#WWDC18

Using Accelerate and simd

Session 701

Matthew Badin, CoreOS, Vector and Numerics
Luke Chang, CoreOS, Vector and Numerics

Accelerate

vDSP

simd

vImage

What Is Accelerate Framework?

Functionality

Performance

Energy Efficiency

Composition of Accelerate Framework

vDSP—Signal processing

vImage—Image processing

vForce—Vector transcendental functions

BLAS, LAPACK, LinearAlgebra—Dense matrix computations

Sparse BLAS, Sparse Solvers—Sparse matrix computations

BNNS—Neural networks

Closely Related

simd—Small vector and matrix computation for CPU

Compression—Lossless data compression

vDSP

Signal Processing Library

Basic operations on arrays

- Add, subtract, multiply, conversion, etc.

Discrete Fourier/Cosine Transform

- 1D DFT/DCT/FFT
- 2D FFT

Convolution and correlation

Demo

Extract signal from noise

Essential Computations

Analyze noisy signal with forward DCT

Remove frequency components of amplitude less than threshold

Reconstruct clean signal with inverse DCT

```swift
// Create a Forward DCT Setup Object for vDSP_DCT_Execute
let dctSetup_FORWARD: vDSP_DFT_Setup = {
    guard let dctSetup = vDSP_DCT_CreateSetup(
        nil, vDSP_Length(numSamples), .II) else {
            fatalError("can't create FORWARD vDSP_DFT_Setup")
    }
    return dctSetup
}()
```

```swift
// Perform Forward DCT
var forwardDCT = [Float](repeating: 0,
                         count: numSamples)
vDSP_DCT_Execute(dctSetup_FORWARD, noisySignalReal, &forwardDCT)
```

```
// All Values in `forwardDCT` Less Than `threshold` To 0
vDSP_vthres(forwardDCT, stride, &threshold, &forwardDCT, stride, count)
```

```swift
// Create an Inverse DCT Setup Object for vDSP_DCT_Execute
let dctSetup_INVERSE: vDSP_DFT_Setup = {
    guard let dctSetup = vDSP_DCT_CreateSetup(
        nil, vDSP_Length(numSamples), .III) else {
            fatalError("can't create INVERSE vDSP_DFT_Setup")
    }
    return dctSetup
}()
```

```swift
// Reconstruct Clean Signal
vDSP_DCT_Execute(dctSetup_INVERSE, forwardDCT, &inverseDCT)

// Apply Normalization Factor
var divisor = Float(count)
vDSP_vsdiv(inverseDCT, stride, &divisor, &inverseDCT, stride, count)
```

Demo

Halftone de-screening

Essential Computations

Transform halftone image with 2D FFT

Remove frequency components of the halftone screen

Reconstruct continuous tone image

```swift
// Create a FFT Setup Object, No Direction Specified
let fftSetUp: FFTSetup = {
    let log2n = vDSP_Length(log2(1024.0 * 1024.0))
    guard let fftSetUp = vDSP_create_fftsetup(log2n, FFTRadix(kFFTRadix2)) else {
        fatalError("can't create FFT Setup")
    }
    return fftSetUp
} ()
```

```
// Perform 2d FFT
let sourceImage_floatPixels_frequency = DSPSplitComplex(
    realp: &sourceImage_floatPixelsReal_spatial,
    imagp: &sourceImage_floatPixelsImag_frequency)
vDSP_fft2d_zrop(fftSetUp, &sourceImageSplitComplex, vDSP_Stride(1), vDSP_Stride(0),
                &sourceImage_floatPixels_frequency, vDSP_Stride(1), vDSP_Stride(0),
                vDSP_Length(log2(Float(width))),
                vDSP_Length(log2(Float(height))),
                FFTDirection(kFFTDirection_Forward))
```

Frequency Removal

zvmags

vthrsc

vclip

zrvmul

```swift
// Perform Inverse FFT to Create Image from Frequency Domain Data
var floatPixels_spatial = DSPSplitComplex(realp: &floatPixelsReal_spatial,
                                          imagp: &floatPixelsImag_spatial)
vDSP_fft2d_zrop(fftSetUp, &sourceImage_floatPixels_frequency,
                stride, 0,
                &floatPixels_spatial,
                stride, 0,
                vDSP_Length(log2(Float(width))),
                vDSP_Length(log2(Float(height))),
                FFTDirection(kFFTDirection_Inverse))
```

The simd Module

The simd Module

Simplified vector programming

Small (fixed-size) vector and matrices

Abstract architecture-specific types and instrinsics

```swift
// Average Two Vectors
var x:[Float] = [1,2,3,4]
var y:[Float] = [3,3,3,3]
var z:[Float](repeating:0, count:4)

for i in 0..<4 {
  z[i] = (x[i] + y[i]) / 2.0
}
```

```swift
// Average Two Vectors
let x = simd_float4(1,2,3,4)
let y = simd_float4(3,3,3,3)

let z = 0.5 * (x + y)
```

simd

Matrices of size 2, 3, or 4 and vectors of 2, 3, 4, 8, 16, 32, or 64

Arithmetic operators (+,-,*,/) work with both vectors and scalars

Supports common vector math and geometry operations (dot, length, clamp)

Support for transcendental functions

Quaternions

simd

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Supports common vector math and geometry operations (dot, length, clamp)

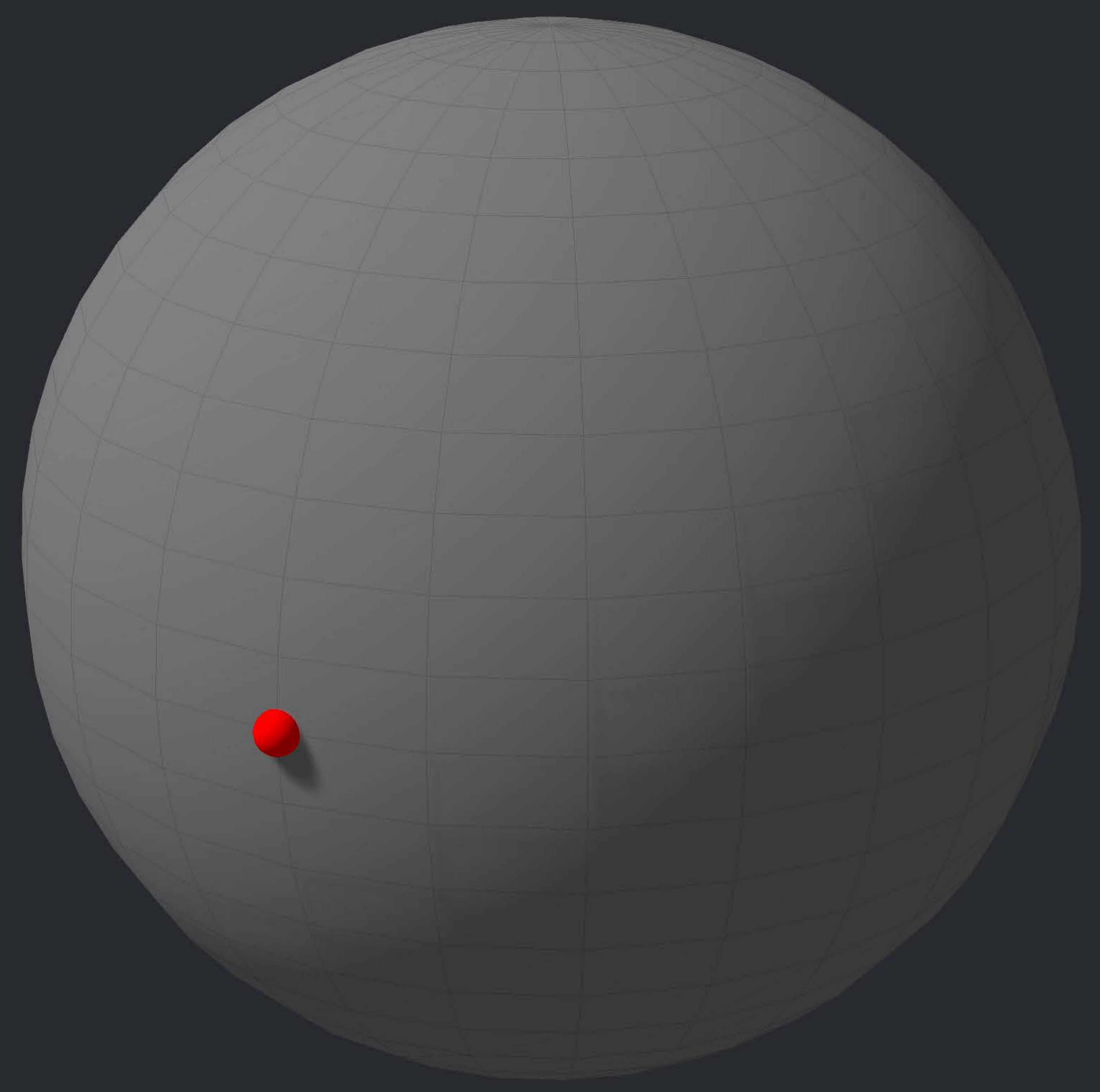
Support for transcendental functions

Quaternions

```swift
// Vector to Rotate
let original = simd_float3(0,0,1)

// Axis of Rotation
let quaternion = simd_quatf(angle: .pi / -3,
                            axis: simd_float3(1,0,0))

// Apply the Rotation
let rotatedVector = simd_act(quaternion, original)
```



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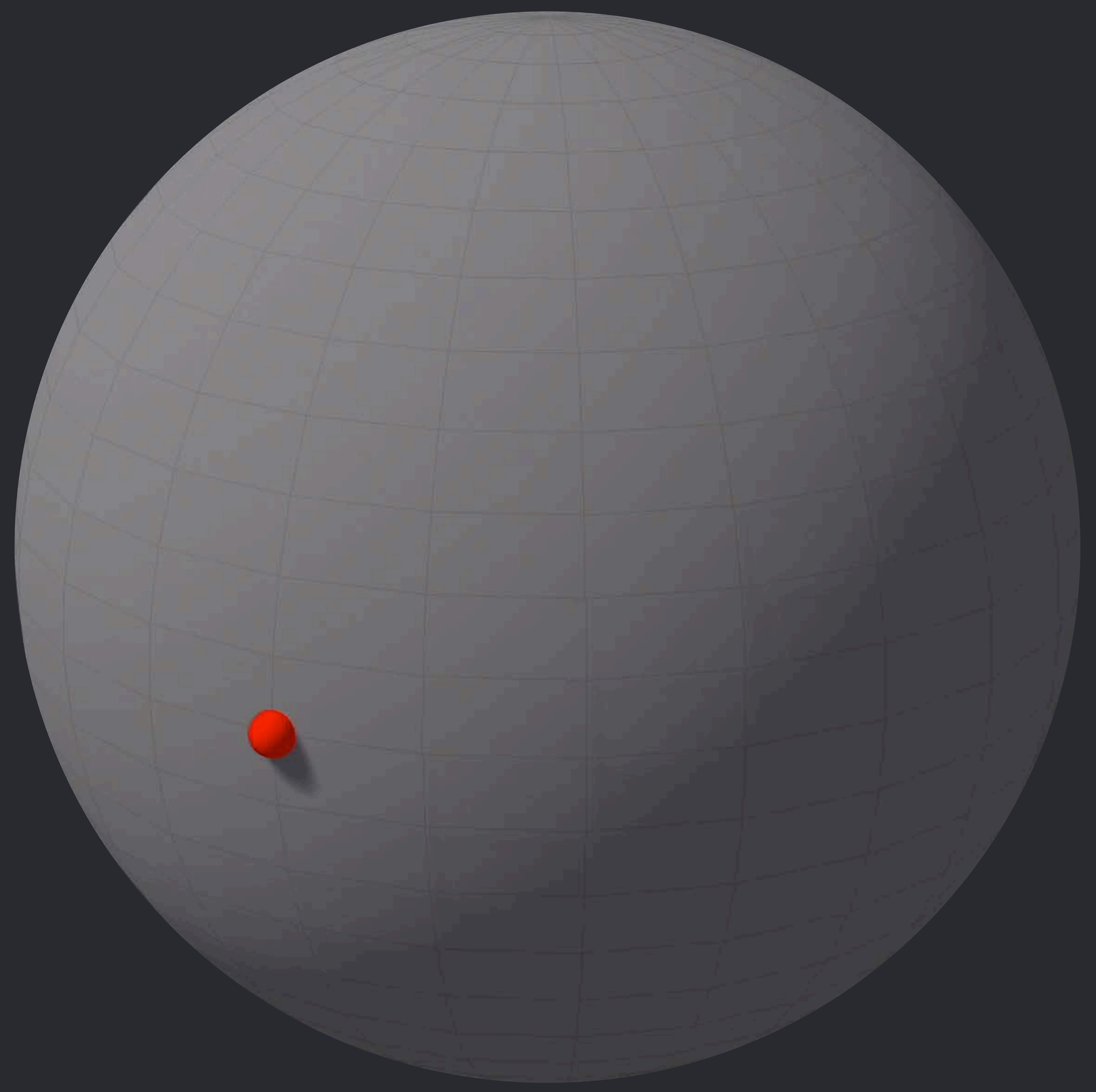

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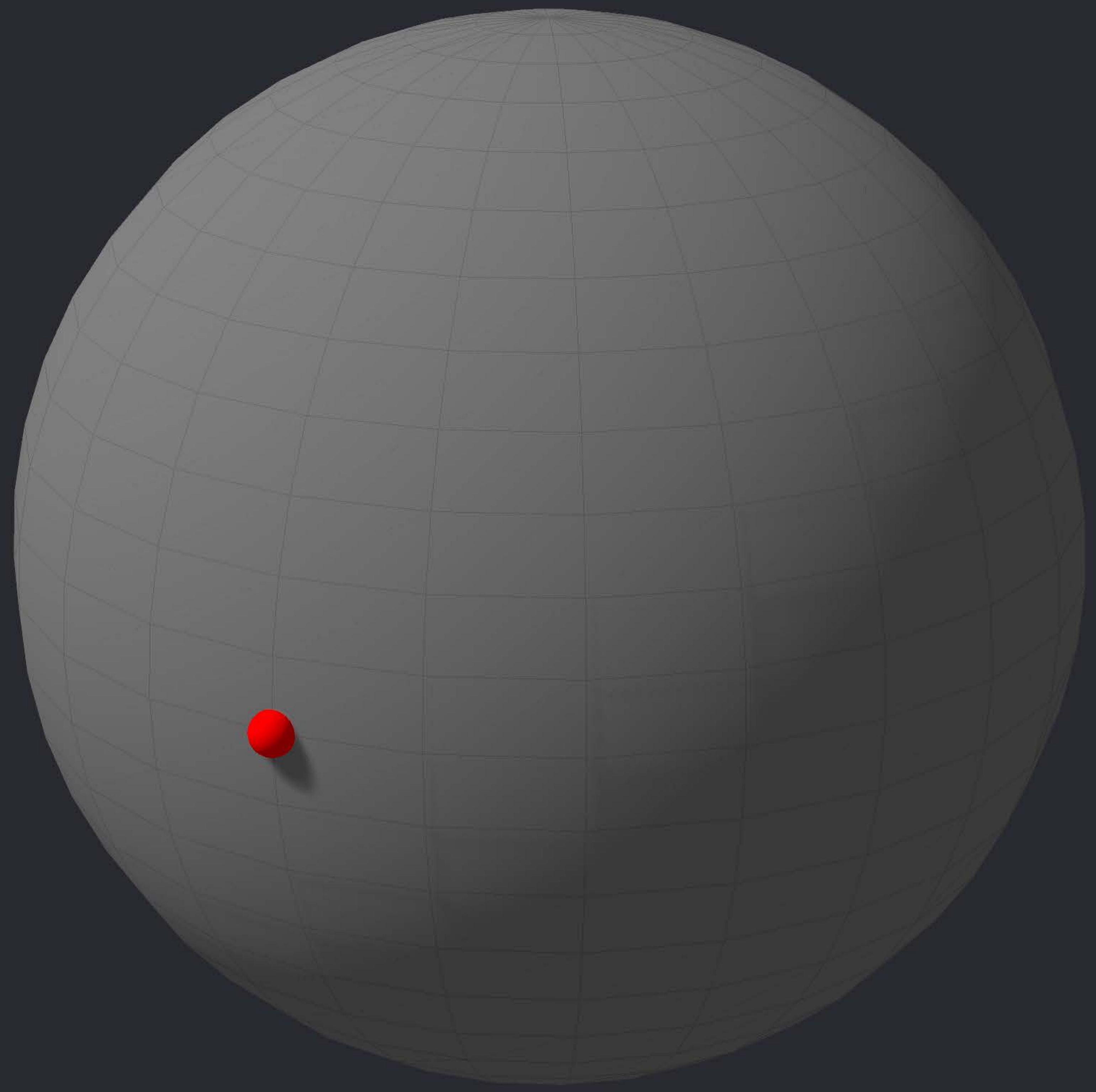

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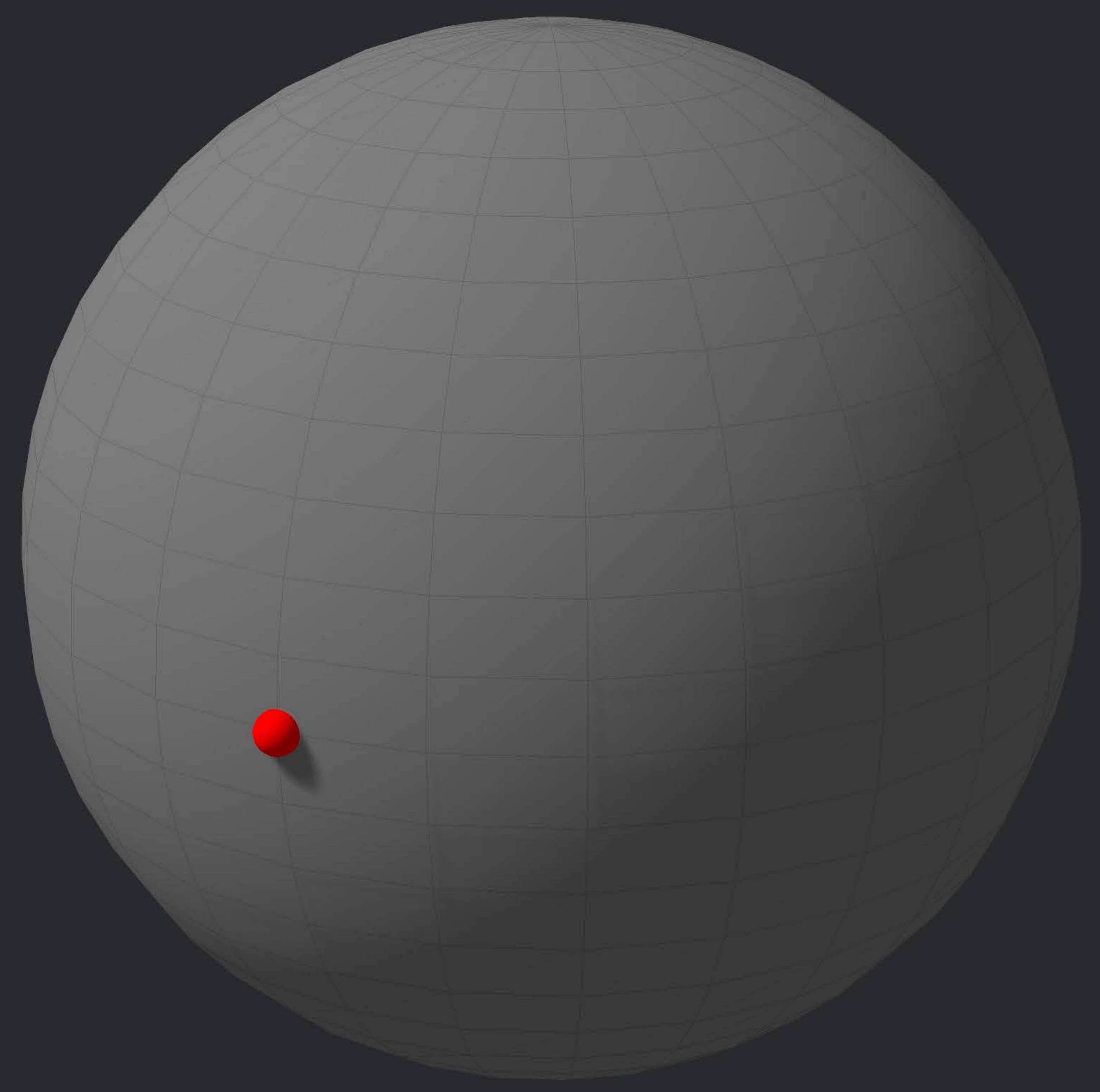

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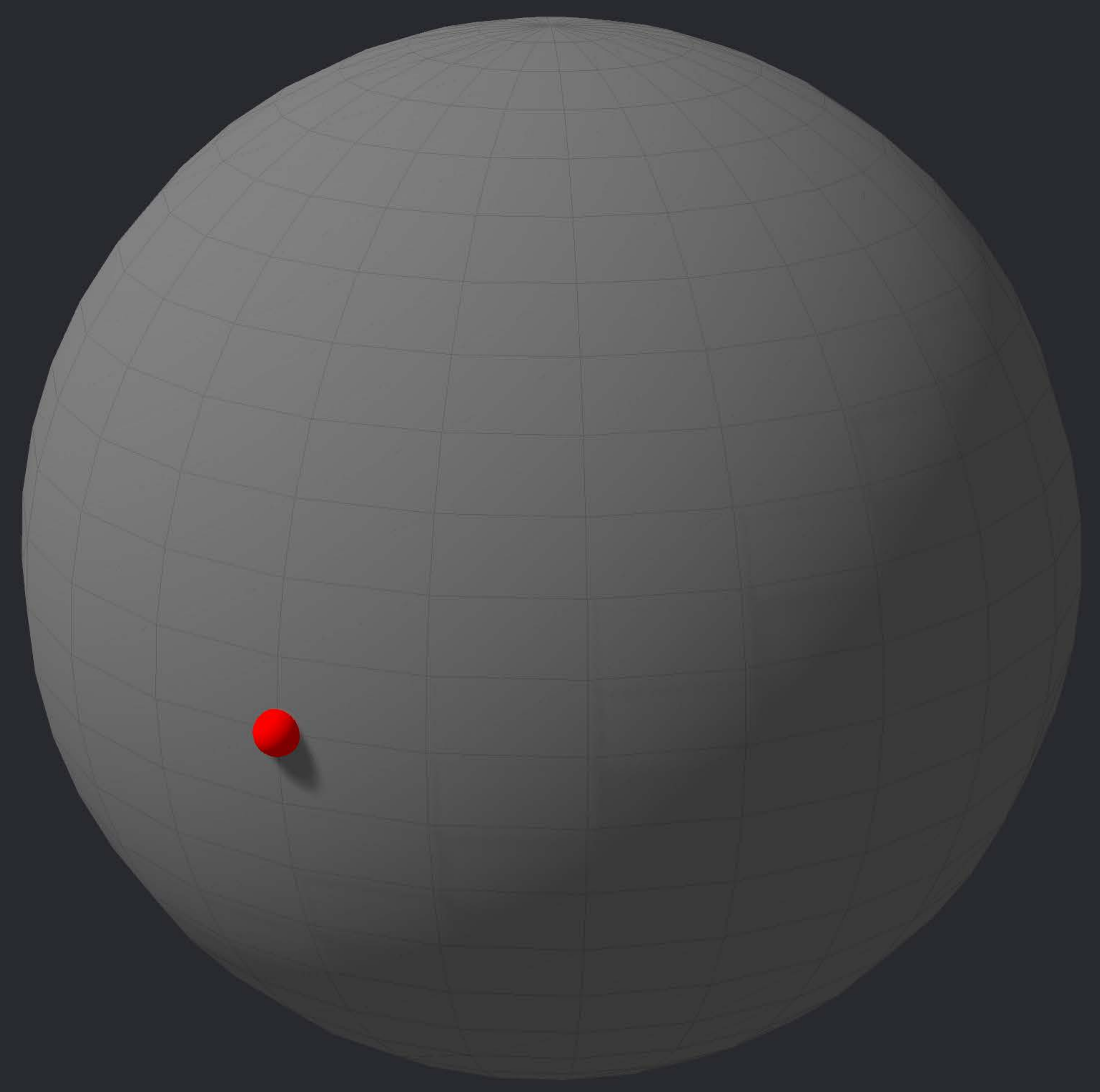
let quaternion = simd_quatf(angle: .pi / -3,
                            axis: simd_float3(1,0,0))

let quaternion2 = simd_quatf(angle: .pi / 3,
                             axis: simd_float3(0,1,0))



// Apply the Rotation
let rotatedVector = simd_act(quaternion, original)
```



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let quaternion2 = simd_quatf(angle: .pi / 3,
                             axis: simd_float3(0,1,0))

// Combine the Two Rotations
let quaternion3 = quaternion2 * quaternion

// Apply the Rotation
let rotatedVector = simd_act(quaternion, original)
```

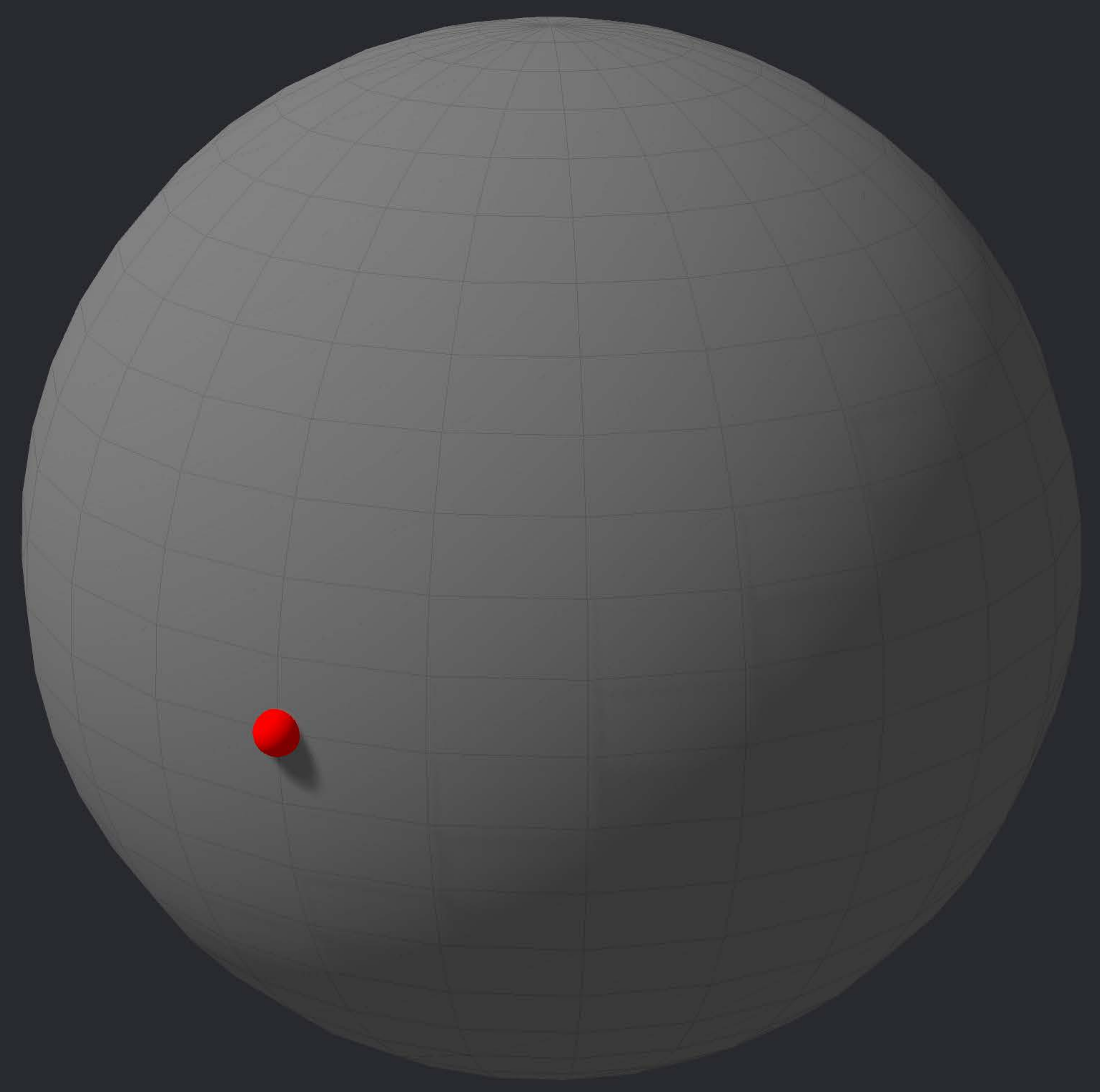

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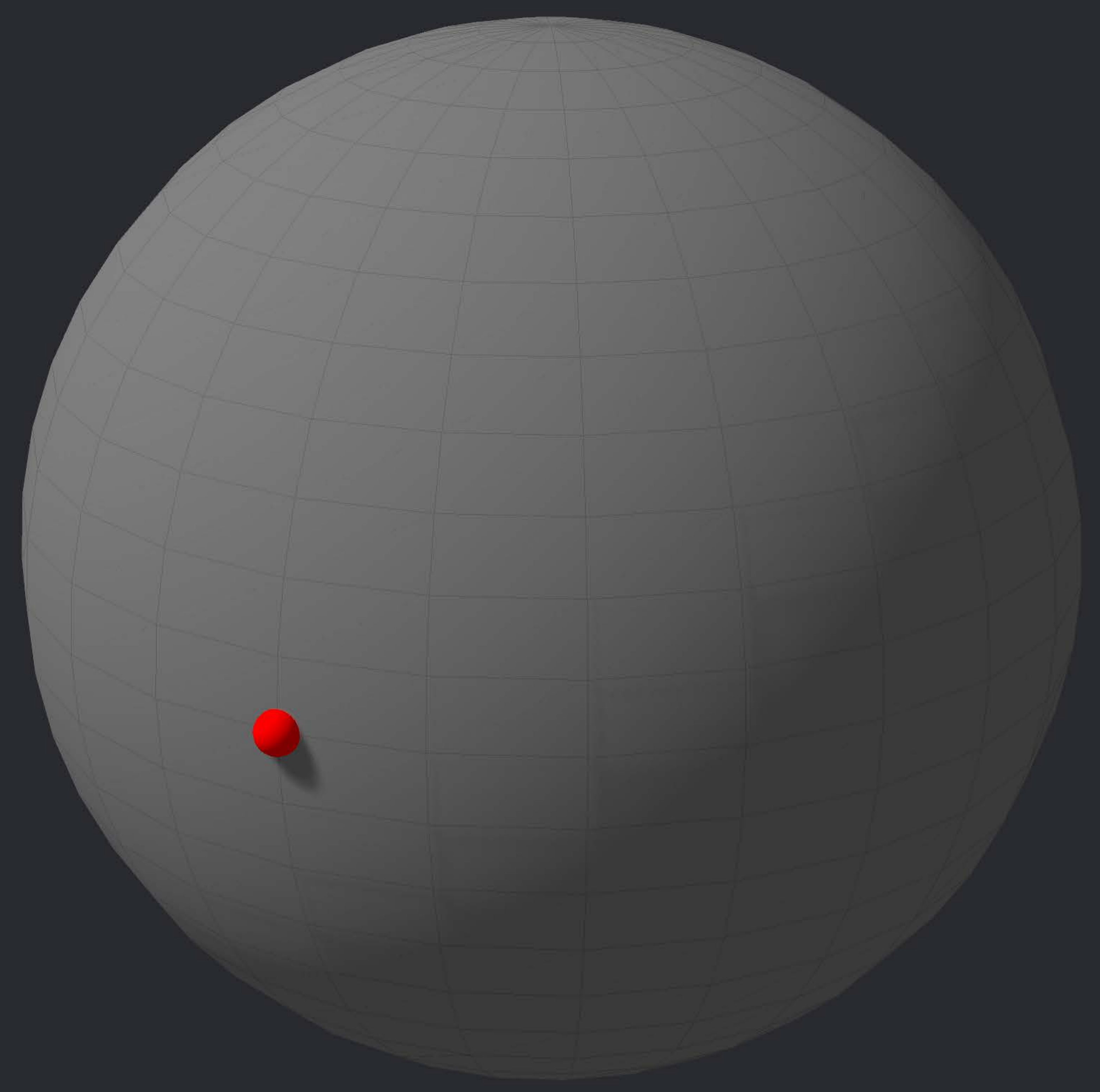

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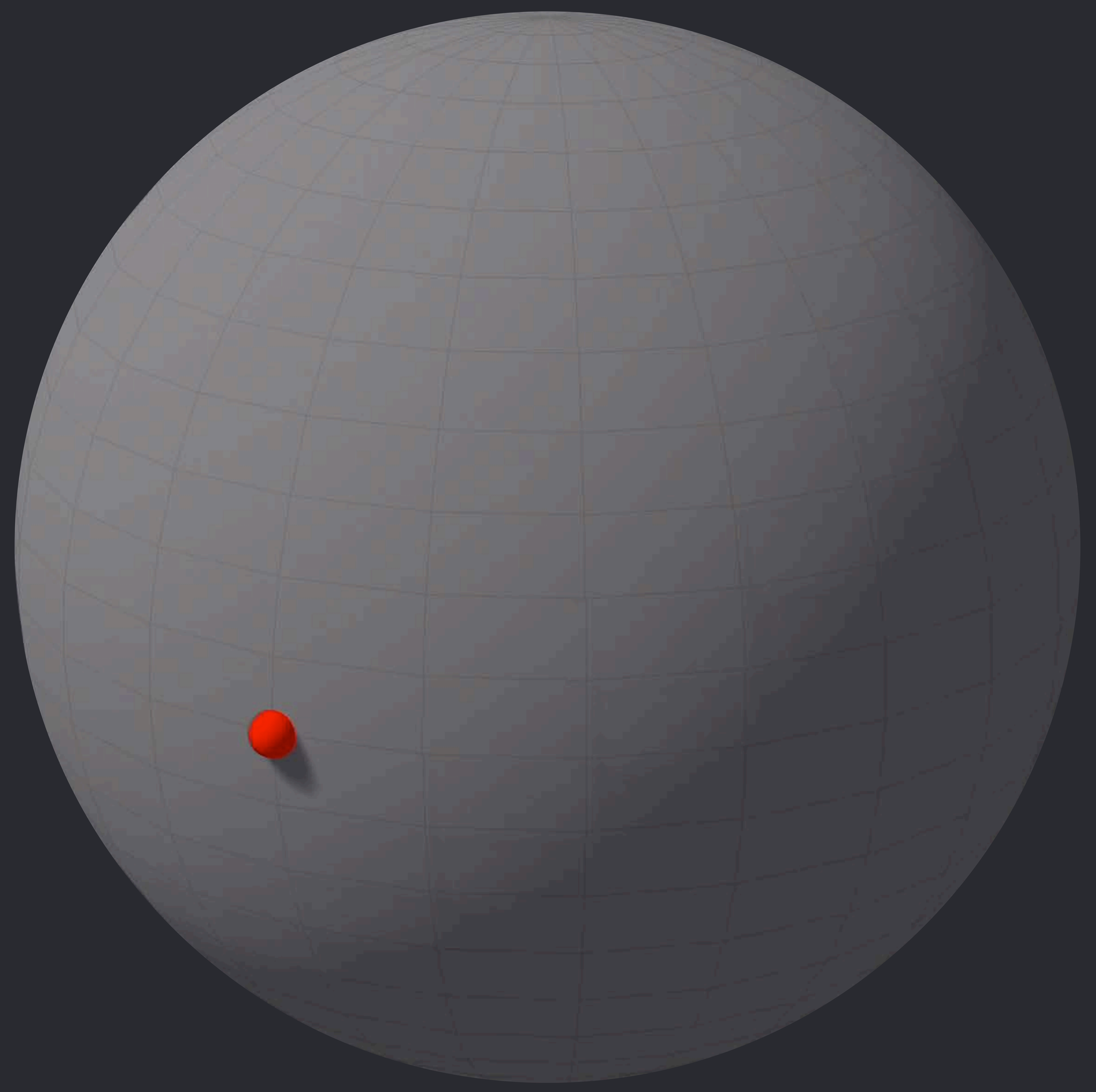


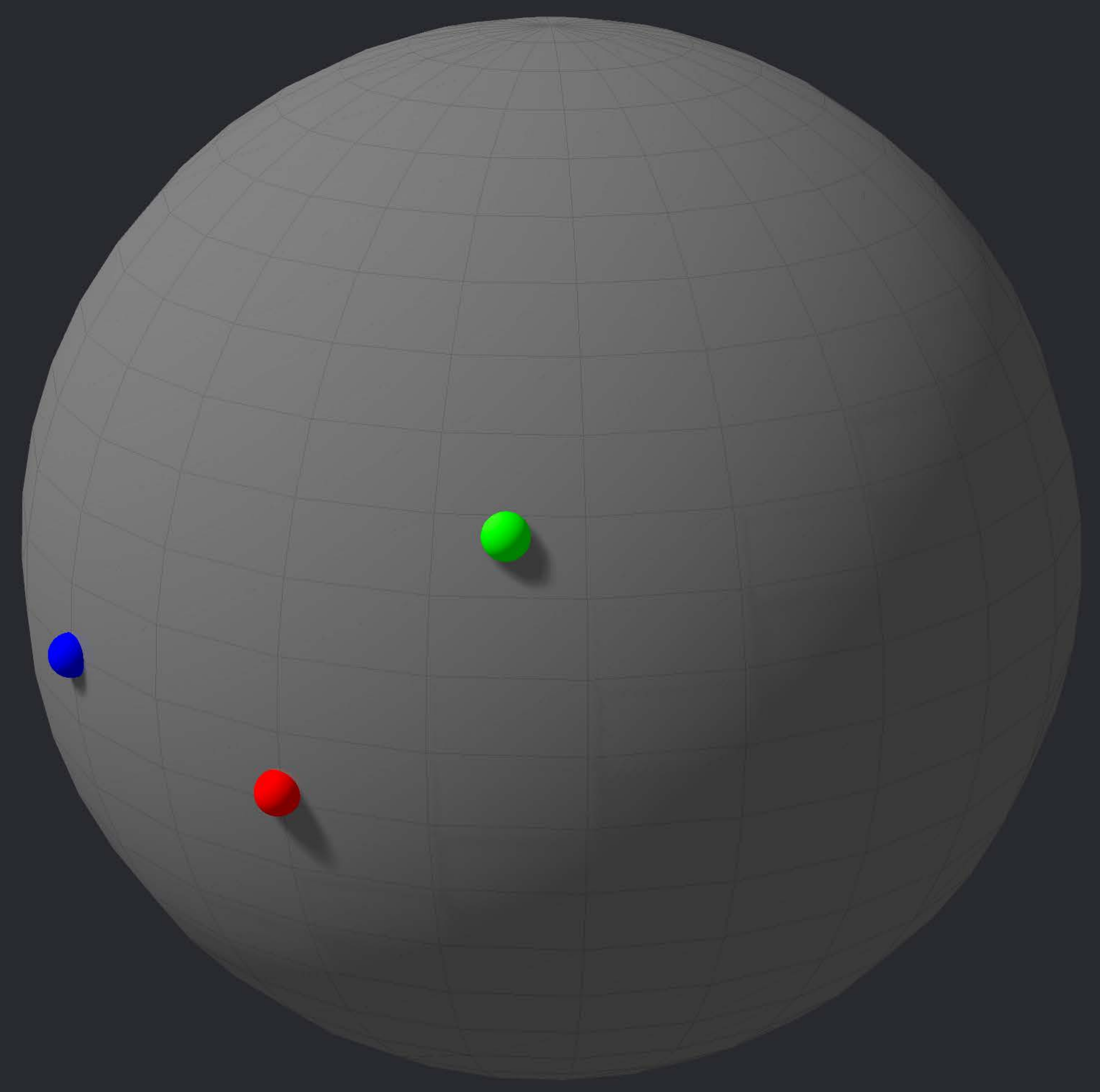
```swift
// Slerp Interpolation
let blue = simd_quatf(…)

let green = simd_quatf(…)

let red = simd_quatf(…)

for t: Float in stride(from: 0, to: 1, by: 0.001) {
    let q = simd_slerp(blue, green, t)
    // Code to Add Line Segment at `q.act(original)`
}

for t: Float in stride(from: 0, to: 1, by: 0.001) {
    let q = simd_slerp_longest(green, red, t)
    // Code to Add Line Segment at `q.act(original)`
}
```



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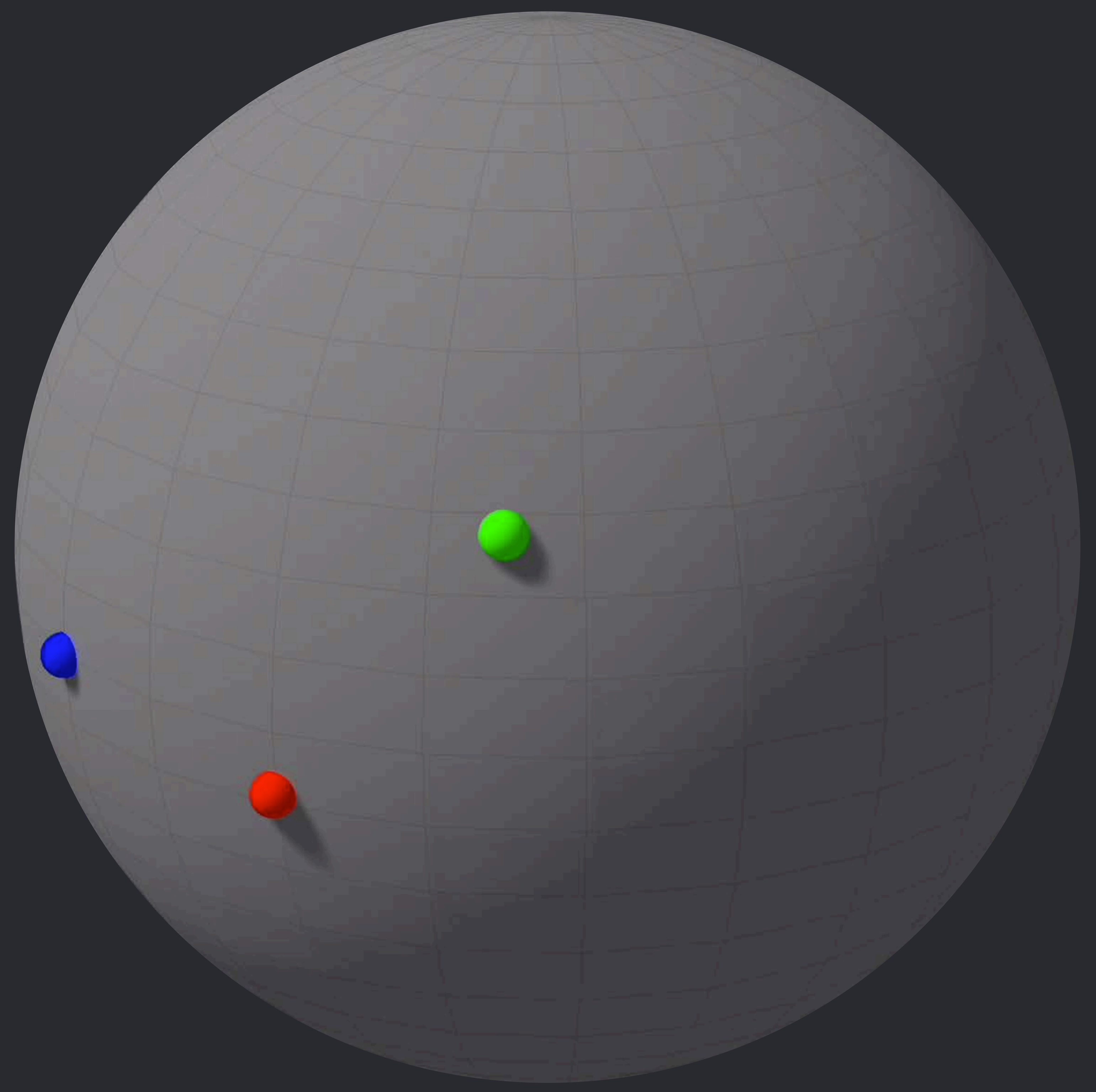
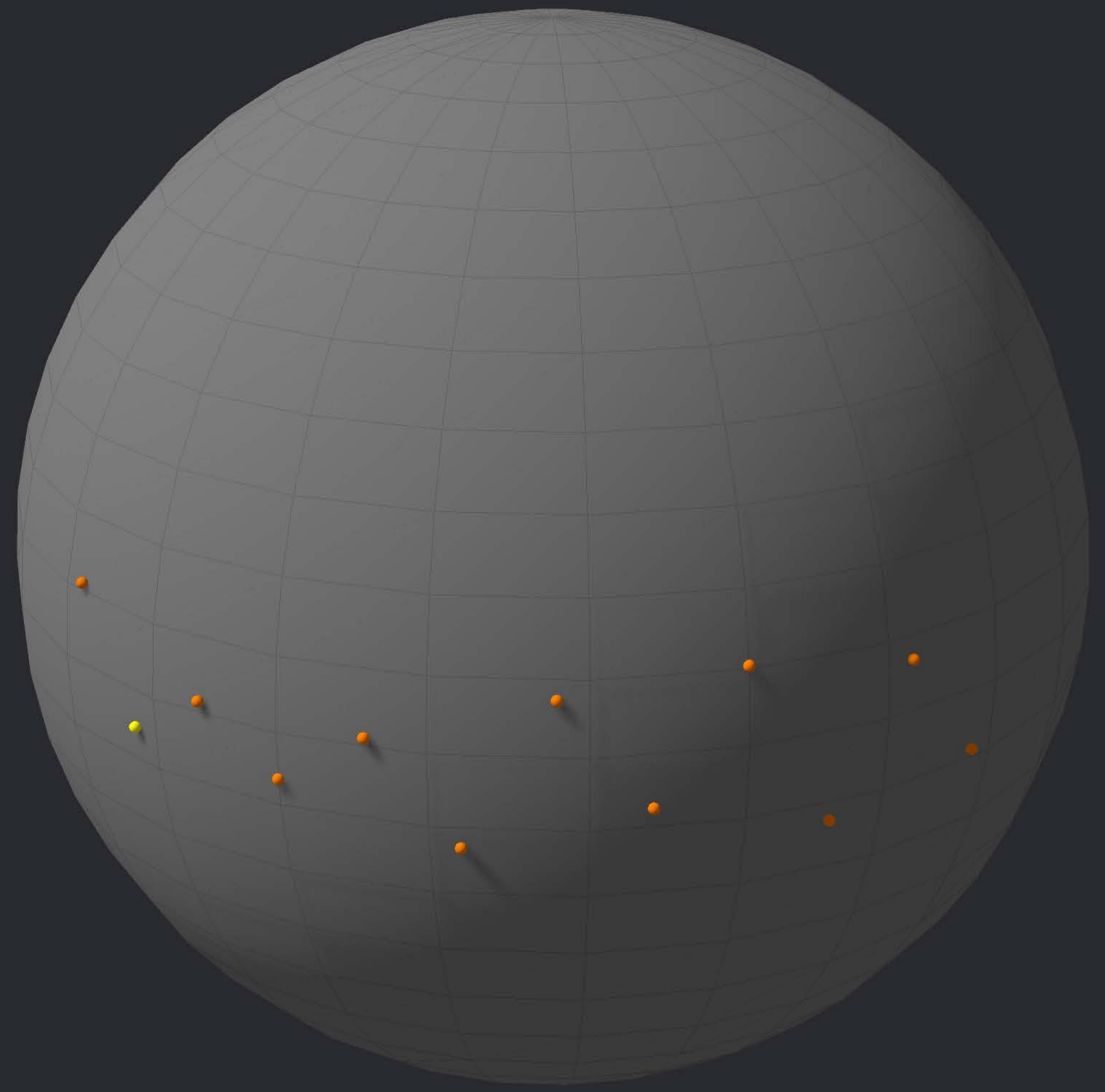


```swift
// Spline Interpolation
let original = simd_float3(0,0,1)
let rotations: [simd_quatf] = ...

for i in 1 ... rotations.count - 3 {
    for t: Float in stride(from: 0, to: 1, by: 0.001) {
        let q = simd_spline(rotations[i - 1],
                            rotations[i],
                            rotations[i + 1],
                            rotations[i + 2],
                            t)
        // Code to Add Line Segment at `q.act(original)`
    }
}
```



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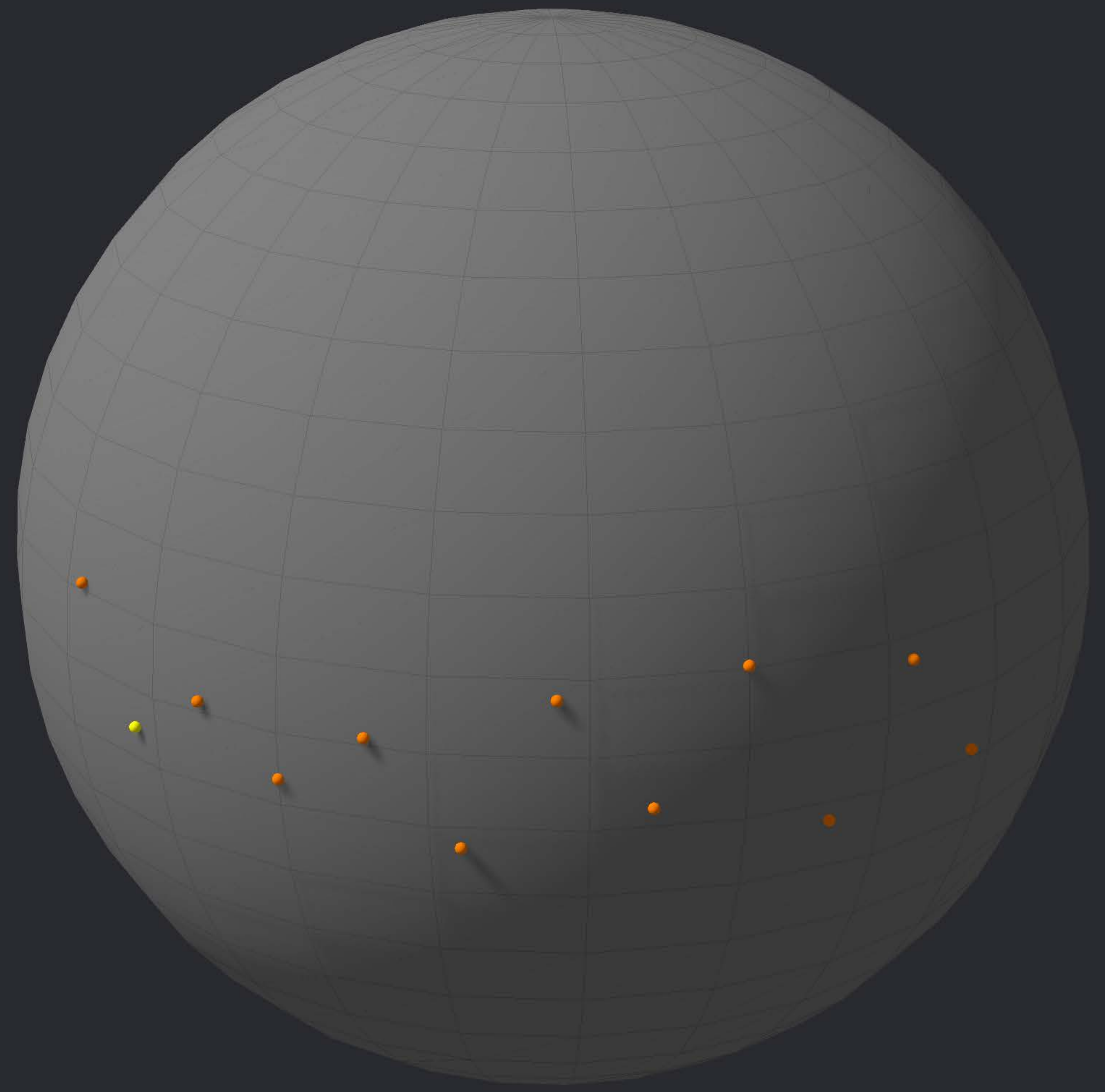
```



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```
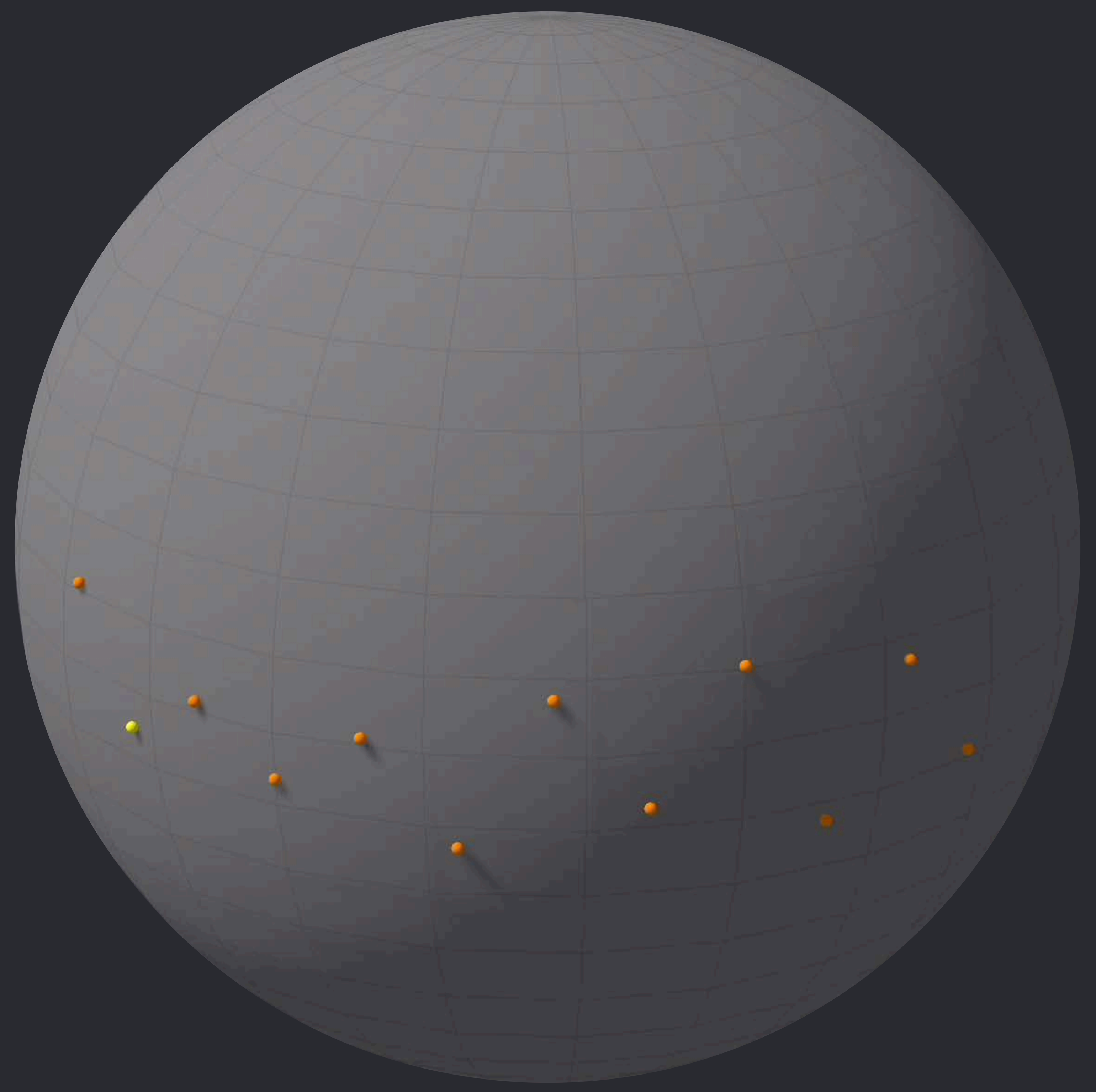
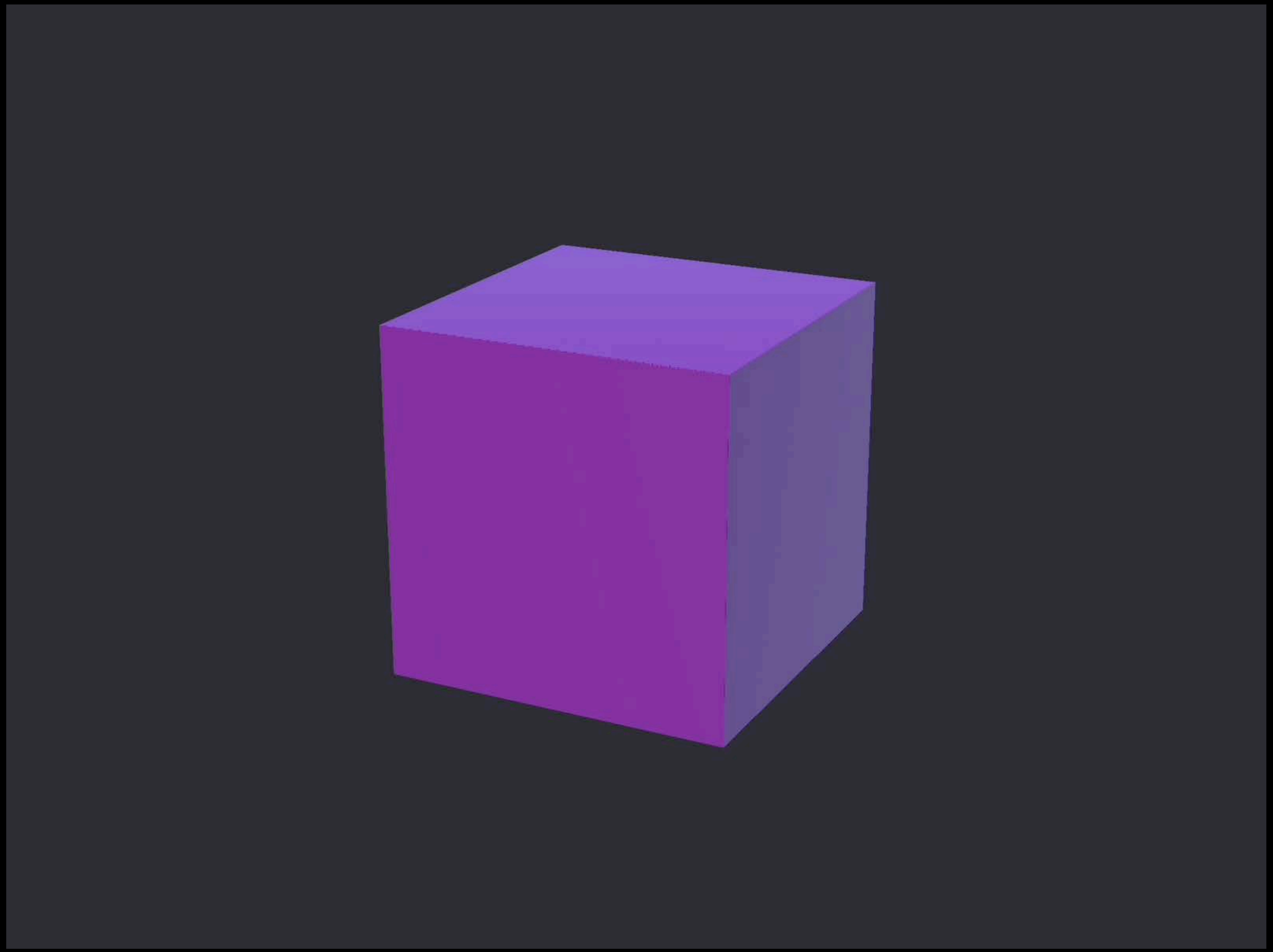
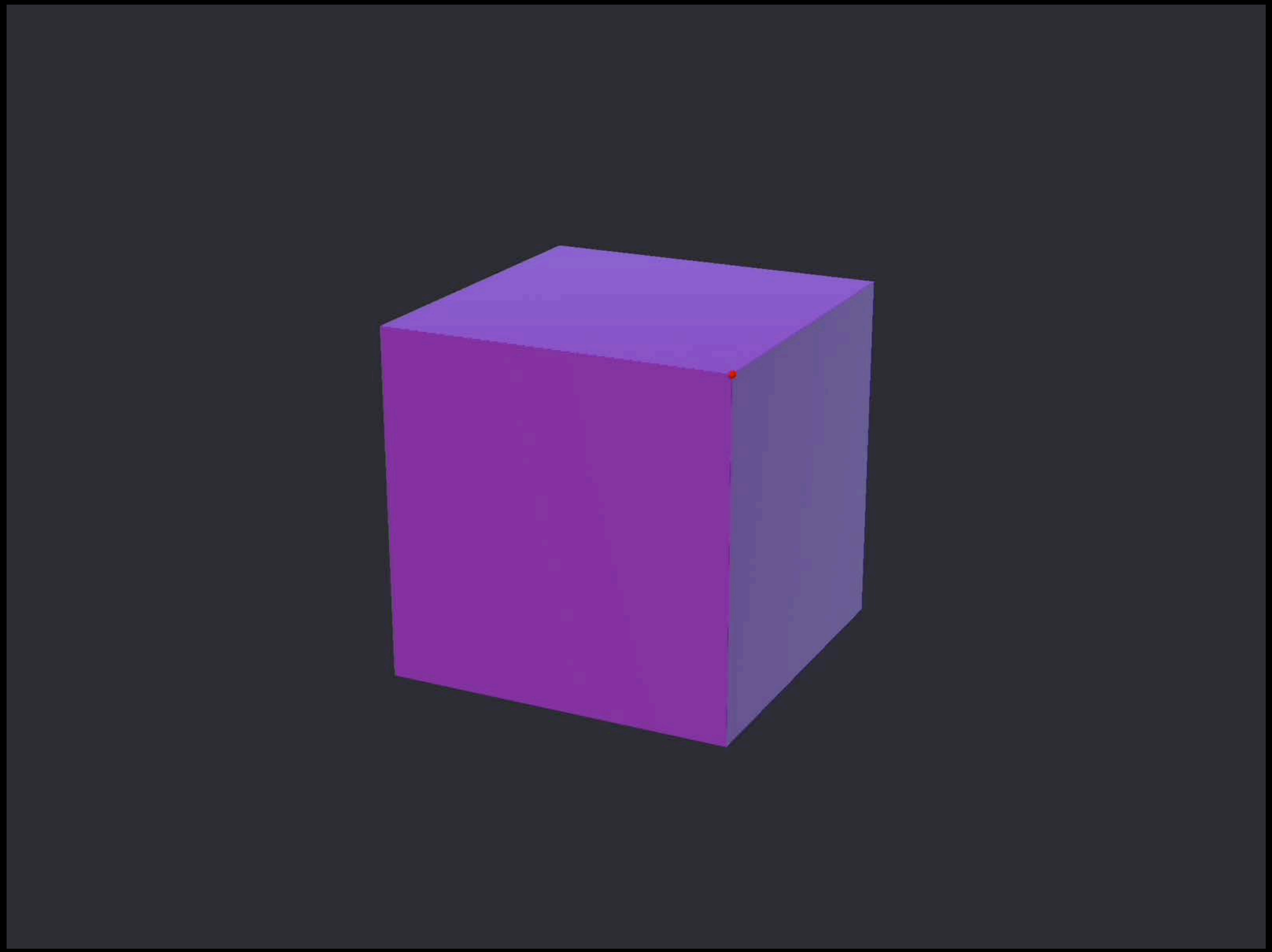
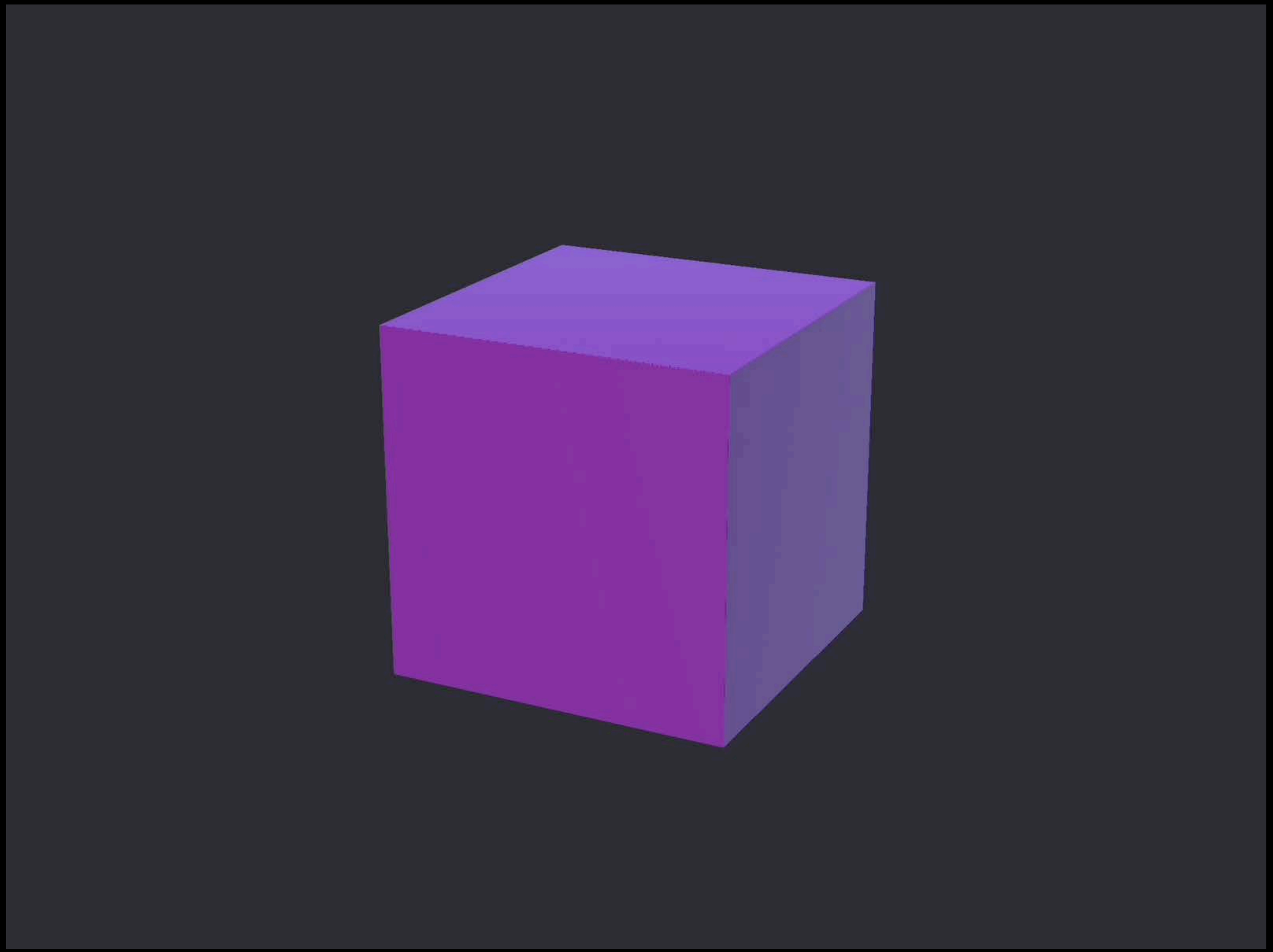





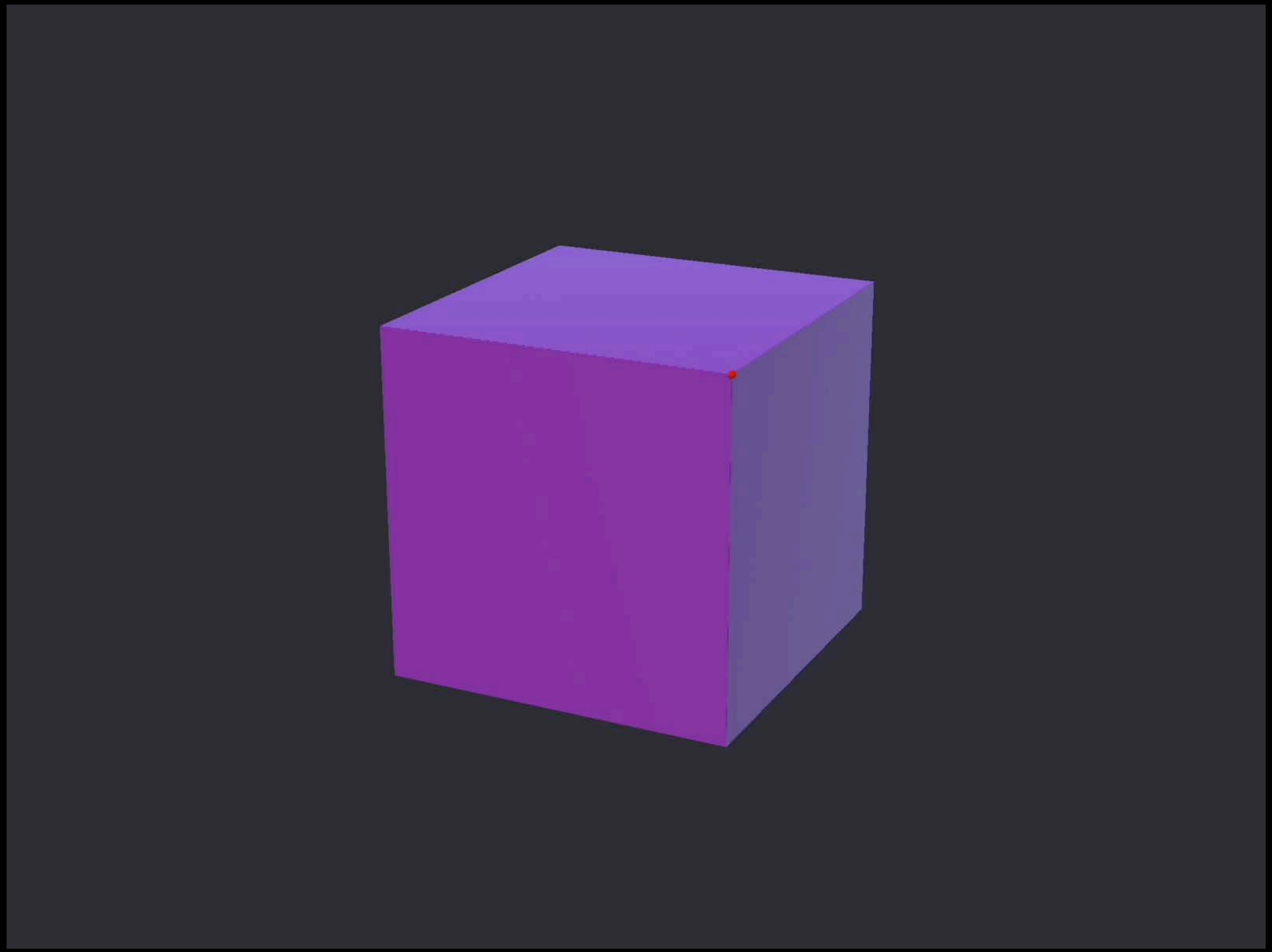
Slerp



Spline



Slerp



Spline

Sparse

LinearAlgebra

simd

LAPACK

vForce

Sparse BLAS

vImage

BNNS

Compression

BLAS

vDSP

vForce BNNS

BLAS LAPACK LinearAlgebra

vDSP simd vImage

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vDSP simd **vImage**

Sparse BLAS Sparse

Compression

vImage

Luke Chang, CoreOS, Vector and Numerics

Image Processing Library

Conversion

Geometry

Convolution

Transform

Morphology

Demo

Video effects app

Workflow

Receive captured image from camera

Prepare vImage input/output buffers

Apply effects with vImage functions

Display output image on screen

Workflow

Receive captured image from camera

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Display output image on screen

Adjust Color Saturation

The formula to adjust color saturation is:

Cb = ((Cb - 128) * saturation) + 128
Cr = ((Cr - 128) * saturation) + 128

```swift
var preBias: Int16 = -128
// Fixed-Point Arithmetics in Q12 Format
let divisor: Int32 = 0x1000
var postBias: Int32 = 128 * divisor
```

```swift
// Convert Saturation to Q12 Format
var matrix = [ Int16(saturation * Float(divisor)) ]
```

```swift
vImageMatrixMultiply_Planar8(&sources, &destinations, 1, 1,
                             &matrix, divisor, &preBias, &postBias,
                             vImage_Flags(kvImageNoFlags))
```

Workflow

Receive captured image from camera

Prepare vImage input/output buffers

Apply effects with vImage functions

Display output image on screen

```swift
// AVCaptureVideoDataOutputSampleBufferDelegate
func captureOutput(_ output: AVCaptureOutput,
                   didOutput sampleBuffer: CMSampleBuffer,
                   from connection: AVCaptureConnection) {
    // Get CVImageBuffer from CMSampleBuffer
    let pixelBuffer = sampleBuffer.imageBuffer

    // Make Sure pixelBuffer Is Accessible to CPU
    CVPixelBufferLockBaseAddress(pixelBuffer, .readOnly)

    // Apply Effects with vImage Functions
    …

    // Unlock the BaseAddress of pixelBuffer
    CVPixelBufferUnlockBaseAddress(pixelBuffer, .readOnly)
}
```

Workflow

Receive captured image from camera

Prepare vImage input/output buffers

Apply effects with vImage functions

Display output image on screen

```swift
// Prepare vImage Input Buffer for Luminance
let lumaBaseAddress = CVPixelBufferGetBaseAddressOfPlane(pixelBuffer, 0)
let lumaWidth = CVPixelBufferGetWidthOfPlane(pixelBuffer, 0)
let lumaHeight = CVPixelBufferGetHeightOfPlane(pixelBuffer, 0)
let lumaRowBytes = CVPixelBufferGetBytesPerRowOfPlane(pixelBuffer, 0)
var sourceLumaBuffer = vImage_Buffer(data: lumaBaseAddress,
                                     height: vImagePixelCount(lumaHeight),
                                     width: vImagePixelCount(lumaWidth),
                                     rowBytes: lumaRowBytes)

// Prepare vImage Input Buffer for Chrominance
…
```

```swift
// Initialize vImage Output Buffer
var destinationBuffer = vImage_Buffer()

vImageBuffer_Init(&destinationBuffer,
                  sourceLumaBuffer.height, sourceLumaBuffer.width,
                  cgImageFormat.bitsPerPixel, vImage_Flags(kvImageNoFlags))
```

Workflow

Receive captured image from camera

Prepare vImage input/output buffers

Apply effects with vImage functions

Display output image on screen

```swift
// Convert YCbCr Image to ARGB
vImageConvert_420Yp8_CbCr8ToARGB8888(&sourceLumaBuffer, &sourceChromaBuffer,
                                     &destinationBuffer, &infoYpCbCrToARGB,
                                     nil, 255, vImage_Flags(kvImageNoFlags))

// Create CGImage from vImage_Buffer for Display
// Creating CGImage Object Does Not Copy Image Buffers
let cgImage = vImageCreateCGImageFromBuffer(&destinationBuffer, &cgImageFormat,
                                            nil, nil, vImage_Flags(kvImageNoFlags),
                                            &error)
```

```swift
// Display the Image on Screen
if let cgImage = cgImage, error == kvImageNoError {
    DispatchQueue.main.async {
        self.imageView.image = UIImage(cgImage: cgImage.takeRetainedValue())
    }
}
```

Other Effects

Rotation

Blur

Dither

Color quantization

Demo

More video effects

Rotation Effect

```
let backcolor: [UInt8] = [255, 255, 255, 255]
vImageRotate_ARGB8888(&destinationBuffer, &destinationBuffer, nil,
                    fxValue, backColor, vImage_Flags(kvImageBackgroundColorFill))
```

Blur Effect

```
vImageTentConvolve_ARGB8888(&tmpBuffer, &destinationBuffer, nil,
                            0, 0, kernelSize, kernelSize, nil,
                            vImage_Flags(kvImageEdgeExtend))
```

Dither Effect

```
vImageConvert_Planar8toPlanar1(&sourceLumaBuffer,
                               &ditheredLuma,
                               nil,
                               Int32(kvImageConvert_DitherAtkinson),
                               vImage_Flags(kvImageNoFlags))
```

Color Quantization Effect

```
var lookUpTable = (0...255).map {
    return Pixel_8(($0 /quantizationLevel) * quantizationLevel)
}

vImageTableLookUp_ARGB8888(&destinationBuffer, &destinationBuffer,
                           nil, &lookUpTable, &lookUpTable, &lookUpTable,
                           vImage_Flags(kvImageNoFlags))
```

LINPACK Benchmark

LINPACK Benchmark

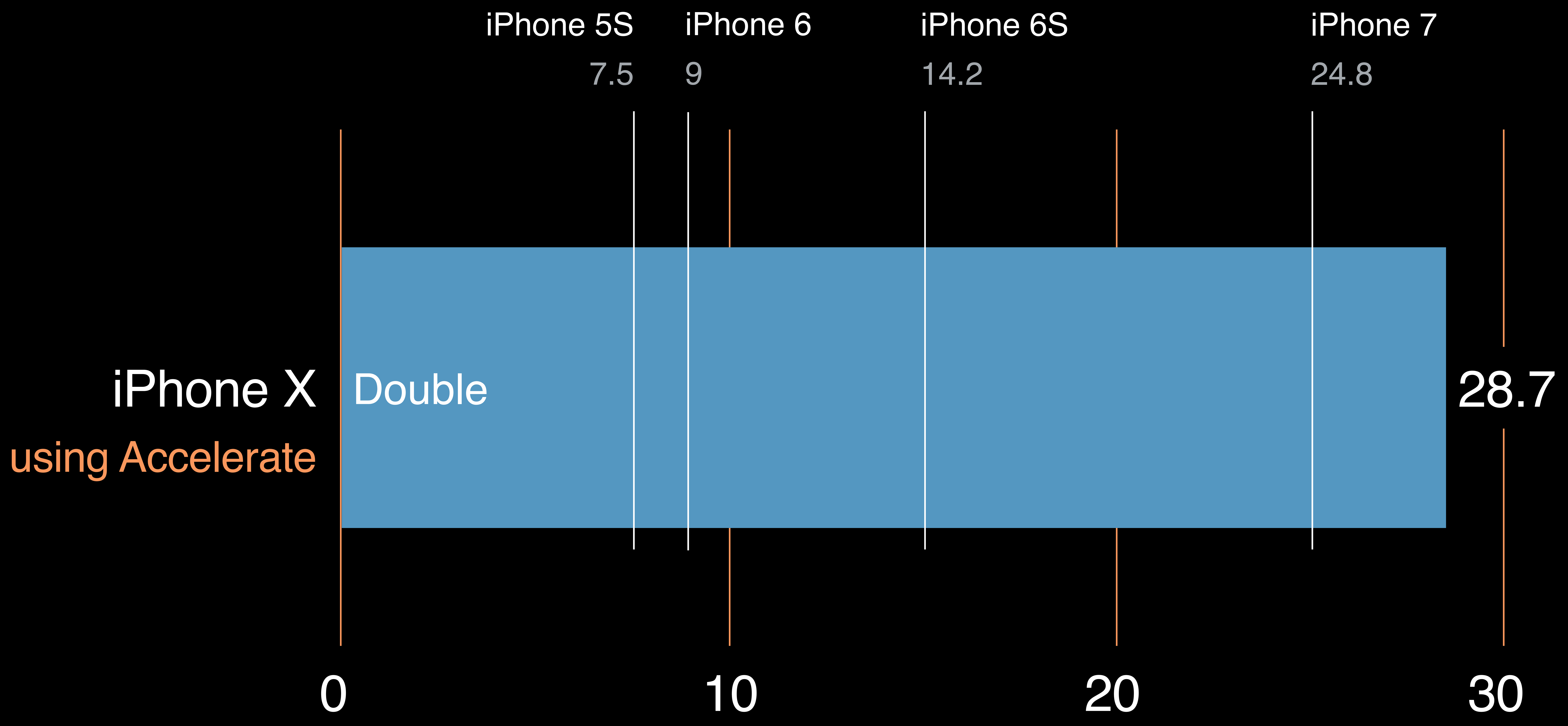
How fast can you solve a system of equations?

Actually three separate benchmarks:

- 100-by-100 system
- 1000-by-1000 system
- “No holds barred”

LINPACK Benchmark

Performance in GFLOPS (bigger is better)



LINPACK Benchmark

Performance in GFLOPS (bigger is better)

LINPACK Benchmark

Performance in GFLOPS (bigger is better)

macOS iOS tvOS watchOS

Summary

Wide varieties of functionalities

Easy to use

Fast and energy efficient

Portable across platforms and architectures

More Information

https://developer.apple.com/wwdc18/701

Accelerate Lab	Technology Lab 2	Wednesday 2:00PM

WWDC18