Skin Lesion Analysis

By Umut Celik Email: umut.celik@cix.csi.cuny.edu

CSC 741 - Digital Image Processing Midterm Project

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1. Introduction

The Challenge

- Automated analysis of dermoscopic images is crucial for early skin cancer detection.
- These images present challenges: varying illumination, hair, diverse skin tones, and subtle lesion characteristics.

Project Goal

- To develop an image processing pipeline to:
  1. Segment (isolate) skin lesions from dermoscopic images.
  2. Extract a comprehensive set of visual features from the segmented lesions.
- Apply fundamental Digital Image Processing techniques to a real-world medical imaging problem.

Dataset

- **Source:** SIIM-ISIC Melanoma Classification (Kaggle).
- **Content:** Dermoscopic images (JPEG format) and associated metadata (e.g., labels).

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2. Image Processing Pipeline

A multi-step approach to process images and extract meaningful data:

Image Loading & Conversion -> Preprocessing -> Color Space Transformation -> Segmentation -> Feature Extraction

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Step 1: Image Loading & Initial Conversion

- **Action:** Load JPEG images.
- **Conversion:** Convert from BGR (OpenCV default) to RGB for consistency in processing and display.
  - *Files involved:* `src/data_loader.py`

Step 2: Preprocessing

- **Grayscale Conversion:**
  - Convert RGB images to grayscale for intensity-based operations.
  - *Function:* `rgb_to_grayscale` *in* `src/color_utils.py`
- **Hair Removal:**
  - Technique: Morphological Black-Hat filtering to identify hair structures, followed by inpainting to remove them.
  - Reduces noise and artifacts caused by hair.
  - *Function:* `remove_hair` *in* `src/preprocessing.py`
- **(Illumination Correction):**
  - *Concept: Use morphological opening to estimate and correct non-uniform background illumination.*
  - *Status: Implemented (* `correct_illumination` *in* `src/preprocessing.py` *), but noted as potentially skipped in some display pipelines for directness to segmentation.*

Step 3: Color Space Transformation

- **RGB to HSV:**
  - Convert RGB images to Hue, Saturation, Value (HSV) color space.
  - HSV is often more intuitive for color-based feature extraction:
    - **H (Hue):** Dominant color.
    - **S (Saturation):** Purity/intensity of color.
    - **V (Value):** Brightness.
  - *Function:* `rgb_to_hsv` *in* `src/color_utils.py`
- **Ida (Darkness) Channel:**
  - Calculate Ida channel defined as `max(R,G,B) - min(R,G,B)` per pixel.

- Represents color spread or darkness in the image.
    - Used for darkness-based feature extraction (f19-f28).
    - *Function:* `calculate_ida_channel` *in* `src/color_utils.py`

Step 4: Lesion Segmentation

- **Goal:** Create a binary mask that accurately isolates the lesion area.
- **Method: Otsu's Thresholding**
    - Applied to the preprocessed (hair-removed) grayscale image.
    - Automatically determines an optimal threshold value to separate lesion pixels from background.
    - *Function:* `otsu_threshold` *in* `src/segmentation.py`
- **Mask Refinement:**
    - Technique: Morphological operations.
        - **Opening:** Erosion followed by dilation (removes small noise/objects).
        - **Closing:** Dilation followed by erosion (fills small holes within the lesion).
    - Improves the quality and contiguity of the mask.
    - *Functions:* `opening`*,* `closing` *in* `src/morphology.py`*, utilized by* `apply_threshold` *in* `src/segmentation.py`

Step 5: Feature Extraction

Extracted from the segmented lesion area (defined by the refined mask):

Feature Extraction: Intensity Features

- **From Grayscale image:**
    - Mean pixel intensity
    - Standard deviation of pixel intensities
    - Minimum pixel intensity
    - Maximum pixel intensity
    - *Module:* `calculate_intensity_stats` *in* `src/feature_extraction.py`

Feature Extraction: Color Features (HSV)

- **From HSV channels:**
    - **Hue (H):**
        - Mean Hue (using circular mean calculation for angular data)
        - Standard deviation of Hue
    - **Saturation (S):**
        - Mean Saturation
        - Standard deviation of Saturation
    - **Value (V):**
        - Mean Value (Brightness)
        - Standard deviation of Value
    - *Module:* `calculate_hsv_stats` *in* `src/feature_extraction.py`

Feature Extraction: Border Features

- **From Grayscale image & mask:**
    - Calculated using morphological gradient on the lesion border.
    - Features include:
        - Mean, Standard Deviation, and Max of border gradient values.
        - Border Irregularity (ratio of border pixels to mask area).
    - *Module:* `calculate_gradient_features` *in* `src/border_texture_utils.py`

Feature Extraction: Texture Features

- **From Grayscale image & mask:**
    - Calculated using Morphological Top-Hat (highlights bright details) and Bottom-Hat (highlights dark details) transforms.
    - Features include:
        - Mean and Standard Deviation of Top-Hat transform values.
        - Mean and Standard Deviation of Bottom-Hat transform values.
        - Texture Contrast Index (sum of Top-Hat and Bottom-Hat means).
    - *Module:* `calculate_texture_features` *in* `src/border_texture_utils.py`

Feature Extraction: Histograms

- **Pixel intensity distributions calculated for:**

    - Grayscale channel
    - Hue (H) channel
    - Saturation (S) channel
    - Value (V) channel
    - Ida (Darkness) channel
- All calculated *within the masked lesion area*.
- *Module:* `calc_all_histograms` *in* `src/histogram_utils.py`

Feature Extraction: Advanced Statistical Features (f1-f28)

- **Brightness Features (f1-f9)** from Value (V) channel:
    - Basic statistics: Mean (f1), Standard Deviation (f2)
    - Higher-order moments: Skewness (f3), Kurtosis (f4)
    - Information theory: Entropy (f5)
    - Histogram analysis: Average differences (f6), Sum of 10 largest differences (f7)
    - Range ratios: High-to-mid range (f8), Mid-to-low range (f9)
    - *Module:* `calculate_brightness_features` *in* `src/feature_extraction.py`
- **Saturation Features (f10-f18)** from Saturation (S) channel:
    - Similar statistical metrics (f10-f18) applied to Saturation channel
    - *Module:* `calculate_saturation_features` *in* `src/feature_extraction.py`
- **Darkness Features (f19-f28)** from Ida channel:
    - Similar statistical metrics (f19-f27) applied to Ida (Darkness) channel
    - Additional feature: Bounding box coverage (f28)
    - *Module:* `calculate_darkness_features` *in* `src/feature_extraction.py`

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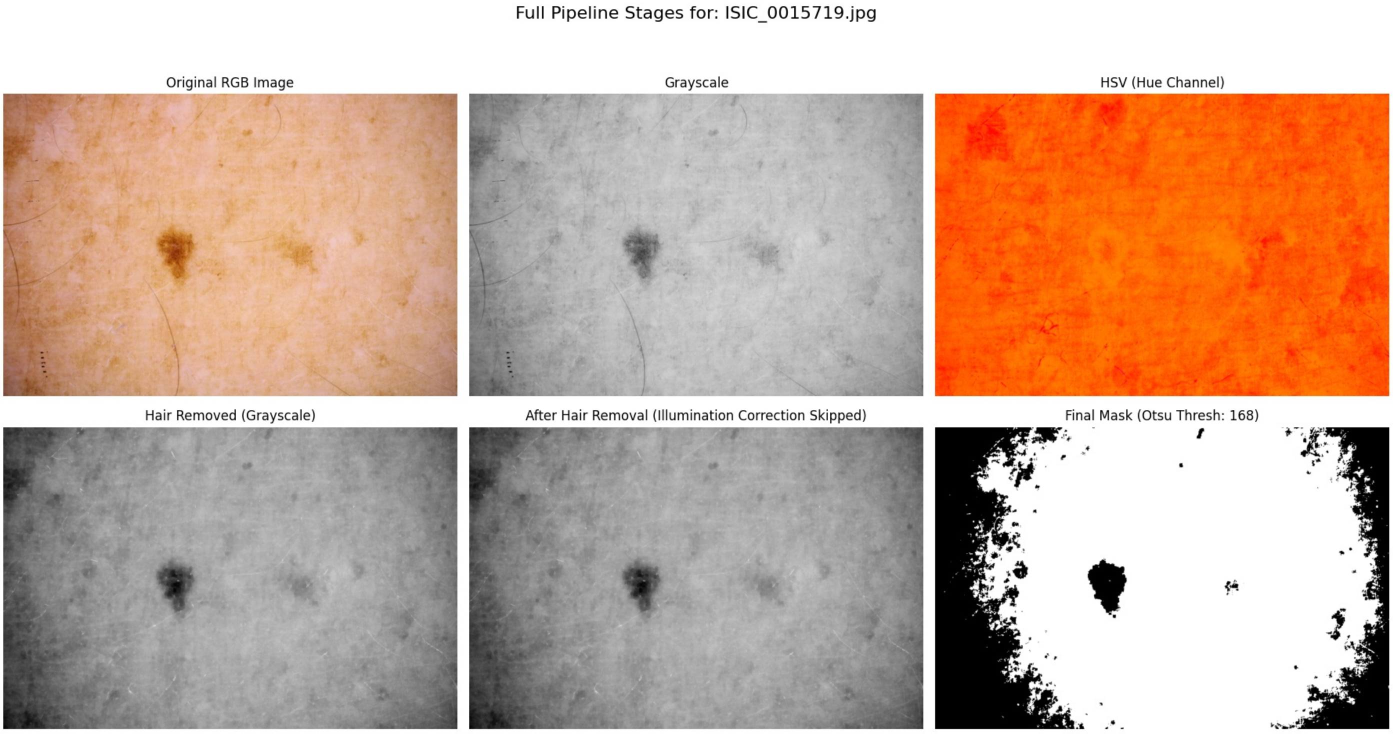
3. Results & Visualizations

This section showcases outputs from processing sample images. *(Assume images are in a local* `img/` *directory for this markdown)*

Pipeline Stages Visualization

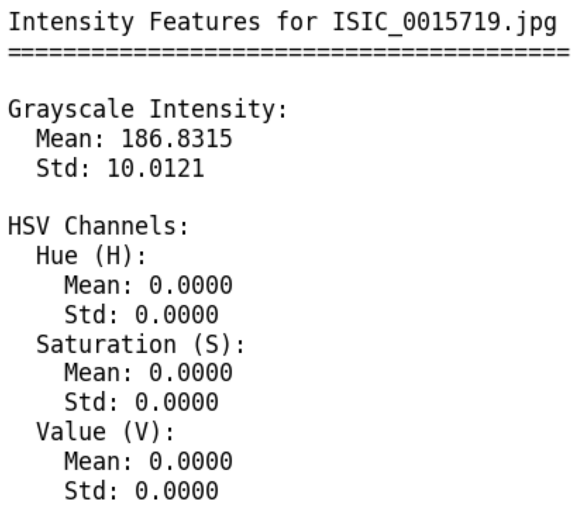
- Illustrates key steps in processing an image.
- Example (`ISIC_0015719.jpg`):
    - Original RGB
    - Grayscale Conversion
    - HSV (Hue Channel shown)
    - Hair Removed (Grayscale)
    - After Hair Removal (Illumination Correction typically skipped for this view)
    - Final Binary Mask (from Otsu's thresholding)


Full Pipeline Stages for: ISIC_0015719.jpg
Original RGB Image
Grayscale
HSV (Hue Channel)
Hair Removed (Grayscale)
After Hair Removal (Illumination Correction Skipped)
Final Mask (Otsu Thresh: 168)

`<p align="center">` *Fig 1: Pipeline stages for ISIC_0015719.jpg (generated by* `src/full_pipeline_display.py` *or* `src/all_features_display.py`*)* `</p>`

Feature Summaries

- Textual and visual representation of extracted *intensity and color features*.
- Example (`ISIC_0015719.jpg`):

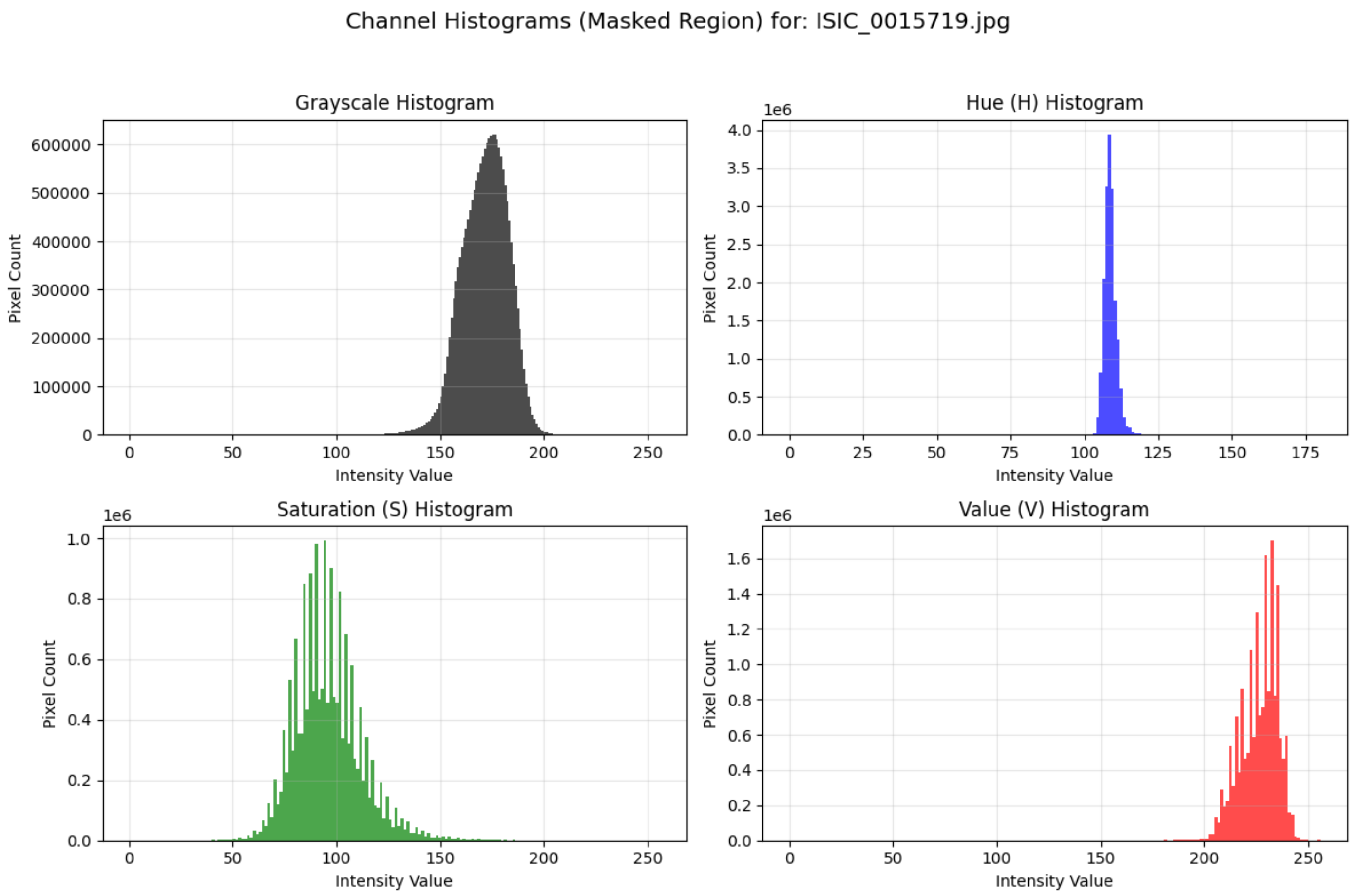


```
Intensity Features for ISIC_0015719.jpg
========================================

Grayscale Intensity:
  Mean: 186.8315
  Std: 10.0121

HSV Channels:
  Hue (H):
    Mean: 0.0000
    Std: 0.0000
  Saturation (S):
    Mean: 0.0000
    Std: 0.0000
  Value (V):
    Mean: 0.0000
    Std: 0.0000
```

`<p align="center">` *Fig 2: Intensity and HSV Color Features for ISIC_0015719.jpg (generated by* `src/intensity_features_display.py` *or similar)* `</p>`

Channel Histograms (Masked Region)

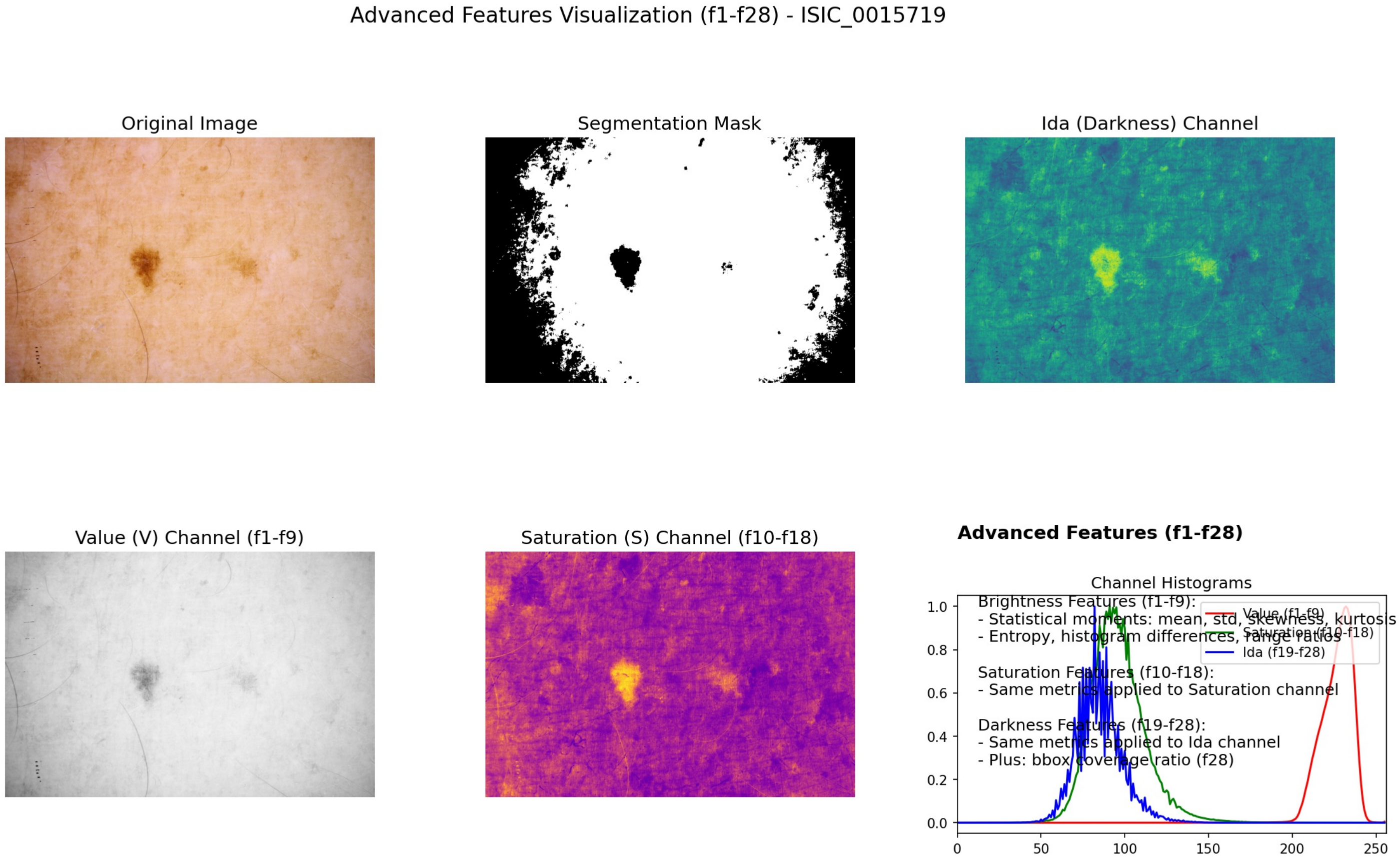
- Visualizes pixel distribution for different channels within the segmented lesion.
- Example (`ISIC_0015719.jpg`): Shows histograms for Grayscale, Hue, Saturation, and Value.



`<p align="center">` *Fig 3: Channel Histograms for ISIC_0015719.jpg (generated by* `src/masked_histogram_display.py` *or* `src/full_pipeline_display.py`*)* `</p>`

Advanced Features Visualization (f1-f28)

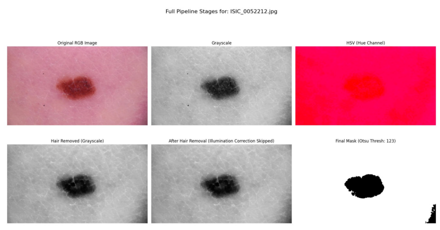
- Visualizes the newly implemented advanced features including the Ida channel.
- Example (`ISIC_0015719.jpg`): Shows Value (V), Saturation (S), and Ida channels along with segmentation and corresponding histograms.

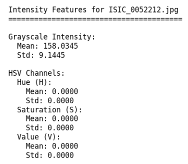

Advanced Features Visualization (f1-f28) - ISIC_0015719
Original Image
Segmentation Mask
Ida (Darkness) Channel
Value (V) Channel (f1-f9)
Saturation (S) Channel (f10-f18)
Advanced Features (f1-f28)
Channel Histograms
Brightness Features (f1-f9):
- Statistical moments: mean, std, skewness, kurtosis
- Entropy, histogram differences, range ratios
Saturation Features (f10-f18):
- Same metrics applied to Saturation channel
Darkness Features (f19-f28):
- Same metrics applied to Ida channel
- Plus: bbox coverage ratio (f28)
Value (f1-f9)
Saturation (f10-f18)
Ida (f19-f28)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250

`<p align="center">` *Fig 4: Advanced Features (f1-f28) Visualization for ISIC_0015719.jpg (generated by* `src/advanced_features_display.py`*)* `</p>`

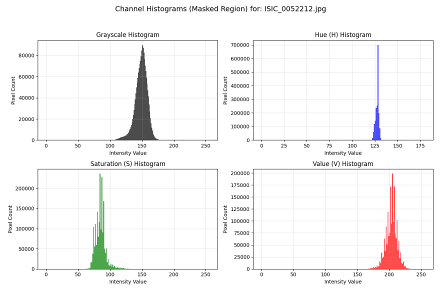
More Examples:

ISIC_0052212.jpg

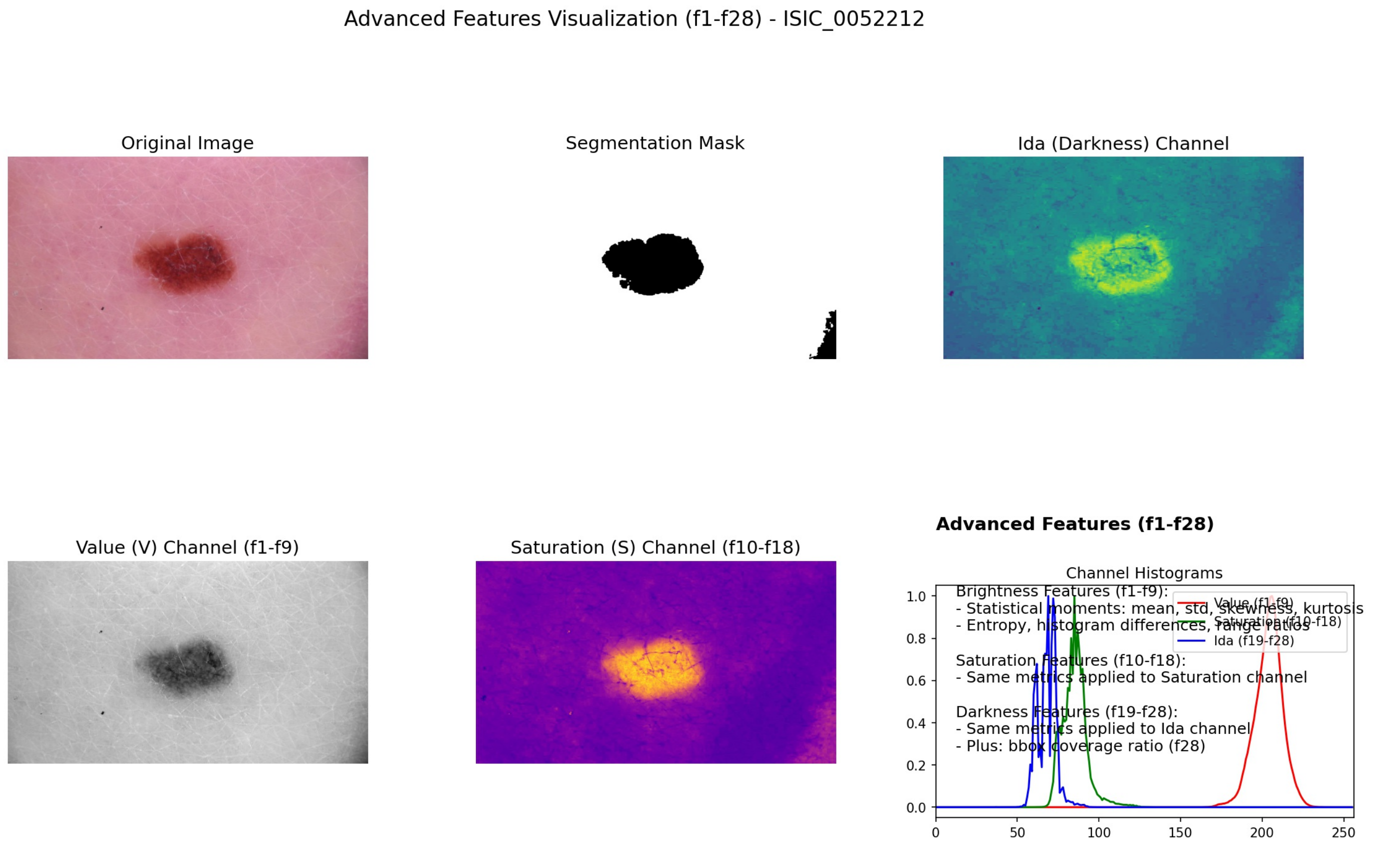

Full Pipeline Stages for: ISIC_0052212.jpg
Original RGB Image
Grayscale
HSV (Hue Channel)
Hair Removed (Grayscale)
After Hair Removal (Illumination Correction Skipped)
Final Mask (Otsu Thresh: 123)



```
Intensity Features for ISIC_0052212.jpg
========================================

Grayscale Intensity:
  Mean: 158.0345
  Std: 9.1445

HSV Channels:
  Hue (H):
    Mean: 0.0000
    Std: 0.0000
  Saturation (S):
    Mean: 0.0000
    Std: 0.0000
  Value (V):
    Mean: 0.0000
    Std: 0.0000
```



Pipeline Stages | Intensity Features | Channel Histograms



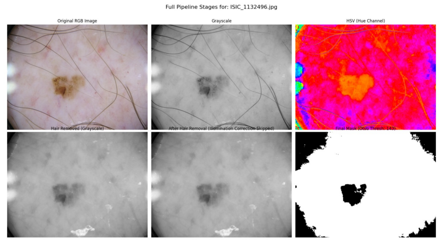
Brightness Features (f1-f9):
- Statistical moments: mean, std, skewness, kurtosis
- Entropy, histogram differences, range ratios

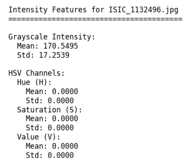
Saturation Features (f10-f18):
- Same metrics applied to Saturation channel

Darkness Features (f19-f28):
- Same metrics applied to Ida channel
- Plus: bbox coverage ratio (f28)

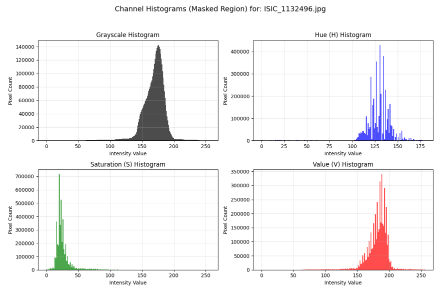
Advanced Features (f1-f28)

ISIC_1132496.jpg

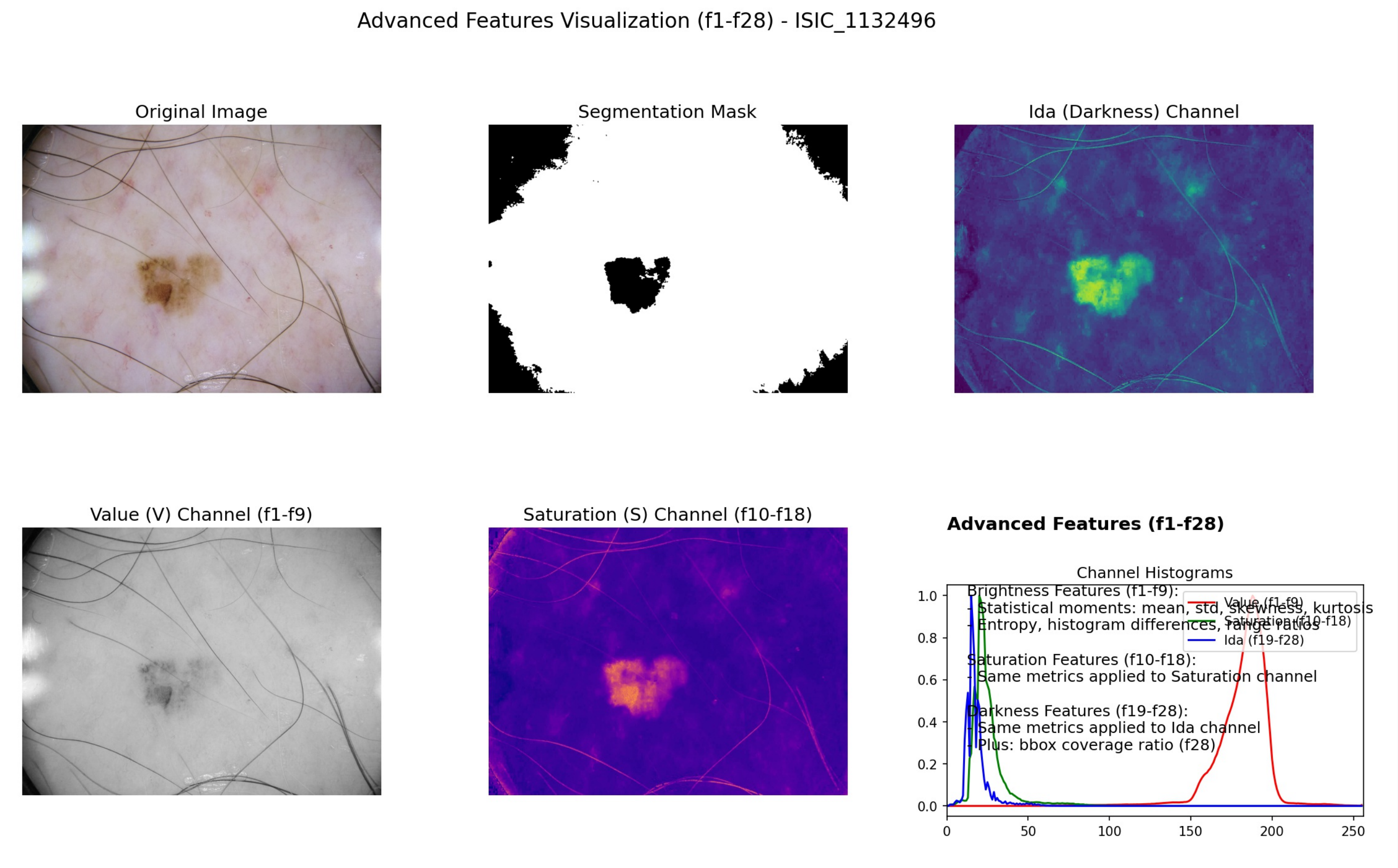

Full Pipeline Stages for: ISIC_1132496.jpg
Original RGB Image
Grayscale
HSV (Hue Channel)
Hair Removed (Grayscale)
After Hair Removal (Illumination Correction Skipped)
Final Mask (Otsu Thresh: 143)



```
Intensity Features for ISIC_1132496.jpg
========================================

Grayscale Intensity:
  Mean: 170.5495
  Std: 17.2539

HSV Channels:
  Hue (H):
    Mean: 0.0000
    Std: 0.0000
  Saturation (S):
    Mean: 0.0000
    Std: 0.0000
  Value (V):
    Mean: 0.0000
    Std: 0.0000
```



Pipeline Stages | Intensity Features | Channel Histograms


Advanced Features Visualization (f1-f28) - ISIC_1132496
Original Image
Segmentation Mask
Ida (Darkness) Channel
Value (V) Channel (f1-f9)
Saturation (S) Channel (f10-f18)
Advanced Features (f1-f28)
Channel Histograms
Brightness Features (f1-f9):
- Statistical moments: mean, std, skewness, kurtosis
- Entropy, histogram differences, range ratios
Saturation Features (f10-f18):
- Same metrics applied to Saturation channel
Darkness Features (f19-f28):
- Same metrics applied to Ida channel
- Plus: bbox coverage ratio (f28)
Value (f1-f9)
Saturation (f10-f18)
Ida (f19-f28)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250

Advanced Features (f1-f28)

4. Code Structure & Key Modules

The project is organized into several Python modules within the `src/` directory:

- `color_utils.py` : Color space conversions, Ida channel calculation.
- `preprocessing.py` : Hair removal, illumination correction.
- `segmentation.py` : Thresholding methods, mask application.
- `morphology.py` : Morphological operations (opening, closing).
- `histogram_utils.py` : Masked histogram calculations, advanced statistical functions.
- `feature_extraction.py` : Core logic for calculating features (intensity, color, advanced f1-f28).
- `border_texture_utils.py` : Calculates border and texture specific features.
- `data_loader.py` : Handles image and metadata loading.
- `batch_processor.py` : Enables processing of multiple images.
- `advanced_features_display.py` : Visualizes advanced features (f1-f28).

Display Scripts: Numerous scripts like `full_pipeline_display.py` , `all_features_display.py` , `intensity_features_display.py` , etc., allow visualization of different pipeline stages and extracted features.

5. Challenges & Learnings

- **Segmentation Accuracy:** Achieving perfect lesion segmentation is challenging due to image variability (hair, bubbles, skin lines, low contrast). Otsu's method provides a good baseline, and morphological cleanup helps significantly.
- **Feature Relevance:** Understanding how different features (intensity, color, texture, border) capture various aspects of lesion appearance.
- **Pipeline Integration:** Ensuring each step correctly feeds into the next and that data formats are consistent.
- **Modularity:** Structuring the code into reusable functions and modules (e.g., for color conversion, preprocessing, feature calculation) was key for development and testing.

6. Conclusion & Future Work

Achievements

- Successfully implemented an end-to-end image processing pipeline for skin lesion analysis.
- Developed modules for key DIP tasks: preprocessing, segmentation, and feature extraction.
- Extracted a comprehensive set of features:

    - Intensity (Grayscale statistics)
    - Color (HSV channel statistics)
    - Border (Gradient-based metrics)
    - Texture (Top-hat/Bottom-hat based metrics)
    - Advanced Statistical Features (f1-f28):
        - Brightness Features (Value channel analysis)
        - Saturation Features (Saturation channel analysis)
        - Darkness Features (Ida channel analysis)
- Created comprehensive visualization tools to inspect pipeline stages and results.
- Implemented batch processing capabilities for analyzing multiple images.

Future Work

- **Advanced Segmentation:** Explore more robust segmentation techniques (e.g., active contours, watershed, machine learning-based segmentation).
- ✓ **Implemented PRD Feature Set (f1-f28):**
    - ✓ Introduced the "Ida (Darkness)" channel.
    - ✓ Implemented the specific Brightness (f1-f9), Saturation (f10-f18), and Darkness (f19-f28) features involving higher-order statistics (skewness, kurtosis), entropy, etc., as outlined in the project's PRD.
- **Feature Analysis:** Evaluate the discriminative power of each feature for melanoma detection, particularly the newly implemented advanced features.
- **Machine Learning Integration:** Use the extracted features to train classification models (e.g., SVM, Random Forest, Neural Networks) to predict lesion malignancy.
- **Quantitative Evaluation:** If detailed ground truth masks become available, perform quantitative evaluation of segmentation accuracy (e.g., Dice coefficient, Jaccard index).
- **Expanded Dataset Processing:** Utilize the `batch_processor.py` to analyze a larger subset of the dataset and generate comprehensive feature statistics.

Thank You & Questions?