Experiment Run

Experiment Run Report

Experiment Title: Numerosity-Based Categorization - Experiment Run 5

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1. Experiment Details

Parameter	Value
Seed	42
Dataset Size	5000 samples
Image Size	128x128 pixels
Categories	Few (1-5), Medium (6-15), Many (>16)
Batch Size	256
Learning Rate	0.0001
Epochs	20
Optimizer	AdamW
Dropout Rate	0.4
Weight Decay	5e-4
Loss Function	CrossEntropyLoss
Early Stopping	Yes (Patience = 5)
Device Used	GPU – NVIDIA L4
eps	1e-6
betas	0.9, 0.98
Accumulation steps	2

2. Experiment Setup

- **Dataset:** Synthetic Dot Patterns
- **Model Architecture:** CNN-Transformer architecture
- **Training Strategy:**
    - Train on 70% of data.
    - Validate on 15%.
    - Test on 15%.
- **Evaluation Metrics:**
    - Accuracy
    - Loss Curves
    - Confusion Matrix
    - Precision, Recall, and F1-Score

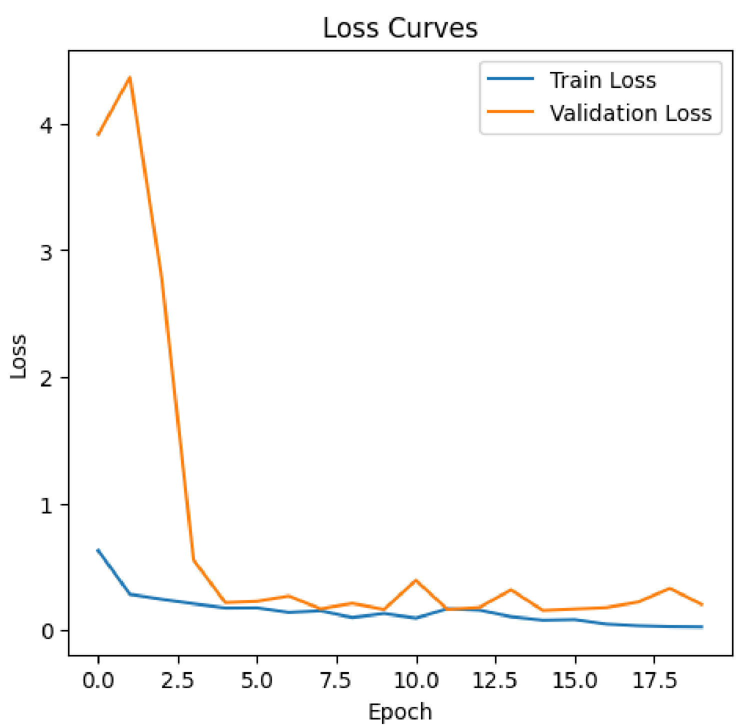
3. Training & Validation Performance

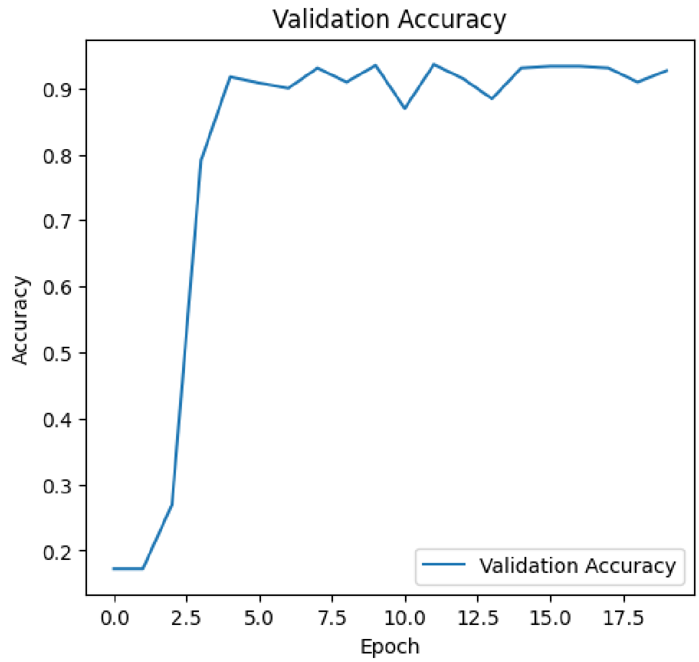
3.1 Loss and Accuracy Trends

Epoch	Train Loss	Validation Loss	Validation Accuracy (%)
1	0.6258	3.9177	17.20%
2	0.2809	4.3694	17.20%
3	0.2418	2.7796	26.93%
4	0.2068	0.5529	79.07%
5	0.1733	0.2157	91.73%
6	0.1746	0.2260	90.80%
7	0.1380	0.2675	90.00%
8	0.1507	0.1666	93.07%
9	0.0973	0.2100	90.93%
10	0.1296	0.1616	93.47%

Epoch	Train Loss	Validation Loss	Validation Accuracy (%)
11	0.0927	0.3915	86.93%
12	0.1672	0.1621	93.60%
13	0.1563	0.1776	91.47%
14	0.1040	0.3166	88.40%
15	0.0768	0.1538	93.07%
16	0.0817	0.1654	93.33%
17	0.0450	0.1765	93.33%
18	0.0314	0.2202	93.07%
19	0.0246	0.3278	90.93%
20	0.0223	0.2017	92.67%

3.2 Loss Curve & Accuracy Plot





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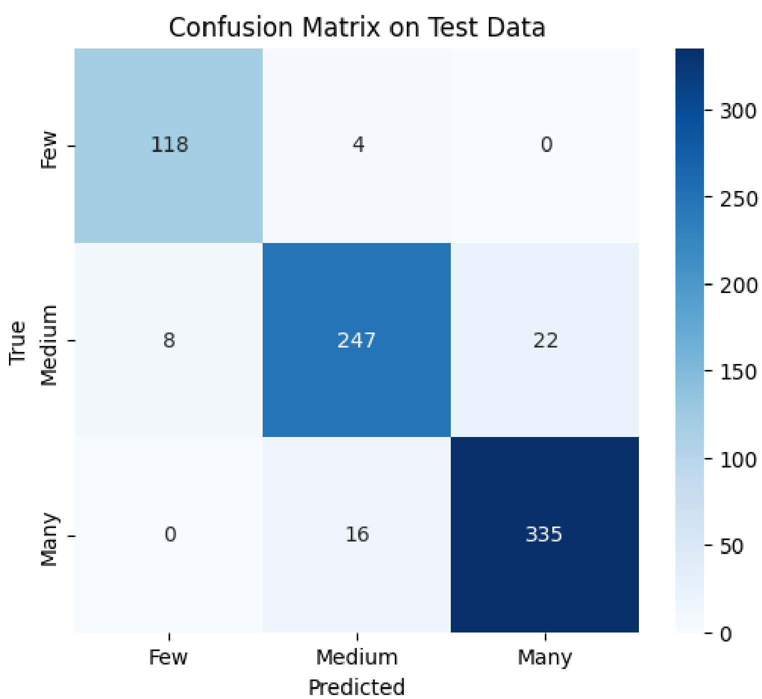
4. Test Set Evaluation

Final Test Accuracy: 93.33%

4.1 Confusion Matrix



4.2 Classification Report

Class	Precision	Recall	F1-Score	Support
Few	0.94	0.97	0.95	122
Medium	0.93	0.89	0.91	277
Many	0.94	0.95	0.95	351

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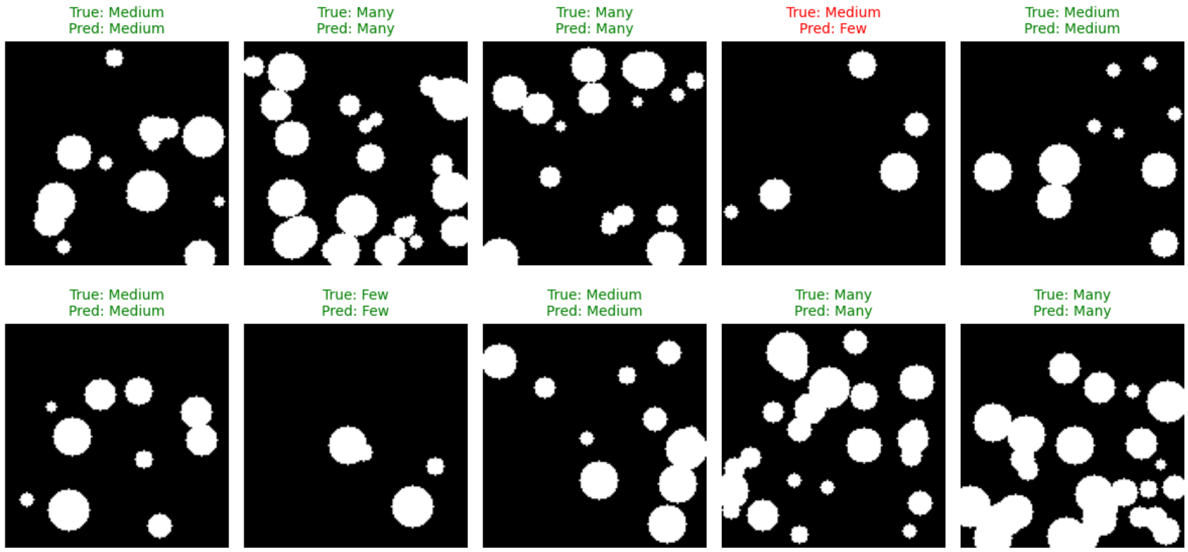
5. Observations & Insights

- **Key Findings:**
  - Architecture Change: The model was modified from a pure CNN to a hybrid CNN-Transformer architecture.
  - Better generalization, increasing the batch size to 256 improved validation accuracy and helped the model generalize better.
  - There is performance improvement since the final model reached a test accuracy of 93.33%, showing a consistent improvement in accuracy and stability across epochs.
  - The loss trends in both training and validation loss curves are smoother, indicating better convergence and reduced overfitting.
  - The generalization is better, the model now effectively classifies across all categories (Few, Medium, Many), with a high precision and recall for all three classes.

- **Error Analysis:**



- The "Few" and "Many" classes performed best, achieving over 95% recall.
- The "Medium" class saw a few misclassifications, particularly with "Many" samples. However, the model still maintained an F1-score of 0.91 for this category.
- While the validation loss is slightly higher towards the end, the accuracy remains stable, suggesting minor overfitting but still strong generalization.
- Some Overfitting Still Present: Even with increased dropout and weight decay, the validation loss fluctuates in later epochs, meaning further regularization might still be needed.

- **Next Steps:**
  - Shape Generalization Study: Now that the baseline performance is strong, the next phase will test generalization by introducing different shapes beyond circles.
  - Further Regularization: Experiment with dropout tuning and weight decay adjustments to ensure the model does not overfit to specific patterns.
  - Data Augmentation: Consider applying transformations (rotation, scaling, contrast changes) to make the model more robust to visual variations.
  - Transformer Attention Analysis: Investigate how the self-attention layers influence classification decisions.

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6. Conclusion

This final run successfully demonstrated that combining CNNs with Transformer-based representations significantly improves classification performance. The model generalizes well, but there is still potential for further refinement through architectural optimizations and additional generalization tests.

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7. Additional Notes

- Reproducibility was ensured by setting a fixed random seed and using pre-saved datasets.
- This run also followed the structured experiment template, making future runs easy to compare.
- Some variability in validation loss was observed, which may indicate the need for better regularization techniques.
- Early stopping was applied, preventing overfitting, but further adjustments may be needed.
