

Framework

Accelerate

Make large-scale mathematical computations and image calculations, optimized for high performance and low energy consumption.

iOS 4.0+ | iPadOS 4.0+ | Mac Catalyst 13.1+ | macOS 10.3+ | tvOS 9.0+ | visionOS 1.0+ | watchOS 2.0+

Overview

Accelerate provides high-performance, energy-efficient computation on the CPU by leveraging its vector-processing capability. The following Accelerate libraries abstract that capability so that code written for them executes appropriate instructions for the processor available at runtime:

BNNS

Subroutines for constructing and running neural networks for both training and inference.

vImage

A wide range of image-processing functions, including Core Graphics and Core Video interoperation, format conversion, and image manipulation.

vDSP

Digital signal processing functions, including 1D and 2D fast Fourier transforms, biquadratic filtering, vector and matrix arithmetic, convolution, and type conversion.

vForce

Functions for performing arithmetic and transcendental functions on vectors.

Sparse Solvers, BLAS, and LAPACK

Libraries for performing linear algebra on sparse and dense matrices.

Although not part of the Accelerate framework, the following libraries are closely related:

Apple Archive

A framework for performing multithreaded lossless compression of directories, files, and data.

Compression

Algorithms for lossless data compression that support LZFSE, LZ4, LZMA, and ZLIB algorithms.

simd

A module for performing computations on small vectors and matrices.

Spatial

Spatial is a lightweight 3D mathematical library that provides a simple API for working with 3D primitives.

Topics

Neural Networks

{} Training a neural network to recognize digits

Build a simple neural network and train it to recognize randomly generated numbers.

:≡ BNNS

Implement and run neural networks for training and inference.

Directories, Files, and Data Archives

📄 Compressing single files

Compress a single file and store the result on the file system.

📄 Decompressing single files

Recreate a single file from a compressed file.

📄 Compressing file system directories

Compress the contents of an entire directory and store the result on the file system.

📄 Decompressing and extracting an archived directory

Recreate an entire file system directory from an archive file.

📄 Compressing and saving a string to the file system

Compress the contents of a Unicode string and store the result on the file system.

📄 Decompressing and Parsing an Archived String

Recreate a string from an archive file.

Compression

- { Compressing and decompressing files with stream compression
 - Perform compression for all files and decompression for files with supported extension types.
- 📄 Compressing and decompressing data with buffer compression
 - Compress a string, write it to the file system, and decompress the same file using buffer compression.
- 📄 Compressing and decompressing data with input and output filters
 - Compress and decompress streamed or from-memory data, using input and output filters.

Image Processing Essentials

- 📄 Converting bitmap data between Core Graphics images and vImage buffers
 - Pass image data between Core Graphics and vImage to create and manipulate images.
- 📄 Creating and Populating Buffers from Core Graphics Images
 - Initialize vImage buffers from Core Graphics images.
- 📄 Creating a Core Graphics Image from a vImage Buffer
 - Create displayable representations of vImage buffers.
- 📄 Building a Basic Image-Processing Workflow
 - Resize an image with vImage.
- 📄 Applying geometric transforms to images
 - Reflect, shear, rotate, and scale image buffers using vImage.
- 📄 Compositing images with alpha blending
 - Combine two images by using alpha blending to create a single output.
- 📄 Compositing images with vImage blend modes
 - Combine two images by using blend modes to create a single output.
- 📄 Applying vImage operations to regions of interest
 - Limit the effect of vImage operations to rectangular regions of interest.
- 📄 Optimizing image-processing performance
 - Improve your app's performance by converting image buffer formats from interleaved to planar.
- ☰ vImage
 - Manipulate large images using the CPU's vector processor.

Signal Processing Essentials

- 📄 Controlling vDSP operations with stride
Operate selectively on the elements of a vector at regular intervals.
- 📄 Using linear interpolation to construct new data points
Fill the gaps in arrays of numerical data using linear interpolation.
- 📄 Using vDSP for vector-based arithmetic
Increase the performance of common mathematical tasks with vDSP vector-vector and vector-scalar operations.
- 📄 Resampling a signal with decimation
Reduce the sample rate of a signal by specifying a decimation factor and applying a custom antialiasing filter.
- ☰ vDSP
Perform basic arithmetic operations and common digital signal processing (DSP) routines on large vectors.

Fourier and Cosine Transforms

- 📄 Understanding data packing for Fourier transforms
Format source data for the vDSP Fourier functions, and interpret the results.
- 📄 Finding the component frequencies in a composite sine wave
Use 1D fast Fourier transform to compute the frequency components of a signal.
- 📄 Performing Fourier transforms on interleaved-complex data
Optimize discrete Fourier transform (DFT) performance with the vDSP interleaved DFT routines.
- 📄 Reducing spectral leakage with windowing
Multiply signal data by window sequence values when performing transforms with noninteger period signals.
- { } Signal extraction from noise
Use Accelerate's discrete cosine transform to remove noise from a signal.
- 📄 Performing Fourier Transforms on Multiple Signals

Use Accelerate's multiple-signal fast Fourier transform (FFT) functions to transform multiple signals with a single function call.

- { } Halftone descreening with 2D fast Fourier transform
 - Reduce or remove periodic artifacts from images.
- :≡ Fast Fourier transforms
 - Transform vectors and matrices of temporal and spatial domain complex values to the frequency domain, and vice versa.
- :≡ Discrete Fourier transforms
 - Transform vectors of temporal and spatial domain complex values to the frequency domain, and vice versa.
- :≡ Discrete Cosine transforms
 - Transform vectors of temporal and spatial domain real values to the frequency domain, and vice versa.

Core Video Interoperation

- { } Using vImage pixel buffers to generate video effects
 - Render real-time video effects with the vImage Pixel Buffer.
- { } Integrating vImage pixel buffers into a Core Image workflow
 - Share image data between Core Video pixel buffers and vImage buffers to integrate vImage operations into a Core Image workflow.
- { } Applying vImage operations to video sample buffers
 - Use the vImage convert-any-to-any functionality to perform real-time image processing of video frames streamed from your device's camera.
- { } Improving the quality of quantized images with dithering
 - Apply dithering to simulate colors that are unavailable in reduced bit depths.
- :≡ Core Video interoperability
 - Pass image data between Core Video and vImage.

Vectors, Matrices, and Quaternions

- 📄 Working with Vectors

Use vectors to calculate geometric values, calculate dot products and cross products, and interpolate between values.

Working with Matrices

Solve simultaneous equations and transform points in space.

Working with Quaternions

Rotate points around the surface of a sphere, and interpolate between them.

Rotating a cube by transforming its vertices

Rotate a cube through a series of keyframes using quaternion interpolation to transition between them.

simd

Perform computations on small vectors and matrices.

vForce

Perform transcendental and trigonometric functions on vectors of any length.

Audio Processing

Visualizing sound as an audio spectrogram

Share image data between vDSP and vImage to visualize audio that a device microphone captures.

Applying biquadratic filters to a music loop

Change the frequency response of an audio signal using a cascaded biquadratic filter.

Equalizing audio with discrete cosine transforms (DCTs)

Change the frequency response of an audio signal by manipulating frequency-domain data.

Biquadratic IIR filters

Apply biquadratic filters to single-channel and multichannel data.

Discrete Cosine transforms

Transform vectors of temporal and spatial domain real values to the frequency domain, and vice versa.

Conversion Between Image Formats

Building a basic image conversion workflow

Learn the fundamentals of the convert-any-to-any function by converting a CMYK image to an RGB image.

{} Converting color images to grayscale

Convert an RGB image to grayscale using matrix multiplication.

📄 Applying color transforms to images with a multidimensional lookup table

Precompute translation values to optimize color space conversion and other pointwise operations.

📄 Building a basic image conversion workflow

Learn the fundamentals of the convert-any-to-any function by converting a CMYK image to an RGB image.

{} Converting luminance and chrominance planes to an ARGB image

Create a displayable ARGB image using the luminance and chrominance information from your device's camera.

:≡ Conversion

Convert an image to a different format.

Image Resampling

📄 Resampling in vImage

Learn how vImage resamples image data during geometric operations.

{} Reducing artifacts with custom resampling filters

Implement custom linear interpolation to prevent the ringing effects associated with scaling an image with the default Lanczos algorithm.

:≡ Image shearing

Shear images horizontally and vertically.

Convolution and Morphology

{} Blurring an image

Filter an image by convolving it with custom and high-speed kernels.

{} Adding a bokeh effect to images

Simulate a bokeh effect by applying dilation.

☰ Convolution

Apply a convolution kernel to an image.

☰ Morphology

Dilate and erode images.

Color and Tone Adjustment

{ } Adjusting the brightness and contrast of an image

Use a gamma function to apply a linear or exponential curve.

{ } Adjusting saturation and applying tone mapping

Convert an RGB image to discrete luminance and chrominance channels, and apply color and contrast treatments.

{ } Applying tone curve adjustments to images

Use the vImage library's polynomial transform to apply tone curve adjustments to images.

{ } Adjusting the hue of an image

Convert an image to L*a*b* color space and apply hue adjustment.

{ } Specifying histograms with vImage

Calculate the histogram of one image, and apply it to a second image.

📄 Enhancing image contrast with histogram manipulation

Enhance and adjust the contrast of an image with histogram equalization and contrast stretching.

☰ Histogram

Calculate or manipulate an image's histogram.

vImage / vDSP Interoperability

{ } Finding the sharpest image in a sequence of captured images

Share image data between vDSP and vImage to compute the sharpest image from a bracketed photo sequence.

{ } Visualizing sound as an audio spectrogram

Share image data between vDSP and vImage to visualize audio that a device microphone captures.

Sparse Matrices

Creating sparse matrices

Create sparse matrices for factorization and solving systems.

Solving systems using direct methods

Use direct methods to solve systems of equations where the coefficient matrix is sparse.

Solving systems using iterative methods

Use iterative methods to solve systems of equations where the coefficient matrix is sparse.

Creating a sparse matrix from coordinate format arrays

Use separate coordinate format arrays to create sparse matrices.

Sparse Solvers

Solve systems of equations where the coefficient matrix is sparse.

Arithmetic and Transcendental Functions

vecLib

Perform computations on large vectors.

Linear Algebra

Solving systems of linear equations with LAPACK

Select the optimal LAPACK routine to solve a system of linear equations.

Finding an interpolating polynomial using the Vandermonde method

Use LAPACK to solve a linear system and find an interpolating polynomial to construct new points between a series of known data points.

Compressing an image using linear algebra

Reduce the storage size of an image using singular value decomposition (SVD).

BLAS

Perform common linear algebra operations with Apple's implementation of the Basic Linear Algebra Subprograms (BLAS).

Definite Integration

☰ Quadrature

Approximate the definite integral of a function over a finite or infinite interval.

Macros

☰ Macros