INTEL® HARDWARE INTRINSICS IN .NET CORE

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What Do These Have in Common?

Domain	Example
Image processing	Color extraction
High performance computing (HPC)	Matrix multiplication
Data processing	Hamming code
Text processing	UTF-8 conversion
Data structures	Bit array
Machine learning	Classification

For performance sensitive code, consider using Intel® hardware intrinsics

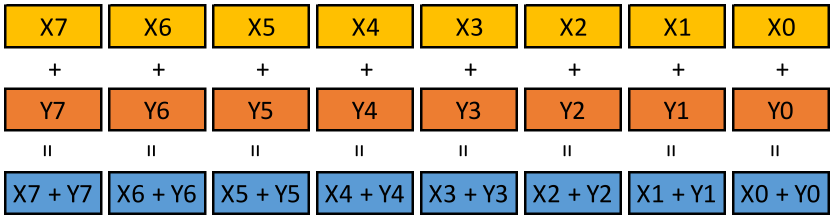
Objectives

- (Very brief) Intro to SIMD
- Design Motivation
- Hardware Intrinsics
- Call to Action

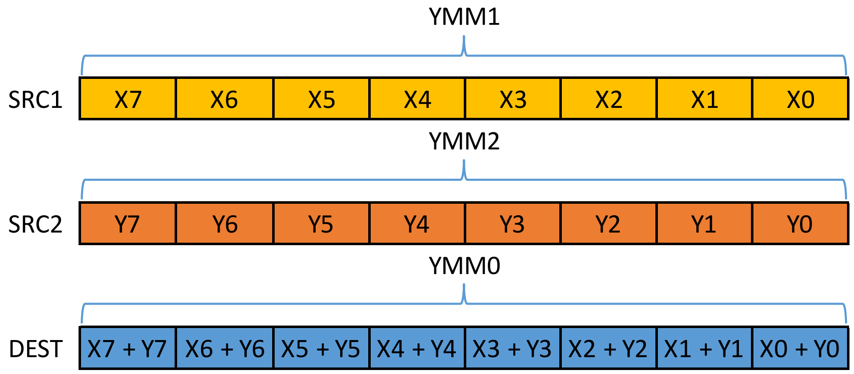
Single Instruction, Multiple Data (SIMD)

Perform same operation on multiple data using a single instruction

- Intel Advanced Vector Extensions 2 (Intel® AVX2) supports 256-bit SIMD instructions
  - Add eight 32-bit integers using one *vpaddd* instruction



8x ADD R32, R32



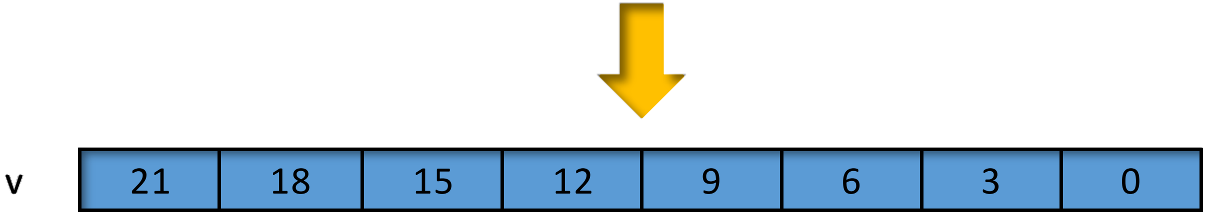
`VPADDD YMM0, YMM1, YMM2`

Single Instruction, Multiple Data (SIMD)

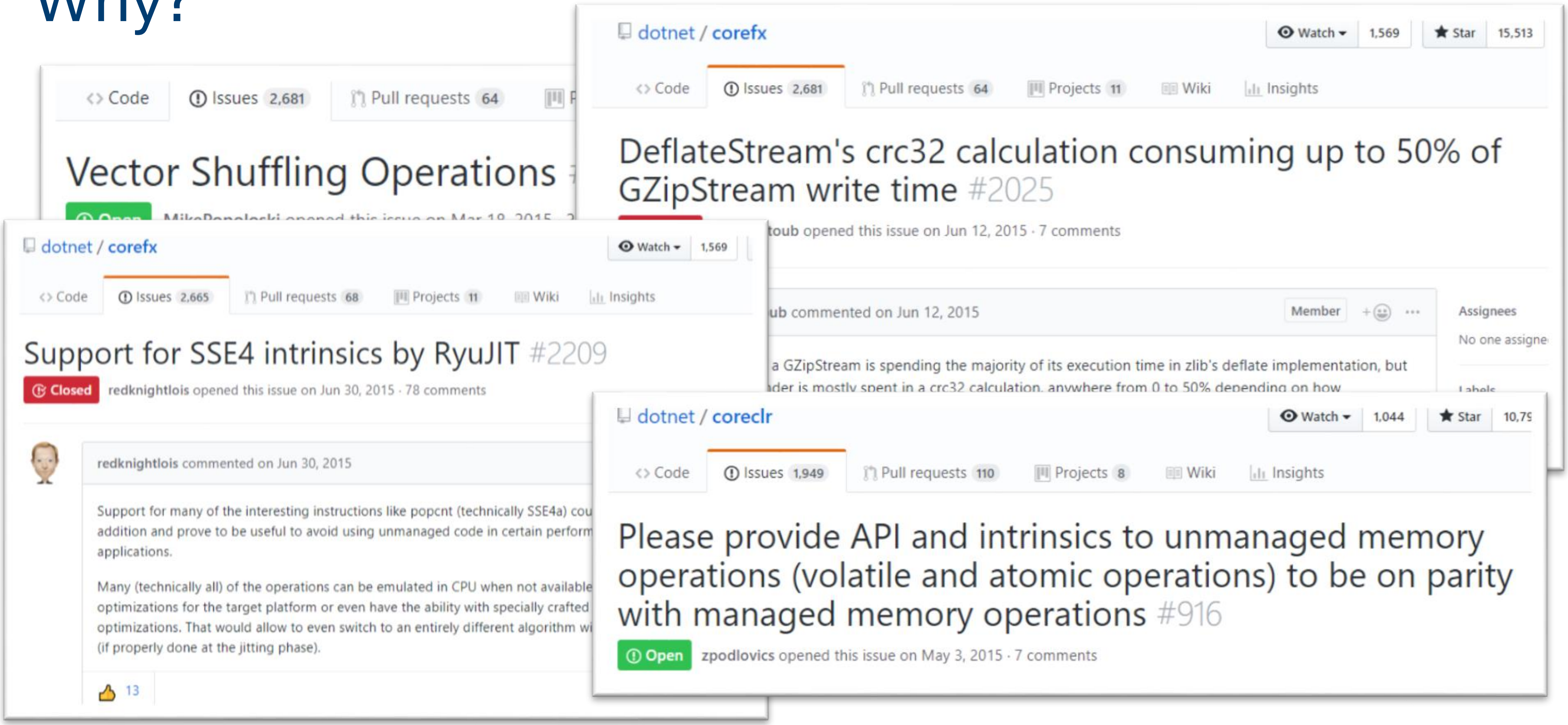
C# abstraction is System.Numerics.Vector*

- *System.Numerics.Vector<T>*
  - On Intel AVX2 system, *Vector<int>.Count* is 8
  - On Intel Streaming SIMD Extensions 2 (Intel SSE2) system, *Vector<int>.Count is 4*

```
Vector<int> v = New Vector<int>(0, 1, 2, 3, 4, 5, 6, 7)
              + New Vector<int>(0, 2, 4, 6, 8, 10, 12, 14)
```



Why?



*https://github.com/dotnet/corefx/issues/1168, https://github.com/dotnet/corefx/issues/2209, https://github.com/dotnet/corefx/issues/2025, https://github.com/dotnet/coreclr/issues/916

Hardware Intrinsics (a.k.a. Intrinsic functions / Platform Dependent Intrinsics)

Special functions that directly map to hardware instructions

- Useful when
  - Algorithms can better be mapped to underlying hardware
  - Maximum control over code generation is desired
- Mainstream C/C++ compilers have intrinsic functions
  - Field tested and proven to be useful
  - Provides design guidelines
- Both SIMD and non-SIMD

Intel Hardware Intrinsics

- APIs originally designed and proposed by Intel
- Major enhancements with the help of .NET Core community and Microsoft
- Implementation by Intel, Microsoft and .NET Core community
- Namespace *System.Runtime.Intrinsics* contains platform-agnostic types & functions
  - E.g., *Vector256<int>, Vector256<int>.GetLower()*
- New namespace System.Runtime.Intrinsics.X86 contains 15 top-level classes corresponding to different Instruction Set Architectures (ISAs)
  - *AES, AVX, AVX2, BMI1, BMI2, FMA, LZCNT, PCLMULQDQ, POPCNT, SSE, SSE2, SSE3, SSE4.1, SSE4.2, and SSSE3*
- Available as an experimental features since .NET Core 2.1
- Available in .NET Core 3.0 Preview

Intel Hardware Intrinsics Design

- ISA class contains *IsSupported* boolean property to check hardware support
- ISA class contains intrinsic methods corresponding to underlying instructions
- Methods closely mirror C/C++ intrinsic function

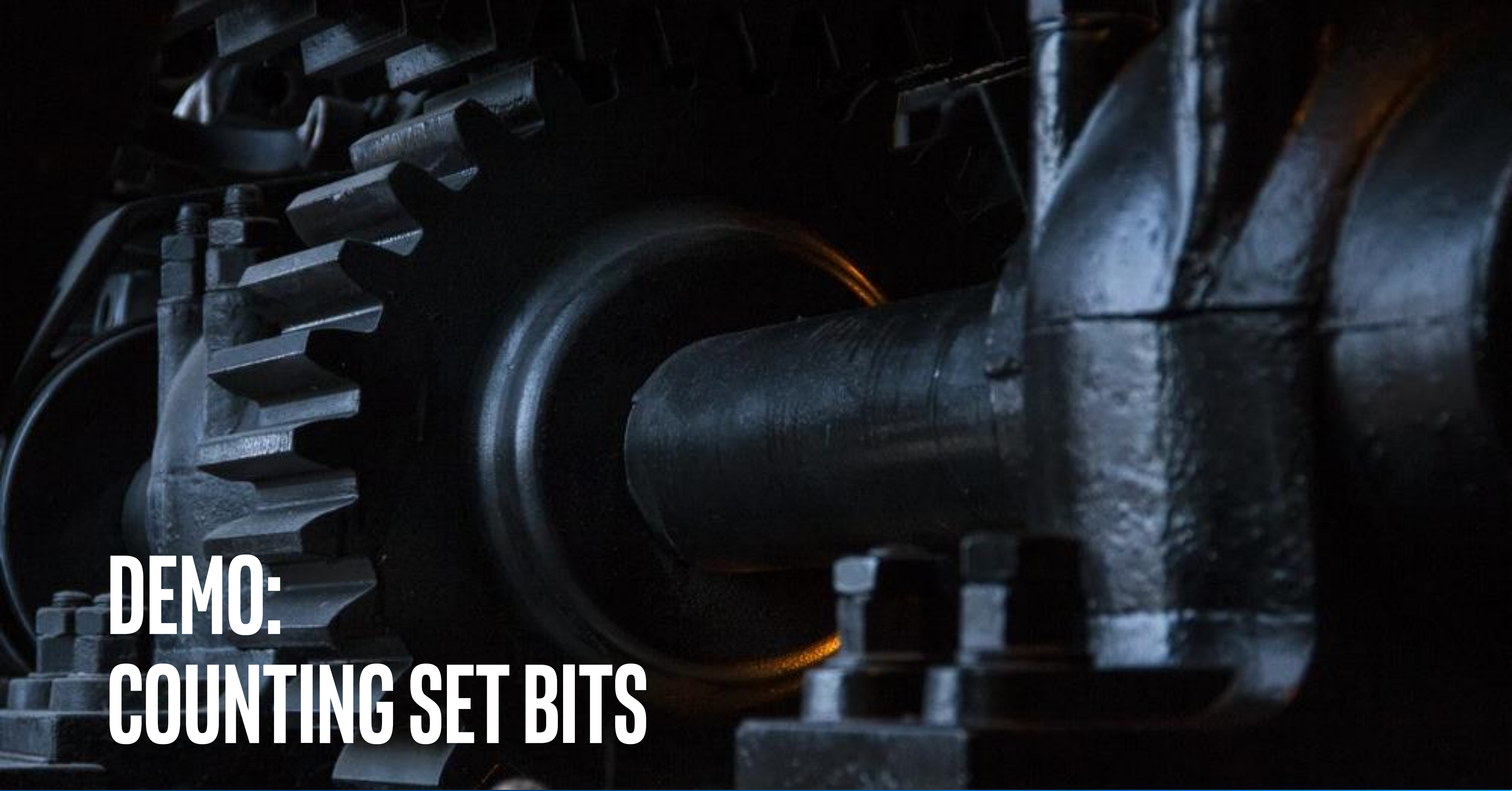
```
/// <summary>
/// int _mm_popcnt_u32 (unsigned int a)
///   POPCNT reg, reg/m32
/// </summary>
public static uint PopCount(uint value);
```

- Majority of Intel hardware intrinsics operate over *Vector128/256<T>*

```
public static Vector256<int> Add(Vector256<int> left, Vector256<int> right)
```

- Unsafe methods for operating over pointers

```
public static unsafe Vector256<sbyte> LoadVector256(sbyte* address)
```



DEMO: COUNTING SET BITS

Using Intel Hardware Intrinsics in .NET Core

```
using System.Runtime.Intrinsics.X86;
using System.Runtime.Intrinsics;

static int[] Func(int[] data)
{
    if (Avx2.IsSupported)
    {
        // AVX2 implementation
    }
    else if (Sse.IsSupported)
    {
        // SSE implementation
    }
    else
    {
        // Software scalar implementation
    }
}
```

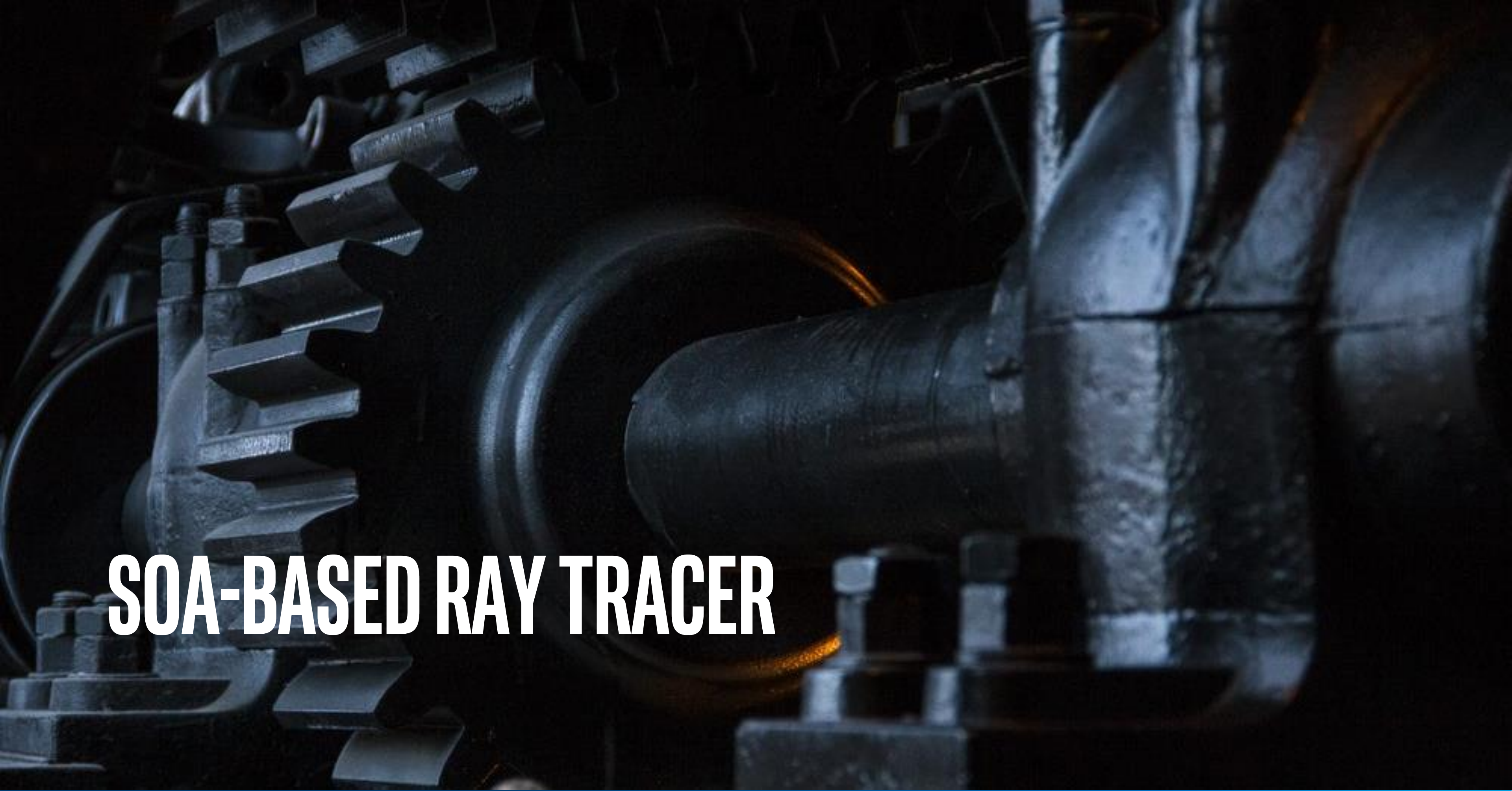
Import the namespace to use Intel HW intrinsic

Import the namespace to use Vector128/256<T> as needed

Check hardware ISA support before using any HW intrinsic

The checks will be optimized away by the Just-In-Time compiler

NOTE: Calling HW intrinsic on unsupported hardware will result in *System.PlatformNotSupportedException*



SOA-BASED RAY TRACER

How to Vectorize a Ray-tracer?

Ray-tracer based on 3D vector computation

- Most of the underlying structures can be abstracted to 3D vectors
  - Position/direction (x, y, z) in 3D space, color (R, G, B)

Vectorize the underlying 3D vector computation

- AoS (Array of Structure)
- SoA (Structure of Array)

AoS vectorization

Example: Add 3D vectors of float on AVX-capable machine

Scalar

x_1	y_1	z_1	+	x_2	y_2	z_2

$$x = x_1 + x_2$$
$$y = y_1 + y_2$$
$$z = z_1 + z_2$$

AoS

x_1	y_1	z_1	-	+	x_2	y_2	z_2	-

XMM1 XMM2

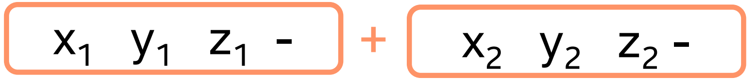
vaddps xmm, xmm1, xmm2

Cannot leverage wider SIMD architecture!

SoA vectorization

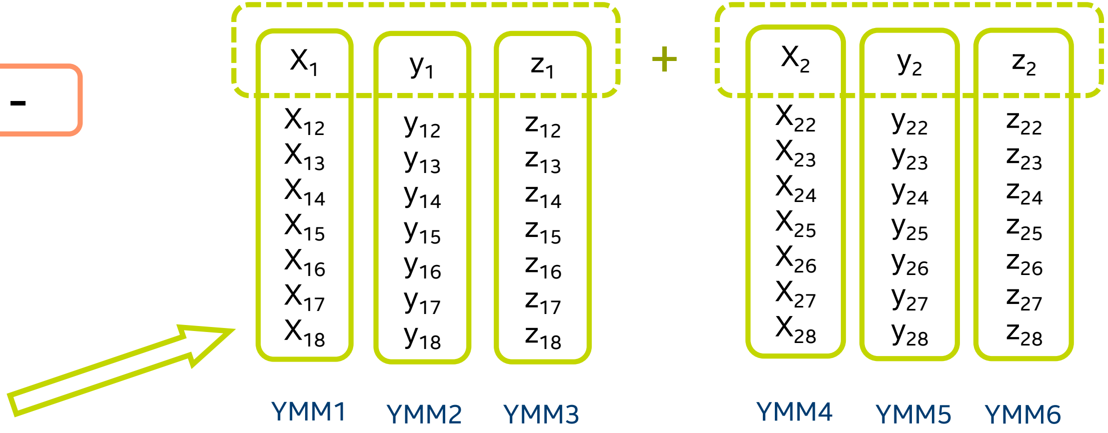
Example: Add 3D vectors of float on AVX-capable machine

AoS



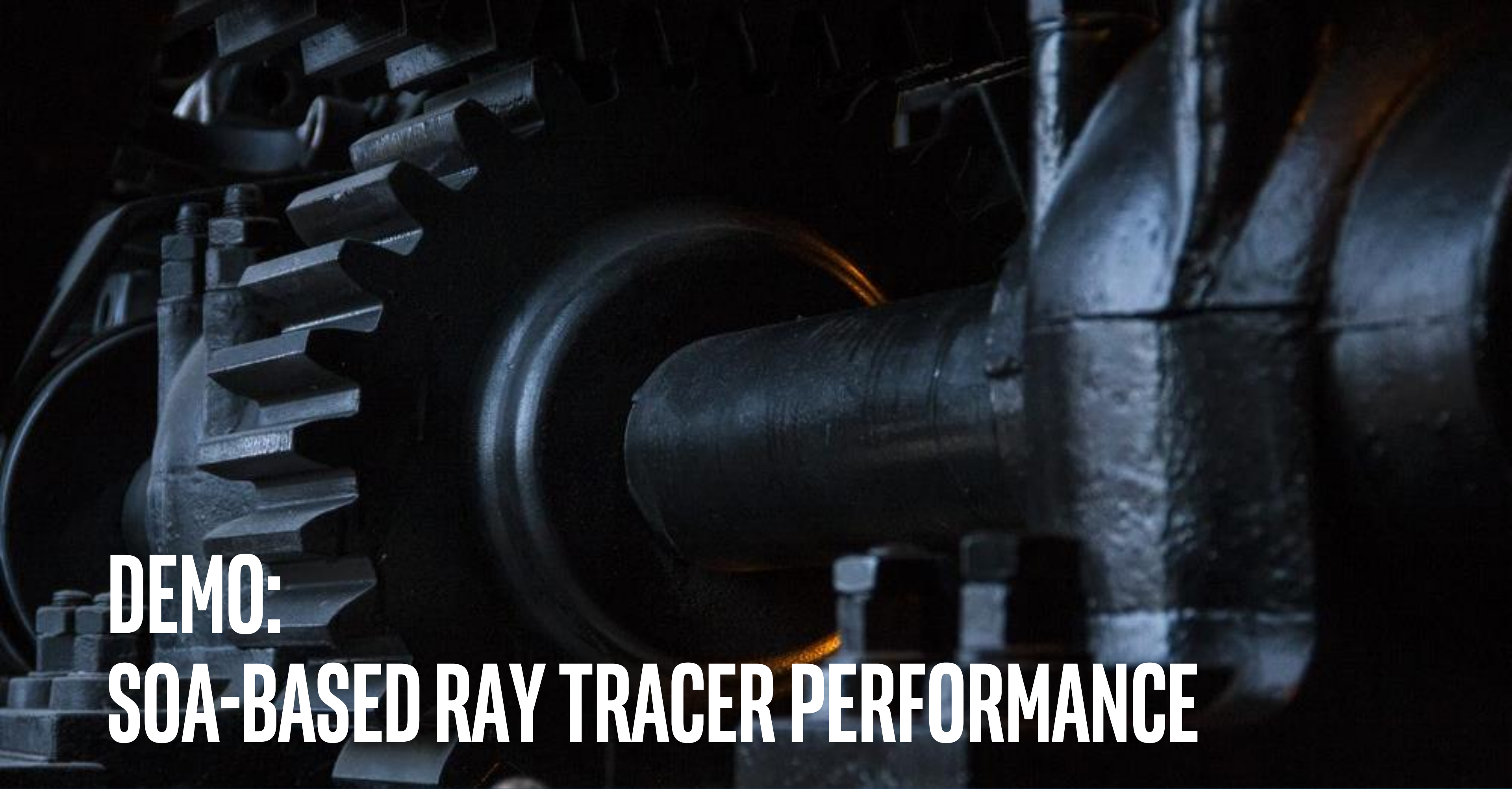
vaddps xmm, xmm1, xmm2

SoA




```
class VectorPacket256
{
    public Vector256<float> Xs;
    public Vector256<float> Ys;
    public Vector256<float> Zs;
}
```

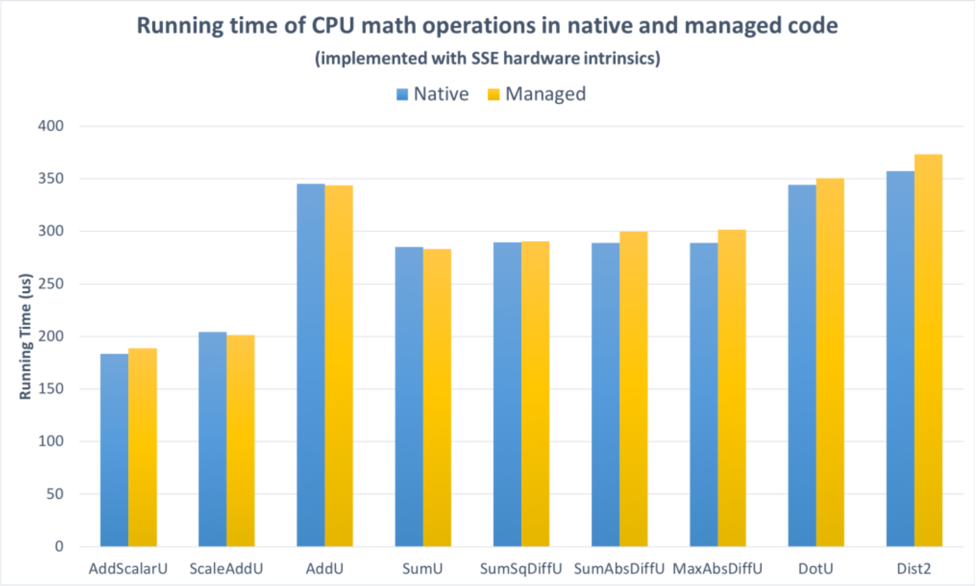
vaddps ymm, ymm1, ymm4
vaddps ymm, ymm2, ymm5
vaddps ymm, ymm3, ymm6



DEMO:
SOA-BASED RAY TRACER PERFORMANCE

Intel Hardware Intrinsics in Use

- CPU math operations in ML.NET
- SoA implementation of C# Raytracer
- Bit operations
- Matrix4x4 operations
- BLAKE2 hashing
- Your application!



*The figure shown above is from Microsoft blog on ML.NET

TURBOCHARGE YOUR APPLICATIONS WITH INTEL® HARDWARE INTRINSICS IN .NET CORE 3.0

Accelerate Your Applications

- Understand your bottlenecks
  - Intel VTune™ Amplifier is a great tool for profiling .NET Core application
- Use existing wealth of knowledge available on hardware intrinsics
  - Intel Intrinsics Guide: https://software.intel.com/sites/landingpage/IntrinsicsGuide/
  - How-to guides: https://software.intel.com/en-us/articles/how-to-use-intrinsics
- Explore existing solutions in C/C++
  - E.g., "Fast conversion from UTF-8 with C++, DFAs, and SSE intrinsics" (https://github.com/BobSteagall/CppCon2018)
- Optimize your application & re-measure
- Contribute to .NET Core and hardware intrinsics

BACKUP

Intrinsic Programming Tips

- Developers are responsible for checking hardware support
  - Different from higher-level SIMD APIs where software fallback is provided
- Test your application with different ISA levels
  - Use environment variables: e.g., COMPlus_EnableAVX
- Instruction encoding issues are handled automatically
  - No need to worry about AVX/SSE transitions
  - Best encoding by the JIT
- Use *using static* for concise syntax

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