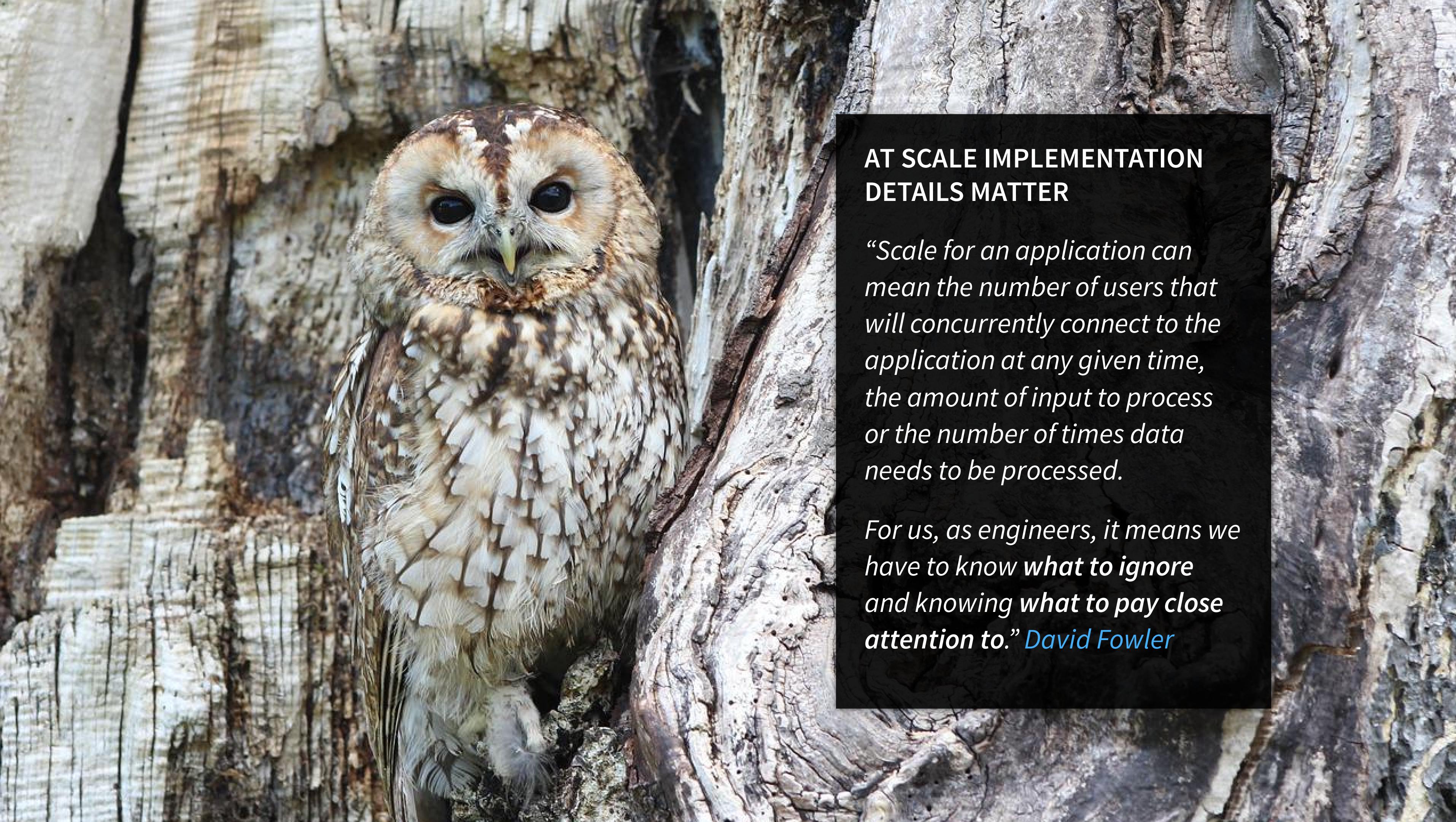
# INTRODUCTION

Focus on performance optimization in .NET Code and  
not architecture.



# ESOTERIC

Being called out for premature optimizations.



## AT SCALE IMPLEMENTATION DETAILS MATTER

*“Scale for an application can mean the number of users that will concurrently connect to the application at any given time, the amount of input to process or the number of times data needs to be processed.*

*For us, as engineers, it means we have to know **what to ignore** and knowing **what to pay close attention to.**” **David Fowler***

A close-up photograph of a person's hand holding a black Sharpie marker, writing the word "Rules" in a bold, black, cursive font on a light-colored wooden surface. The wood has a prominent grain and some darker knots. The hand is positioned in the lower right, with the marker tip pointing towards the bottom left. The background is blurred, showing what appears to be a garden or outdoor setting.

Rules

- Avoid excessive allocations to reduce the GC overhead
- Avoid unnecessary copying of memory

## Avoid excessive allocations to reduce the GC overhead

Think at least twice before using LINQ or unnecessary  
enumeration on the hot path

```
1 public class AmqpReceiver {
2
3     ConcurrentBag<Guid> _lockedMessages = new ();
4
5     public Task CompleteAsync(IEnumerable<string> lockTokens)
6         => CompleteInternalAsync(lockTokens);
7
8     Task CompleteInternalAsync(IEnumerable<string> lockTokens)
9     {
10        Guid[] lockTokenGuids = lockTokens.Select(token => new Guid(token)).ToArray();
11        if (lockTokenGuids.Any(lockToken => _lockedMessages.Contains(lockToken)))
12        {
13            // do special path accessing lockTokenGuids
14            return Task.CompletedTask;
15        }
16        // do normal path accessing lockTokenGuids
17        return Task.CompletedTask;
18    }
19 }
```

Avoid LINQ on the hot path.





```
1 public Task CompleteAsync(IEnumerable<string> lockTokens)
2   => CompleteInternalAsync(lockTokens);
3
4 Task CompleteInternalAsync(IEnumerable<string> lockTokens)
5 {
6   Guid[] array = Enumerable.ToArray(Enumerable.Select(lockTokens,
7     <>c.<>9_2_0 ??
8     (<>c.<>9_2_0 = new Func<string, Guid>(<>c.<>9.<CompleteInternalAsync>b_2_0))));
```

Avoid LINQ on the hot path.



# Benchmarking Time!

We can only know the before and after when we measure it.

| Method  | Size | Collection | Mean      | Error      | StdDev    | Ratio | RatioSD | Gen 0  | Allocated |
|---------|------|------------|-----------|------------|-----------|-------|---------|--------|-----------|
| Before  | 0    | Array      | 28.96 ns  | 18.868 ns  | 1.034 ns  | 1.00  | 0.00    | 0.0102 | 64 B      |
| AfterV1 | 0    | Array      | 17.62 ns  | 1.285 ns   | 0.070 ns  | 0.61  | 0.02    | -      | -         |
| Before  | 0    | Enumerable | 29.73 ns  | 3.246 ns   | 0.178 ns  | 1.00  | 0.00    | 0.0102 | 64 B      |
| AfterV1 | 0    | Enumerable | 23.25 ns  | 2.844 ns   | 0.156 ns  | 0.78  | 0.00    | -      | -         |
| Before  | 0    | HashSet    | 67.52 ns  | 24.479 ns  | 1.342 ns  | 1.00  | 0.00    | 0.0267 | 168 B     |
| AfterV1 | 0    | HashSet    | 54.60 ns  | 5.831 ns   | 0.320 ns  | 0.81  | 0.01    | 0.0166 | 104 B     |
| Before  | 0    | List       | 48.46 ns  | 11.809 ns  | 0.647 ns  | 1.00  | 0.00    | 0.0229 | 144 B     |
| AfterV1 | 0    | List       | 35.27 ns  | 23.899 ns  | 1.310 ns  | 0.73  | 0.03    | 0.0127 | 80 B      |
| Before  | 1    | Array      | 128.64 ns | 72.000 ns  | 1.305 ns  | 1.00  | 0.00    | 0.0381 | 240 B     |
| AfterV1 | 1    | Array      | 93.27 ns  | 23.817 ns  | 1.305 ns  | 0.73  | 0.02    | 0.0229 | 144 B     |
| Before  | 1    | Enumerable | 147.40 ns | 148.138 ns | 8.120 ns  | 1.00  | 0.00    | 0.0458 | 288 B     |
| AfterV1 | 1    | Enumerable | 115.77 ns | 29.583 ns  | 1.622 ns  | 0.79  | 0.04    | 0.0305 | 192 B     |
| Before  | 1    | HashSet    | 311.50 ns | 53.412 ns  | 2.928 ns  | 1.00  | 0.00    | 0.0596 | 376 B     |
| AfterV1 | 1    | HashSet    | 226.89 ns | 87.069 ns  | 4.773 ns  | 0.73  | 0.01    | 0.0443 | 280 B     |
| Before  | 1    | List       | 195.72 ns | 274.095 ns | 15.024 ns | 1.00  | 0.00    | 0.0420 | 264 B     |
| AfterV1 | 1    | List       | 150.91 ns | 91.677 ns  | 5.025 ns  | 0.77  | 0.06    | 0.0267 | 168 B     |
| Before  | 4    | Array      | 277.94 ns | 41.392 ns  | 2.269 ns  | 1.00  | 0.00    | 0.0687 | 432 B     |
| AfterV1 | 4    | Array      | 235.52 ns | 28.813 ns  | 1.579 ns  | 0.85  | 0.01    | 0.0534 | 336 B     |
| Before  | 4    | Enumerable | 353.15 ns | 152.507 ns | 8.359 ns  | 1.00  | 0.00    | 0.0763 | 480 B     |
| AfterV1 | 4    | Enumerable | 287.29 ns | 86.240 ns  | 4.727 ns  | 0.81  | 0.03    | 0.0610 | 384 B     |

 ~20-40%  
 ~20-40%

A close-up photograph of a person's hand holding a black Sharpie marker, writing the word "Rules" in a flowing, cursive script on a light-colored wooden surface. The wood has a prominent grain and some darker knots. The hand is positioned in the lower right, with the marker tip pointing towards the bottom left. The background is blurred, showing what appears to be a garden or outdoor setting.

Rules

# LINQ TO COLLECTION-BASED OPERATIONS

- Use `Array.Empty<T>` to represent empty arrays
- Use `Enumerable.Empty<T>` to represent empty enumerables
- Prevent collections from growing
- Use concrete collection types
- Leverage pattern matching or `Enumerable.TryGetNonEnumeratedCount`
- Wait with instantiating collections until really needed



```
1 public Task CompleteAsync(IEnumerable<string> lockTokens) {
2     IReadOnlyCollection<string> readOnlyCollection = lockTokens switch
3     {
4         IReadOnlyCollection<string> asReadOnlyCollection => asReadOnlyCollection,
5         _ => lockTokens.ToArray(),
6     };
7     return CompleteInternalAsync(readOnlyCollection);
8 }
9
10 Task CompleteInternalAsync(IReadOnlyCollection<string> lockTokens)
11 {
12     int count = lockTokens.Count;
13     Guid[] lockTokenGuids = count == 0 ? Array.Empty<Guid>() : new Guid[count];
14     int index = 0;
15     foreach (var token in lockTokens)
16     {
17         var tokenGuid = new Guid(token);
18         lockTokenGuids[index++] = tokenGuid;
19         if (_requestResponseLockedMessages.Contains(tokenGuid))
20         {
21             return Task.CompletedTask;
22         }
23     }
24     return Task.CompletedTask;
25 }
```

Avoid LINQ on the hot path.



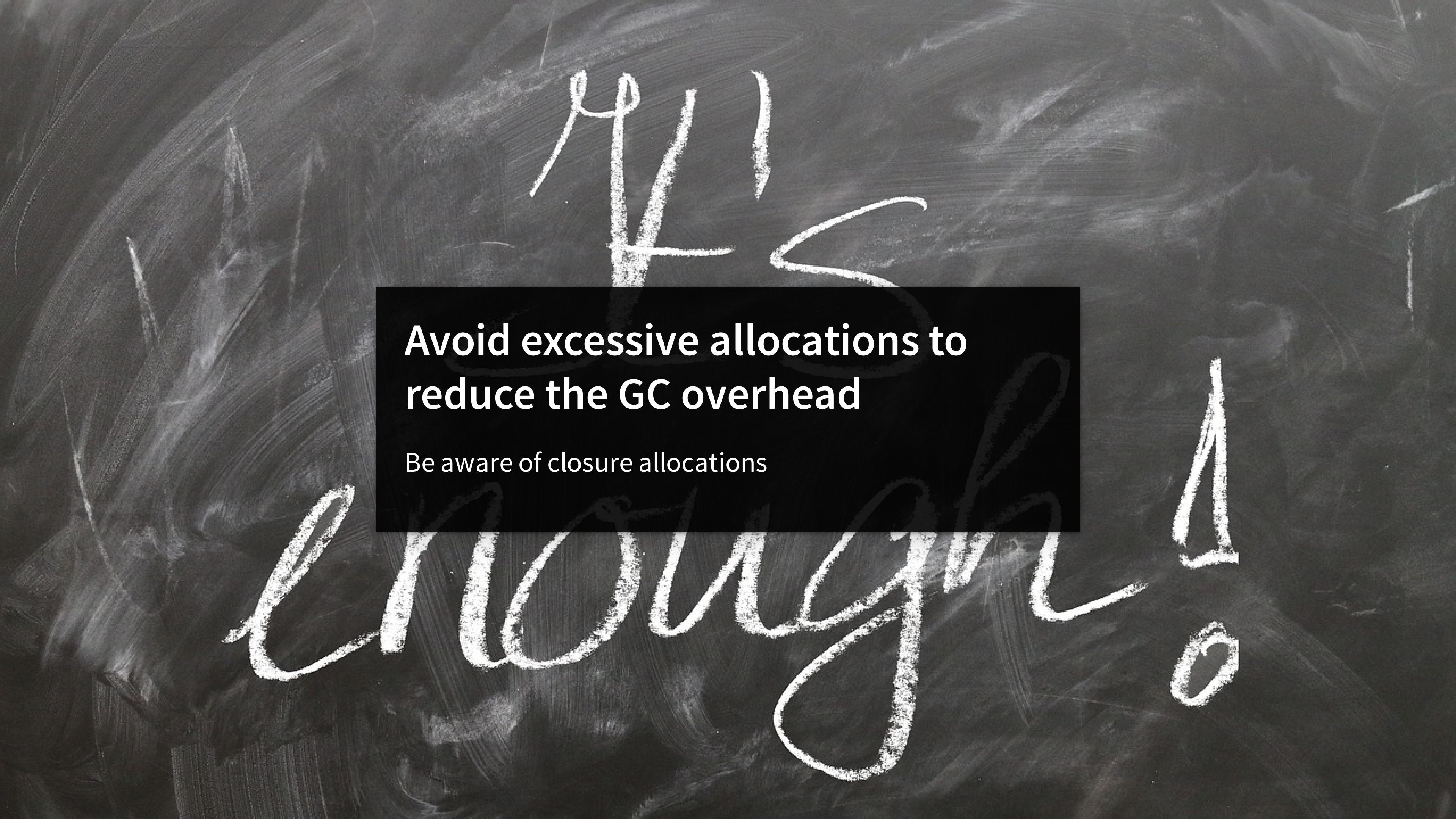
# Benchmarking Time!

We can only know the before and after when we measure it.

| Method  | Size | Collection | Mean      | Error      | StdDev    | Ratio | RatioSD | Gen 0  | Allocated |
|---------|------|------------|-----------|------------|-----------|-------|---------|--------|-----------|
| AfterV1 | 0    | Array      | 19.81 ns  | 29.413 ns  | 1.612 ns  | 1.00  | 0.00    | -      | -         |
| AfterV2 | 0    | Array      | 16.35 ns  | 0.722 ns   | 0.040 ns  | 0.83  | 0.07    | -      | -         |
| AfterV1 | 0    | Enumerable | 20.25 ns  | 34.142 ns  | 1.871 ns  | 1.00  | 0.00    | -      | -         |
| AfterV2 | 0    | Enumerable | 31.26 ns  | 76.364 ns  | 4.186 ns  | 1.56  | 0.29    | -      | -         |
| AfterV1 | 0    | HashSet    | 53.28 ns  | 78.903 ns  | 4.325 ns  | 1.00  | 0.00    | 0.0166 | 104 B     |
| AfterV2 | 0    | HashSet    | 29.80 ns  | 4.916 ns   | 0.269 ns  | 0.56  | 0.04    | 0.0063 | 40 B      |
| AfterV1 | 0    | List       | 37.30 ns  | 17.950 ns  | 0.984 ns  | 1.00  | 0.00    | 0.0127 | 80 B      |
| AfterV2 | 0    | List       | 26.72 ns  | 3.334 ns   | 0.183 ns  | 0.72  | 0.02    | 0.0063 | 40 B      |
| AfterV1 | 1    | Array      | 91.51 ns  | 76.518 ns  | 4.194 ns  | 1.00  | 0.00    | 0.0229 | 144 B     |
| AfterV2 | 1    | Array      | 76.42 ns  | 18.677 ns  | 1.024 ns  | 0.84  | 0.04    | 0.0191 | 120 B     |
| AfterV1 | 1    | Enumerable | 112.50 ns | 8.332 ns   | 0.457 ns  | 1.00  | 0.00    | 0.0305 | 192 B     |
| AfterV2 | 1    | Enumerable | 117.57 ns | 18.812 ns  | 1.022 ns  | 1.05  | 0.01    | 0.0241 | 152 B     |
| AfterV1 | 1    | HashSet    | 147.98 ns | 25.249 ns  | 1.384 ns  | 1.00  | 0.00    | 0.0446 | 280 B     |
| AfterV2 | 1    | HashSet    | 80.78 ns  | 9.157 ns   | 0.502 ns  | 0.55  | 0.01    | 0.0204 | 128 B     |
| AfterV1 | 1    | List       | 97.80 ns  | 41.142 ns  | 2.255 ns  | 1.00  | 0.00    | 0.0267 | 168 B     |
| AfterV2 | 1    | List       | 92.70 ns  | 31.934 ns  | 1.750 ns  | 0.95  | 0.00    | 0.0204 | 128 B     |
| AfterV1 | 4    | Array      | 244.28 ns | 92.399 ns  | 5.065 ns  | 1.00  | 0.00    | 0.0534 | 336 B     |
| AfterV2 | 4    | Array      | 350.87 ns | 180.579 ns | 9.898 ns  | 1.44  | 0.01    | 0.0496 | 312 B     |
| AfterV1 | 4    | Enumerable | 426.69 ns | 283.441 ns | 15.536 ns | 1.00  | 0.00    | 0.0610 | 384 B     |
| AfterV2 | 4    | Enumerable | 441.16 ns | 108.507 ns | 5.948 ns  | 1.03  | 0.03    | 0.0587 | 368 B     |
| AfterV1 | 4    | HashSet    | 225.05 ns | 12.186 ns  | 0.668 ns  | 1.00  | 0.00    | 0.0443 | 280 B     |
| AfterV2 | 4    | HashSet    | 80.35 ns  | 28.545 ns  | 1.565 ns  | 0.36  | 0.01    | 0.0204 | 128 B     |
| AfterV1 | 4    | List       | 249.84 ns | 89.131 ns  | 4.886 ns  | 1.00  | 0.00    | 0.0572 | 360 B     |
| AfterV2 | 4    | List       | 229.86 ns | 98.608 ns  | 5.405 ns  | 0.92  | 0.01    | 0.0508 | 320 B     |

+56%

~23-61%



**Avoid excessive allocations to  
reduce the GC overhead**

Be aware of closure allocations



```
1 TransportMessageBatch messageBatch = null;  
2 Task createBatchTask = _retryPolicy.RunOperation(async (timeout)  
3 {  
4     messageBatch =  
5         await CreateMessageBatchInternalAsync(options, timeout);  
6 },  
7 _connectionScope,  
8 cancellationToken);  
9 await createBatchTask;  
10 return messageBatch;
```

Remove closure allocations.

```
1 if (num1 != 0) {
2     this._u003C\u003E8_1 = new AmqpSender.\u003C\u003Ec__DisplayClass16_0();
3     this._u003C\u003E8_1.\u003C\u003E4__this = this.\u003C\u003E4__this;
4     this._u003C\u003E8_1.options = this.options;
5     this._u003C\u003E8_1.messageBatch = (TransportMessageBatch) null;
6
7     configuredTaskAwaiter = amqpSender._retryPolicy.RunOperation(
8         new Func<TimeSpan, Task>((object) this._u003C\u003E8_1,
9             __methodptr(\u003CCreateMessageBatchAsync\u003Eb_0)),
10            (TransportConnectionScope) amqpSender._connectionScope,
11            this.cancellationToken).ConfigureAwait(false).GetAwaiter();
12
13    // rest omitted
14 }
```

Remove closure allocations.



```
1 internal async ValueTask RunOperation<T1>(
2     Func<T1, TimeSpan, CancellationToken, ValueTask> operation,
3     T1 t1,
4     TransportConnectionScope scope,
5     CancellationToken cancellationToken) =>
6     await RunOperation(static async (value, timeout, token) =>
7     {
8         var (t1, operation) = value;
9         await operation(t1, timeout, token);
10        return default(object);
11    },
12    (t1, operation),
13    scope, cancellationToken);
```

Remove closure allocations.

```
1 if (num1 != 0) {
2     configuredTaskAwaiter = t1._retryPolicy
3         .RunOperation<AmqpSender, CreateMessageBatchOptions, TransportMessageBatch>(
4             AmqpSender.\u003C\u003Ec.\u003C\u003E9__16_0 ?? (AmqpSender.\u003C\u003Ec.\u003C\u003E9__16_0 =
5                 new Func<AmqpSender, CreateMessageBatchOptions, TimeSpan, CancellationToken, Task<TransportMessageBatch>>(
6                     (object) AmqpSender.\u003C\u003Ec.\u003C\u003E9,
7                     __methodptr(\u003CCreateMessageBatchAsync\u003Eb__16_0))),
8             t1,
9             this.options,
10            (TransportConnectionScope) t1._connectionScope,
11            this.cancellationToken).ConfigureAwait(false).GetAwaiter();
12     // rest omitted
13 }
```

Remove closure allocations.

| Method                         | Calls | PipelineDepth | Mean      | Error  | StdDev    | Ratio | RatioSD | Gen 0      | Allocated    |
|--------------------------------|-------|---------------|-----------|--|-----------|-------|---------|------------|--------------|
| V8_PipelineBeforeOptimizations | 20000 | 10            | 7.083 ms  | 3.1550 ms  | 0.1729 ms | 1.00  | 0.00    | 3054.6875  | 19,200,023 B |
| V8_PipelineAfterOptimizations  | 20000 | 10            | 1.588 ms  | 1.1607 ms  | 0.0636 ms | 0.22  | 0.01    | -          | 1 B          |
| V8_PipelineBeforeOptimizations | 20000 | 20            | 10.989 ms | ~74-78%   | 4983 ms   | 1.00  | 0.00    | 6109.3750  | 38,400,049 B |
| V8_PipelineAfterOptimizations  | 20000 | 20            | 2.830 ms  | ~Gone!  | 0.1338 ms | 0.26  | 0.00    | -          | 2 B          |
| V8_PipelineBeforeOptimizations | 20000 | 40            | 23.054 ms | 11.1449 ms   | 0.6109 ms | 1.00  | 0.00    | 12218.7500 | 76,800,012 B |
| V8_PipelineAfterOptimizations  | 20000 | 40            | 5.192 ms  | 4.4372 ms  | 0.2432 ms | 0.23  | 0.02    | -          | 3 B          |

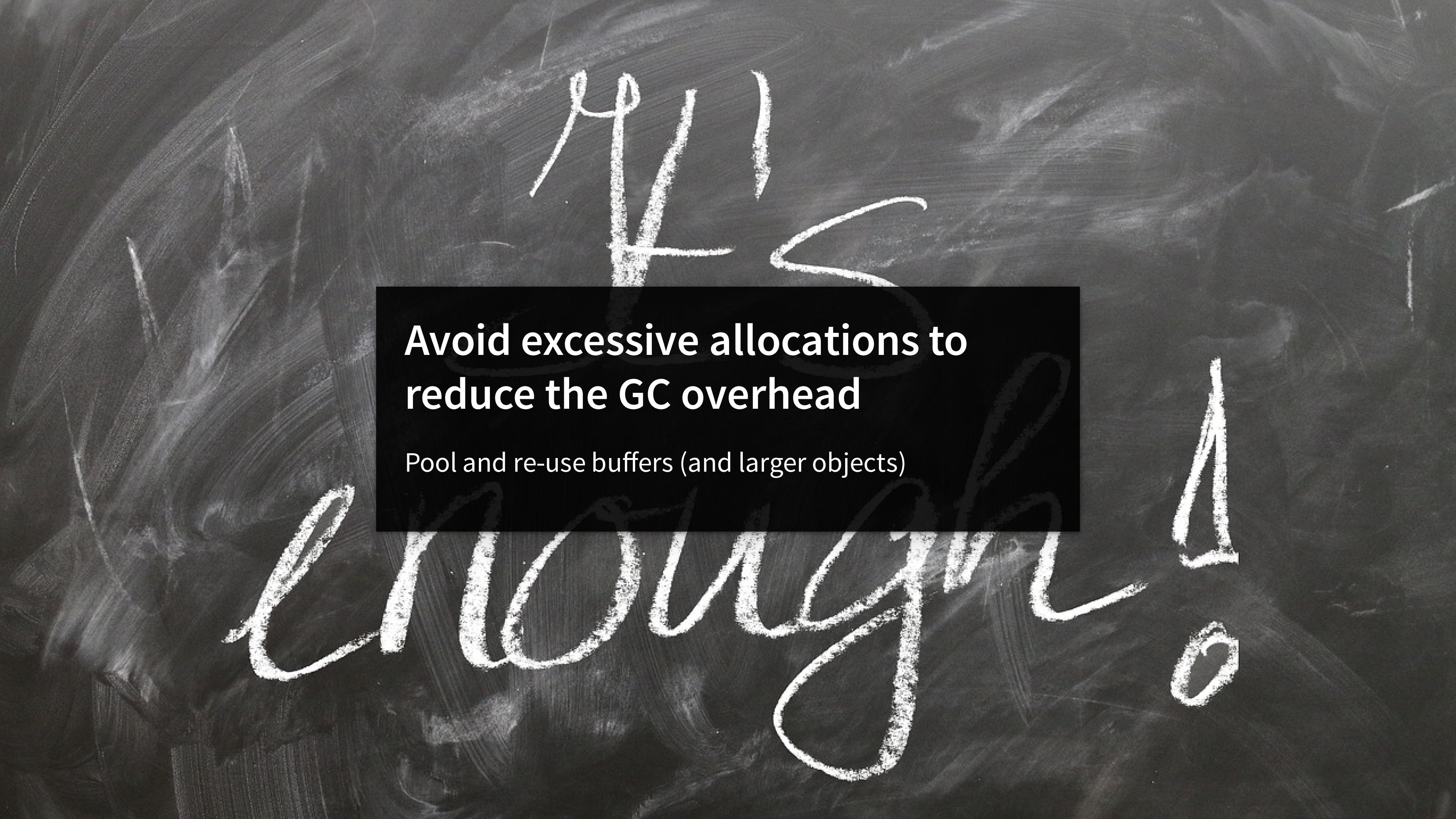
[particular.net/blog/pipeline-and-closure-allocations](http://particular.net/blog/pipeline-and-closure-allocations)

# HOW TO DETECT THOSE ALLOCATIONS?

- Use memory profilers and watch out for excessive allocations of \*`__DisplayClass`\* or various variants of `Action`\* and `Func`\*
- Use tools like [Heap Allocation Viewer \(Rider\)](#) or [Heap Allocation Analyzer \(Visual Studio\)](#)
- Many built-in .NET types that use delegates have nowadays generic overloads that allow to pass state into the delegate.

```
1 var someState1 = new object();
2 var someOtherState = 42;
3
4 var dictionary = new ConcurrentDictionary<string, string>();
5
6 dictionary.GetOrAdd("SomeKey", static (key, state) => {
7     var (someState, someOtherState) = state;
8
9     return $"{someState}_{someOtherState}";
10 }, (someState1, someOtherState));
```

Remove closure allocations.



**Avoid excessive allocations to  
reduce the GC overhead**

Pool and re-use buffers (and larger objects)

```
1 var data = new ArraySegment<byte>(Guid.NewGuid().ToByteArray());
2
3 var guidBuffer = new byte[16];
4 Buffer.BlockCopy(data.Array, data.Offset, guidBuffer, 0, 16);
5 var lockTokenGuid = new Guid(guidBuffer);
```

Pool and re-use buffers.

```
1 byte[] guidBuffer = ArrayPool<byte>.Shared.Rent(16);
2 Buffer.BlockCopy(data.Array, data.Offset, guidBuffer, 0, 16);
3 var lockTokenGuid = new Guid(guidBuffer);
4 ArrayPool<byte>.Shared.Return(guidBuffer);
```

Pool and re-use buffers.

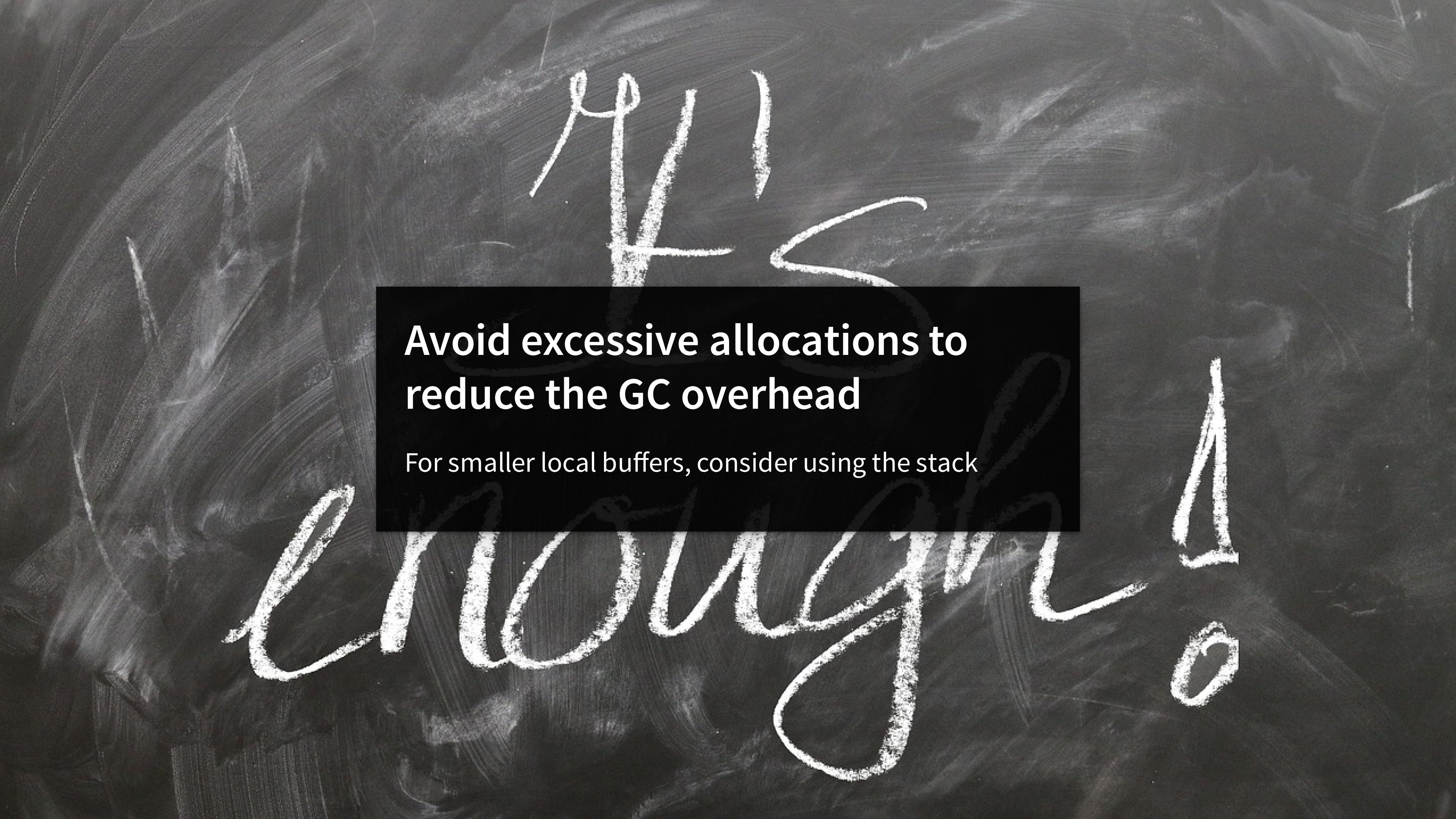


## Benchmarking Time!

We can only know the before and after when we measure it.

| Method             | Mean      | Error     | StdDev    | Ratio | RatioSD | Gen 0  | Allocated |
|--------------------|-----------|-----------|-----------|-------|---------|--------|-----------|
| BufferAndBlockCopy | 10.975 ns | 0.1860 ns | 0.1740 ns | 1.00  | 0.00    | 0.0064 | 40 B      |
| BufferPool         | 24.718 ns | 0.3030 ns | 0.2555 ns | 2.26  | 0.03    | -      | -         |

+226%  
~Gone!



**Avoid excessive allocations to  
reduce the GC overhead**

For smaller local buffers, consider using the stack

```
1 Span<byte> guidBytes = stackalloc byte[16];  
2 data.AsSpan().CopyTo(guidBytes);  
3 var lockTokenGuid = new Guid(guidBytes);
```

Small local buffers on stack.



## Benchmarking Time!

We can only know the before and after when we measure it.

| Method             | Mean      | Error L   | StdDev    | Ratio | RatioSD | Gen 0  | Allocated |
|--------------------|-----------|-----------|-----------|-------|---------|--------|-----------|
| BufferAndBlockCopy | 10.975 ns | 0.1860 ns | 0.1740 ns | 1.00  | 0.00    | 0.0064 | 40 B      |
| BufferPool         | 24.718 ns | 0.2552 ns | 0.2555 ns | 2.26  | 0.03    | -      | -         |
| StackallocWithGuid | 6.078 ns  | 0.0362 ns | 0.0321 ns | 0.55  | 0.01    | -      | -         |



Rules



- Avoid excessive allocations to reduce the GC overhead
  - Think at least twice before using LINQ or unnecessary enumeration on the hot path
  - Be aware of closure allocations
  - Pool and re-use buffers
  - For smaller local buffers, consider using the stack
  - Be aware of parameter overloads
  - Where possible and feasible use value types but pay attention to unnecessary boxing



Avoid unnecessary copying of  
memory

## Avoid unnecessary copying of memory

- Look for Stream and Byte-Array usages that are copied or manipulated without using Span or Memory
- Replace existing data manipulation methods with newer Span or Memory based variants

```
1 private static short GenerateHashCode(string partitionKey) {
2     if (partitionKey == null) {
3         return 0;
4     }
5
6     var encoding = Encoding.UTF8;
7     ComputeHash(encoding.GetBytes(partitionKey), 0, 0, out uint hash1, out uint hash2);
8     return (short)(hash1 ^ hash2);
9 }
10
11 private static void ComputeHash(byte[] data, uint seed1, uint seed2,
12     out uint hash1, out uint hash2) {
13
14     uint a, b, c;
15
16     a = b = c = (uint)(0xdeadbeef + data.Length + seed1);
17     c += seed2;
18
19     int index = 0, size = data.Length;
20     while (size > 12) {
21         a += BitConverter.ToInt32(data, index);
22         b += BitConverter.ToInt32(data, index + 4);
23         c += BitConverter.ToInt32(data, index + 8);
24
25     // rest omitted
26 }
```

Avoid unnecessary copying of memory.





# Benchmarking Time!

We can only know the before and after when we measure it.

| Method | Size | Mean      | Error     | StdDev   | Ratio | RatioSD | Gen 0  | Allocated |
|--------|------|-----------|-----------|----------|-------|---------|--------|-----------|
| Before | 8    | 30.46 ns  | 10.493 ns | 0.575 ns | 1.00  | 0.00    | 0.0010 | 32 B      |
| After  | 8    | 18.47 ns  | 2.863 ns  | 0.157 ns | 0.61  | 0.02    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 12   | 31.88 ns  | 5.089 ns  | 0.279 ns | 1.00  | 0.00    | 0.0012 | 40 B      |
| After  | 12   | 18.71 ns  | 2.281 ns  | 0.125 ns | 0.59  | 0.01    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 24   | 38.95 ns  | 3.828 ns  | 0.210 ns | 1.00  | 0.00    | 0.0014 | 48 B      |
| After  | 24   | 24.19 ns  | 0.476 ns  | 0.026 ns | 0.62  | 0.00    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 32   | 45.05 ns  | 6.978 ns  | 0.383 ns | 1.00  | 0.00    | 0.0017 | 56 B      |
| After  | 32   | 27.53 ns  | 1.200 ns  | 0.61     | 0.61  | 0.00    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 64   | 74.93 ns  | 7.068 ns  | 0.387 ns | 1.00  | 0.00    | 0.0026 | 38 B      |
| After  | 64   | 39.59 ns  | 1.935 ns  | 0.106 ns | 0.53  | 0.00    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 128  | 123.84 ns | 12.736 ns | 0.698 ns | 1.00  | 0.00    | 0.0045 | 152 B     |
| After  | 128  | 78.06 ns  | 2.420 ns  | 0.133 ns | 0.63  | 0.00    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 255  | 199.68 ns | 11.492 ns | 0.630 ns | 1.00  | 0.00    | 0.0083 | 280 B     |
| After  | 255  | 126.24 ns | 1.639 ns  | 0.090 ns | 0.63  | 0.00    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 257  | 206.22 ns | 8.201 ns  | 0.450 ns | 1.00  | 0.00    | 0.0086 | 288 B     |
| After  | 257  | 128.98 ns | 2.596 ns  | 0.142 ns | 0.63  | 0.00    | -      | -         |
|        |      |           |           |          |       |         |        |           |
| Before | 512  | 380.75 ns | 74.100 ns | 4.062 ns | 1.00  | 0.00    | 0.0157 | 536 B     |
| After  | 512  | 212.34 ns | 14.202 ns | 0.778 ns | 0.56  | 0.01    | -      | -         |

A close-up photograph of a person's hand holding a black Sharpie marker, writing the word "Rules" in a flowing, cursive script on a light-colored wooden surface. The wood has a prominent grain and some darker knots. The hand is positioned in the lower right, with the marker tip pointing towards the bottom left. The background is blurred, showing what appears to be a garden or outdoor setting.

Rules

- Look for Stream and Byte-Array usages that are copied or manipulated without using Span or Memory
- Replace existing data manipulation methods with newer Span or Memory based variants

- Avoid excessive allocations to reduce the GC overhead
  - Be aware of closure allocations
  - Be aware of parameter overloads
  - Where possible and feasible use value types but pay attention to unnecessary boxing
  - Think at least twice before using LINQ or unnecessary enumeration on the hot path
    - Use `Array.Empty<T>` to represent empty arrays
    - Use `Enumerable.Empty<T>` to represent empty enumerables
    - Prevent collections from growing
    - Use concrete collection types
    - Leverage pattern matching or `Enumerable.TryGetNonEnumeratedCount`
    - Wait with instantiating collections until really needed
  - Pool and re-use buffers
  - For smaller local buffers, consider using the stack
- Avoid unnecessary copying of memory
  - Look for Stream and Byte-Array usages that are copied or manipulated without using `Span` or `Memory`
  - Replace existing data manipulation methods with newer `Span` or `Memory` based variants

# In case you are up for a challenge

The original `ComputeHash` method had a .

Did you spot it?

```
static void ComputeHash(byte[] data, uint seed1, uint seed2,
    out uint hash1, out uint hash2) {

    uint a, b, c;

    a = b = c = (uint)(0xdeadbeef + data.Length + seed1);
    c += seed2;

    int index = 0, size = data.Length;
    while (size > 12) {
        a += BitConverter.ToInt32(data, index);
        b += BitConverter.ToInt32(data, index + 4);
        c += BitConverter.ToInt32(data, index + 8);

        // rest omitted
    }
}
```

# Strategy Innovation

## AT SCALE IMPLEMENTATION DETAILS MATTER

Tweak expensive I/O operations first.

Pay close attention to the context of the code.

Apply the principles where they matter.

Everywhere else, favor readability.

[github.com/danielmarbach/PerformanceTricksAzureSDK](https://github.com/danielmarbach/PerformanceTricksAzureSDK)

Happy coding!

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