

FastEnum is SUPER fast !!

速さは正義

ちょっとした工夫で案外メチャクチャ速くなる！
速いコードを書くひとつの参考になれば幸いです

本当は FastEnum は存在しない方が良い
標準が速ければ最高だし、そうあってほしい
.NET Core 頑張れ



Inside FastEnum

.NET Conf in Tokyo 2019
鈴木 孝明



.NET Conf in Tokyo 2019

鈴木 孝明

About

Name

鈴木 孝明 a.k.a @xin9le

Work

Application Engineer

Award

Microsoft MVP
for Developer Technologies

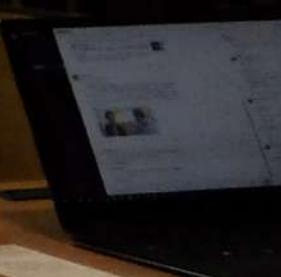
Web Site

<https://xin9le.net>



空港がない
陸の孤島

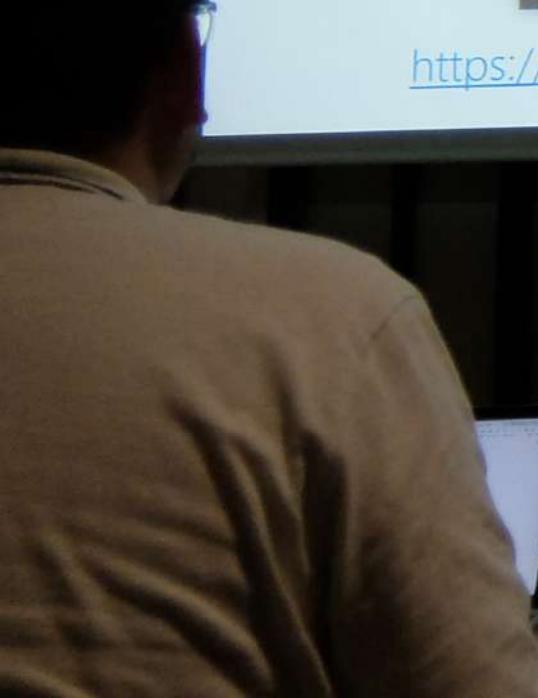
Remote Worker @福井



という話をしました



<https://www.slideshare.net/xin9le/dotnetperformancetips-170268354>



という話をしました



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狂気に満ちた世界 (その壱)

最速のC#の書き方

C#大統一理論へ向けて性能的課題を払拭する

CEDEC 2018

2018/08/22 - Yoshifumi Kawai / neuecc

<https://www.slideshare.net/neuecc/cedec-2018-c-c>

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Understanding C# Struct All Things

Cysharp, Inc.

Kawai Yoshifumi



<https://learning.unity3d.jp/3305/>

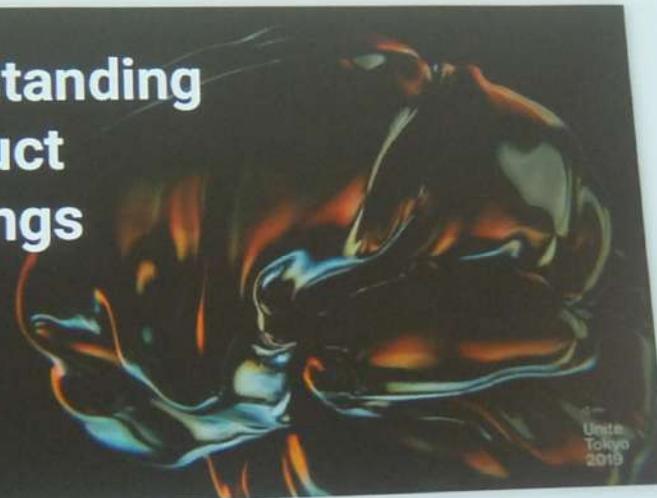


狂気に満ちた世界 (その弐)

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Unite
Tokyo
2019

<https://learning.unity3d.jp/3305/>



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Ben Adams 
@ben_a_adams

ASP.NET Core 3.0 has had a +30% performance improvement in
the last 2 months alone!

Compared to 2.2:

+42% in throughput and -92% reduction in memory usage!

Always improving #aspnetcore #dotnet #dotnetcore

ツイートを翻訳



3.0 vs 2.2.x

4,414,377
3,100,114 (+42.4 %)

3.0 vs 2.2

104 MB
1,332 MB (-92.2 %)

午後7:49 · 2019年4月10日 · Twitter Web Client

683件のリツイート 1,589件のいいね

スループット
+42%



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ツイート先説明



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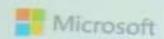
メモリ消費量
-92%

スループット
+42%

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Performance Improvements in .NET Core 3.0



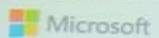
May 15th, 2019.

Back when we were getting ready to ship .NET Core 2.0, I wrote a [blog post](#) exploring some of the many performance improvements that had gone into it. I enjoyed putting it together so much and received such a positive response to the post that I did it [again for .NET Core 2.1](#), a version for which performance was also a significant focus. With [//build](#) last week and [.NET Core 3.0's release now on the horizon](#), I'm thrilled to have an opportunity to do it again.

.NET Core 3.0 has a lot to offer, from Windows Forms and WPF, to console file execution, to `async`.

超絶長編記事も公開
The article is now available in Chinese. I'm excited to go to work in the morning, and there's a staggering amount of performance goodness in .NET Core 3.0.

In this post, we'll take a tour through some of the many improvements, big and small, that have gone into the .NET Core runtime and core libraries in order to make your apps and services leaner and faster.



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Performance Improvements in .NET Core 3.0



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.NET Core 3.0 has a ton to offer. From Windows Forms and WPF, to single-file executables, to async

and parallel file operations, there's a lot to like. And with the introduction of the new .NET Core 3.0

SDK, you can get started with .NET Core 3.0 today. I'm excited to go to work in the morning, and there's a staggering amount of performance goodness

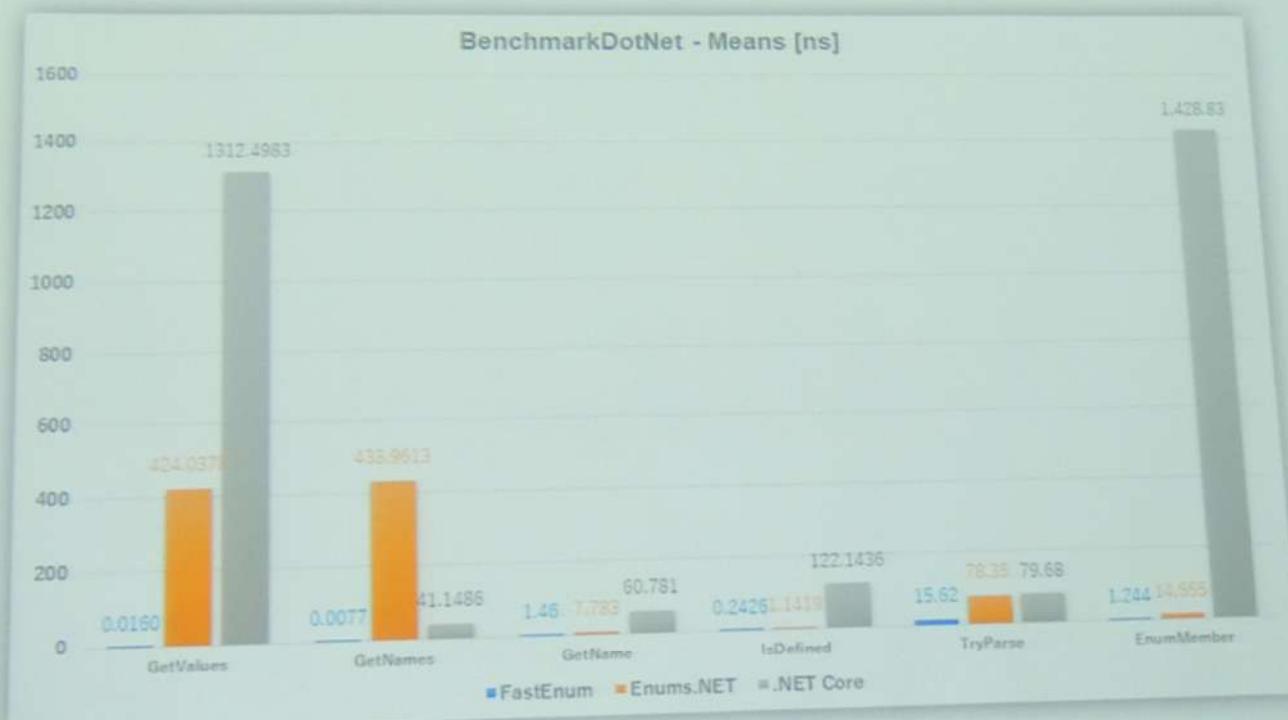
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超絶長編記事も公開



The world fastest Enum (FastEnum)



<https://github.com/xin9le/FastEnum>

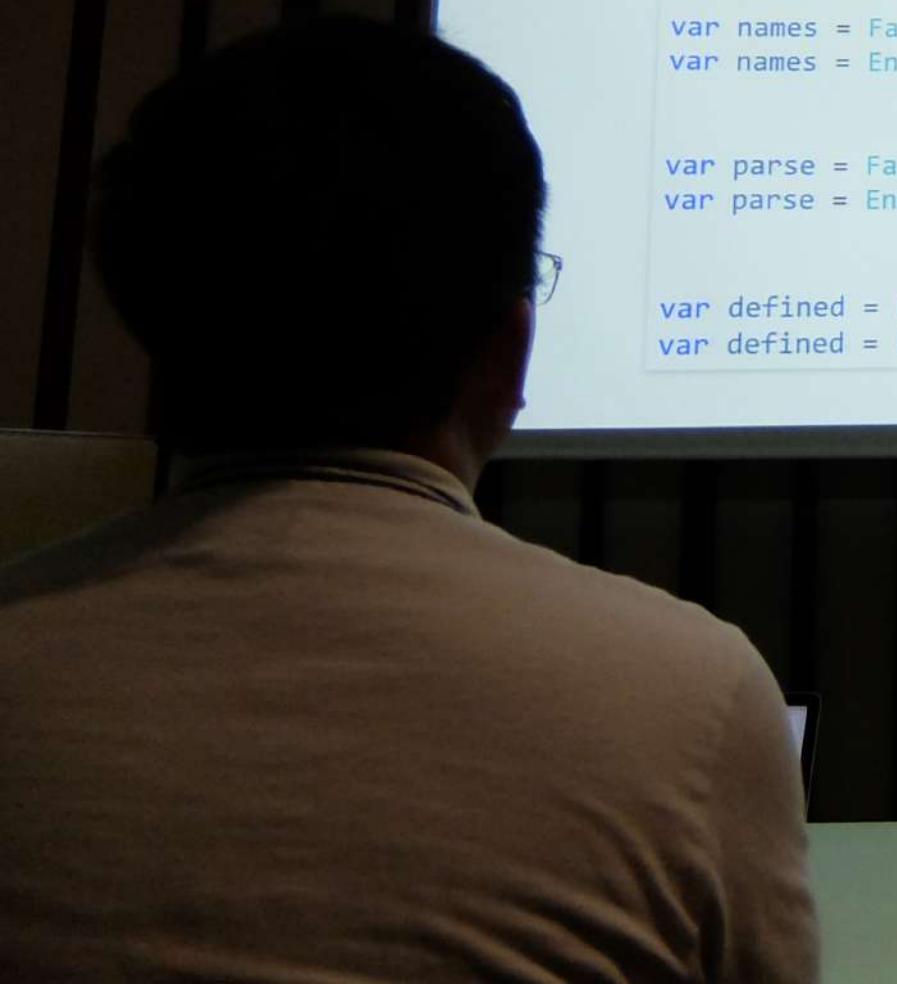
System.Enum とほぼ同様の使用感

```
var values = FastEnum.GetValues<Fruits>();
var values = Enum.GetValues(typeof(Fruits)) as Fruits[];

var names = FastEnum.GetNames<Fruits>();
var names = Enum.GetNames(typeof(Fruits));

var parse = FastEnum.Parse<Fruits>("Apple");
var parse = Enum.Parse<Fruits>("Apple");

var defined = FastEnum.IsDefined(Fruits.Lemon);
var defined = Enum.IsDefined(typeof(Fruits), Fruits.Lemon);
```



System.Enum とほぼ同様の使用感

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```

Member<T>

フィールドの値/名前などを一纏めに

値/名前のペアって案外使うのに、ペアを作る処理は地味に面倒

// フィールド情報

```
public sealed class Member<T>
    where T : struct, Enum
{
    public T Value { get; }
    public string Name { get; }
    public FieldInfo FieldInfo { get; }
    public EnumMemberAttribute EnumMemberAttribute { get; }
}
```

// 超高速で簡単な取得

```
var xs = FastEnum.GetMembers<Fruits>();
var x1 = FastEnum.GetMember(Fruits.Apple);
var x2 = Fruits.Apple.ToMember();
```

Member<T>

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```

Label 属性

フィールドに複数の名前を付けられる

[EnumMember] だと AllowMultiple = false なので不便
Grani 社内で使われていた便利機能のひとつ

```
// こんな定義があったとして  
  
public enum Fruits  
{  
    [Label("りんご", 0)]  
    [Label("りんご", 1)]  
    Apple,  
}
```

```
// インデックス指定で取得できる  
  
var a = Fruits.Apple.GetLabel(0); //   
var b = Fruits.Apple.GetLabel(1); // りんご
```

Why standard enum is slow?

速くなったと言われる .NET Core 3.0 なのに、なぜ！

中途半端なキャッシュ

`RuntimeType.GenericCache` を使ってる

そこまでは良いのだけど、キャッシュの持ち方がよくない

`ulong[] / string[]` を持つだけで、それ以上のトリックがない

都度 `Reflection` している箇所も

`Enum.GetName / Enum.IsDefined` などなど

キャッシュとは何だったのか...

Box / Unbox の雨霰

ほぼ必ず object 型を経由する

Non Generics な `Array` とか `Enum.ToObject` とかを普通に使う
`ulong` で持っていたものを有効活用しないとか超クール

Parse<T> / TryParse<T>はまとも

`System.Enum` で Generics 版が使えるときは積極的に使う

※ .NET Core に限る

※ .NET Framework の実装は残念過ぎる

A screenshot of a Windows desktop showing a code editor window for a .NET Core project named "FastEnum". The file being edited is "GetValuesBenchmark.cs". The code implements benchmarks for getting values from enums. A tooltip is visible over the `Array` method of the `Enum` class.

```
public void Setup()
{
    _ = Enum.GetValues(typeof(Fruits));
    public _ = Enums.GetValues<Fruits>();
    _ = _FastEnum.GetValues<Fruits>();
}

[Benchmark(Baseline = true)]
0 個の参照 | Takaaki Suzuki、40 日前 | 11 人の作成者、1 件の変更
public IReadOnlyList<Fruits> NetCore()
=> Enum.GetValues(typeof(Fruits)) as Fruits[];

public IReadOnlyList<Fruits> EnumsNet()
[Benchmark]
=> Enums.GetValues<Fruits>().ToArray();

public IReadOnlyList<Fruits> FastEnum()
[Benchmark]
0 個の参照 | Takaaki Suzuki、40 日前 | 11 人の作成者、1 件の変更
=> TDemandOnlyInt+Enum+FastEnum()
```

The tooltip for the `Array` method of the `Enum` class is:

Array(Enum.GetValues(Type enumType))
Retrieves an array of the values of the constants in a specified enumeration.

```
20     _ = Enums.GetValues<Fruits>(),
21     _ = _FastEnum.GetValues<Fruits>();
22 }
23
24 [Benchmark(Baseline = true)]
25 0 個の参照 | Takaaki Suzuki、40 日前 | 11 人の作成者、1 件の変更
26 public IReadOnlyList<Fruits> NetCore()
27     => Enum.GetValues(typeof(Fruits)) as Fruits[];
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29
30 [Benchmark]
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32 public IReadOnlyList<Fruits> EnumsNet()
33     => Enums.GetValues<Fruits>().ToArray();
34
35
36 [Benchmark]
37 0 個の参照 | Takaaki Suzuki、40 日前 | 11 人の作成者、1 件の変更1
38 public IReadOnlyList<Fruits> FastEnum()
39     => _FastEnum.GetValues<Fruits>();
```

```
GetValuesBenchmarks.cs
```

```
FastEnum.cs
```

```
BenchmarkConfig.cs
```

```
Program.cs
```

```
HasFruitBenchmark.cs
```

```
FastEnumUtility.Benchmark.Scenarios.GetValuesBenchmark
```

```
FastCore
```

```
Enums
```

```
GetValues<Fruits>()
```

```
_FastEnum.GetValues<Fruits>();
```

```
}
```

```
[Benchmark(Baseline = true)]
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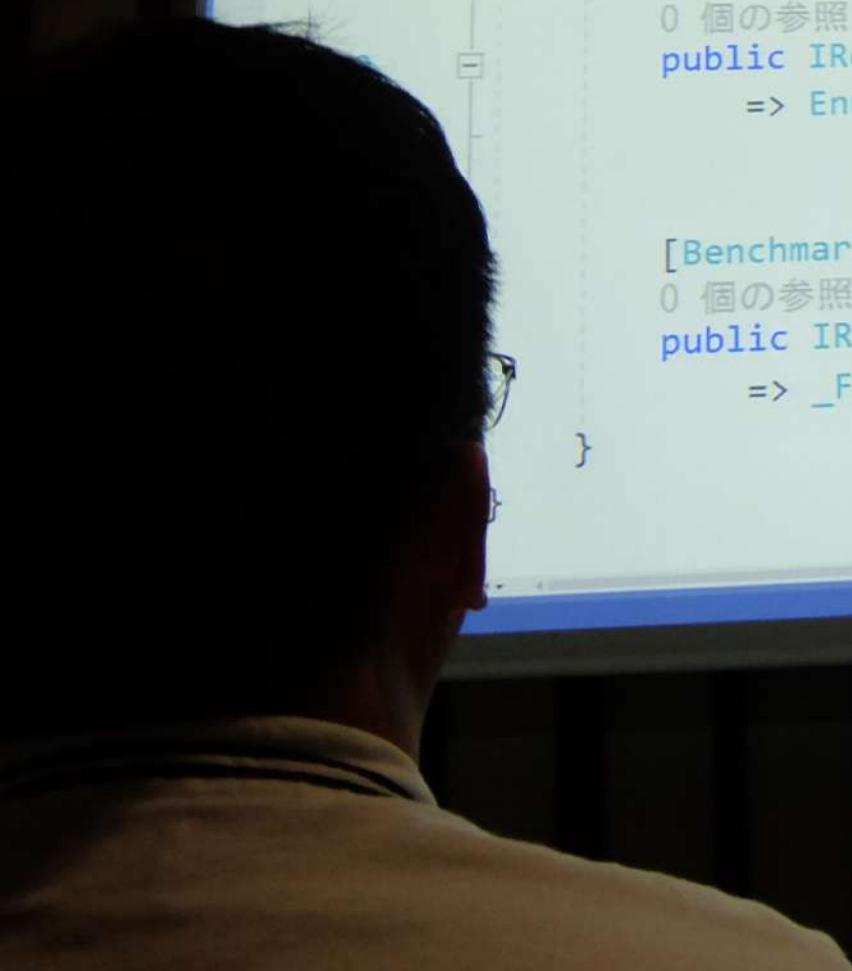
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```

```
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```

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    => _FastEnum.GetValues<Fruits>();  
}
```

せんでした

22日

9月

9文字

挿入

FastEnum

master

hortRun : .NET Core 3.0.0 (CoreCLR 4.700.19.46205, CoreFX 4.700.19.46214), 64bit
=ShortRun IterationCount=1 LaunchCount=1
mupCount=1

| Method | Mean | Error | Ratio | Gen 0 | Gen 1 | Gen 2 | Allocated |
|---------|---------------|-------|-------|--------|-------|-------|-----------|
| NetCore | 1,276.9216 ns | NA | 1.000 | 0.0839 | - | - | 352 B |
| numsNet | 443.2403 ns | NA | 0.347 | 0.0916 | - | - | 384 B |
| astEnum | 0.0000 ns | NA | 0.000 | - | - | - | - |

* Legends *

ean : Arithmetic mean of all measurements
rror : Half of 99.9% confidence interval
io : Mean of the ratio distribution ([Current]/[Baseline])
0 : GC Generation 0 collects per 1000 operations
1 : GC Generation 1 collects per 1000 operations
2 : GC Generation 2 collects per 1000 operations
ated : Allocated memory per single operation (managed only, inclusive, 1KB =
: 1 Nanosecond (0.000000001 sec)

agnostic Output - MemoryDiagnoser *

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* Diagnostic Output - MemoryDiagnoser *

```
        return enumType.GetEnumUnderlyingType();
    }

0 個の参照
public static Array GetValues(Type enumType)
{
    if (enumType == null)
        throw new ArgumentNullException(nameof(enumType));

    return enumType.GetEnumValues();
}

3 個の参照
public static bool IsDefined(Type enumType, object value)
{
    if (enumType == null)
        throw new ArgumentNullException(nameof(enumType));
```

```
19
20     return enumType.GetEnumUnderlyingType();
21 }
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27         throw new ArgumentNullException(nameof(enumType));
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29     return enumType.GetEnumValues();
30 }
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32 3 個の参照
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34 {
35     if (enumType == null)
36         throw new ArgumentNullException(nameof(enumType));
```

```
        return new ReadOnlySpan<string>(ret).ToArray();
    }

3 個の参照
public override Array GetEnumValues()
{
    if (!IsEnum)
        throw new ArgumentException(SR.Arg_MustBeEnum, "enum");

    // Get all of the values
    ulong[] values = Enum.InternalGetValues(this);

    // Create a generic Array
    Array ret = Array.CreateInstance(this, values.Length);
    for (int i = 0; i < values.Length; i++)
    {
        object val = Enum.ToObject(this, values[i]);
```

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        return new ReadOnlySpan<string>(ret).ToArray();
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    Array ret = Array.CreateInstance(this, values.Length);

    for (int i = 0; i < values.Length; i++)
    {
        object val = Enum.ToObject(this, values[i]);
```

```
    }

    return entry;
}

2 個の参照
internal static ulong[] InternalGetValues(RuntimeType enumType)
{
    // Get all of the values
    return GetEnumInfo(enumType, false).Values;
}

2 個の参照
internal static string[] InternalGetNames(RuntimeType enumType)
{
    // Get all of the names
    return GetEnumInfo(enumType, true).Names;
}
```

```
        values = values;
        Names = names;
    }
}

6 個の参照
private static EnumInfo GetEnumInfo(RuntimeType enumType, bool getNames)
{
    EnumInfo? entry = enumType.GenericCache as EnumInfo;
    if (entry == null || (getNames && entry.Names == null))
    {
        ulong[]? values = null;
        string[]? names = null;
        RuntimeTypeHandle enumTypeHandle = enumType.GetTypeHandle();
        GetEnumValuesAndNames(
            JitHelpers.GetQCallTypeHandleOnStack(ref enumTypeHandle),
            JitHelpers.GetObjectHandleOnStack(ref values),
            JitHelpers.GetObjectHandleOnStack(ref names));
    }
}
```

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            JitHelpers.GetObjectHandleOnStack(ref values),
            JitHelpers.GetObjectHandleOnStack(ref names));
    }
}
```

```
private class EnumInfo
{
    public readonly bool HasFlagsAttribute;
    public readonly ulong[] Values;
    public readonly string[] Names;

    // Each entry contains a list of sorted pair of enum file
}
```

1 個の参照

```
public EnumInfo(bool hasFlagsAttribute, ulong[] values, string[] names)
{
    HasFlagsAttribute = hasFlagsAttribute;
    Values = values;
    Names = names;
}
```

6 個の参照

9 個の参照

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6 個の参照

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59         GetEnumValuesAndNames(
60             JitHelpers.GetQCallTypeHandleOnStack(ref enumTypeHandle),
61             JitHelpers.GetObjectHandleOnStack(ref values),
62             JitHelpers.GetObjectHandleOnStack(ref names),
63             getNames ? Interop.BOOL.TRUE : Interop.BOOL.FALSE);
64         bool hasFlagsAttribute = enumType.IsDefined(typeof(Foo));
65
66         entry = new EnumInfo(hasFlagsAttribute, values!, names!);
67         enumType.GenericCache = entry;
68     }
69
70     return entry;
71 }
```

```
enumCoreCLR.cs 54 RuntimeTypeHandle
RuntimeTypeHandle enumTypeHandle = enumType.GetTypeHandle();
GetEnumValuesAndNames(
    JitHelpers.GetQCALLTYPEHandleOnStack(ref enumTypeHandle),
    JitHelpers.GetObjectHandleOnStack(ref values),
    JitHelpers.GetObjectHandleOnStack(ref names),
    getNames ? Interop.BOOL.TRUE : Interop.BOOL.FALSE);
bool hasFlagsAttribute = enumType.IsDefined(typeof(FooAttribute));
entry = new EnumInfo(hasFlagsAttribute, values!, names!);
enumType.GenericCache = entry;
}

return entry;
```

3 個の参照

```
116     public override Array GetEnumValues()
117     {
118         if (!IsEnum)
119             throw new ArgumentException(SR.Arg_MustBeEnum, "enum");
120
121         // Get all of the values
122         ulong[] values = Enum.InternalGetValues(this);

123         // Create a generic Array
124         Array ret = Array.CreateInstance(this, values.Length);

125         for (int i = 0; i < values.Length; i++)
126         {
127             object val = Enum.ToObject(this, values[i]);
128             ret.SetValue(val, i);
129         }
130     }
```

```
121 // Get all of the values
122 ulong[] values = Enum.InternalGetValues(this);
123
124 // Create a generic Array
125 Array ret = Array.CreateInstance(this, values.Length);
126
127 for (int i = 0; i < values.Length; i++)
128 {
129     object val = Enum.ToObject(this, values[i]);
130     ret.SetValue(val, i);
131 }
132
133 return ret;
134 }
```

25 個の参照

```
public override Type GetEnumUnderlyingType()
{
}
```

Why FastEnum is fast?

高速化のアプローチとちょっとした工夫

Static Type Caching

```
public static class FastEnum
{
    public static IReadOnlyList<T> GetValues<T>()
        where T : struct, Enum
        => Cache<T>.Values; // キャッシュを直接参照

    // 静的 Generics 型のフィールドにキャッシュを持つ
    private static class Cache<T>
        where T : struct, Enum
    {
        public static readonly T[] Values;
        static Cache()
            => Values = (T[])Enum.GetValues(typeof(T));
    }
}
```

Static Type Caching

```
public static class FastEnum
{
    public static IReadOnlyList<T> GetValues<T>()
        where T : struct, Enum
        => Cache<T>.Values; // キャッシュを直接参照

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        static Cache()
            => Values = (T[])Enum.GetValues(typeof(T));
    }
}
```

T型ごとに
別の型扱い

Static Type Caching

呼び出しコスト ≈ 0

型をキーにした辞書から Lookup するよりもずっと速い
BenchmarkDotNet が「計測できない」と音を上げるレベル

静的コンストラクタで事前計算

静的コンストラクタはスレッドセーフが保証されている
ロックフリーにできるので、呼び出しコスト低減に大きく寄与

Generics API のみをサポート

Non Generics API は box 化を避けられない

Generics API だけでも大抵のケースに耐えられる

```
// .NET Core (Box 化する)
```

```
var a = Enum.GetValues(typeof(Fruits));
var b = Enum.GetName(typeof(Fruits), Fruits.Banana);
var c = (Fruits)Enum.Parse(typeof(Fruits), "Apple");
var d = Enum.IsDefined(typeof(Fruits), Fruits.Lemon);
```

```
// FastEnum (一切 Box 化しない)

var a = FastEnum.GetValues<Fruits>();
var b = FastEnum.GetName(Fruits.Banana);
var c = FastEnum.Parse<Fruits>("Apple");
var d = FastEnum.IsDefined(Fruits.Lemon);
```

カンマ区切り文字列は非サポート

[Flags] な列挙型を Parse する機能

カンマが入っているかどうかを算出するコストが大きい

滅多に使わない機能を落として大多数を救う方が理に適っている

```
// こんな定義があるとき  
  
[Flags]  
enum Fruits  
{  
    Apple = 1,  
    Lemon = 2,  
    Melon = 4,  
}
```

```
// System.Enum はカンマ区切り文字を Parse できる  
  
var value = Enum.Parse<Fruits>("Apple, Melon");  
Console.WriteLine((int)value); // 5
```

IsDefined<T>(value); の最適化

列挙型の値の連続性を利用

値が連続しているなら最大/最小範囲に入っているかを比較

辞書の ContainsKey をするより範囲チェックの方が何倍も高速

```
// 連続した値の列挙型

enum Fruits
{
    Apple = 1,
    Lemon, // 2
    Melon, // 3
    Banana, // 4
}
```

```
// こんな感じのイメージで判定すると速い
// 連続しているかどうかは事前に判定してキャッシュ

public static bool IsDefined<T>(T value)
    where T : struct, Enum
    => IsContinuous
        ? MinValue <= value && value <= MaxValue
        : Values.ContainsKey(value);
```

Parse<T>("value/name"); の最適化

"123", "Apple" をどう判別/解析するか

「1文字目が数字か +/-」の場合は値で解析する

```
public static bool TryParse<T>(string value, out T result)
    where T : struct, Enum
{
    // フィールド名は数字/特殊記号で始められない仕様を利用
    return IsNumeric(value[0])
        ? TryParseByValue(value, out result)
        : TryParseByName(value, out result);

    static bool IsNumeric(char c)
        => char.IsDigit(c) || c == '-' || c == '+';
}
```

大小無視の文字列比較

string.Equals(OrdinalIgnoreCase) が最速
StringComparison.InvariantCultureIgnoreCase より 4 倍速い

```
Microsoft Visual Studio のデバッグコンソール

// * Summary *

BenchmarkDotNet=v0.11.5, OS=Windows 10.0.18382
Intel Core i7-8565U CPU 1.80GHz (Whiskey Lake), 1 CPU, 8 logical and 4 physical cores
.NET Core SDK=3.0.100
[Host] : .NET Core 3.0.0 (CoreCLR 4.700.19.46205, CoreFX 4.700.19.46214), 64bit RyuJIT
ShortRun : .NET Core 3.0.0 (CoreCLR 4.700.19.46205, CoreFX 4.700.19.46214), 64bit RyuJIT

Job=ShortRun IterationCount=3 LaunchCount=1
#WarmupCount=3

    Method | Mean | Error | StdDev | Ratio | RatioSD | Gen 0 | Gen 1 | Gen 2 | Allocated |
-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
String_OrdinalIgnoreCase | 22.09 ns | 27.4044 ns | 1.5021 ns | 1.00 | 0.00 | - | - | - | -
Span_OrdinalIgnoreCase | 25.35 ns | 0.5400 ns | 0.0296 ns | 1.15 | 0.08 | - | - | - | -
String_InvariantCultureIgnoreCase | 93.60 ns | 118.9444 ns | 6.5197 ns | 4.24 | 0.06 | - | - | - | -
Span_InvariantCultureIgnoreCase | 108.26 ns | 111.6337 ns | 0.6377 ns | 4.92 | 0.35 | - | - | - | -
```

温もりティ溢れる手作り辞書

キーの特殊化で EqualityComparer を廃止

GetHashCode(); と Equals(); を直呼び出しにするハック

<http://engineering.grani.jp/entry/2017/07/28/145035>

```
// 正味たった 2 行だけの違い
// 最終的にこの差がベンチマークに効いてくる

var hash = EqualityComparer<int>.Default.GetHashCode(key);
var hash = key.GetHashCode(); // faster

if (EqualityComparer< TKey >.Default.Equals(next.Key, key))
if (next.Key == key) // faster
```

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if (EqualityComparer< TKey >.Default.Equals(next.Key, key))
if (next.Key == key) // faster
```

列挙型を等値/大小で比較する

```
// 具象型の場合はできるけれど...
public static void Compare(Fruits left, Fruits right)
{
    var a = left == right; // OK
    var b = left <= right; // OK
}
```

```
// Enum 制約を置いても Generics 型だとできない！
public static void Compare<T>(T left, T right)
    where T : struct, Enum
{
    var a = left == right; // コンパイルエラー
    var b = left <= right; // コンパイルエラー
    var c = EqualityComparer<T>.Default.Equals(left, right); // OK
}
```

列挙型を等値/大小で比較する

```
// 具象型の場合はできるけれど...
public static void Compare(Fruits left, Fruits right)
{
    var a = left == right; // OK
    var b = left <= right; // OK
}
```

なんとか
解決したい

```
// Enum 制約を置いても Generics 型だとできない!
public static void Compare<T>(T left, T right)
    where T : struct, Enum

    var a = left == right; // コンパイルエラー
    var b = left <= right; // コンパイルエラー
    var c = EqualityComparer<T>.Default.Equals(left, right); // OK
```



Unsafe.As を使った強制型変換

System.Runtime.CompilerServices.Unsafe

unsafe オプションを使わずに unsafe なことをする悪い子 😠

```
public static void Compare<T>(T left, T right)
    where T : struct, Enum
{
    // ref を使った型変換 = 同一メモリ領域を別の型として参照
    ref var l = ref Unsafe.As<T, int>(ref left);
    ref var r = ref Unsafe.As<T, int>(ref right);

    var a = l == r;    // OK
    var b = l <= r;   // OK
}
```

Unsafe.As のちょっとズルい使い方

UnderlyingType の TryParse に委譲

同一メモリ領域を参照した強制型変換なので、できちゃう 😊

```
internal sealed class Int32Operation<T> : IUnderlyingOperation<T>
    where T : struct, Enum
{
    public bool TryParse(string text, out T result)
    {
        // x に書き込めば result にも書き込まれることになる
        result = default;
        ref var x = ref Unsafe.As<T, int>(ref result);
        return int.TryParse(text, out x);
    }
}
```

Enum.HasFlag の脅威的性能

FastEnum が唯一勝てなかったメソッド

引数が `Enum` なので呼び出すだけで box 化して超遅そうだが...
自作したものより 200 倍以上高速でアロケーションもない

```
// 特殊な最適化がかかってる（たぶん  
[Intrinsic]  
public bool HasFlag(Enum flag)  
{}
```

| Method | Mean | Error | StdDev | Median | Ratio | RatioSD | Gen 0 | Gen 1 | Gen 2 | Allocated |
|----------|-----------|-----------|-----------|-----------|-------|---------|-------|-------|-------|-----------|
| NetCore | 0.0125 ns | 0.3945 ns | 0.0216 ns | 0.0000 ns | ? | ? | : | : | : | : |
| FastEnum | 2.2857 ns | 3.0054 ns | 0.1647 ns | 2.3766 ns | ? | ? | : | : | : | : |

Enum.HasFlag の脅威的性能

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```
// 特殊な最適化がかかってる (たぶん
```

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[Intrinsic]  
public bool HasFlag(Enum flag)  
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| Method | Mean | Error | StdDev | Median | Ratio | RatioSD | Gen 0 | Gen 1 | Gen 2 | Allocated |
|----------|-----------|-----------|-----------|-----------|-------|---------|-------|-------|-------|-----------|
| NetCore | 0.0125 ns | 0.3945 ns | 0.0216 ns | 0.0000 ns | ? | ? | - | - | - | - |
| FastEnum | 2.2857 ns | 3.0054 ns | 0.1647 ns | 2.3766 ns | ? | ? | - | - | - | - |

```
void Main()
{
    var a = Fruits.Banana | Fruits.Peach;
    var b = a.HasFlag(Fruits.Banana);
}

public enum Fruits
{
    Apple = 1,
    Banana = 2,
    Lemon = 4,
    Peach = 8,
    Grape = 16,
    ...
}
```



```
1 void Main()
2 {
3     var a = Fruits.Banana | Fruits.Peach;
4     var b = a.HasFlag(Fruits.Banana);
5 }
6
7 public enum Fruits
8 {
9     Apple = 1,
10    Banana = 2,
11    Lemon = 4,
12    Peach = 8,
13    Grape = 16,
14 }
```

▼ Results SQL IL Tree

```
8    {
9        Apple = 1,
10       Banana = 2,
11       Lemon = 4,
12       Peach = 8,
13       Grape = 16,
...
```

▼ Results λ SQL IL Tree

| | | |
|----------|----------|---------------------|
| IL_0000: | ldc.i4.s | 0A |
| IL_0002: | stloc.0 | |
| IL_0003: | ldloc.0 | |
| IL_0004: | box | UserQuery.Fruits |
| IL_0009: | ldc.i4.2 | |
| IL_000A: | box | UserQuery.Fruits |
| IL_000F: | call | System.Enum.HasFlag |
| IL_0014: | pop | |
| IL_0015: | ret | |

```
8     {
9         Apple = 1,
10        Banana = 2,
11        Lemon = 4,
12        Peach = 8,
13        Grape = 16,
14    }
```

▼ Results λ SQL IL Tree

| | | |
|----------|----------|---------------------|
| IL_0000: | ldc.i4.s | 0A |
| IL_0002: | stloc.0 | |
| IL_0003: | ldloc.0 | |
| IL_0004: | box | UserQuery.Fruits |
| IL_0009: | ldc.i4.2 | |
| IL_000A: | box | UserQuery.Fruits |
| IL_000F: | call | System.Enum.HasFlag |
| IL_0014: | pop | |
| IL_0015: | ret | |

ReadOnlyArray

ReadOnlyCollection は foreach が超遅い

Struct Enumerator を利用した配列の読み取り専用 wrapper で解決

<https://ufcpp.net/blog/2018/12/howtoenumerate/>

```
public sealed class ReadOnlyArray<T> : IReadOnlyList<T>
{
    private readonly T[] source;
    public ReadOnlyArray(T[] source) => this.source = source;

    public Enumerator GetEnumerator() => new Enumerator(this.source);
    public struct Enumerator : IEnumerator<T> { /* 省略 */ }
    // 以下略...
}
```

ReadOnlyArray

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    public struct Enumerator : IEnumerator<T> { /* 省略 */ }
    // 以下略...
}
```