ObscuraDrive: Traffic Sign Recognition Under Real-World Conditions

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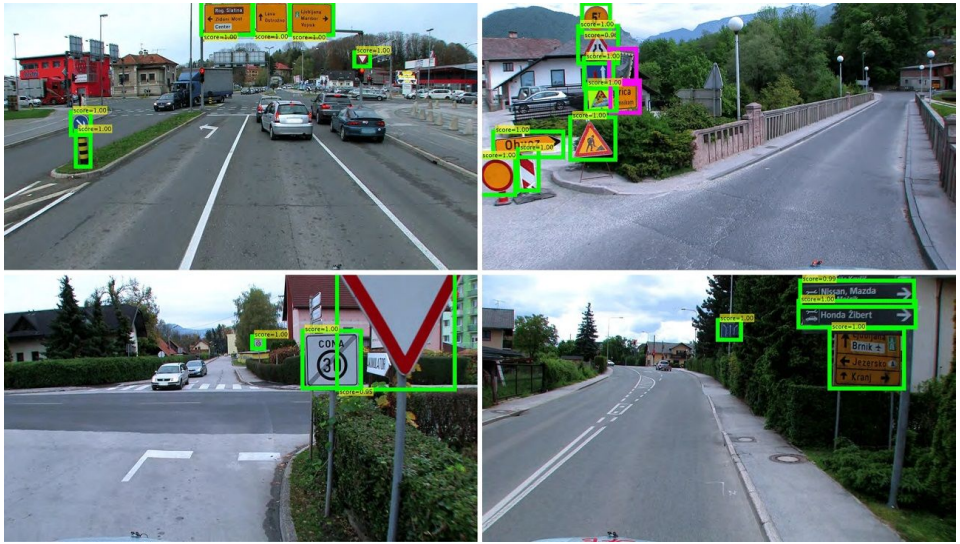
The Problem - Why it is interesting?

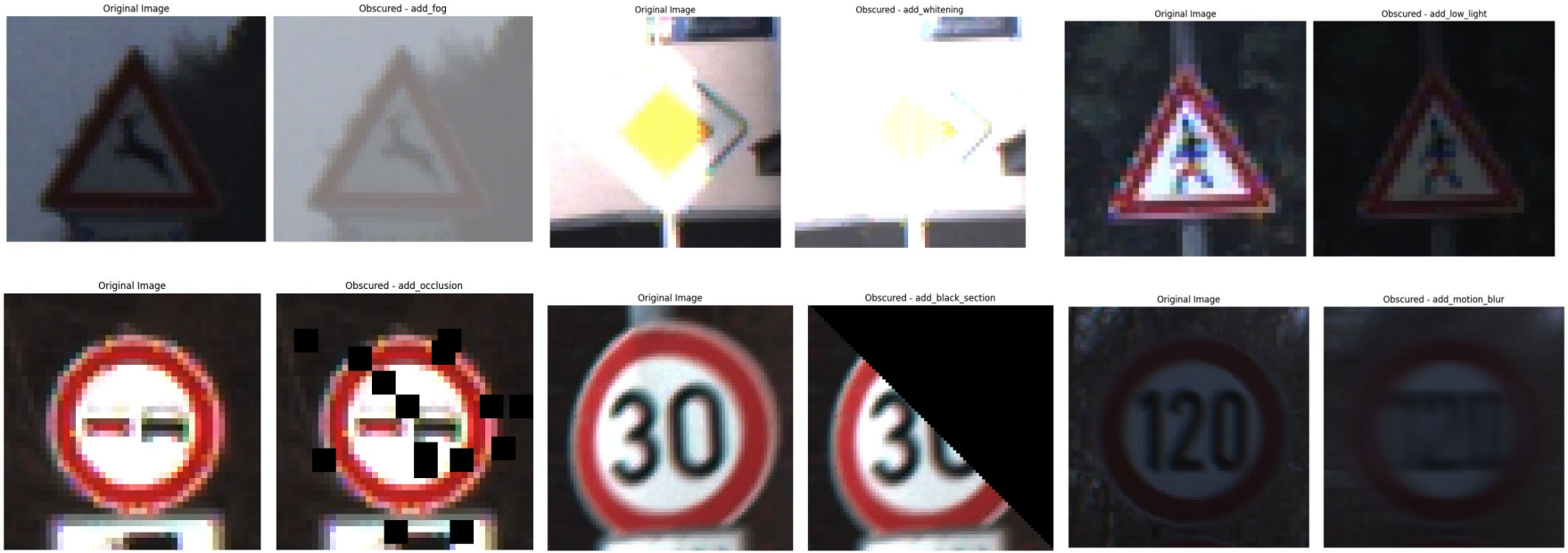
- What is traffic sign recognition?
  - A critical component of autonomous driving systems
  - Vehicles rely on accurate sign recognition to navigate safely, follow speed limits, and make crucial driving decisions
- What is the problem?
  - Current autonomous driving systems struggle in no controlled environments (only work well with specific settings like: clear weather, straight roads, no occlusions)
  - Real-world conditions include **fog, motion blur, and dirt** degrade performance
- Why it is interesting?
  - Considering these conditions is needed for autonomous vehicle adoption and safety
- Goal: comparing how obscured data affects the performance of the models



Approach & Methodology

- Dataset: German Traffic Sign Recognition Benchmark (GTSRB)
- Data Preparation:
  - Baseline: Original traffic sign images
  - Obscured
    - 11 cases: blur, sensor noise, fog, object block, motion blur, dirt on the lens, night vision, etc.
    - Total 33% of sample images obscured (3% x 11 obscuration techniques)
- Models:
  - Used the same data setting/preprocessing for fair comparison
  - Fully Connected Neural Network (FCNN)
  - Convolutional Neural Network (CNN)
  - Transfer Learning (ResNet50, ResNet18)
- Evaluation Metrics:
  - Test accuracy, test loss, and confusion matrix

Obscured Image Samples



Project Scope Change

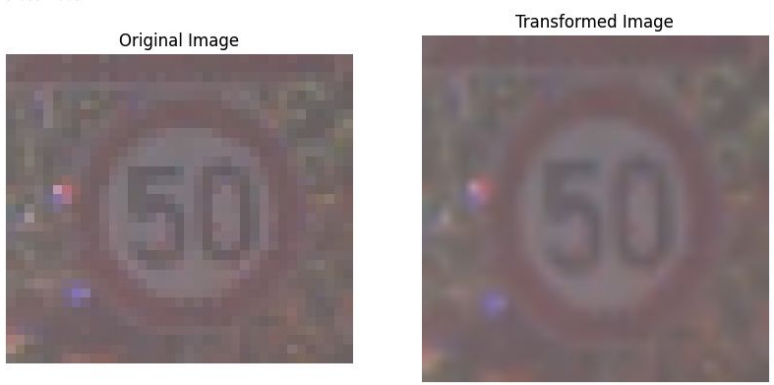
Original Project Scope	New Project Scope
● Have two dataset (Original/Obscured) ● 2 layer FCNN ● CNN ● Compare 4 models	● Have two dataset (Origina/Obscured) ● 2 layer FCNN ● CNN ● Transfer Learning (ResNet50) ● Transfer Learning (ResNet18) ● Compare 8 models Why changed? ● Believe it would be a great opportunity to learn more about transfer learning and it could be a powerful tool for traffic sign classification ● Also expected transfer learning will outperform CNN and FCNN due to its robust feature extraction capabilities

Hypothesis

- Obscured data would degrade model performance due to missing or corrupted features, especially for class 0 to class 9 (speed limit signs)
- CNNs would outperform FCNNs, since CNNs are better at extracting image features
- ResNet50 would achieve the best performance, as it leverages pre-trained ImageNet features

Problem: Image Resizing for TL

- Original images are 29x30, 30x30 or 32x32 pixels
- With ResNet50, I resized the images to 224x224, and session crashed due to computational overload

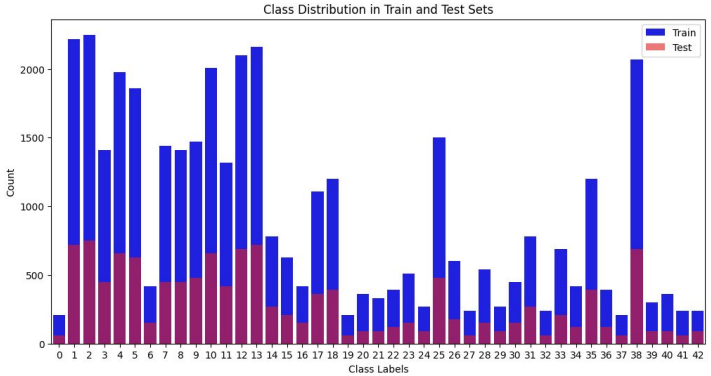


Solution:

- Reduced ResNet50’s input size to 128x128 to fit my hardware limitations
- Also tried ResNet18 with 224x224 resized images - simpler and smaller model than ResNet50 and could handle the resolution better

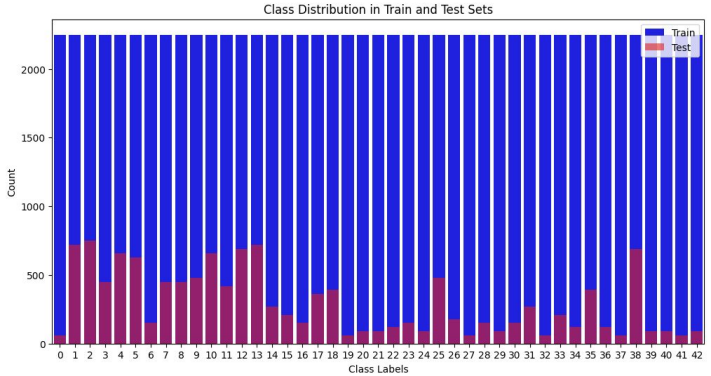
Problem: Class Imbalance & Overfitting

- Class Imbalance: Originally had an uneven distribution of traffic signs
- Overfitting: Extreme overfitting observed after initial training. The model performed well on the training set but poorly on the test set, suggesting that it was memorizing the data rather than learning general features.

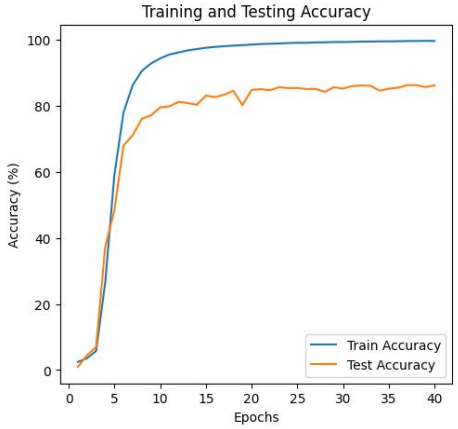


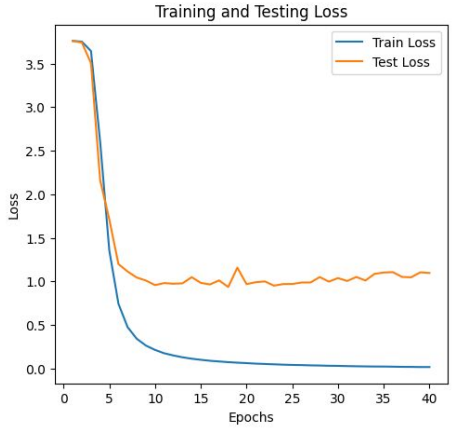
Solution: Class Imbalance & Overfitting

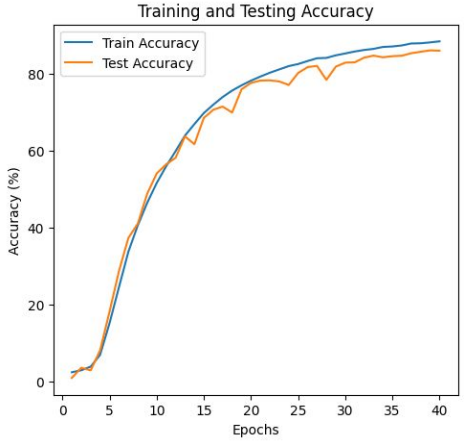
- Oversampling (Initial Attempt): Used oversampling to replicate minority class samples
- Enhanced with Data Augmentation: But overfitting persisted as the model was still seeing the same images repeatedly. Used augmentation to increase data variability

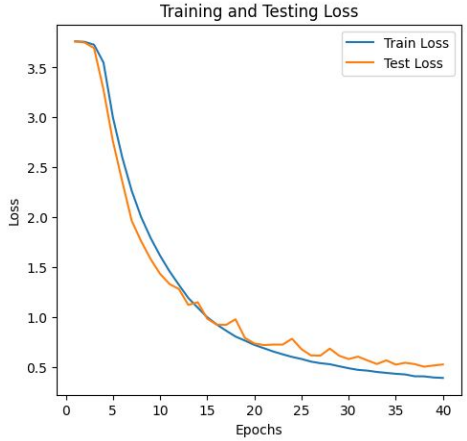


Before Augmentation vs. After Augmentation









After applying data augmentation, a significant improvement in generalization, and the model's performance on the test set improved. The overfitting issue was reduced, and the model was able to better classify both majority and minority classes.

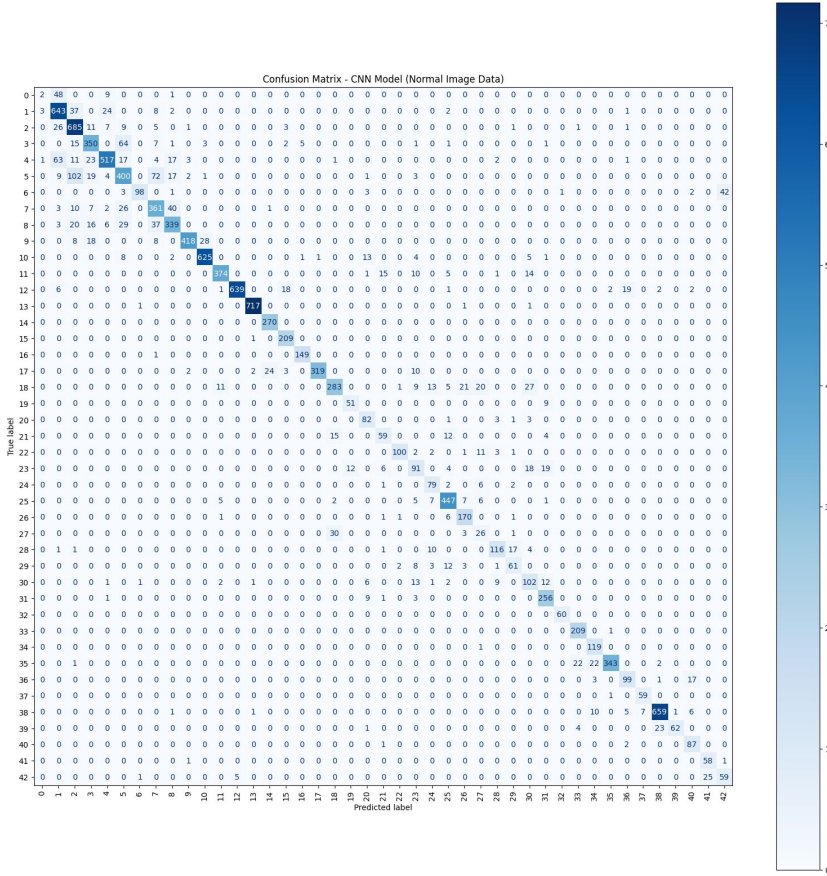
Results

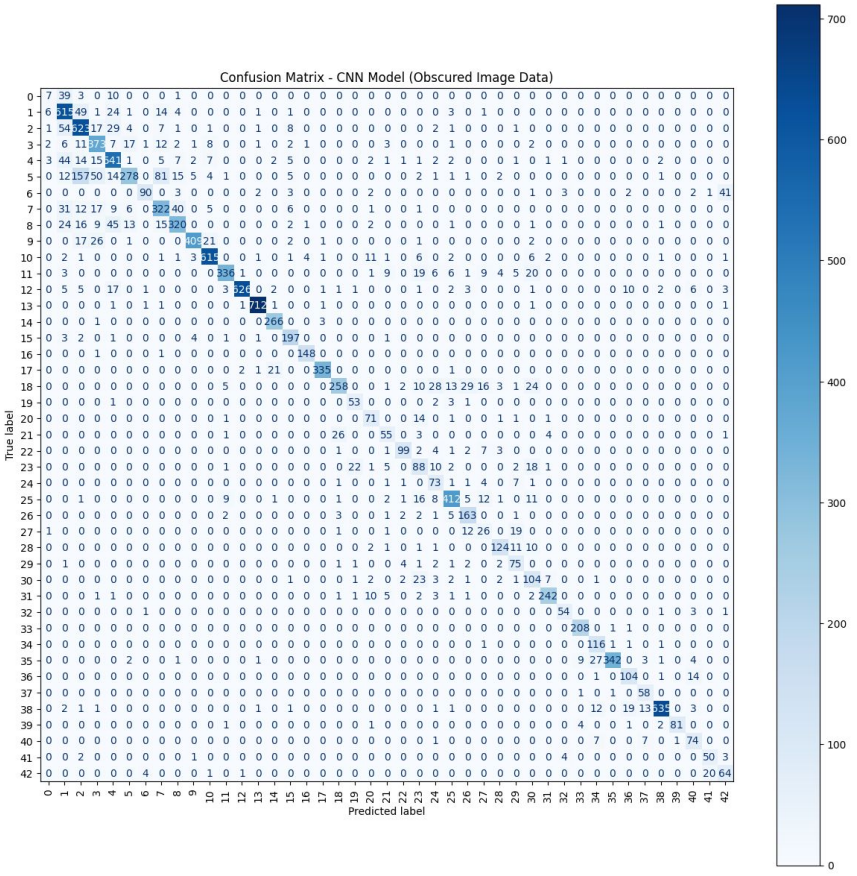
Model Performance on Normal vs. Obscured Data

Model	Dataset	Test Error	Test Accuracy
FCNN	Normal	1.2453	62.11%
FCNN	Obscured	1.2848	61.32%
CNN	Normal	0.5263	85.92%
CNN	Obscured	0.6395	82.68%
ResNet50 (128x128)	Normal	1.191	67.66%
ResNet50 (128x128)	Obscured	1.3007	62.10%
ResNet18 (224x224)	Normal	1.2783	65.35%
ResNet18 (224x224)	Obscured	1.2841	61.33%

- FCNN performs poorly overall (highest test error and lowest accuracy for both dataset), and no difference for original vs obscured dataset - does not use convolutional layers, it cannot extract spatial features from images
- CNN (30x30) performs best among all models, with 85.92% accuracy on the normal dataset
- CNN also generalizes well to the obscured data, with only a small drop (from 85.92% → 82.68%)
- CNN is optimized for small, structured images like traffic signs, making it more effective than larger models like ResNet
- ResNet50 and 18 underperform compared to CNN
    - Domain mismatch: ResNet models are pretrained on ImageNet (natural images), so might not be best option
    - Resizing issues: This might due to resizing artifacts (from 30x30 to 128x128 or 224x224 may create noise) - increasing image resolution without proper tuning does not necessarily improve performance
    - Too many parameters: ResNet models are over-parameterized for this task and might be overfitting the training data

CNN Confusion Matrix Result (Original vs. Obscured)





Next Steps

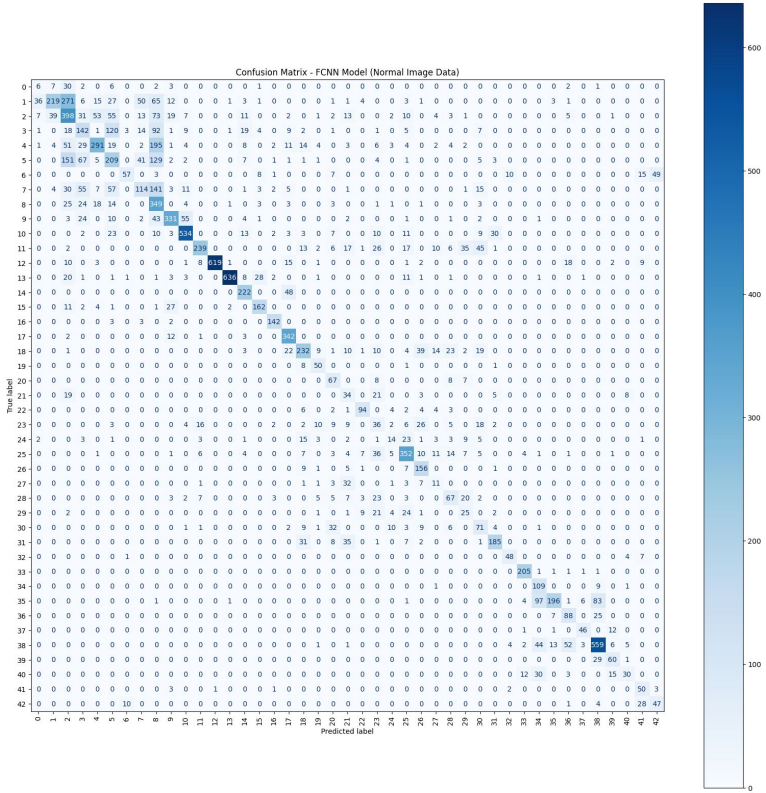
- Try a different model like:
  - Vision Transformers (ViTs) - can capture long-range dependencies in images
  - ConvNext - more efficient than ResNet
  - Or a self-driving dataset pretrained model
- Train a small, customized CNN with better augmentation to improve generalization
- Can models trained on artificially obscured data generalize to real-world occlusions?
- Explore the effect of obscuration by changing obscured image percentages
- Explore how do different obscuration type affect recognition (blur, weather effects, dirt, etc)
- Investigate whether human perception aligns with model errors

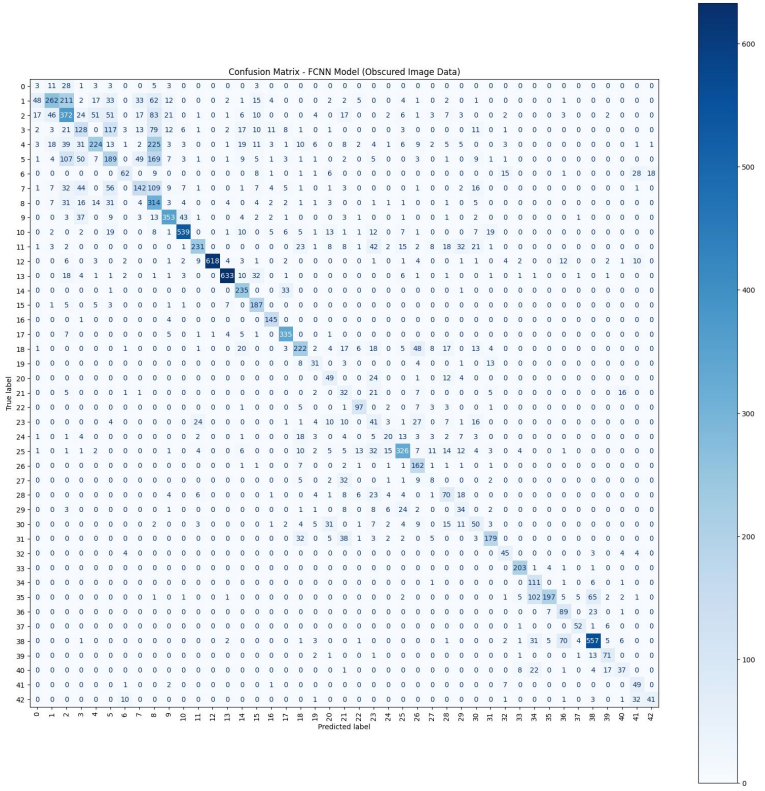
Thank you

Reference

- Traffic Sign Image Data: https://www.kaggle.com/datasets/meowmeowmeowmeowmeow/gtsrb-german-traffic-sign
- https://www.youtube.com/watch?v=SpCCCFcxzIU
- https://innovationatwork.ieee.org/autonomous-vehicles-for-today-and-for-the-future/
- https://ieeexplore.ieee.org/document/6909583
- https://www.isca-archive.org/odyssey_2018/zhang18_odyssey.pdf

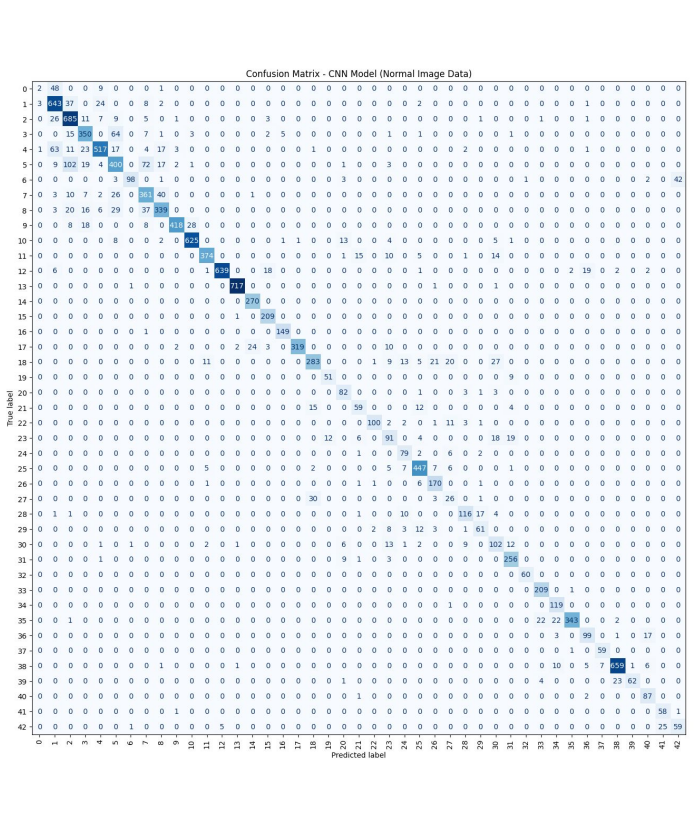
FCNN Confusion Matrix Result (Original vs. Obscured)

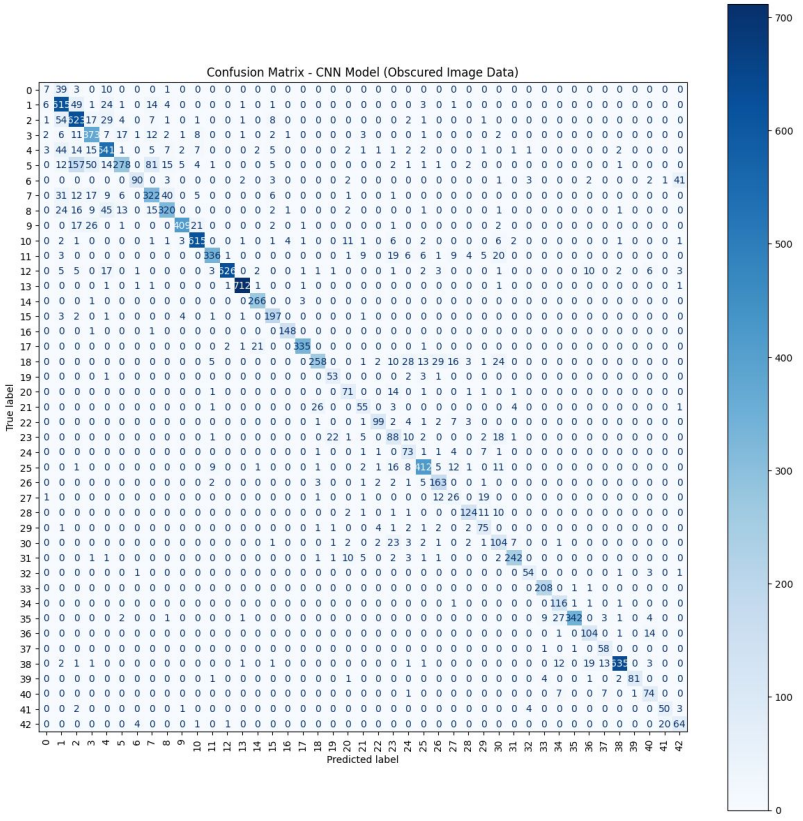




- Left is with original dataset, right is with obscured dataset

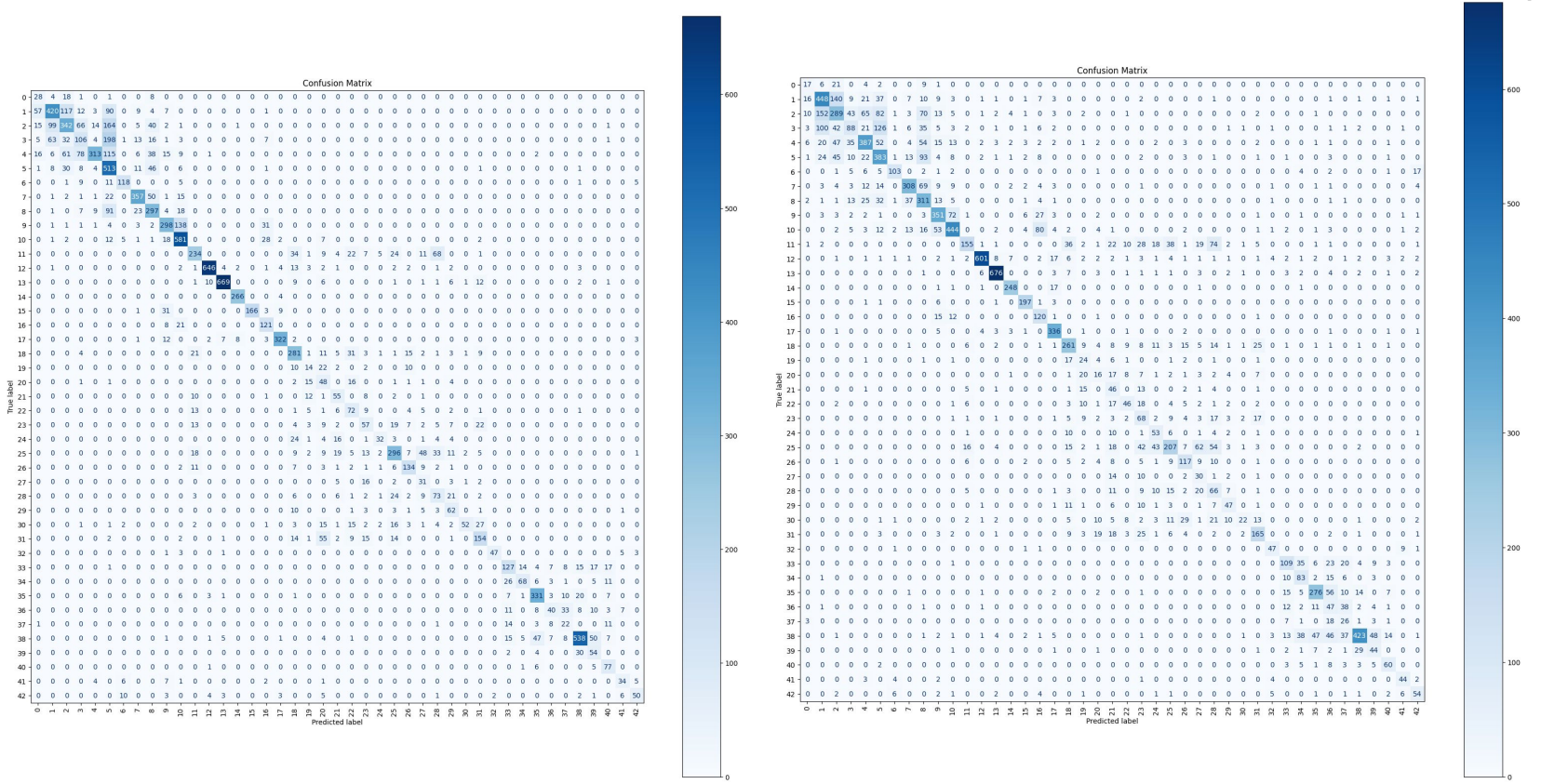
CNN Confusion Matrix Result (Original vs. Obscured)





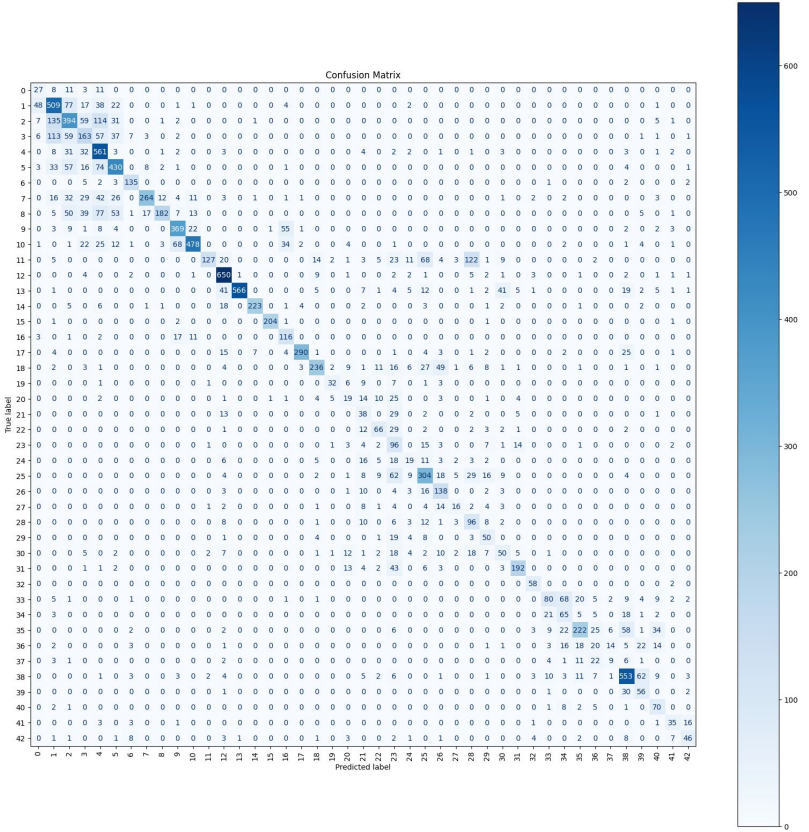
- Left is with original dataset, right is with obscured dataset

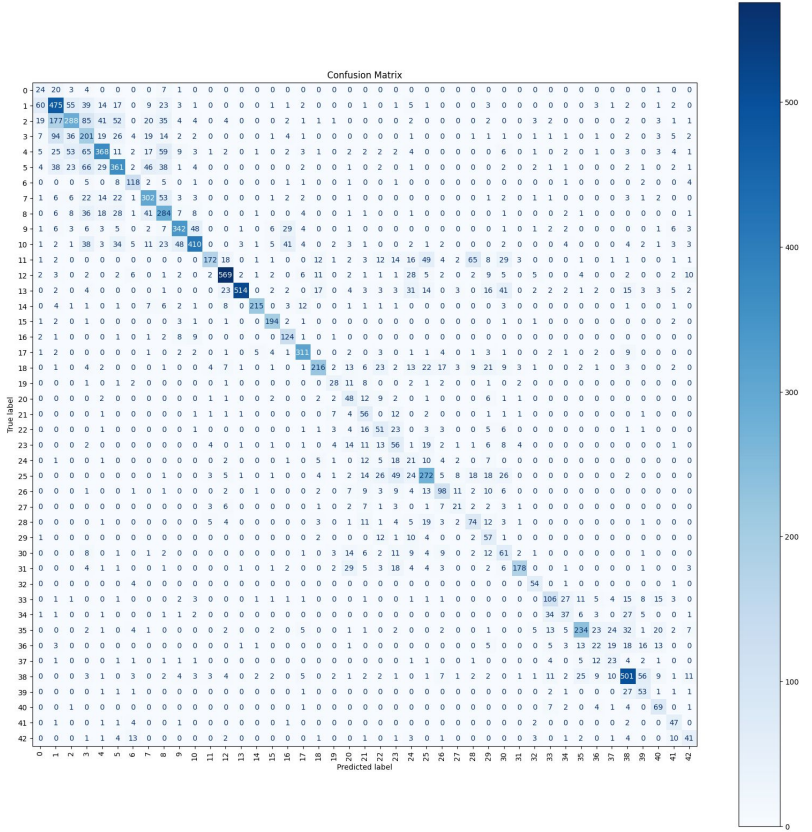
ResNet50 Confusion Matrix Result (Original vs. Obscured)



- Left is with original dataset, right is with obscured dataset

ResNet18 Confusion Matrix Result (Original vs. Obscured)





- Left is with original dataset, right is with obscured dataset