Manual Convolution and Kernel Analysis for Image Processing

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Introduction

This report covers experiments performed using manual convolution on images and the effects of different kernels, kernel sizes, strides, and padding. Additionally, an ablation study is presented to analyze the impact of hyperparameters on test accuracy.

Detailed Experiment Report

1. Effect of Different Kernels on the Image

Different kernels have varying effects on images as they emphasize specific features or suppress others:

- **Edge Detection Kernels:** Highlight transitions in pixel intensity, making edges visible (e.g., Sobel or Prewitt kernels).

- **Blur Kernels:** Average neighboring pixel values, reducing noise and fine details.

- **Sharpen Kernels:** Enhance edges by amplifying differences between pixel intensities, making the image crisper.

2. Impact of Kernel Size, Stride, and Padding

Kernel Size:

- Larger kernels capture more global features but may blur details.

- Smaller kernels capture finer details but miss broader patterns.

Stride:

- Higher strides reduce resolution and details.

- Smaller strides preserve more information.

Padding:

- *Same Padding:* Retains the original size, preserving edge features.

- *Valid Padding:* Reduces output size, possibly truncating edge features.

3. Observations from Convolution vs. Correlation Results

Convolution:

- Flips the kernel both vertically and horizontally before applying it.

- Sensitive to the orientation of features in the image.

Correlation:

- Applies the kernel directly without flipping.

- Easier to interpret when the kernel represents a feature detector.

Symmetric Kernels: Convolution and correlation produce identical results as flipping does not alter the structure. **Non-Symmetric Kernels:** Produce different results due to the flipping operation in convolution.

4. Analysis of Kernels for Edge Detection

- **Sobel Kernel:** Detects vertical or horizontal edges.

- **Laplacian Kernel:** Highlights edges in all directions.

Edge detection kernels are effective for object boundary detection in computer vision.

5. Analysis of Kernels for Blurring

- **Box Blur:** Uniformly averages neighboring pixels, resulting in a smooth blur.

- **Gaussian Blur:** Provides a smoother blur with less noise than box blur.

Blurring kernels are useful for noise reduction or edge detection preparation.

6. Analysis of Kernels for Sharpening

- **Simple Sharpen Kernel:** Enhances edges by amplifying contrast between center and neighbors.

- **Unsharp Masking Kernel:** Combines blurred and original images for edge enhancement.

Sharpening kernels improve clarity and highlight features for further processing.

7. Advantage of Applying Multiple Kernels

- **Edge Detection After Smoothing:** Reduces noise, preventing false edges.

- **Multi-Scale Feature Extraction:** Combines local and global feature capture.

- **Enhanced Image Processing:** Sequential kernel application emphasizes important details.

For example, applying a Gaussian blur followed by a Sobel edge detector produces clean edges without noise interference.

Conclusion

The experiments demonstrate the power of kernels in image processing. Understanding the effects of kernel size, stride, and padding, along with distinguishing between convolution and correlation, allows for tailored image transformations. Applying multiple kernels sequentially enhances processing capabilities, offering robust solutions for complex image analysis challenges.

Ablation Study Results

The table below summarizes the impact of different hyperparameters on test accuracy.

Learning Rate	Batch Size	Num Filters	Num Layers	Test Accuracy
0.001	16	32	3	0.6689
0.001	16	32	5	0.6308
0.001	16	64	3	0.6736
0.001	16	64	5	0.6725
0.001	32	32	3	0.6658
0.001	32	32	5	0.6255
0.001	32	64	3	0.6851
0.001	32	64	5	0.6736
0.01	16	32	3	0.1000
0.01	16	32	5	0.1000
0.01	16	64	3	0.1000
0.01	16	64	5	0.1000
0.01	32	32	3	0.1000
0.01	32	32	5	0.1000
0.01	32	64	3	0.4228
0.01	32	64	5	0.1000

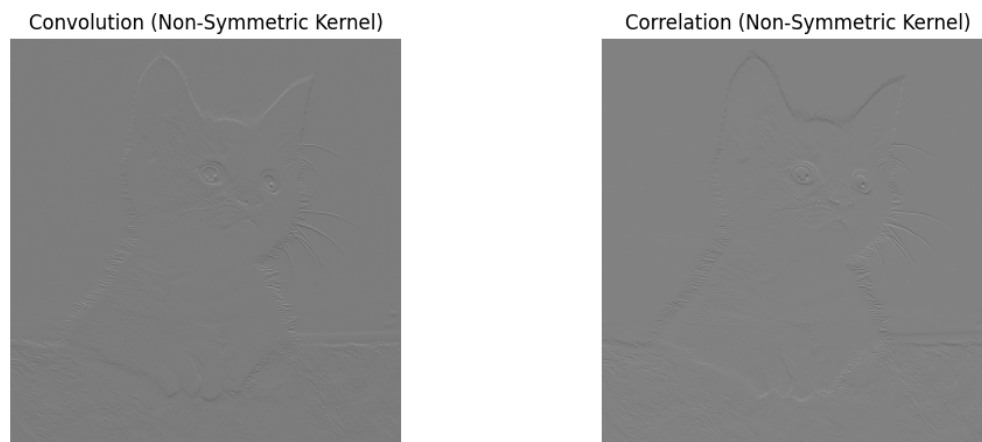Table 1: Ablation Study Results

Visualizations

Figure 1: Edge Detection Results

Figure 2: Blurred Images

Figure 3: Sharpened Images