Image Processing Ops as first class citizens in MLIR: write once, vectorise everywhere!

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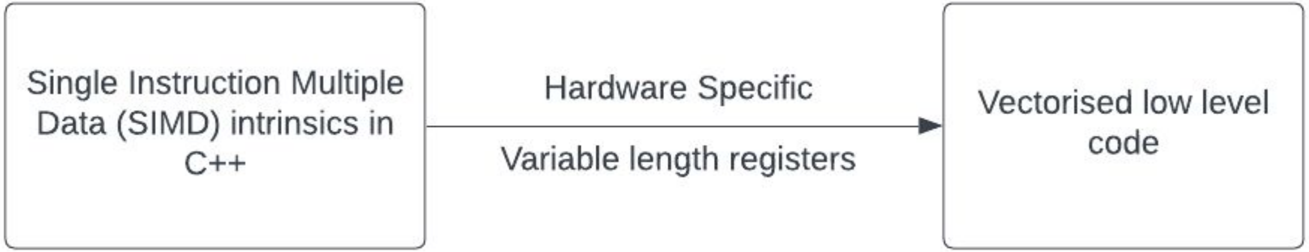
Challenge

Make Image Processing faster 🚄 to make life easier

A possible solution

Use Vectorisation?

CPU Vectorisation in Image Processing

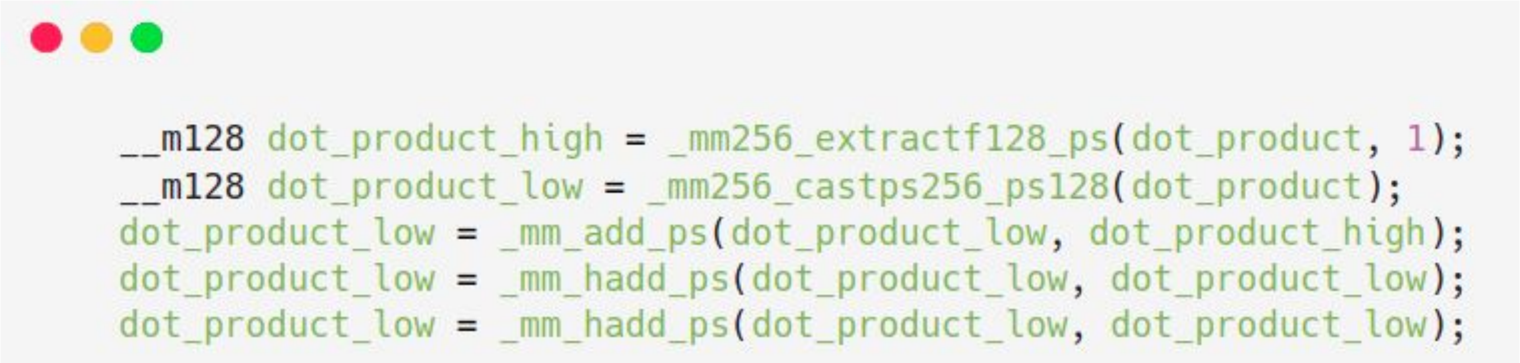


Single Instruction Multiple Data (SIMD) intrinsics in C++

Hardware Specific

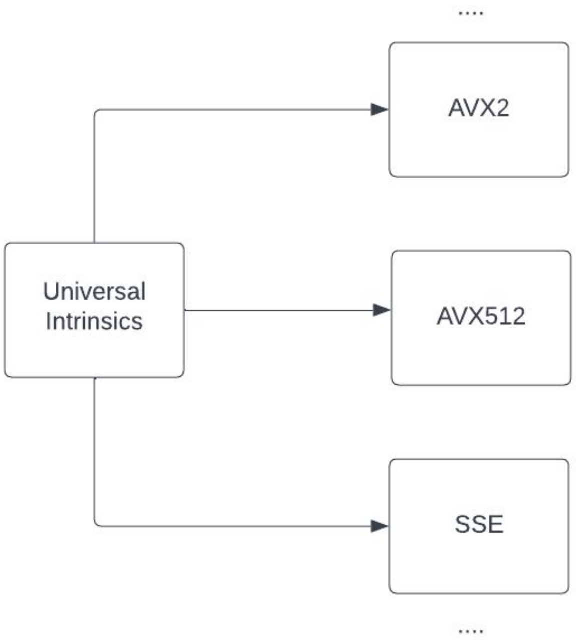
Variable length registers

Vectorised low level code



```
__m128 dot_product_high = _mm256_extractf128_ps(dot_product, 1);
__m128 dot_product_low = _mm256_castps256_ps128(dot_product);
dot_product_low = _mm_add_ps(dot_product_low, dot_product_high);
dot_product_low = _mm_hadd_ps(dot_product_low, dot_product_low);
dot_product_low = _mm_hadd_ps(dot_product_low, dot_product_low);
```

Universal intrinsics



Potential problems while dealing with SIMD intrinsics

- ❖ Reliance on a wrapper to provide unified API for targeting each abstraction (Ex. Universal Intrinsics)

More Code Maintainance

Separate support for emerging technologies

Non-trivial design decisions for novel features

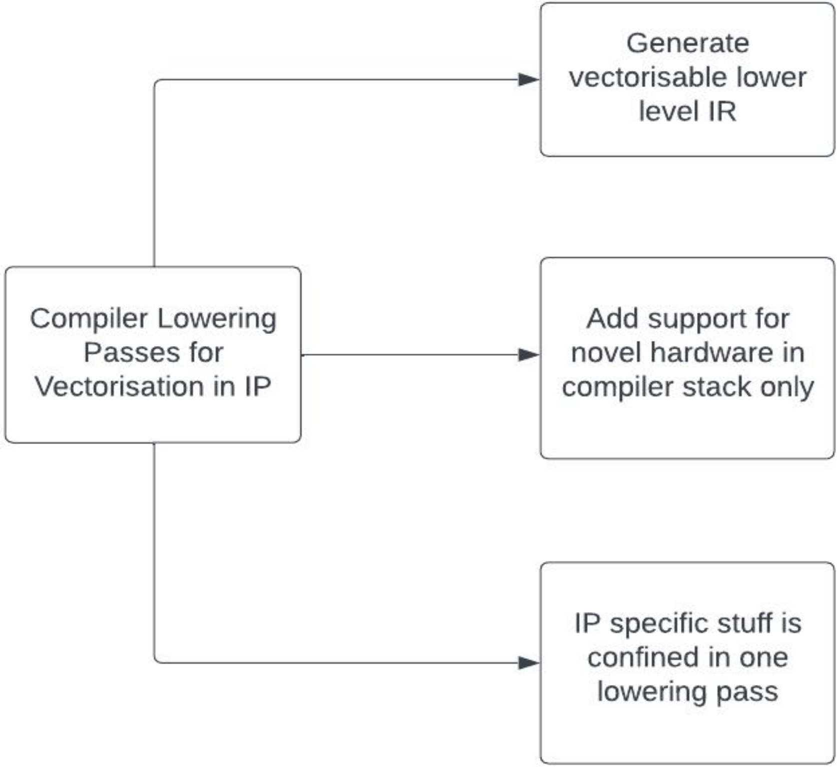
Potential problems while dealing with SIMD intrinsics

- ❖ Manual reimplementation of existing algorithms for each hardware technology

More Code Maintainance

Separate support for emerging technologies

Potential Solution



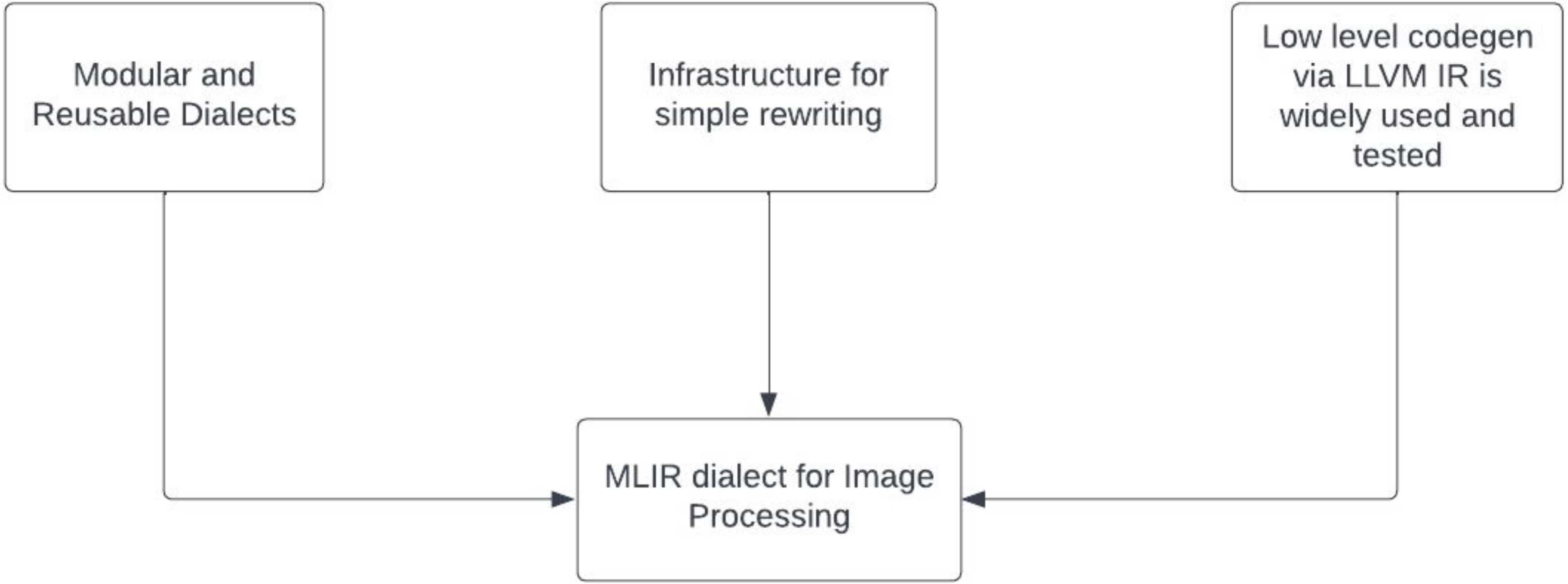
Compiler Lowering Passes for Vectorisation in IP

Generate vectorisable lower level IR

Add support for novel hardware in compiler stack only

IP specific stuff is confined in one lowering pass

Why we chose MLIR



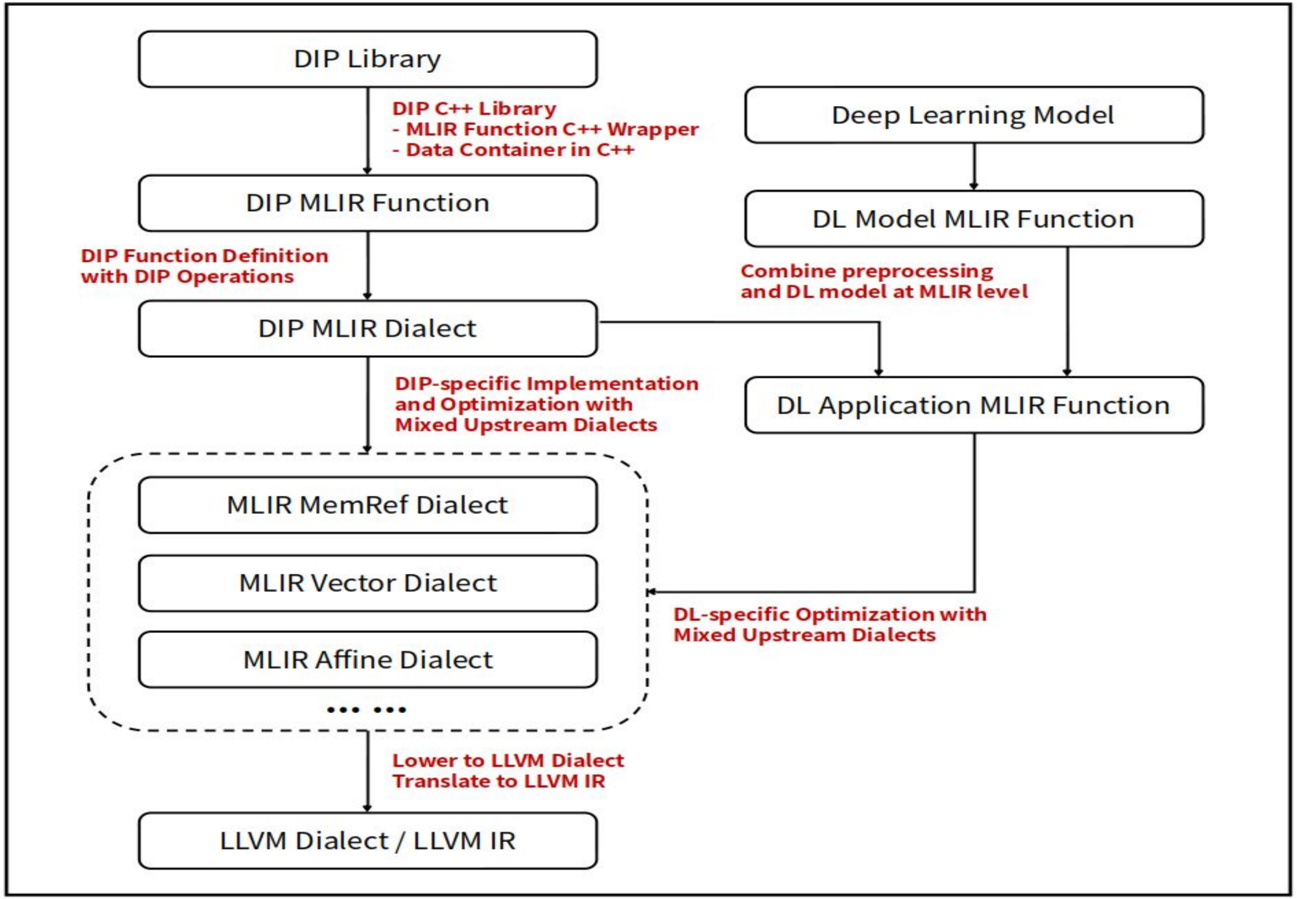
Modular and Reusable Dialects

Infrastructure for simple rewriting

Low level codegen via LLVM IR is widely used and tested

MLIR dialect for Image Processing

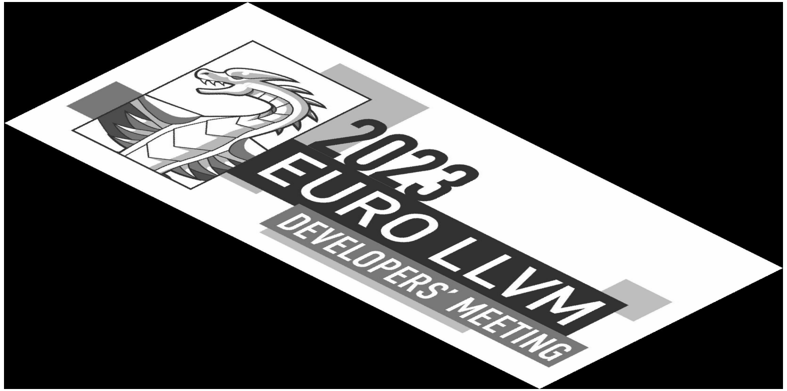
DIP (Digital Image Processing) Dialect Overview



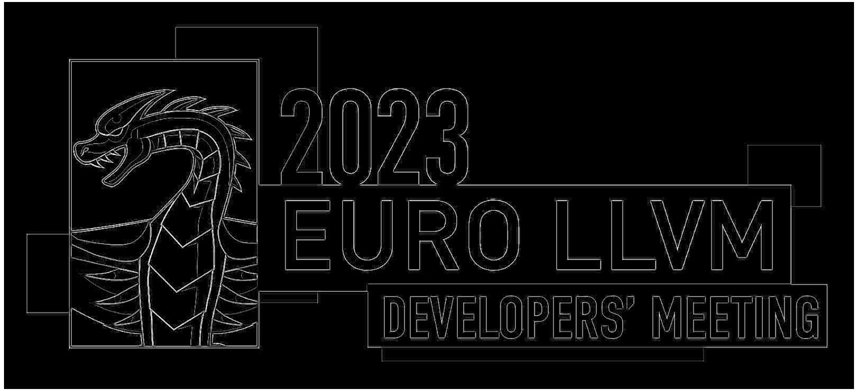
DIP Dialect Examples

2023
EURO LLVM
DEVELOPERS' MEETING

Original Image



Rotation (45°) Output



Laplacian Filter Output

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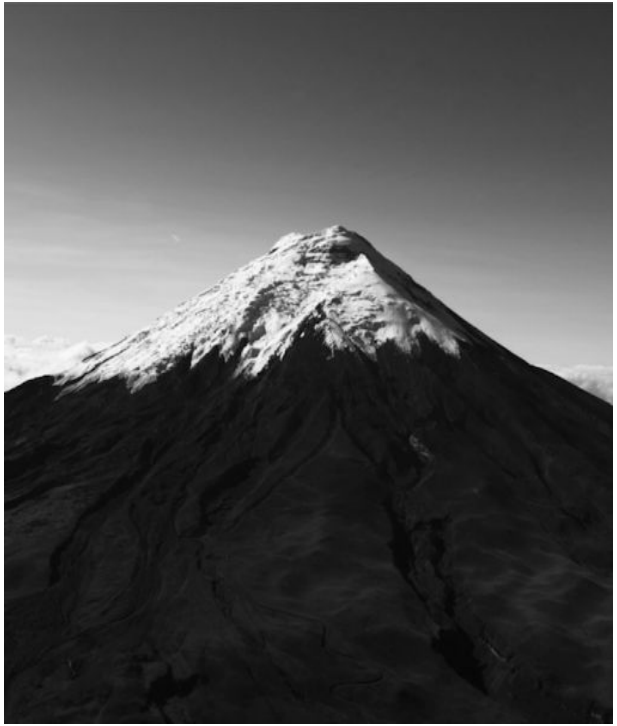
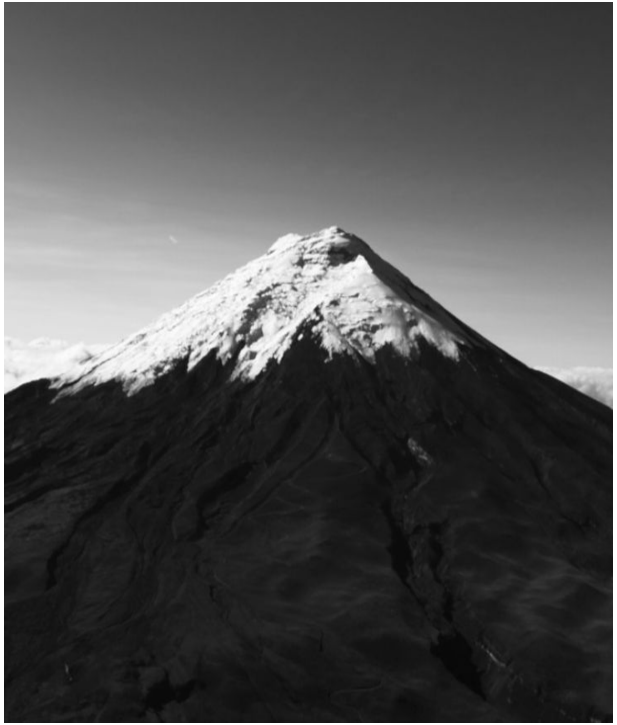
Resize Output

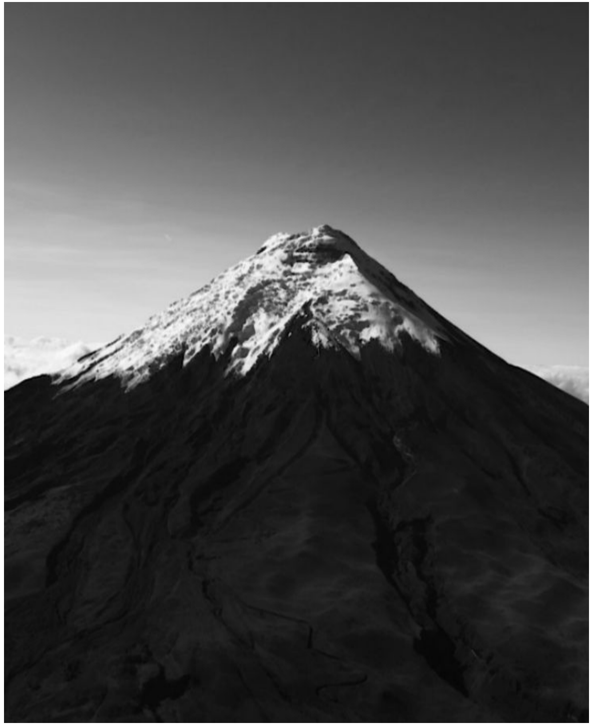
DIP Dialect Examples



Original Image

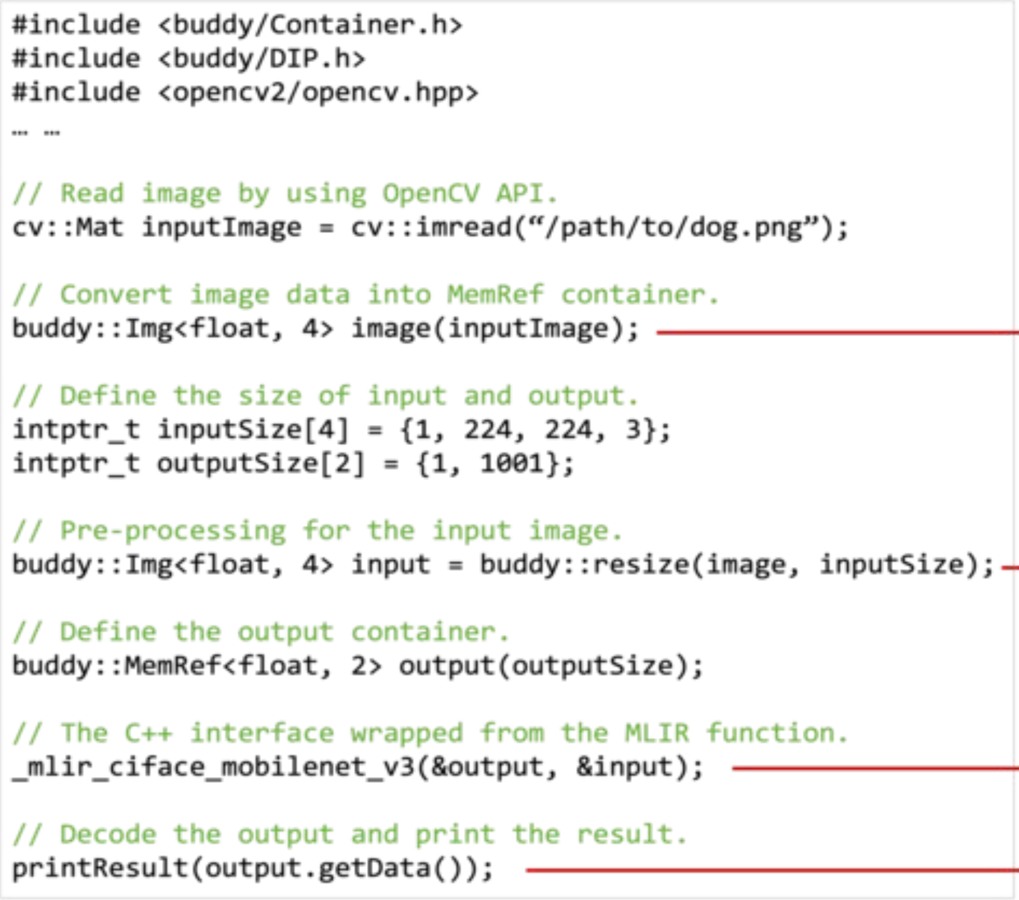


Dilation Output



Erosion Output

DL Inference



```
#include <buddy/Container.h>
#include <buddy/DIP.h>
#include <opencv2/opencv.hpp>
… …

// Read image by using OpenCV API.
cv::Mat inputImage = cv::imread(“/path/to/dog.png”);

// Convert image data into MemRef container.
buddy::Img<float, 4> image(inputImage);

// Define the size of input and output.
intptr_t inputSize[4] = {1, 224, 224, 3};
intptr_t outputSize[2] = {1, 1001};

// Pre-processing for the input image.
buddy::Img<float, 4> input = buddy::resize(image, inputSize);

// Define the output container.
buddy::MemRef<float, 2> output(outputSize);

// The C++ interface wrapped from the MLIR function.
_mlir_ciface_mobilenet_v3(&output, &input);

// Decode the output and print the result.
printResult(output.getData());
```

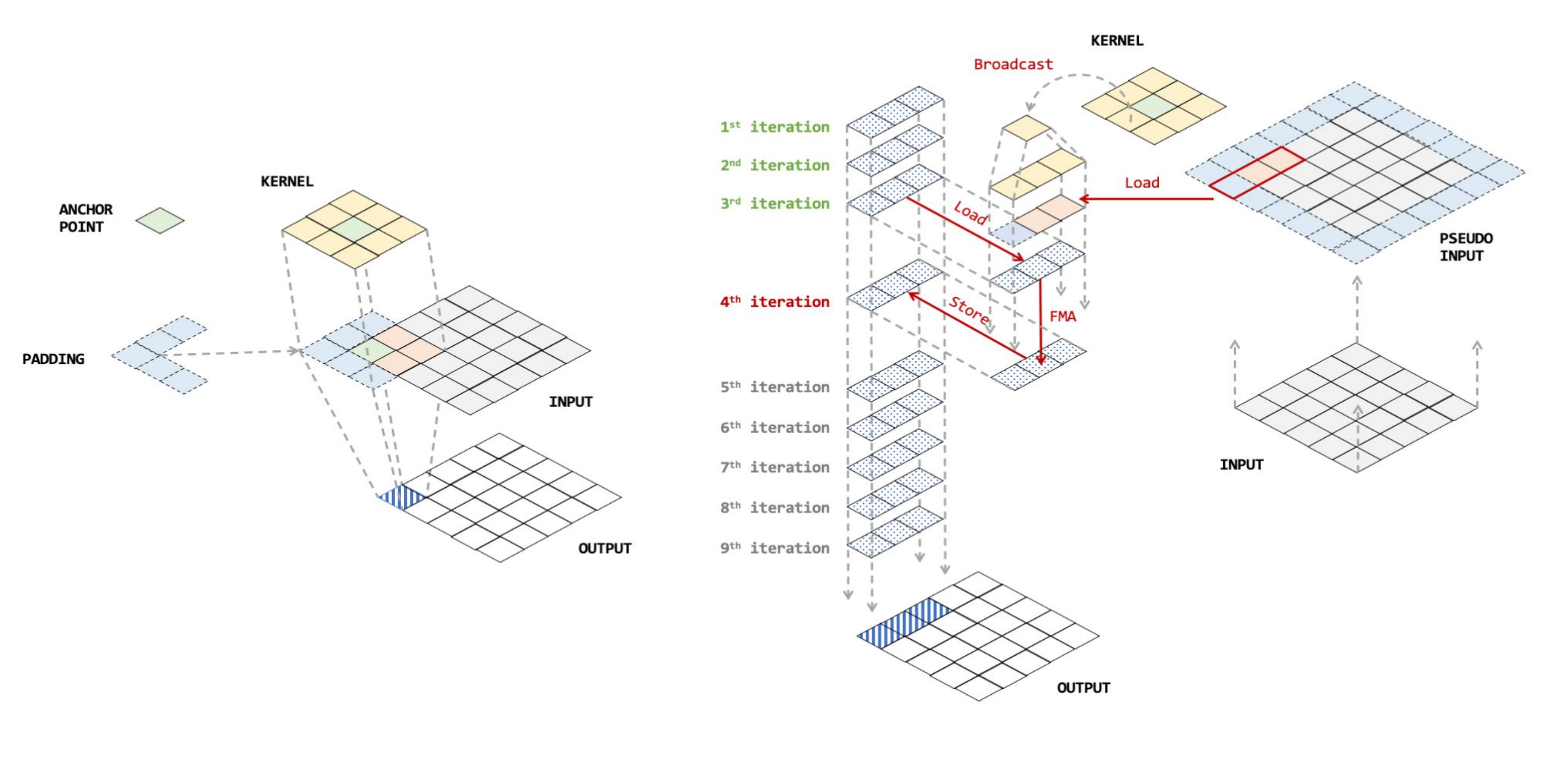
MemRef container in Buddy Compiler is compatible with existing libraries.

The C++ interface is wrapped from custom DIP dialect operations for deep learning pre-processing.

Deep learning model optimized using buddy-mlir.

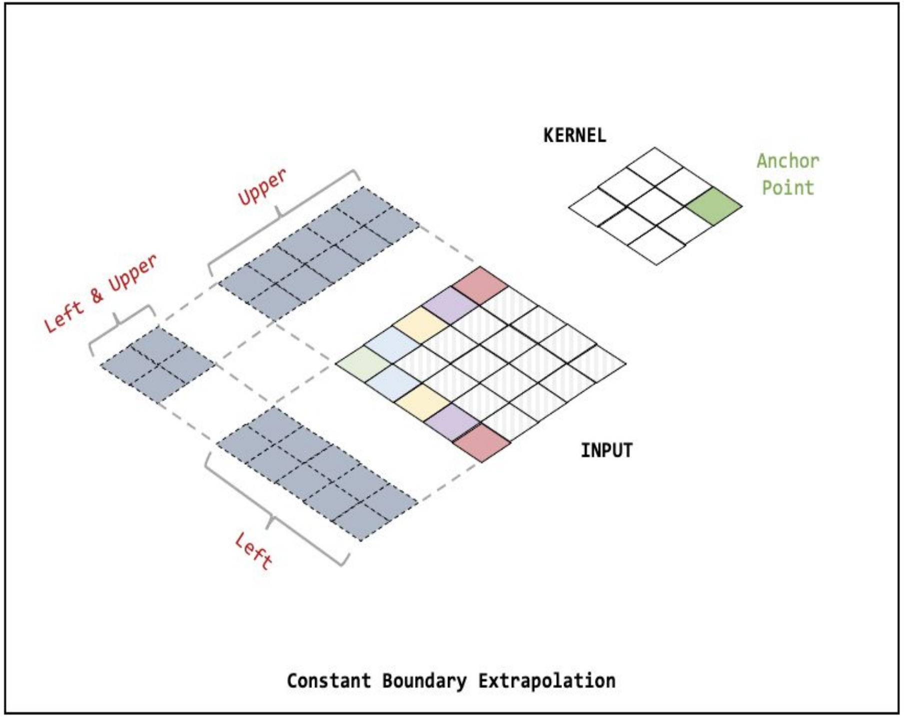
Classification: Samoyed
Probability: 0.529544

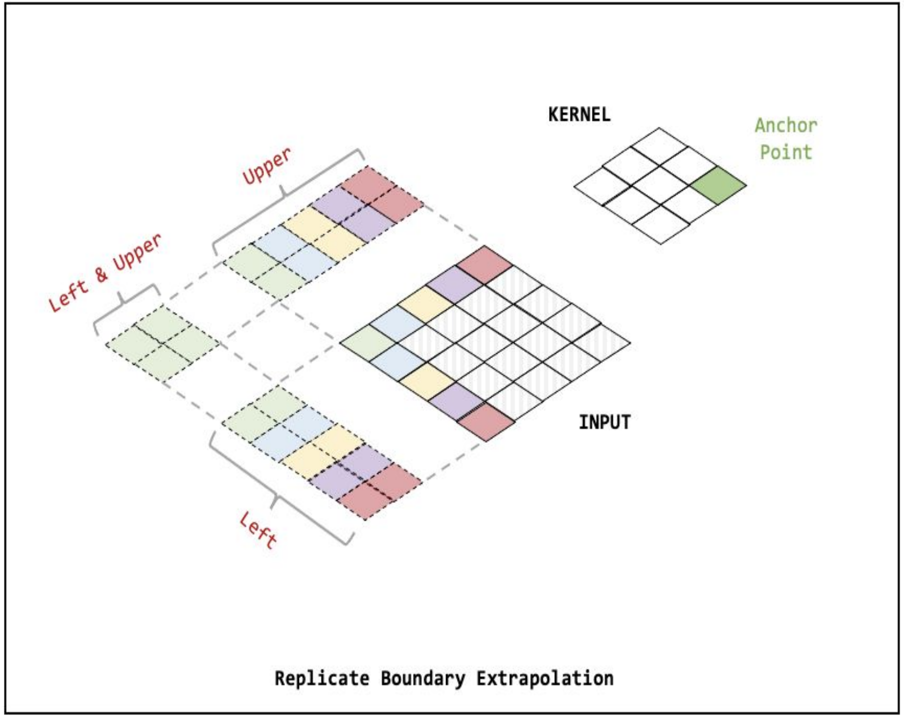
Single Channel 2D Image Filtering



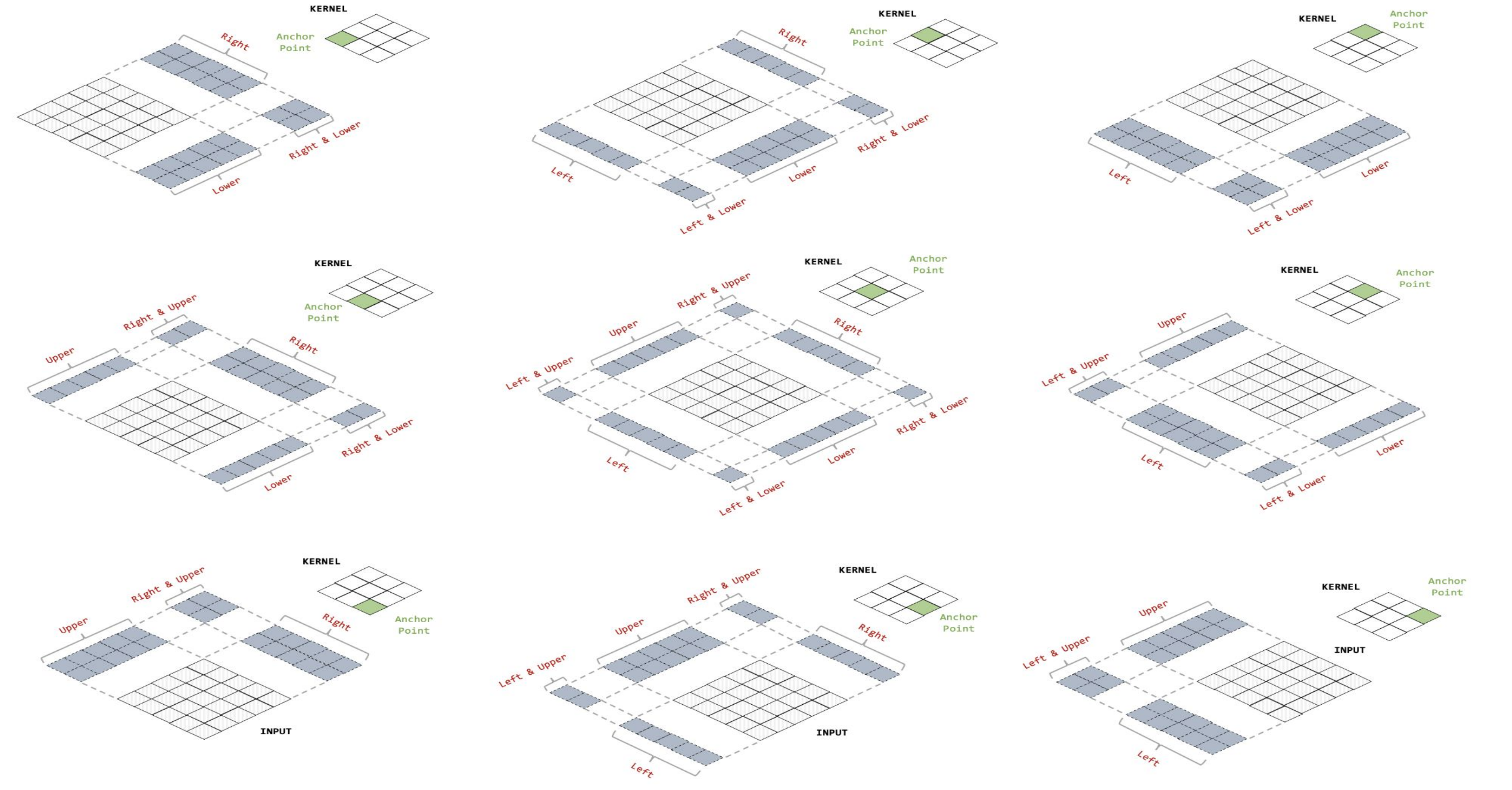
Normal Convolution Algorithm (9 iterations give 1 element) vs Coefficients Broadcasting Algorithm (9 iterations give N elements)

Considered boundary extrapolation strategies for 2D Image Filtering



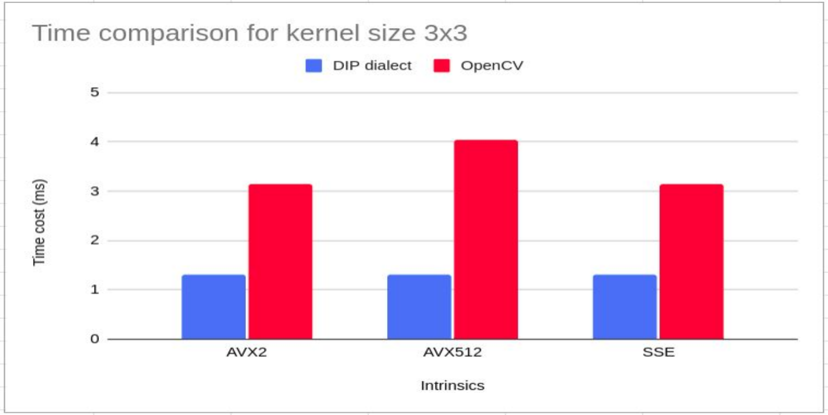


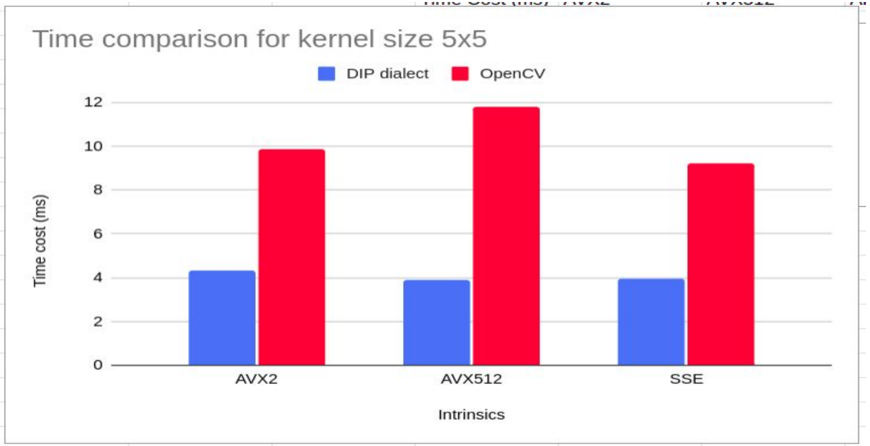
Anchor point position and padding

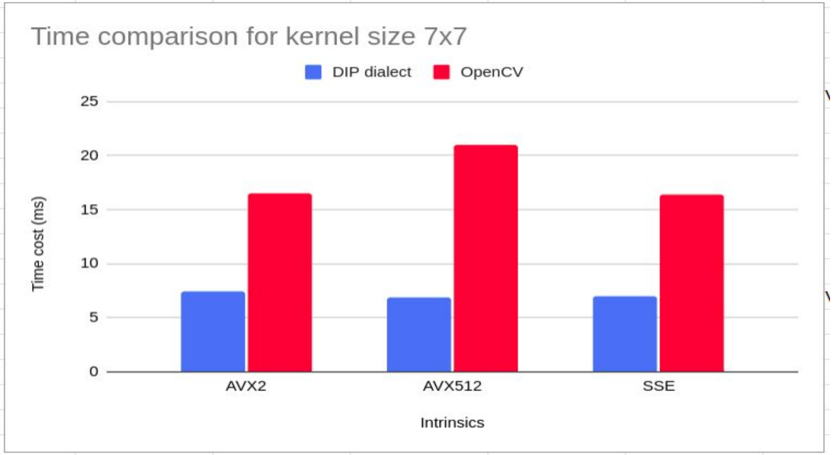


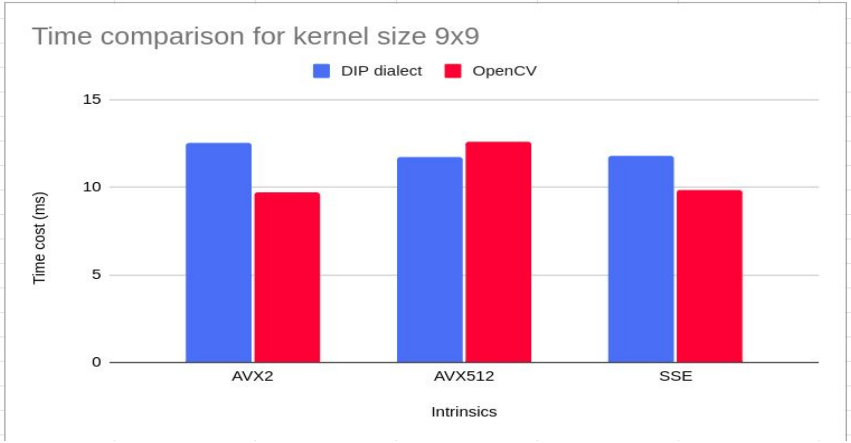
Anchor Point and Boundary Extrapolation

Performance Data

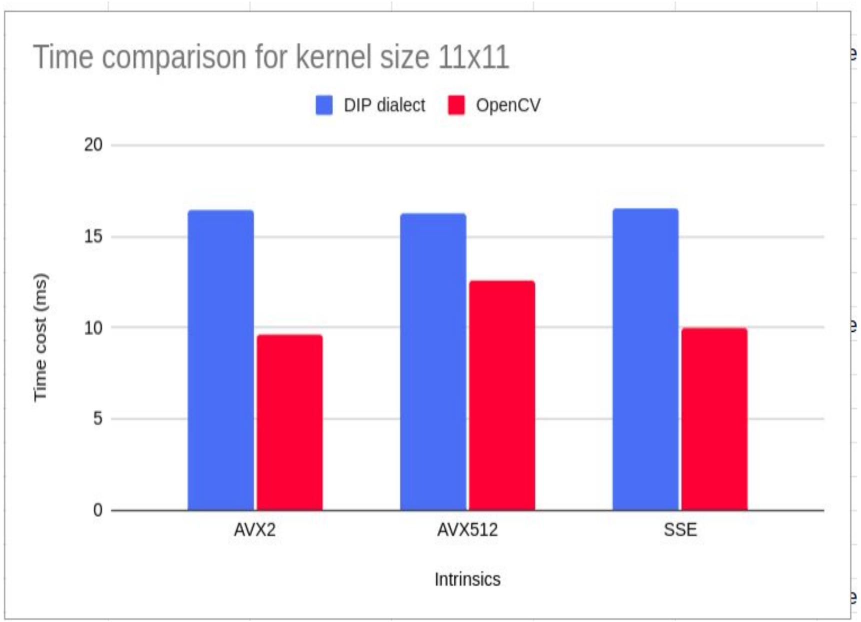


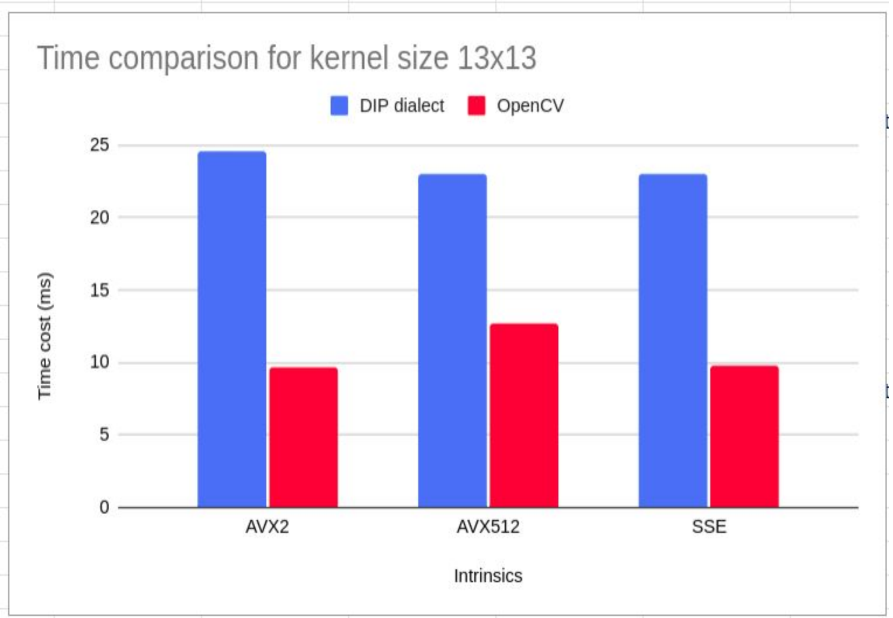






Performance data





Operations currently supported by the DIP dialect:

- 1D and 2D Image Filtering
- Image Resizing
- IFFT on Images
- Image Rotation
- FFT on Images
- Image Morphology

Potential Scope

Target more hardware?

Integrate with existing MLIR based ML workflows

Interoperability with linalg dialect

Networking

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References

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- https://github.com/buddy-compiler/buddy-benchmark
- https://carbon.now.sh/
- Lucidchart