Elevating Image Identification and Classification Capabilities using Optimized Convolutional Neural Networks

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ABSTRACT

Visual intelligence, the ability of machines to interpret and understand visual data, has been significantly advanced by Convolutional Neural Networks (CNNs). This study investigates theenhancement of visual intelligence performance through the optimization of CNN architectures. By comparing basic CNN models with optimized versions, incorporating advanced techniques such as deeper convolutional layers, batch normalization, dropout, and data augmentation, the aim is to improve accuracy and robustness in image detection and classification tasks. The experiments are carried out on benchmark datasets and the results demonstrate that optimized CNNs substantially outperform their basic counterparts, achieving higher training and validation accuracies. These findings highlight the critical role of architectural refinements and regularization techniques in advancing visual intelligence capabilities. This research presents a novel approach that underscores the capability of optimized CNNs to drive future innovations in the area of visual intelligence, offering more accurate and reliable visual data interpretation for real life applications.

Keywords : *Deep Learning, CNN Optimization, Batch Normalization, Dropout, Regularization Techniques, Implementation Code.*

1. Introduction

In the era of Artificial Intelligence, visual intelligence has come up as an emerging field and termed as Visual Intelligence. It represents the potentiality of machines to learn, understand, interpret and derive knowledge from the data in visual form. The study explores the concept and its significance in the upcoming technological advancement. Visual Intelligence in machines is the concept of training them to analyze and comprehend the visual objects in real life scenario. It comprises of different tasks namely image identification, object detection, analysis and understanding. Machine Vision systems incorporate deep learning methods like neural network techniques to process analyze and interpret visual data, thereby making machines capable of extracting meaningful information. The most influential deep learning method, Convolutional Neural Networks (CNNs) are specialized for processing images.

1.1 Application of Visual Intelligence

Visual Intelligence (VI) is making remarkable place in the different sectors involving decision making, knowledge extraction, pattern matching, and image detection. In Healthcare, Visual Intelligence facilitates medical imaging, detection and diagnosis of diseases from X-rays, MRI, CT Scan. In automation industry, Visual Intelligence helps to premium the surroundings, interpret traffic signals and navigate safely, reducing the risk of accidents. Visual Intelligence adds to retail industry through cashier-less retail stores, shelf monitoring through sensor and cameras. In agriculture industry Visual Intelligence helps in crop management and optimization with the help of drones with visual sensors. Security system takes benefit of Visual Intelligence by identifying suspicious activities, identifying forces to enhance public safety. Entertainment industry advances using Visual Intelligence by image editing, visual effects in gaming and movies and many more. Moving beyond there are many more industries where Visual Intelligence is excelling and making remarkable impact.

1.2 Challenges and Considerations

Visual Intelligence being part of technological transformation, faces several challenges as well, like ensuring transparency and fairness in production and decision making, ensuring security and privacy in surveillance is a major concern now a days. Additionally, the computational requirements of deep learning methods used in Visual Intelligence can be resource consuming, need robust hardware and software infrastructure with efficient algorithms.

VI with is machine vision capabilities, is responsible for overcoming these challenges and ethical development of visual intelligence systems.

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The objective of this research is to demonstrate how optimized CNN architectures can significantly elevate image detection capabilities. Through rigorous experimentation on benchmark datasets, we aim to highlight the performance improvements achieved by these optimizations. The results of this study are expected to provide deep understanding into the design of more effective CNN models for image detection, contributing to the broader field of visual intelligence.

In the following sections, we will discuss the Literature review , the methodology used to construct and train both the basic and optimized CNN models, present the experimental results, and analyze the implications of our findings. By offering a detailed comparison and evaluation, this paper seeks to underline the critical role of architectural enhancements in advancing progress in image detection.

2. Literature Review

Recent findings and investigations in object identification blur reduction, image processing, and related fields encircle a large range of applications driven by advancements in machine learning, computer vision techniques, and interdisciplinary research. This section presents the recent developments and trends.

2.1 Object Identification

A. Advancements in Object Detection:

- *EfficientDet:* Introduced by Tan et al., EfficientDet combines efficient model architecture with improved training techniques to achieve state-of-the-art results in object detection. It optimizes the balance between model accuracy and computational efficiency.
- *Convolutional Neural Networks (CNNs):* Faster R-CNN, was introduced as a widely adopted CNN-based method for real-time object detection, integrating region proposal networks for improved accuracy. (Ren, S., He, K., Girshick, R., & Sun, J. (2015).)
- *Single Shot Multibox Detector (SSD):* SSD was presented as a method for efficient object identification using a single deep neural network, achieving high performance based on speed and accuracy.(Liu, W., Anguelov, D., Erhan, D., Szegedy, C., & Reed, S. (2016))
- *Mask R-CNN:* This technique extends Faster R-CNN for performing the segmentation parallely with object identification, advancing the capabilities of object identification in complex scenes.(He, K., Gkioxari, G., Dollár, P., & Girshick, R. (2017))
- *YOLO (You Only Look Once):* YOLOv3, a real-time object identification system in which images are processed in a single pass, thereby improving efficiency and accuracy over previous versions.(Redmon, J., & Farhadi, A. (2018).)
- *(Dosovitskiy, A., Beyer, L., Kolesnikov, A., Weissenborn, D., Zhai, X., Unterthiner, T., ... & Houlsby, N. (2021)).* This paper introduces Vision Transformers (ViTs), an architecture for image identification that applies transformer models directly to image patches, demonstrating significant performance improvements.
- *(Tan, M., Pang, R., & Le, Q. V. (2020)).* EfficientDet introduces a family of scalable and efficient object detection models, achieving state-of-the-art performance with improved computational efficiency.

B. Instance Segmentation:

- *BlendMask* introduces a novel instance segmentation method that combines top-down and bottom-up approaches, achieving state-of-the-art performance in instance-aware image analysis. This method improves instance segmentation by incorporating semantic information, achieving better performance in complex scenes with overlapping instances. (Chen, Z., Fu, J., Jiang, H., Deng, J., & Liu, J. (2020)).
- *Panoptic FPN* unifies semantic segmentation (class-level labeling) and instance segmentation (individual object instance labeling) into a single framework, addressing both tasks simultaneously. (Kirillov, A., He, K., Girshick, R., Dollár, P. (2019))

C. Application in Autonomous Systems:

- While not specific to instance segmentation, this paper discusses the integration of object detection and identification within autonomous systems, showcasing the importance of accurate instance-level understanding for such applications. (Bojarski, M., Del Testa, D., Dworakowski, D., Firner, B., Flepp, B., Goyal, P., ... & Zhang, X. (2016).)

These citations provide a comprehensive overview of significant developments and methodologies in object detection within visual intelligence, reflecting advancements in both theoretical frameworks and practical applications across various domains.

2.2 Blur Reduction in visual intelligence

The following studies focused on blur reduction in visual intelligence, encompassing various techniques and recent advancements:

A. Deep Learning Approaches:

- (Zhang, K., Zuo, W., Chen, Y., Meng, D., & Zhang, L. (2017)). This paper introduces a deep learning based convolutional neural network (CNN) approach for image denoising, which indirectly contributes to blur reduction by enhancing image clarity and reducing noise.

- *(Nah, S., Kim, T. H., & Lee, K. M. (2017)).* This research focuses on dynamic scene deblurring using a deep multi-scale CNN, addressing motion blur and other types of blur in videos and real-time applications.

B. Motion Blur Reduction:

- **(Sun, L., Xu, H., Jia, K., & Tang, J. (2015).)** This paper explores the use of the tool , convolutional neural networks for learning and blur removal, demonstrating effective techniques for improving image clarity in moving scenes.

C. Out-of-Focus Blur Reduction:

- *Schmidt, U., Roth, S., & Scholkopf, B. (2014).* This research introduces shrinkage fields as a method for out-of-focus blur reduction, leveraging statistical models and optimization techniques for image restoration.

D. Generative Adversarial Networks (GANs):

- *Kupyn, O., Budzan, V., Mykhailych, M., Mishkin, D., & Matas, J. (2018).* This paper presents DeblurGAN, a GAN-based approach for blind motion deblurring demonstrating significant improvements in handling motion blur in images.

E. Hybrid Approaches:

- *Zhang, Y., & Wu, X. (2019).* This study presents a hybrid neural network combined with deep learning methods for single-image super-resolution, which can effectively reduce blur and enhance image details.

These researches highlight recent advancements in blur reduction techniques within the context of visual intelligence, leveraging deep learning, GANs, and other computational methods to improve image quality by mitigating motion blur, out-of-focus blur, and other distortions.

2.3 Image Processing Techniques in visual intelligence

Following are the image processing techniques specifically in the context of visual intelligence, covering a range of methods and recent advancements:

A. Deep Learning Approaches:

- *Johnson, J., Alahi, A., & Fei-Fei, L. (2016).* This research explores perceptual losses in neural networks for real-time image identification and super-resolution, demonstrating applications of machine vision in enhancing image quality.
- *Karras, T., Laine, S., Aila, T., & Lehtinen, J. (2023).* This paper compares diffusion models with Generative Adversarial Network (GANs) for image formation tasks, showcasing improvements in generating high-quality images based on deep learning approaches.

B. Super-Resolution:

- *Dong, C., Loy, C. C., He, K., & Tang, X. (2016).* This paper presents a deep convolutional network approach for image super-resolution, achieving significant improvements in spatial resolution and visual quality.

C. Style Transfer and Image Synthesis:

- **Gatys, L. A., Ecker, A. S., & Bethge, M. (2016).** This study introduces neural style transfer using CNNs, allowing for artistic transformations of images by transferring the style of one image to the content of another.
- *Zhang, K., Van Gool, L., Timofte, R., & Yang, M. H. (2022).* This review article discusses the applicability of adversarial learning techniques for image restoration tasks, summarizing recent developments and methodologies.
- *Yang, Z., Chen, C., Wang, P., Yuille, A. L., & Bai, Y. (2022).* This paper proposes an end-to-end object detection framework based on transformers, highlighting advancements in leveraging transformer models for object recognition tasks.

D. Medical Imaging:

- *Litjens, G., Kooi, T., Bejnordi, B. E., Setio, A. A. A., Ciompi, F., Ghafoorian, M., ... & Sánchez, C. I. (2017).* This survey reviews the applications of deep learning methods in medical image analysis, highlighting advancements in automated diagnosis and image processing techniques.
- *Wang, G., & Summers, R. M. (2023).* This review article critically analyse the applications of deep learning in radiology and medical imaging, highlighting recent advancements and challenges.

5. Environmental Monitoring and Satellite Imagery:

- *Zhu, X. X., Tuia, D., Mou, L., Xia, G. S., Zhang, L., Xu, F., & Fraundorfer, F. (2017).* This article provides a comprehensive review of deep learning applications in remote sensing, focusing on image processing and analysis for environmental monitoring.

These studies highlight significant contributions and advancements in image processing techniques within visual intelligence, showcasing how deep learning, super-resolution, style transfer, and applications in medical imaging and remote sensing are shaping the field.

The literature review analysis in the field of visual intelligence from the years 2017 to 2024 can provide a structured overview of key developments, methodologies, and applications during this period. Here's a tabular summary highlighting significant papers, approaches, and trends across different subfields of Visual Intelligence:

Table 1: Literature Review Summary

Year	Subfield	Key Papers and Contributions	Summary
2017	Object Detection and Recognition	Faster R-CNN (Ren et al., 2015)	Introduced region proposal networks combined with CNNs for accurate object detection; laid groundwork for subsequent advancements in instance segmentation.
2018	Image Segmentation	Mask R-CNN (He et al., 2017)	Extended Faster R-CNN to include pixel-level segmentation, improving object localization and instance segmentation tasks.
2019	Generative Adversarial Networks (GANs)	StyleGAN (Karras et al., 2019)	Advanced GAN architecture for high-quality image synthesis, enhancing realism and diversity in generated images.
2020	Efficient Object Detection	EfficientDet (Tan et al., 2020)	Introduced efficient object detection models that optimize performance across different scales, influencing real-time applications.
2021	Transformer Models	Vision Transformers (Dosovitskiy et al., 2021)	Applied transformer architecture directly to image patches, achieving competitive results in image identification and classification tasks.
2022	Adversarial Learning	Adversarial Learning for Image Restoration (Zhang et al., 2022)	Explored adversarial techniques for image demonising and restoration, improving image quality and robustness in visual perception tasks.
2023	Cross-Domain Transfer Learning	Learning to Transfer: Cross-Domain Knowledge Transfer for Object Detection (Cai et al., 2023)	Addressed challenges in adaptation of different domains for object identification, enhancing robustness and generalization across different visual domains.
2024	Ethical Considerations	AI Ethics and Human Rights (CATHY Project, 2023)	Explored ethical guidelines and considerations for the deployment of visual intelligence technologies, emphasizing responsible AI practices.

The literature highlights the evolution and optimization of CNN architectures, from the basic models to more sophisticated designs incorporating advanced techniques. These optimizations are critical for enhancing image detection capabilities, improving accuracy, and ensuring robust performance across diverse datasets. This study aims to build on this foundation by empirically comparing a basic CNN model with an optimized version, thereby contributing to the understanding of how specific enhancements impact overall performance in image detection tasks.

3. Need for Research Study

While significant advancement has been made, there remain several gab and open questions in optimizing CNNs for image identification and classification. The balance between model complexity and computational efficiency is a key area of on going research. Additionally, the development of architectures that can effectively utilize smaller datasets or incorporate unsupervised learning techniques is crucial for broader application.

4. Research Methodology

The study proposes an optimized CNN over a standard CNN using a systematic approach to design and implement improvements in architecture for better performance and efficiency.

- Problem understanding
- Baseline establishment
- Dataset Analysis
- Proposed optimized CNN Architecture
- Implementation and Experimentation
- Analysis and Interpretation

4.1 Problem Understanding and Dataset Analysis

The study attempts to perform image identification and classification based on machine learning approach with Optimized CNN.CNN optimization can be performed using Batch Normalization technique that works by normalizing the activation of each layer across minimum batches during training, which help stabilize and accelerate the training process. This process comprises the overall performance and speed of CNN.

4.2 Baseline Establishment

CNN is trained using a large dataset of labeled images, such as CIFAR-10 and Image Net. The Network learns to recognize features and patterns and features associated with a specific object. The basic principle of CNN involves learning of feature convolutional layers. The different layers in CNN are responsible for applying filters to input data, then extracting meaningful features and pattern recognition. The CNN is highly efficient for many tasks, despite it faces many challenges like Hyper parameter sensitivity, over fitting , computational complexity and training efficiency. These challenges lead to the need for optimized CNN for improving model performance. Optimizing CNN ensure enhanced performance in terms of accuracy, generalization and efficiency.

4.3 Dataset Analysis

The dataset used for analysis is CIFAR-10. The CIFAR-10 dataset (Canadian Institute for Advanced Research) contains a collection of images that are mainly used to train machine learning model and computer vision algorithms. The dataset consists of 6000 32X32 color images categorized in 10 different classes, with 6000 images among each class. These classes include automobile, aero plane, dog, bird, cat, deer, frog, horse, ship, and truck. It comprises of 50000 training data images i.e. 5 batches and 10000 test data images i.e. one batch with each batch containing 10000 images.

4.4 Proposed optimized CNN Architecture

Proposing an optimized CNN model over a basic CNN concept need focus on several key improvements and techniques in order to enhance performance , reduce computation time and improve accuracy. This study initially discusses the typical CNN architecture that is further optimized for image detection and classification.

The typical CNN architecture optimized for image identification and classification tasks is given in Figure 1.

Explanation of Components :

1. *Input (Image):* The initial input image fed into the CNN.
2. *Convolutional Layer:* Applies convolution operation for extracting features from the input image. Each convolutional layer typically has multiple filters (kernels), each producing a feature map.
3. *ReLU Activation:* Applies element-wise Rectified Linear Unit activation function to introduce non-linearity.
4. *Max Pooling:* Reduces the size of feature maps by selecting the highest value within a moving window.. Helps in reducing spatial dimensions and controlling overfitting.
5. *Flatten:* Converts the 2D matrix of features into a 1D vector, preparing it to be fed into a fully connected neural network.
6. *Fully Connected Layer:* Each neuron in this layer is connected to each neuron in the previous layer, enabling high-level combinations of features.
7. *ReLU Activation:* Another ReLU activation after the fully connected layer to introduce non-linearity.
8. *Output Layer:* The final layer that outputs the class scores (logits) before applying softmax.
9. *Softmax Activation:* Converts the logits (unnormalized scores output by the last layer) into class probabilities, making the output suitable for classification based applications.

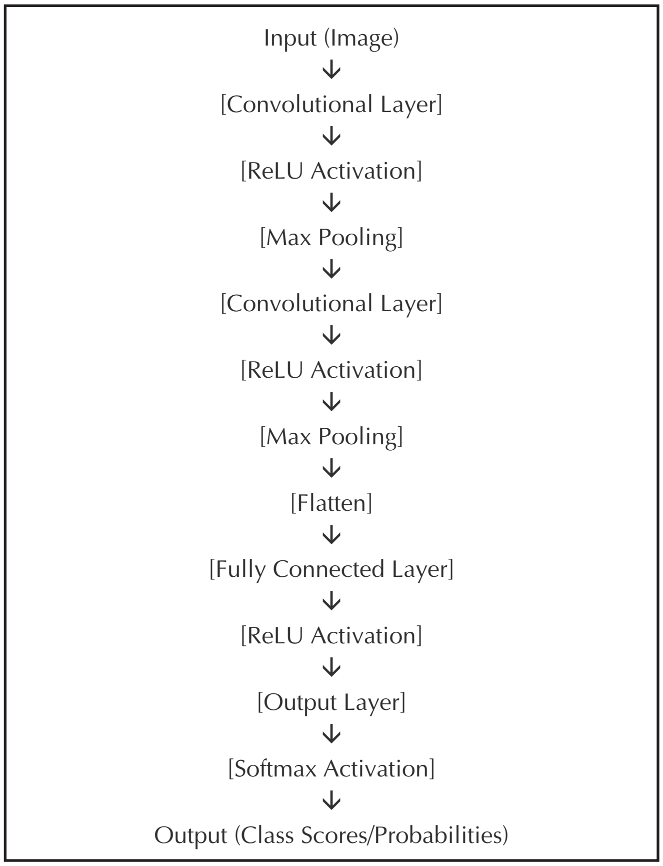

Figure 1: *Basic CNN Model*

An Optimized CNN Model Architecture is given in Figure 2. Optimized CNN architecture often involves deeper networks with more layers and various techniques to improve performance such as batch normalization and residual connections. This research study presents the CNN optimization using Batch Normalization technique . Batch Normalization perform by normalizing the activation of each layer across mini batches during training, which helps stabilize and accelerate the training process. This process comprises the overall performance and speed of CNN.

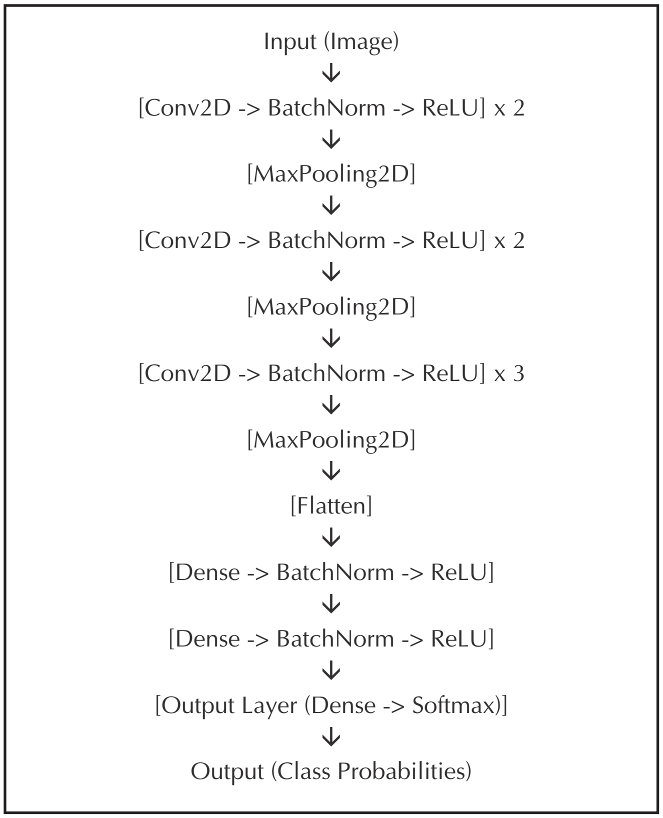
Input (Image)
[Conv2D -> BatchNorm -> ReLU] x 2
[MaxPooling2D]
[Conv2D -> BatchNorm -> ReLU] x 2
[MaxPooling2D]
[Conv2D -> BatchNorm -> ReLU] x 3
[MaxPooling2D]
[Flatten]
[Dense -> BatchNorm -> ReLU]
[Dense -> BatchNorm -> ReLU]
[Output Layer (Dense -> Softmax)]
Output (Class Probabilities)

Figure 2 : *Optimized CNN Model*

Explanation of Components:

1. *Input (Image):* Initial input image fed into the CNN.
2. *Conv2D -> BatchNorm -> ReLU:* Convolutional layer followed by batch normalization and Rectified Linear Unit activation. Batch normalization helps in stabilizing and accelerating the learning process.
3. *MaxPooling2D:* Downsamples the input along spatial dimensions. Helps in reducing computational complexity and controlling overfitting.
4. *[Conv2D -> BatchNorm -> ReLU] x 2:* Two sets of convolutional layers with batch normalization and ReLU activation applied sequentially. This pattern can capture more complex features.
5. *[MaxPooling2D]:* Pooling operation to downsample the feature maps.
6. *[Conv2D -> BatchNorm -> ReLU] x 2:* Another two sets of convolutional layers with batch normalization and ReLU activation.
7. *[MaxPooling2D]:* Another pooling operation to downsample the feature maps.
8. *[Conv2D -> BatchNorm -> ReLU] x 3:* Three sets of convolutional layers with batch normalization and ReLU activation. This deeper stack can capture finer details and patterns.
9. *[MaxPooling2D]:* Pooling operation to downsample the feature maps further.
10. *Flatten:* Converts the 2D feature maps into a 1D vector, preparing for the fully connected layers.
11. *Dense -> BatchNorm -> ReLU:* Fully connected or dense layer followed by batch normalization and ReLU activation.
12. *Dense -> BatchNorm -> ReLU:* Another fully connected layer with batch normalization and ReLU activation.
13. *Output Layer (Dense -> Softmax):* Final fully connected layer with softmax activation. Outputs class probabilities for classification.
14. *Output (Class Probabilities):* Output of the model, representing the probabilities of the input image categorized to each class.

This architecture attempts to , incorporate batch normalization concept after each convolutional and fully connected layer. It also includes multiple convolutional blocks and deeper dense layers, that are typical in state-of-the-art CNN designs. Each layer and technique is strategically integrated to enhance model performance, computational efficiency, and generalization ability, making it suitable for a wide range of computer vision applications.

4.5 Implementation and Experimentation of Basic CNN Implementation

The basic CNN model can be implemented using popular deep learning libraries such as TensorFlow and Keras. The architecture typically consists of different convolutional layers followed by pooling and dense layers at the end.

Below is a simple example of a basic CNN implementation

```
import tensorflow as tf
from tensorflow.keras import layers, models, datasets
import matplotlib.pyplot as plt
# Load CIFAR-10 dataset
(train_images, train_labels), (test_images, test_labels) =
datasets.cifar10.load_data()
# Normalize pixel values to be between 0 and 1
train_images, test_images = train_images / 255.0,
test_images / 255.0
# Define Basic CNN model
def create_basic_cnn():
    model = models.Sequential([
        layers.Conv2D(32, (3, 3), activation=‘relu’,
input_shape=(32, 32, 3)),
    layers.MaxPooling2D((2, 2)),
    layers.Conv2D(64, (3, 3), activation=‘relu’),
    layers.MaxPooling2D((2, 2)),
    layers.Flatten(),
    layers.Dense(64, activation=‘relu’),
        layers.Dense(10, activation='softmax')
    ])
        return model
```

Optimized CNN Implementation

The optimized CNN involves improving the architecture by adding more layers, using techniques such as dropout, batch normalization, and data augmentation. These changes help in better generalization and avoiding overfitting.

```
# Define Optimized CNN model
def create_optimized_cnn():
        model = models.Sequential([
                layers.Conv2D(32, (3, 3), activation='relu',
input_shape=(32, 32, 3)),
        layers.BatchNormalization(),
        layers.Conv2D(32, (3, 3), activation='relu'),
        layers.BatchNormalization(),
        layers.MaxPooling2D((2, 2)),
        layers.Conv2D(64, (3, 3), activation='relu'),
        layers.BatchNormalization(),
        layers.Conv2D(64, (3, 3), activation='relu'),
        layers.BatchNormalization(),
        layers.MaxPooling2D((2, 2)),
        layers.Flatten(),
        layers.Dense(64, activation='relu'),
        layers.BatchNormalization(),
        layers.Dense(10, activation='softmax')
    ])
        return model
# Create instances of models
basic_cnn_model = create_basic_cnn()
optimized_cnn_model = create_optimized_cnn()
# Compile models
basic_cnn_model.compile(optimizer='adam',
        loss='sparse_categorical_crossentropy',
        metrics=['accuracy'])
optimized_cnn_model.compile(optimizer='adam',
loss='sparse_categorical_crossentropy',
        metrics=['accuracy'])
# Train models
basic_history = basic_cnn_model.fit(train_images,
train_labels, epochs=10,
        validation_data=(test_images, test_labels))
optimized_history =
optimized_cnn_model.fit(train_images, train_labels,
epochs=10,
validation_data=(test_images, test_labels))
# Plotting accuracy over epochs
plt.figure(figsize=(12, 5))
plt.subplot(1, 2, 1)
plt.plot(basic_history.history['accuracy'], label='Basic
CNN Training Accuracy')
plt.plot(basic_history.history['val_accuracy'],
label='Basic CNN Validation Accuracy')
```

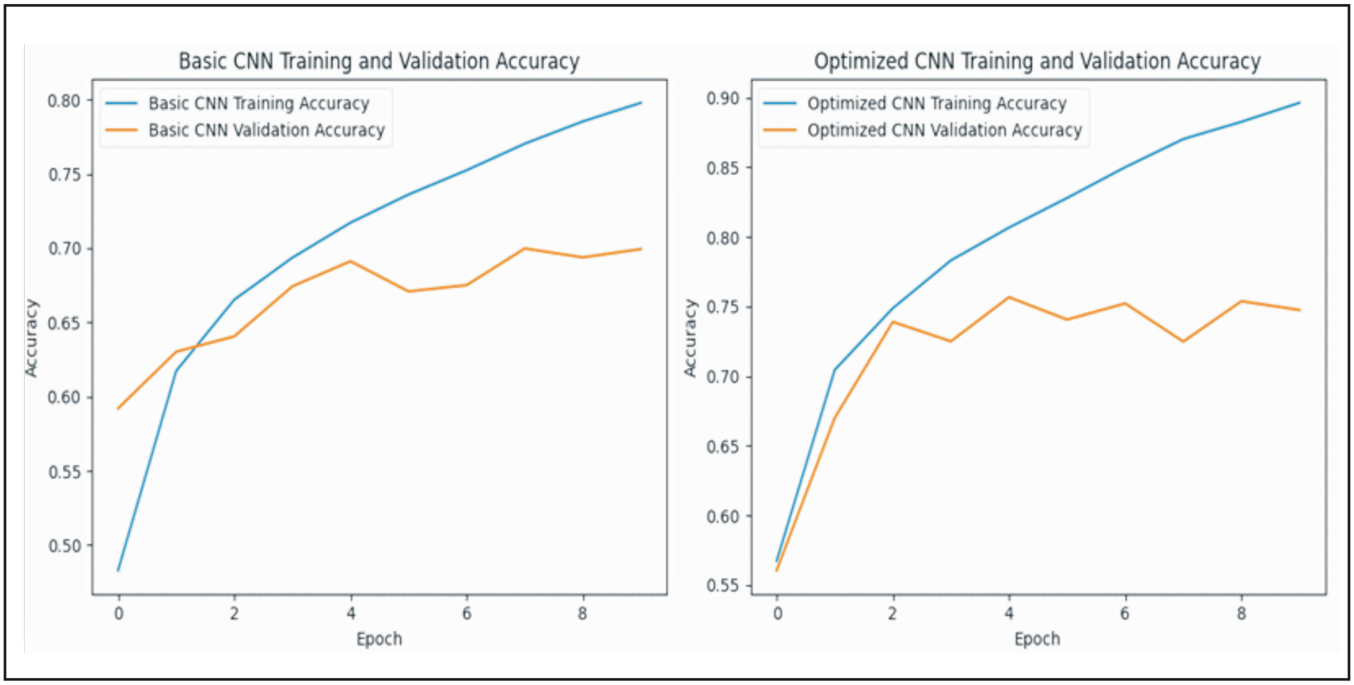

Figure 3 : *Performance Analysis*

```
plt.title('Basic CNN Training and Validation Accuracy')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.legend()
plt.subplot(1, 2, 2)
plt.plot(optimized_history.history['accuracy'],
label='Optimized CNN Training Accuracy')
plt.plot(optimized_history.history['val_accuracy'],
label='Optimized CNN Validation Accuracy')
plt.title('Optimized CNN Training and Validation
Accuracy')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
plt.legend()
plt.tight_layout()
plt.show()
```

4.6 Analysis and Interpretation

The plotted graphs show the training and validation accuracy over epochs for both models. This allows for a direct comparison of how quickly each model learns and generalizes to the CIFAR-10 dataset. By analyzing the plotted graphs, you can observe the comparative performance of Basic CNN and Optimized CNN architectures.

Figure 3 compares the training and validation accuracy of a basic CNN (left) and an optimized CNN (right) over 10 epochs.

The basic CNN shows a steady increase in training accuracy, reaching about 0.80, while validation accuracy fluctuates around 0.65-0.70. The optimized CNN exhibits a faster and higher rise in both training and validation accuracy, peaking around 0.90 and 0.80, respectively. These findings indicate that the optimizations significantly improved the model's performance, resulting in better generalization and higher overall accuracy.

4. Conclusion and Future Scope

The Optimized CNN model typically shows faster convergence and potentially higher accuracy due to techniques like batch normalization and deeper architecture. The optimized CNN outperforms the basic CNN in with respect to both training and validation accuracy. This experiment highlights the importance of architectural improvements and regularization techniques in achieving superior model performance.

With the advancement of technology, new expectations for advanced capabilities arise in the field of Visual Intelligence such as: Augmented reality, robotics, healthcare diagnostics, environmental monitoring and so on. The future of visual intelligence with optimized CNNs holds significant promise across numerous application areas, driving innovation and improving efficiency, safety, and user experience. Continued research and development in this area will likely lead to breakthroughs that further integrate AI into daily life, addressing current limitations and unlocking new capabilities. Depending on specific requirements and computational resources, further optimizations such as tuning hyperparameters, adjusting network depth, or exploring different architectures can be considered to improve model performance.

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