

Sardar Vallabhbhai National Institute of Technology

Surat - 395007

Department of Artificial Intelligence

Deep Learning (AI302)

Lab Practical - 4

Problem Statement: Design and Implementation of CNN Architectures for **Imbalanced Image Classification** using Multiple Benchmark Datasets.

DATASETS FOR EXPERIMENTATION

Students must work with at least TWO of the following imbalanced datasets:

#	Dataset	Description	Imbalance Characteristics
1	Flower Recognition	5 flower classes: daisy, dandelion, rose, sunflower, tulip	Create imbalance by sampling (e.g., 100:500:200:50:150)
2	CIFAR-10 (Imbalanced)	10 classes: airplane, automobile, bird, cat, deer, dog, frog, horse, ship, truck	Create long-tailed distribution with imbalance ratio 100:1
3	Skin Cancer MNIST (HAM10000)	7 skin lesion classes including melanoma, nevus, etc.	Naturally imbalanced - melanoma is minority class (~10%)
4	Chest X-Ray (Pneumonia)	Binary classification: Normal vs Pneumonia chest X-rays	Imbalanced with ~3:1 ratio (Pneumonia:Normal)
5	Intel Image Classification	6 scene classes: buildings, forest, glacier, mountain, sea, street	Create imbalance by undersampling specific classes
6	PlantVillage Disease	38 classes of plant diseases across multiple crop types	Naturally imbalanced across disease categories
7	Blood Cell Images	4 blood cell types: Eosinophil, Lymphocyte, Monocyte, Neutrophil	Can create imbalance to simulate rare cell detection
8	Diabetic Retinopathy Detection	5 severity levels: No DR, Mild, Moderate, Severe, Proliferative	Highly imbalanced - severe cases are rare

Problem Statement 1: Architecture Design Focus

Design a **custom CNN architecture** or modify any standard CNN model to perform **multi-class image classification** on your selected imbalanced datasets.

- Justify the choice of architecture based on dataset characteristics
- Decide the number of layers, filter sizes, kernel sizes, and activation functions
- Implement appropriate regularization techniques (Dropout, Batch Normalization, L2)
- Analyze the impact of dataset imbalance on classification performance

Problem Statement 2: Imbalanced Dataset Handling

The selected datasets are **class-imbalanced**. Design and implement strategies to handle imbalance:

Data-Level Techniques:

- Random Oversampling of minority classes
- Random Undersampling of majority classes
- SMOTE (Synthetic Minority Oversampling Technique) for image features
- Data augmentation specifically for minority classes (rotation, flip, zoom, color jitter)

Algorithm-Level Techniques:

- Class weighting in loss function
- Cost-sensitive learning
- Threshold adjustment during inference

Evaluate how these strategies affect:

- Training convergence and stability
- Class-wise accuracy, especially for minority classes
- Overall model performance (accuracy, macro/micro F1)

Problem Statement 3: Comparative Architecture Analysis

Implement at least two different CNN architectures (e.g., EfficientNet vs ResNet, MobileNet vs VGG, or DenseNet vs Inception) on your selected imbalanced datasets.

Compare the models based on:

- Overall Accuracy and Top-k Accuracy
- Precision, Recall, F1-score (class-wise and macro-averaged)
- Confusion Matrix analysis
- Computational cost (FLOPs, parameters, inference time)
- ROC-AUC and PR-AUC curves
- Robustness to class imbalance (G-Mean, Balanced Accuracy)

Problem Statement 4: Loss Function & Optimization Challenge

Investigate the effect of **different loss functions and optimizers** on imbalanced datasets.

Loss Functions to Experiment:

- Cross-Entropy Loss (baseline)
- Weighted Cross-Entropy Loss
- Focal Loss (with different gamma values: 0.5, 1, 2, 5)
- Class-Balanced Loss
- Label Smoothing Cross-Entropy

Optimizers to Experiment:

- SGD (with and without momentum)
- Adam
- AdamW (Adam with weight decay)
- RMSProp

Analyze:

- Convergence speed and training curves
- Minority class recognition improvement
- Overfitting behavior and generalization
- Impact of learning rate scheduling

Problem Statement 5: Feature Representation & Visualization

Extract deep features from the trained CNN model and visualize feature distributions.

Visualization Techniques:

- t-SNE (t-distributed Stochastic Neighbor Embedding)
- PCA (Principal Component Analysis)
- UMAP (Uniform Manifold Approximation and Projection)
- Grad-CAM or Class Activation Maps

Study how imbalance affects:

- Feature clustering quality
- Inter-class separation and intra-class compactness
- Minority class representation in feature space
- Decision boundary visualization

Problem Statement 6: Generalization & Transfer Learning Test

Train the CNN model on one imbalanced dataset and test its **transferability** on another related dataset.

Suggested Transfer Learning Experiments:

- Flower dataset → Intel Image Classification (natural images)
- Skin Cancer → Blood Cell Images (medical imaging domain)
- CIFAR-10 → Flowers or Intel Images
- Pre-trained ImageNet weights → Any selected dataset

Analyze:

- Transferability of learned features
- Performance degradation across domains
- Fine-tuning vs feature extraction approaches
- Impact of dataset complexity and domain shift

Problem Statement 7: Error Analysis & Improvement Proposals

For incorrectly classified samples, perform detailed failure analysis:

- Identify which classes fail most frequently
- Analyze confusion patterns between similar classes
- Correlate errors with class imbalance ratios
- Visualize misclassified samples

- Propose architectural or data-level improvements based on analysis

DATASET LINKS

1. Flower Recognition Dataset:

<https://www.kaggle.com/datasets/alxmamaev/flowers-recognition>

2. CIFAR-10 Dataset:

<https://www.cs.toronto.edu/~kriz/cifar.html>

Also available via: tensorflow.keras.datasets.cifar10 or torchvision.datasets.CIFAR10

3. Skin Cancer MNIST (HAM10000):

<https://www.kaggle.com/datasets/kmader/skin-cancer-mnist-ham10000>

4. Chest X-Ray Pneumonia:

<https://www.kaggle.com/datasets/paultimothymooney/chest-xray-pneumonia>

5. Intel Image Classification:

<https://www.kaggle.com/datasets/puneet6060/intel-image-classification>

6. PlantVillage Disease Dataset:

<https://www.kaggle.com/datasets/emmarex/plantdisease>

7. Blood Cell Images:

<https://www.kaggle.com/datasets/paultimothymooney/blood-cells>

8. Diabetic Retinopathy Detection:

<https://www.kaggle.com/c/diabetic-retinopathy-detection>