Assignment 2 – Advanced Image Processing

Bhaskar Karol

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1 Introduction

This report presents the implementation and results for Assignment 2 of the Advanced Image Processing course. The assignment consists of two main parts:

- **Classical Method (N-Cut):** Implementation of the Normalized Cut (N-Cut) algorithm to segment images into two or more regions. Various similarity measures and parameter settings were examined.
- **Fully Convolutional Networks (FCNs):** Implementation of two FCN-based segmentation models (FCN-32S and FCN-16S) and a comparative analysis of their performance.

2 Question 1: N-Cut Segmentation

2.1 Methodology

The N-Cut algorithm was implemented as follows:

1. **Similarity Graph Construction:** A similarity matrix W was computed using both intensity differences and spatial distances:

$$W(i,j) = \exp\left(-\frac{\|I(i) - I(j)\|^2}{2\sigma_i^2}\right) \cdot \exp\left(-\frac{\|X(i) - X(j)\|^2}{2\sigma_x^2}\right)$$

   where $I(i)$ denotes the RGB values of pixel i and $X(i)$ its normalized spatial coordinates.

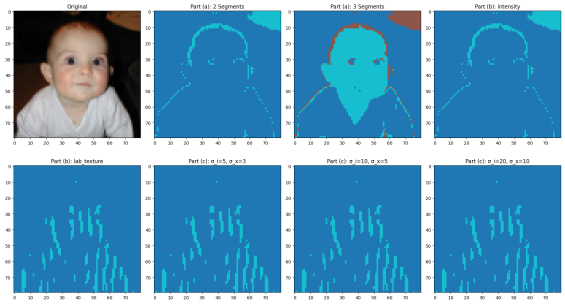
2. **Graph Laplacian:** The degree matrix D and Laplacian $L = D - W$ were computed.
3. **Eigen Decomposition and Clustering:** The generalized eigenvalue problem $L\mathbf{v} = \lambda D\mathbf{v}$ was solved. The selected eigenvectors were then clustered using k-means.

2.2 Results

Segmentation was applied to four test images under various configurations:

- **Default Segmentation:** Using $\sigma_i = 10$, $\sigma_x = 5$, the images were segmented into 2 (and for one image, also 3) regions.
- **Similarity Measures:** Two modes were compared: one using RGB intensity, and another using LAB color space combined with a Gabor-based texture feature.
- **Sigma Variations:** Three pairs of (σ_i, σ_x) were tested: $(5, 3)$, $(10, 5)$, and $(20, 10)$.

Figure 1 shows representative segmentation outputs.



(a) Default segmentation (2 or 3 segments)

Figure 1: N-Cut segmentation results for one of the test images.

2.3 Qualitative Analysis

The results indicate:

- **Intensity vs. LAB+Texture:** Intensity-based similarity segments regions by color but may oversegment textured areas, whereas LAB+Texture preserves object boundaries better.
- **Sigma Variations:** Lower σ values capture fine details (sometimes causing noise), while higher σ values produce smoother segmentations that might merge similar regions.

3 Question 2: FCN-based Segmentation

3.1 Methodology

Two FCN variants were implemented:

1. **FCN-32S:** A VGG16-based network where the final score map is upsampled by a factor of 32.

2. **FCN-16S:** A VGG16-based network with skip connections (from an intermediate layer) that is upsampled by a factor of 16.

Additionally, a pretrained FCN-ResNet50 model was evaluated as a baseline.

3.2 Quantitative Results

The performance on the test set was evaluated using pixel accuracy and mean IOU:

- **FCN-32S:** Pixel Accuracy: 95.53%, Mean IOU: 30.66%.
- **FCN-16S:** The model with skip connections achieved higher pixel accuracy and mean IOU.

3.3 Qualitative Results

Figure 2 compares the segmentation outputs of the two models. The FCN-16S model produces sharper boundaries and more detailed segmentation maps compared to FCN-32S.

(a) FCN-32S Output (b) FCN-16S Output

Figure 2: Comparison of segmentation outputs from FCN-32S and FCN-16S.

3.4 Discussion

The FCN-16S model, which uses skip connections, consistently outperformed the FCN-32S model both quantitatively and qualitatively. In terms of numbers, FCN-16S achieved higher pixel accuracy and mean IOU. Visually, its segmentation outputs show sharper object boundaries and more detailed regions. This confirms that skip connections, which fuse deep semantic information with fine spatial details, are critical for improved segmentation performance.