POINT CLOUD DEEP LEARNING

Innfarn Yoo, 3/29/2018

NVIDIA

AGENDA

- Introduction
- Previous Work
- Method
- Result
- Conclusion

INTRODUCTION

2D OBJECT CLASSIFICATION

Deep Learning for 2D Object Classification

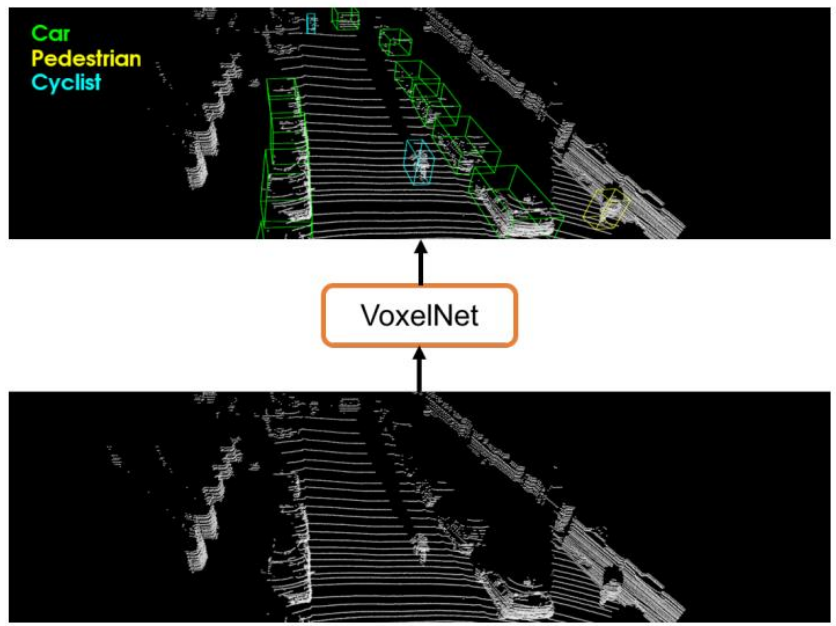
- Convolutional Neural Network (CNN) for 2D images works really well
  - AlexNet, ResNet, & GoogLeNet
  - R-CNN → Fast R-CNN → Faster R-CNN → Mask R-CNN
  - Recent 2D image classification can even extract precise boundaries of objects (FCN → Mask R-CNN)

[1] He et al., Mask R-CNN (2017)

3D OBJECT CLASSIFICATION

Deep Learning for 3D Object Classification

- 3D object classification approaches are getting more attentions
  - Collecting 3D point data is easier and cheaper than before (LiDAR & other sensors)
  - Size of data is bigger than 2D images
  - Open datasets are increasing
  - Recent researches approaches human level detection accuracy
    - MVCNN, ShapeNet, PointNet, VoxNet, VoxelNet, & VRN Ensemble



[2] Zhou and Tuzel, VoxelNet (2017)

GOALS

The goals of our method

- Evaluating & comparing different types of Neural Network models for 3D object classification

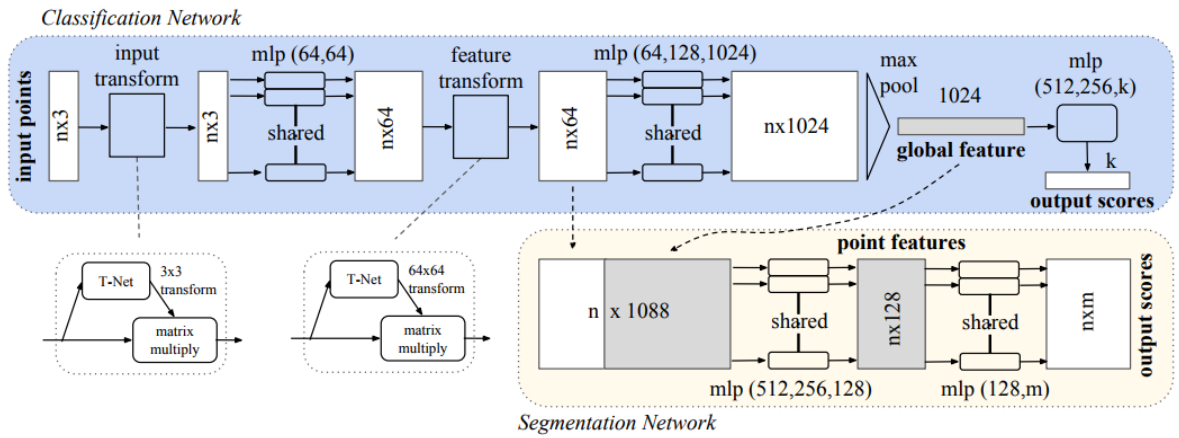
- Providing the generic framework to test multiple 3D neural network models
  - Simple & easy to implement neural network models
  - Fast preprocessing (remove bottleneck of loading, sampling, & jittering 3D data)

PREVIOUS WORK

3D POINT-BASED APPROACHES

3D Points → Neural Nets

- PointNet
  - First 3D point-based classification
  - Unordered dataset
  - Transform → Multi-Layer Perceptron (MLP) → Max Pool (MP) → Classification

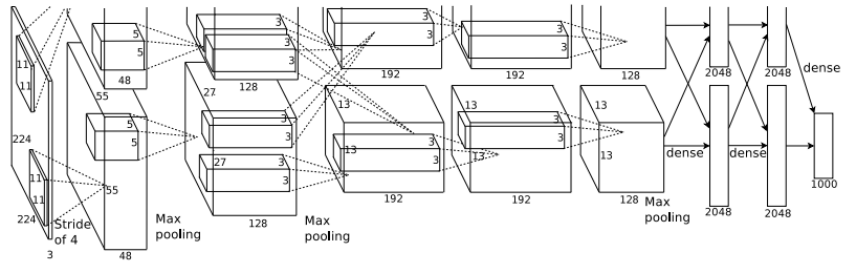


[5] Qi et al., PointNet (2017)

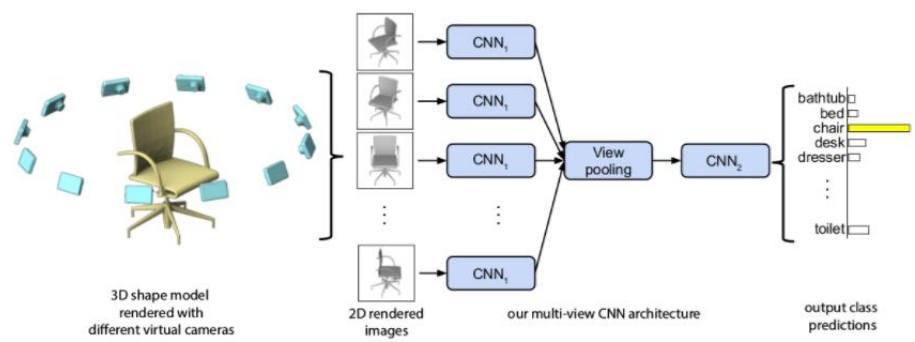
PIXEL-BASED APPROACHES

3D → 2D Projections → Neural Nets

- Multi-Layer Perceptron (MLP)
- Convolutional Neural Network (CNN)
- Multi-View Convolutional Neural Network (MVCNN)



[4] Krizhevsky et al., AlexNet (2012)

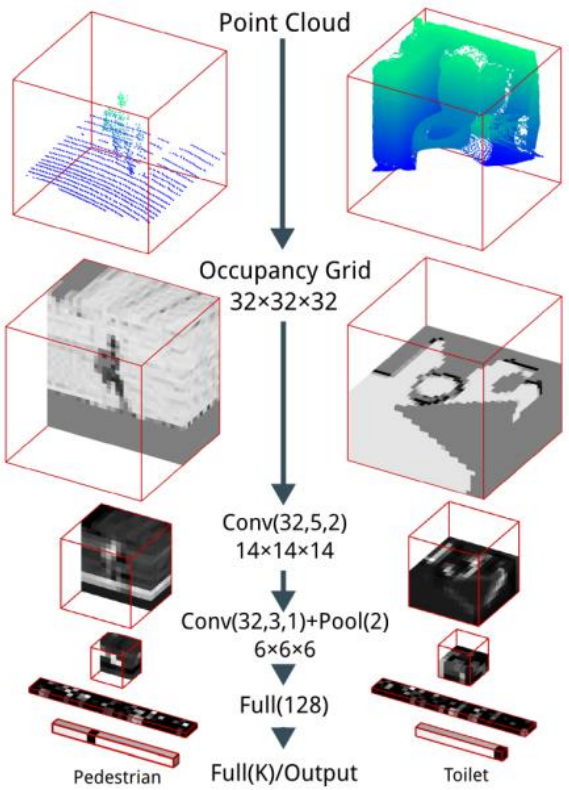


[3] Su et al., MVCNN (2015)

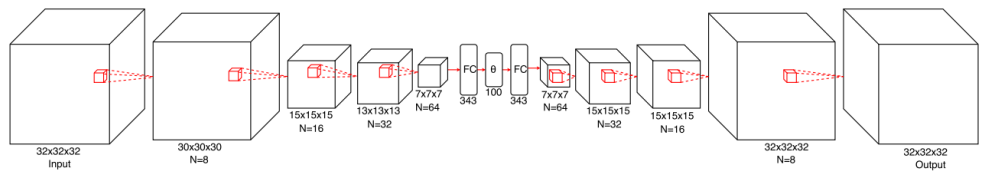
VOXEL-BASED APPROACHES

3D Points → Voxels → Neural Nets

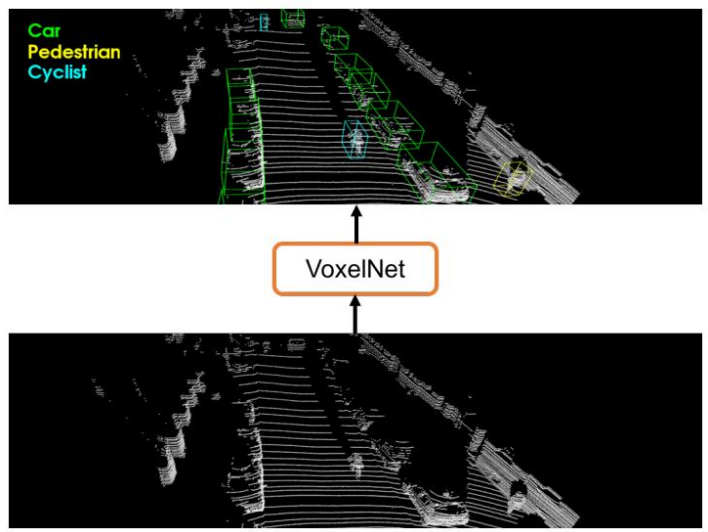
- VoxNet
- VRN Ensemble
- VoxelNet



[6] Maturana and Scherer, VoxNet (2015)



[7] Broke et al., VRN Ensemble (2016)



[2] Zhou and Tuzel, VoxelNet (2017)

METHOD

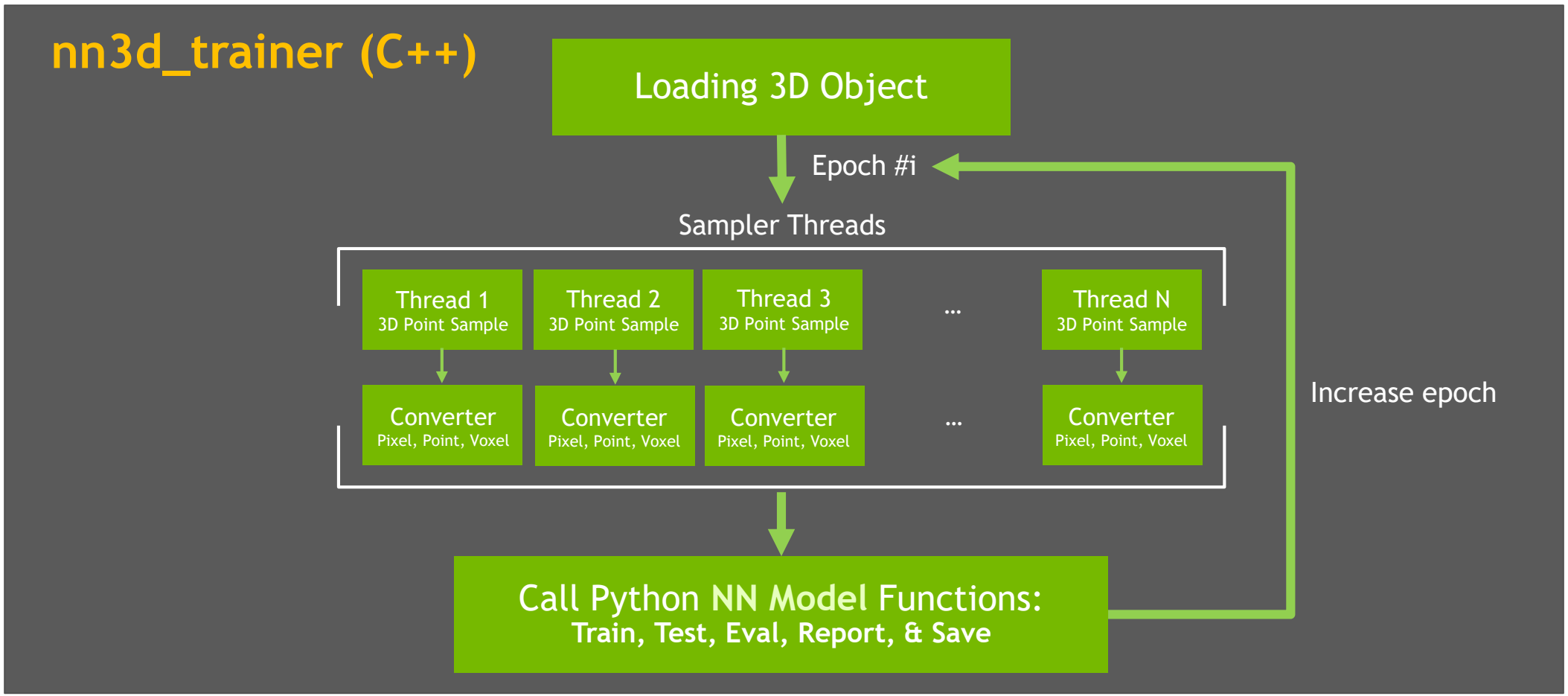
PREPROCESSING

Requirement

- Loading 3D polygonal objects
- Required Operations on 3D objects
  - Sampling, Shuffling, Jittering, Scaling, & Rotating
  - Projection, & Voxelization
- Python interface is not that good for multi-core processing (or multi-threading)
  - # of objects is notoriously for single-core processing

FRAMEWORK

Basic Pipeline



3D DATASETS

MODELNET10

Princeton ModelNet Data

http://modelnet.cs.princeton.edu/

10 Categories

4,930 Objects (2 GB)

OFF (CAD) File Format

MODELNET40

Princeton ModelNet Data

http://modelnet.cs.princeton.edu/

40 Categories

12,431 Objects (10 GB)

OFF (CAD) File Format

SHAPENET CORE V2

ShapeNet

https://www.shapenet.org/

55 Categories

51,191 Objects (90 GB)

OBJ File Format

NEURAL NETWORK MODELS

Point-Based Models

Pixel-Based Models

Voxel-Based Models

POINT-BASED NEURAL NETWORK MODELS

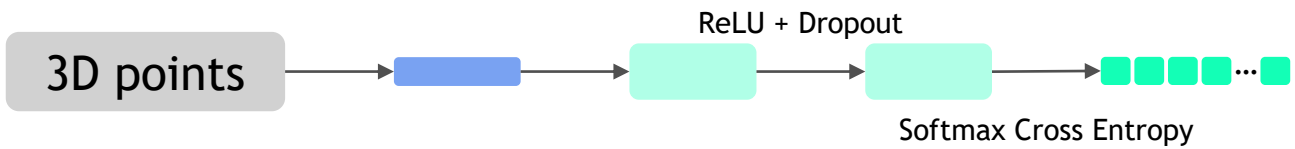
Types of Models

- Preprocessing:
  - Rotate randomly
  - Scale randomly
  - Uniform sampling on 3D object surfaces
  - Sample 2048 points
  - Shuffle points

- Tested Models
  - Multi-Layer Perceptron (MLP)
  - Multi Rotational MLPs
  - Single Orientation CNN
  - Multi Rotational CNNs
  - Multi Rotational Resample & Max Pool Layers
  - ResNet-like

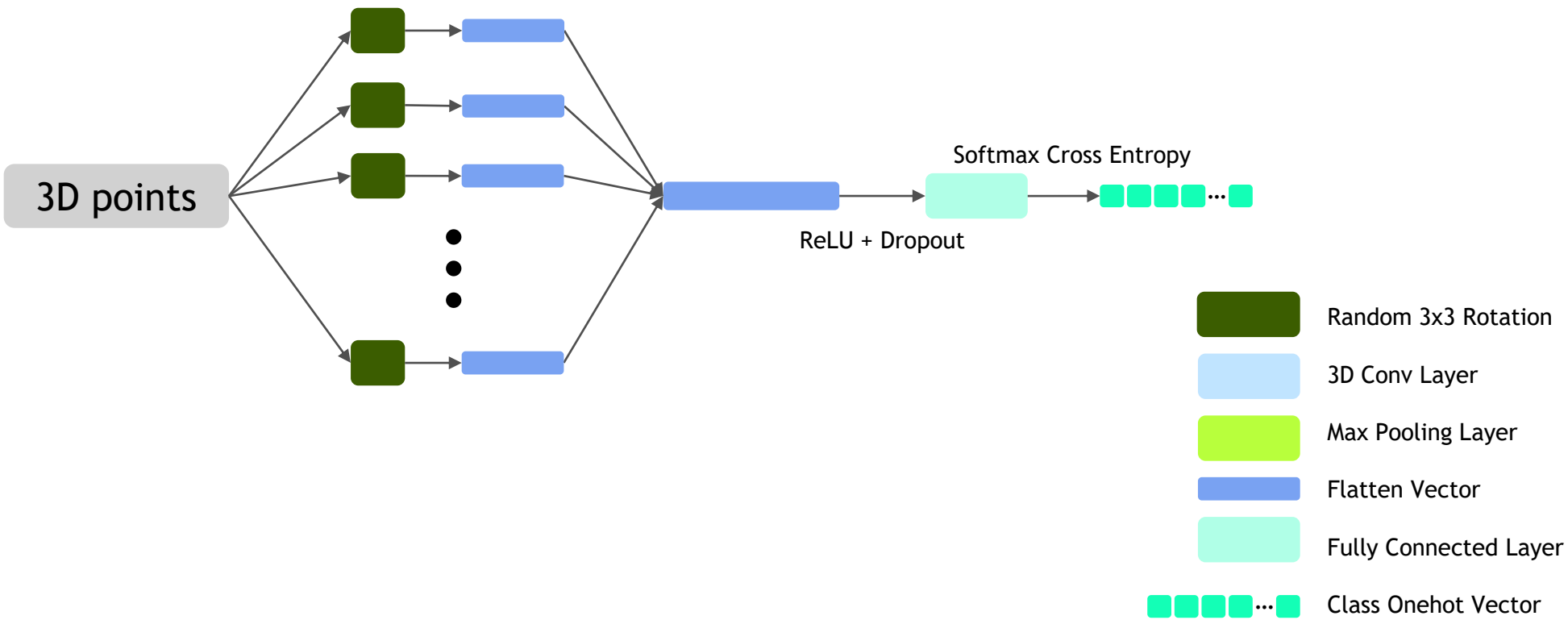
POINT-BASED NEURAL NETWORK MODELS

MLP



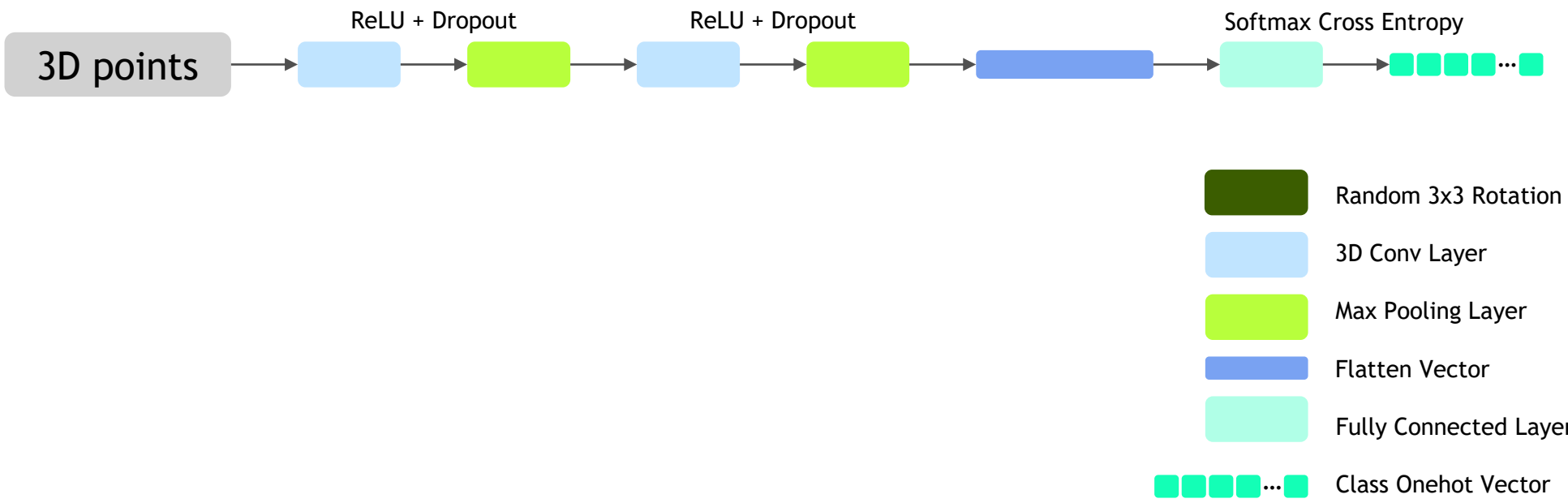
POINT-BASED NEURAL NETWORK MODELS

Multi Rotational MLPs



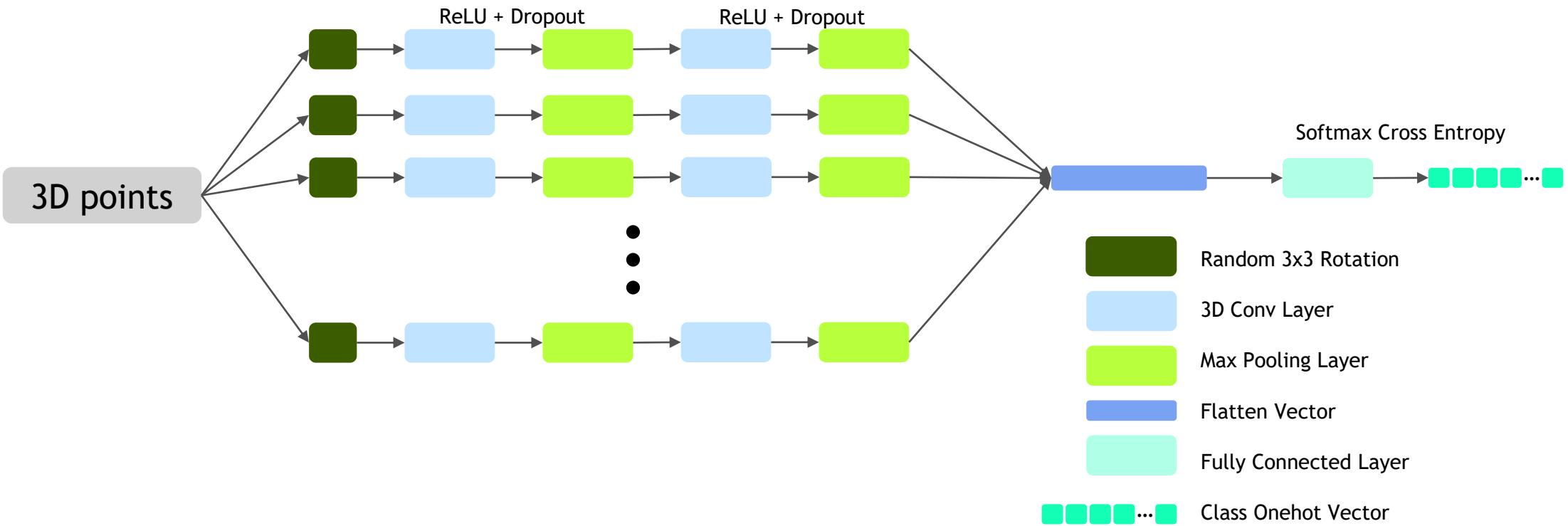
POINT-BASED NEURAL NETWORK MODELS

Single Orientation CNN



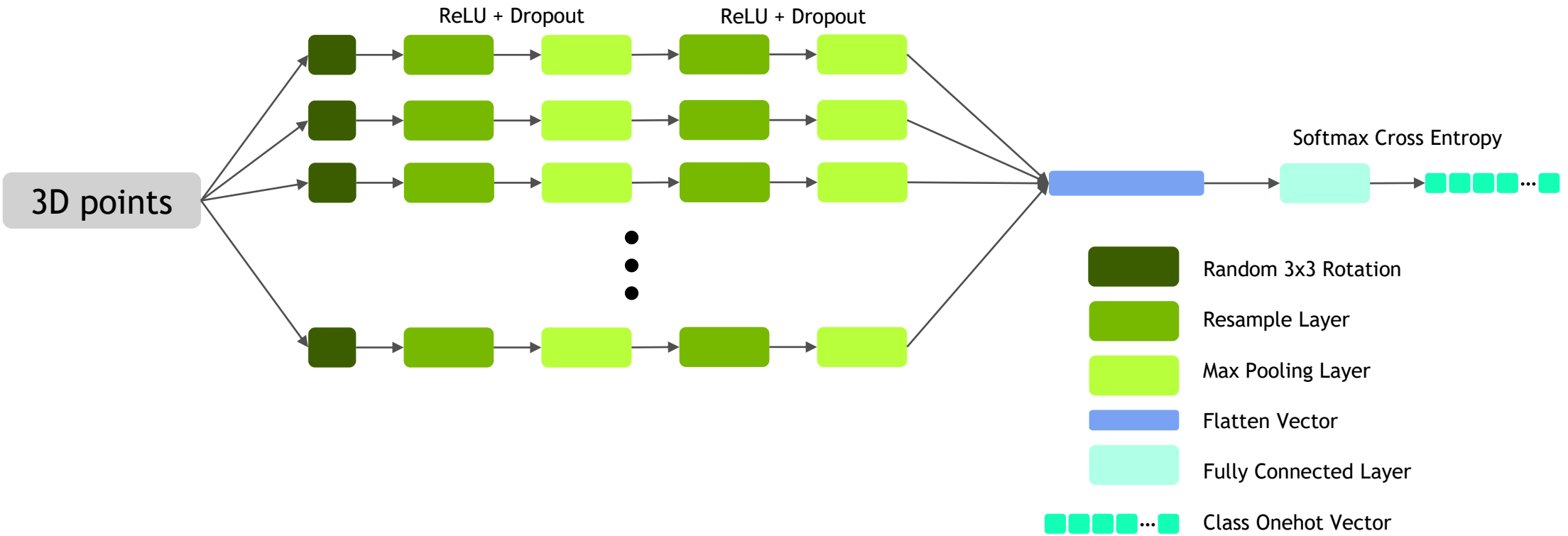
POINT-BASED NEURAL NETWORK MODELS

Multi Rotational CNNs



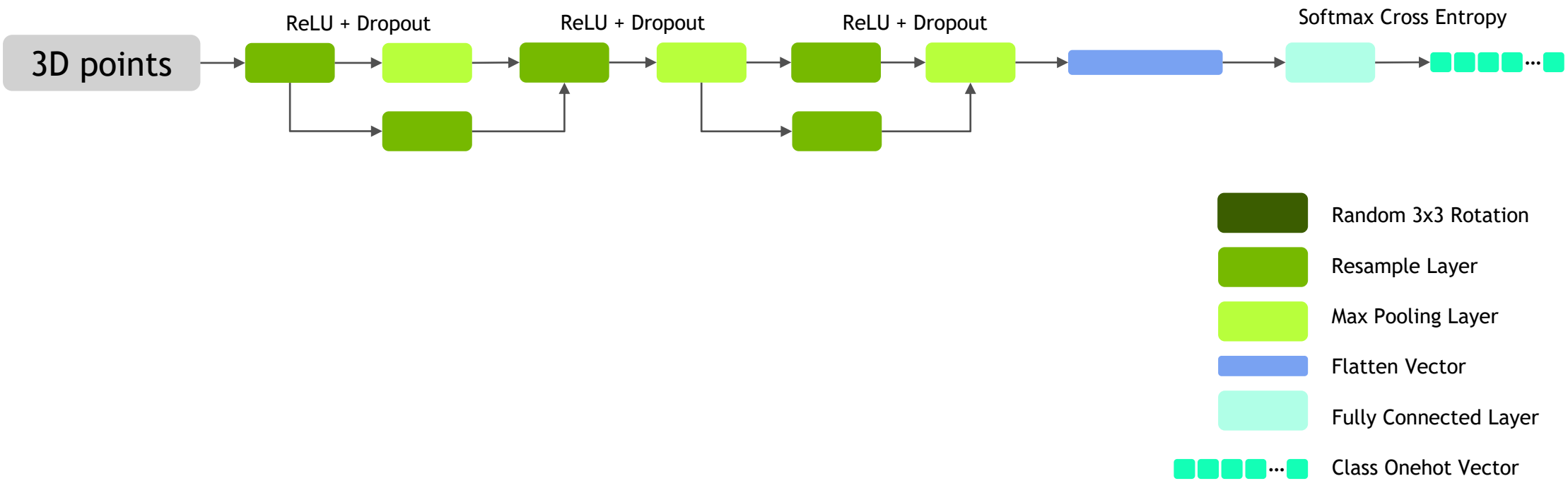
POINT-BASED NEURAL NETWORK MODELS

Multi Rotational Resample & Max Pool Layers



POINT-BASED NEURAL NETWORK MODELS

ResNet-like



PIXEL-BASED NEURAL NETWORK MODELS

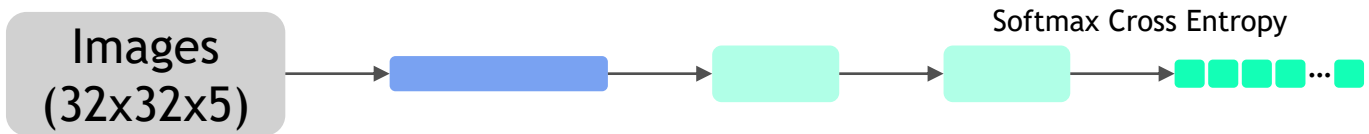
Types of Models

- Preprocessing:
  - Sample 8192 points
    - Same as point-based models
  - Depth-only orthogonal projection
    - 32x32 or 64x64
  - Generating multiple rotations
    - 64x64x5 & 64x64x10

- Tested Models:
  - MLP
  - Depth-Only Orthogonal MVCNN

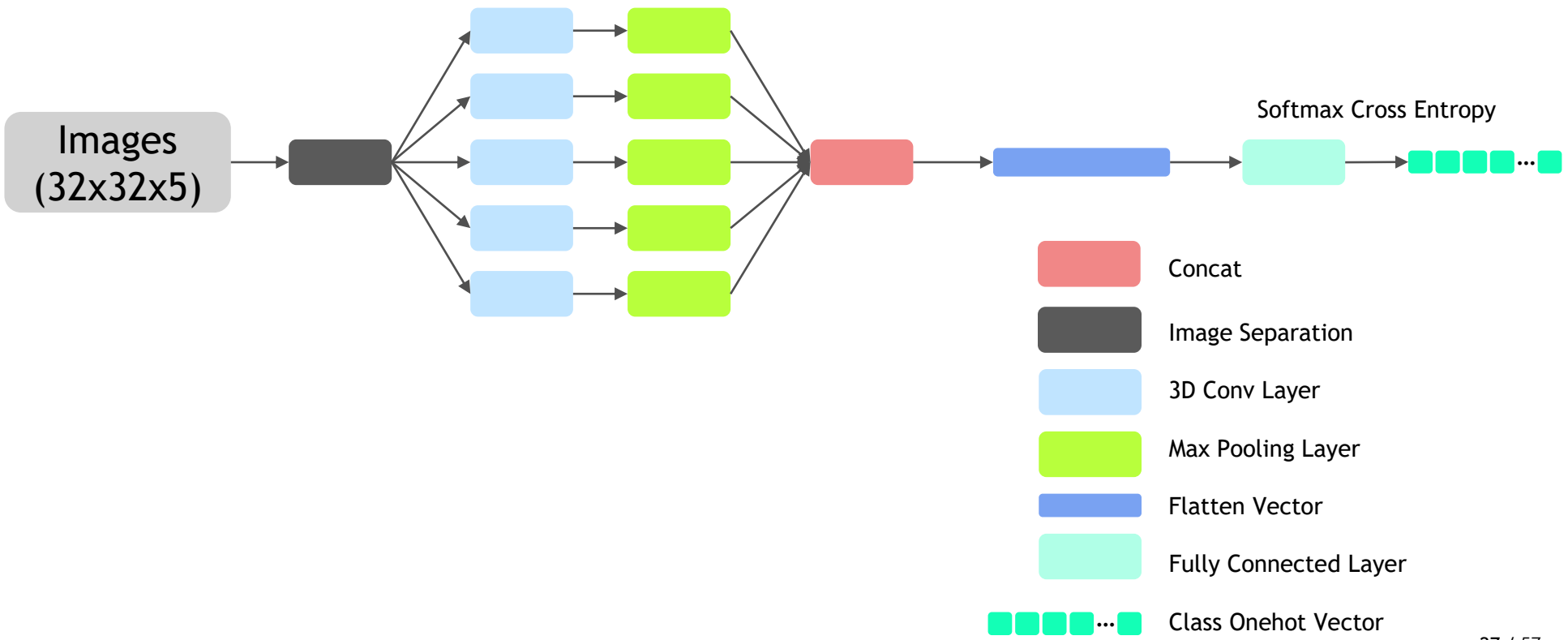
PIXEL-BASED NEURAL NETWORK MODELS

MLP



PIXEL-BASED NEURAL NETWORK MODELS

Depth-Only Orthogonal MVCNN

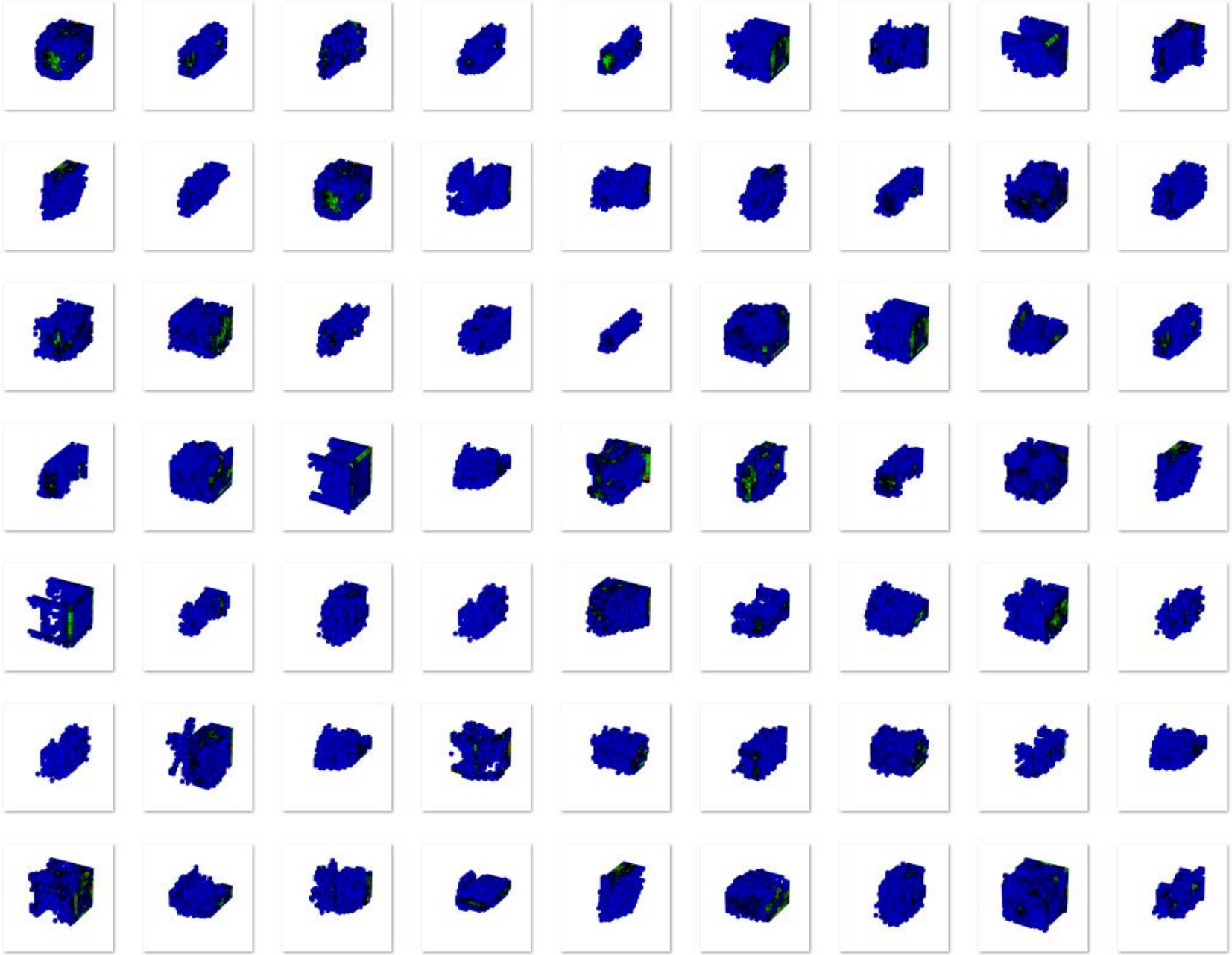


VOXEL-BASED NEURAL NETWORK MODELS

Types of Models

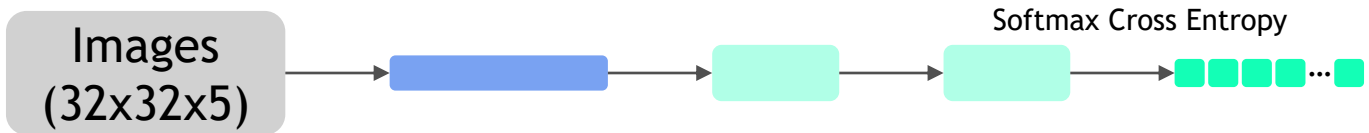
- Preprocessing:
  - Sample 8192 points
    - Same as point based models
  - Voxelization
    - 3D points → Voxels
  - Each voxel has intensity 0.0 ~ 1.0
    - how many points hit same voxel
    - 32x32x32 & 64x64x64

- Tested Models:
  - MLP
  - CNN
  - ResNet-like



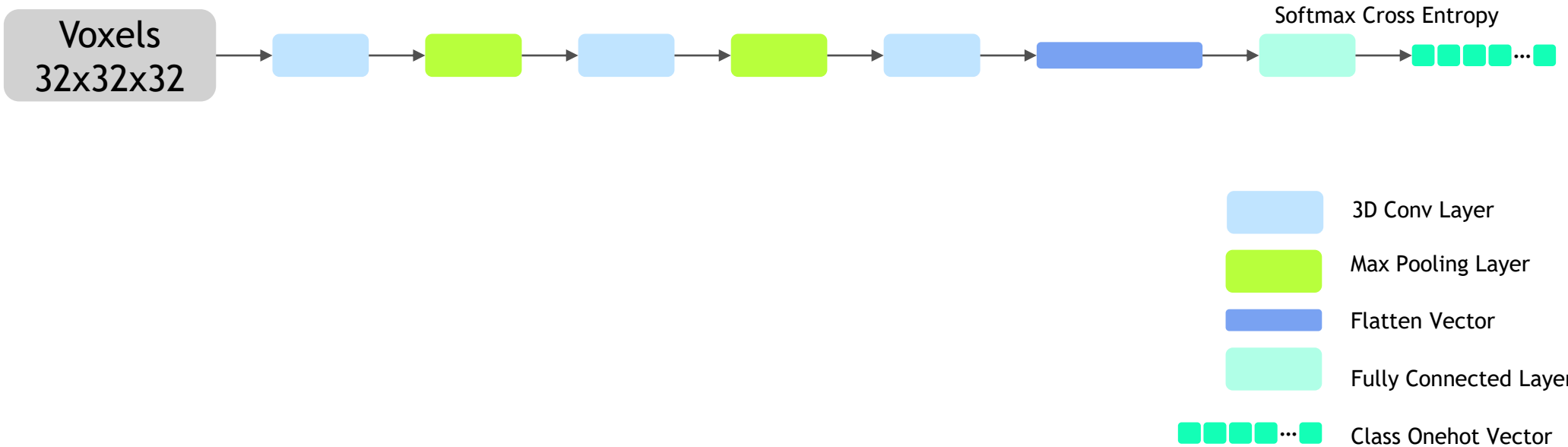
VOXEL-BASED NEURAL NETWORK MODELS

MLP



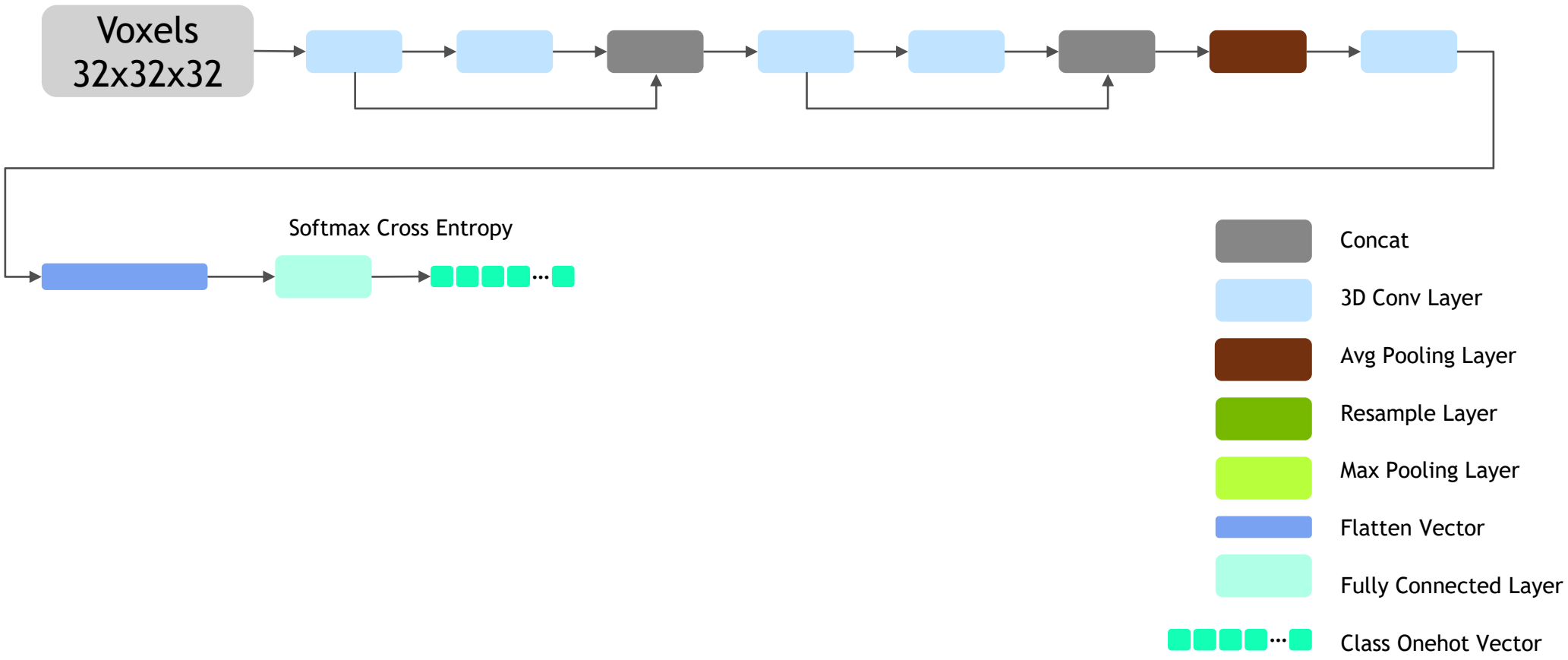
VOXEL-BASED NEURAL NETWORK MODELS

CNN



VOXEL-BASED NEURAL NETWORK MODELS

ResNet-like



IMPLEMENTATION

System Setup

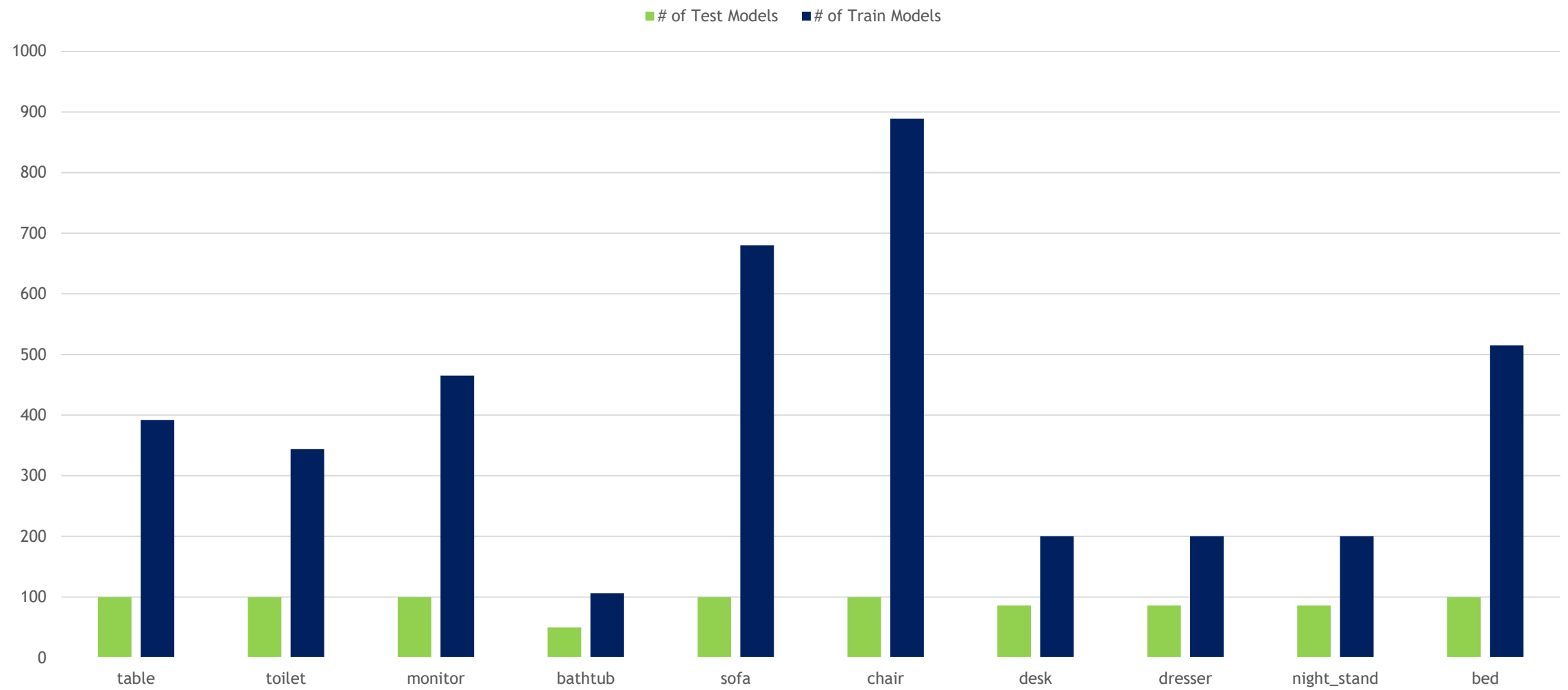
- System: Ubuntu 16.04, RAM 32 GB & 64 GB, & SSD 512 GB
- NVIDIA Quadro P6000, Quadro M6000, & GeForce Titan X
- GCC 5.2.0 for C++ 11x
- Python 3.5
- TensorFlow-GPU v1.5.0
- NumPy 1.0

HYPER PARAMETERS

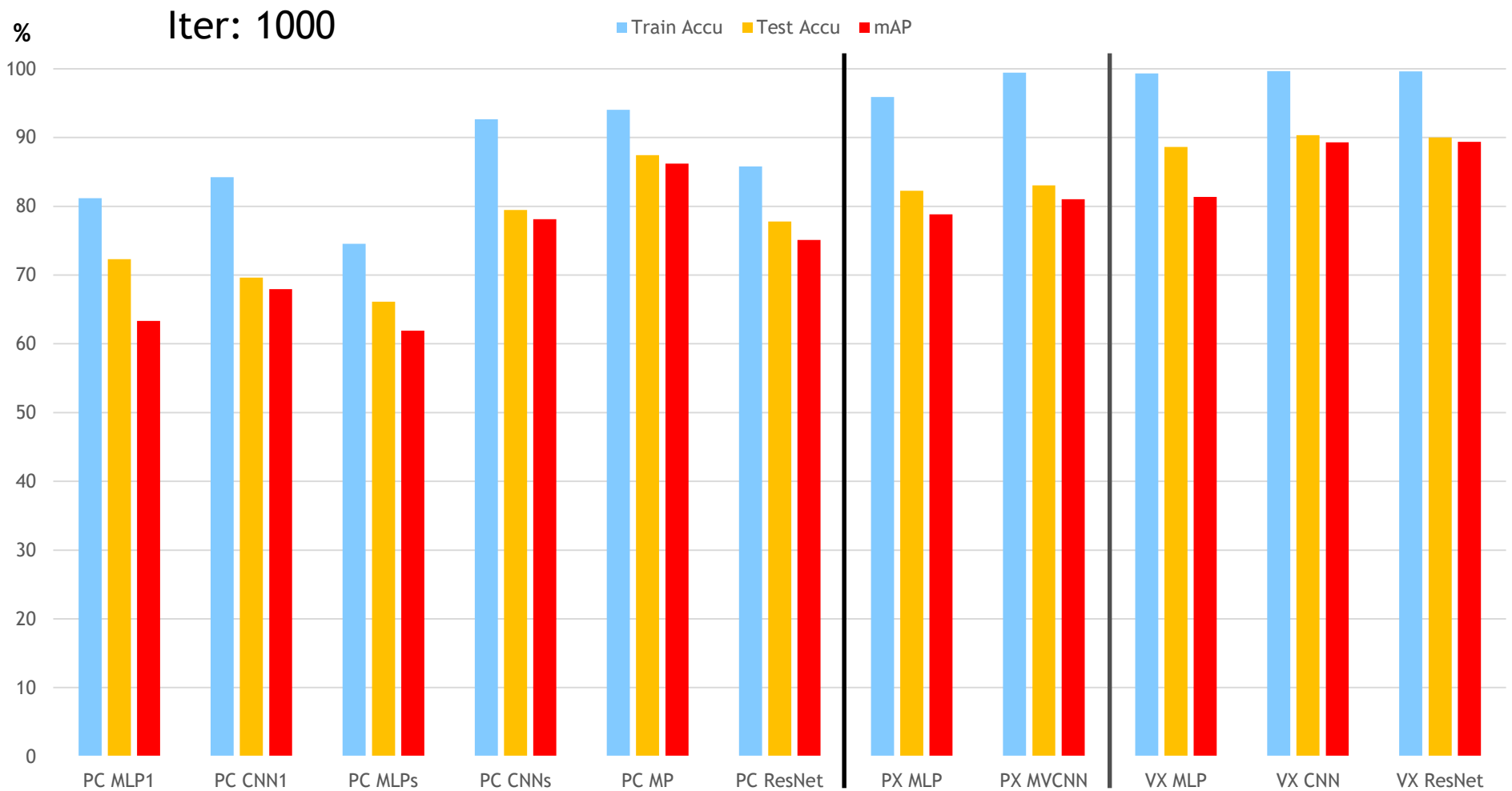
- Object Perturbation
  - Random Rotations: -25 ~ 25 degree
  - Random Scaling: 0.7 ~ 1.0
- Learning Rate: 0.0001
- Keep Probability (Dropout layer): 0.7
- Max Epochs: 1000
- Batch Size: 32
- Number of Random Rotations: 20
- Voxel Dim: 32x32x32
- MVCNN Number of Views: 5

RESULT

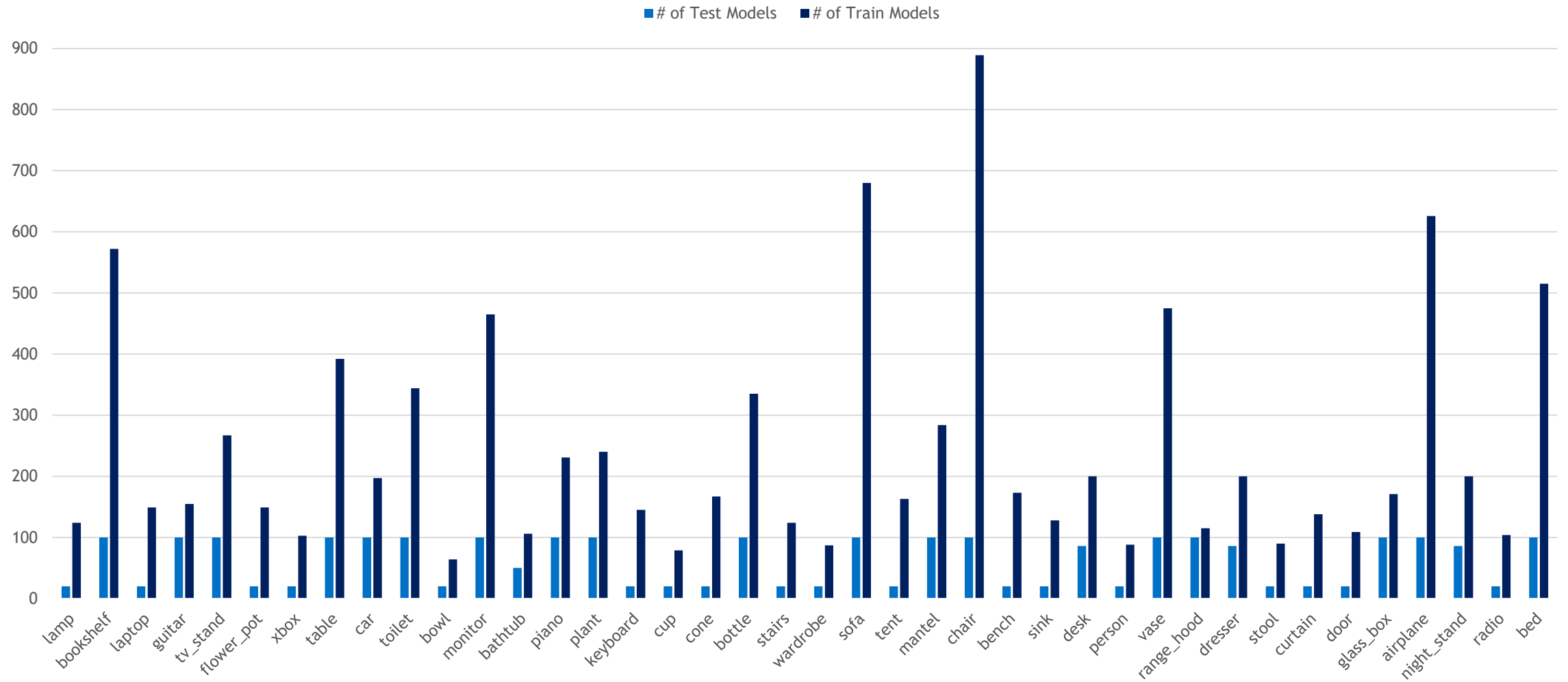
MODELNET10
OF TEST & TRAIN OBJECTS



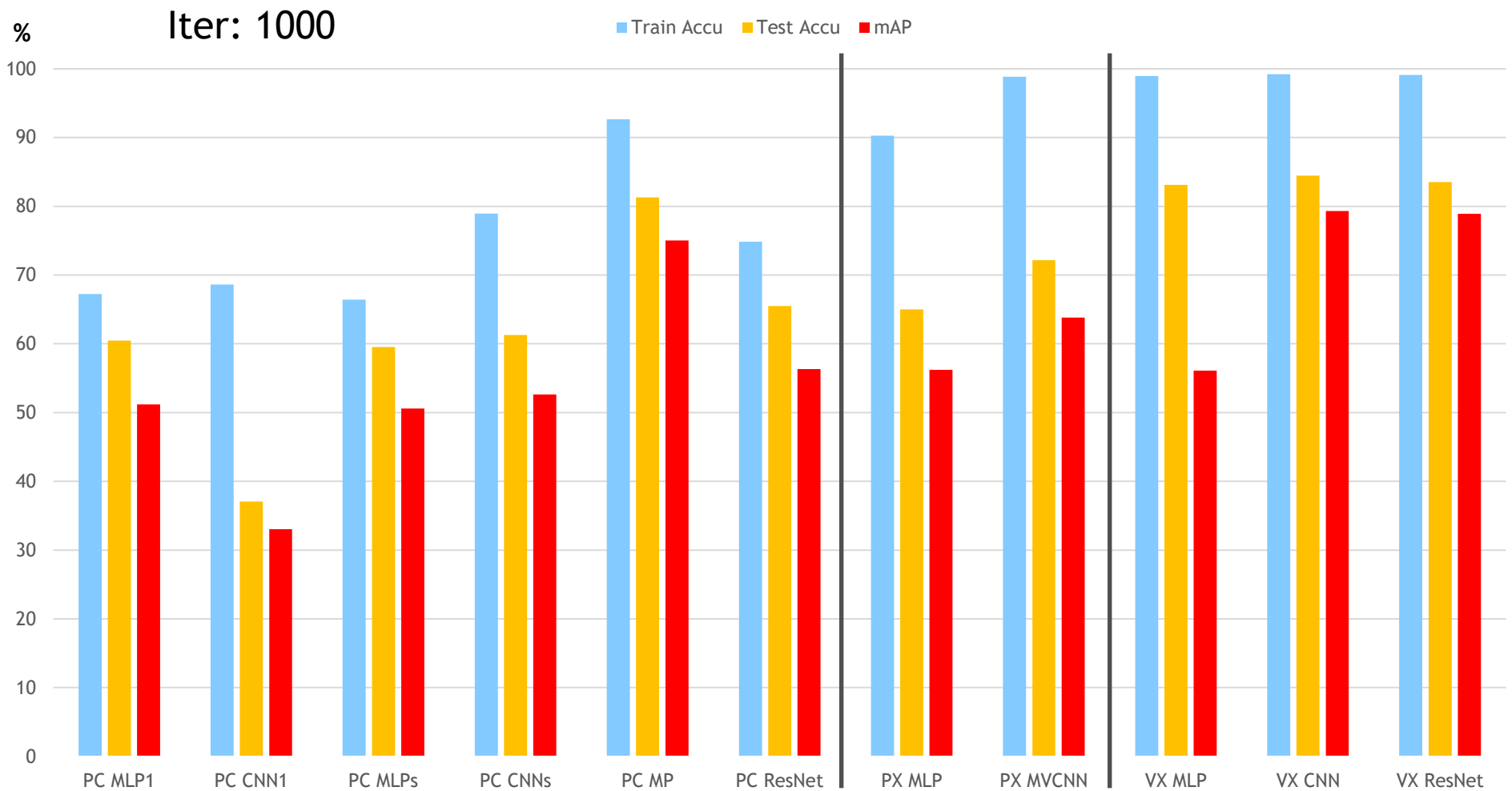
MODELNET10 ACCURACY



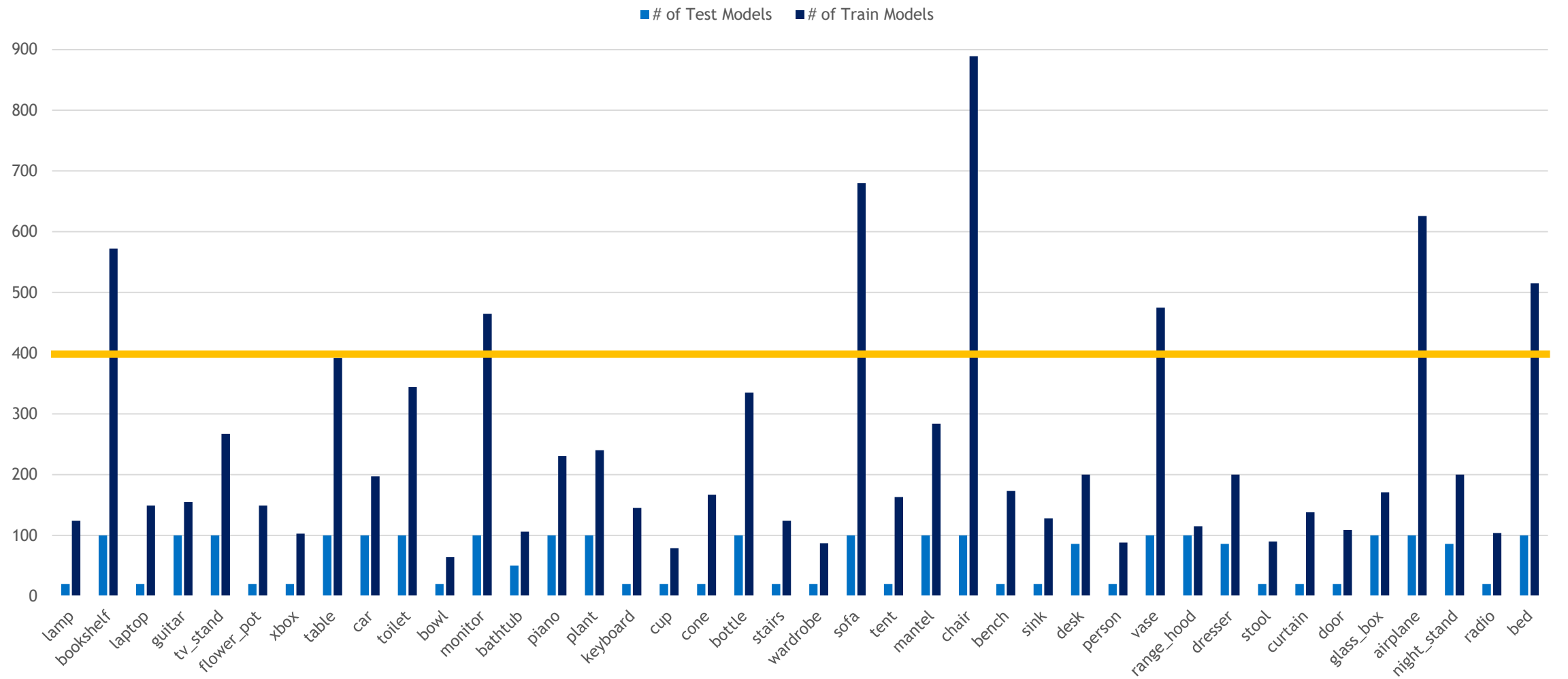
MODELNET40
OF TEST & TRAIN OBJECTS



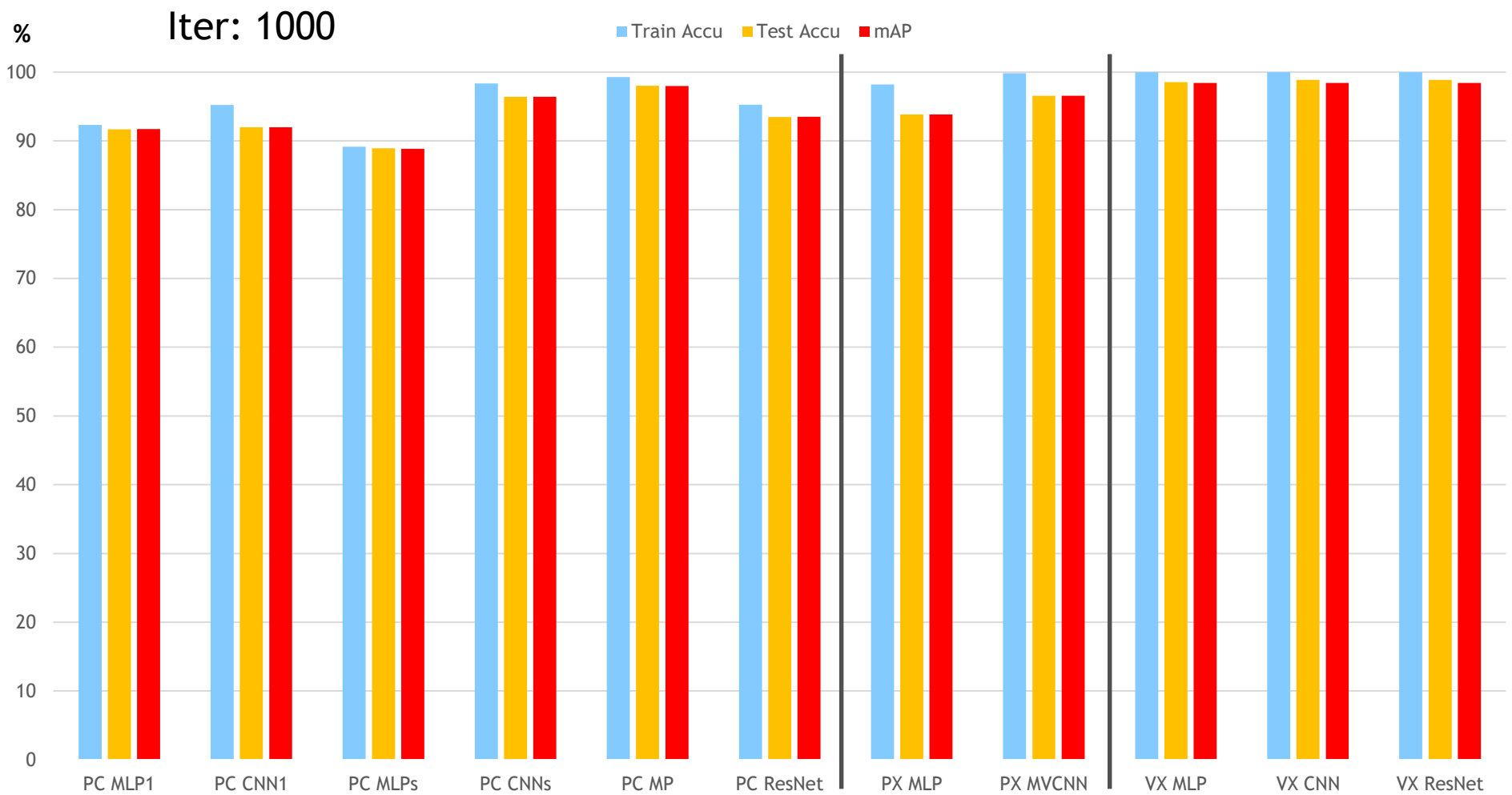
MODELNET40 ACCURACY



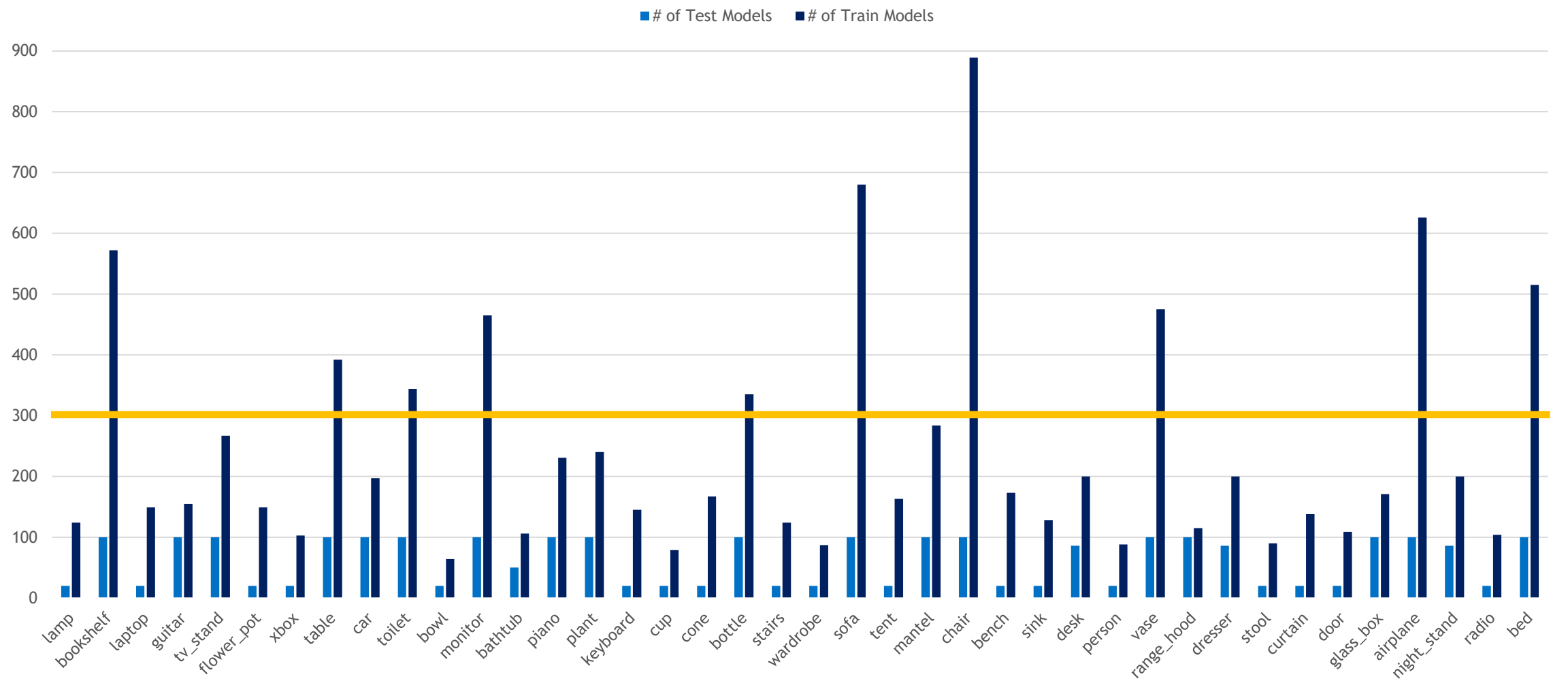
MODELNET40 ACCURACY
7 CATEGORIES (# OF TRAIN OBJECTS > 400)



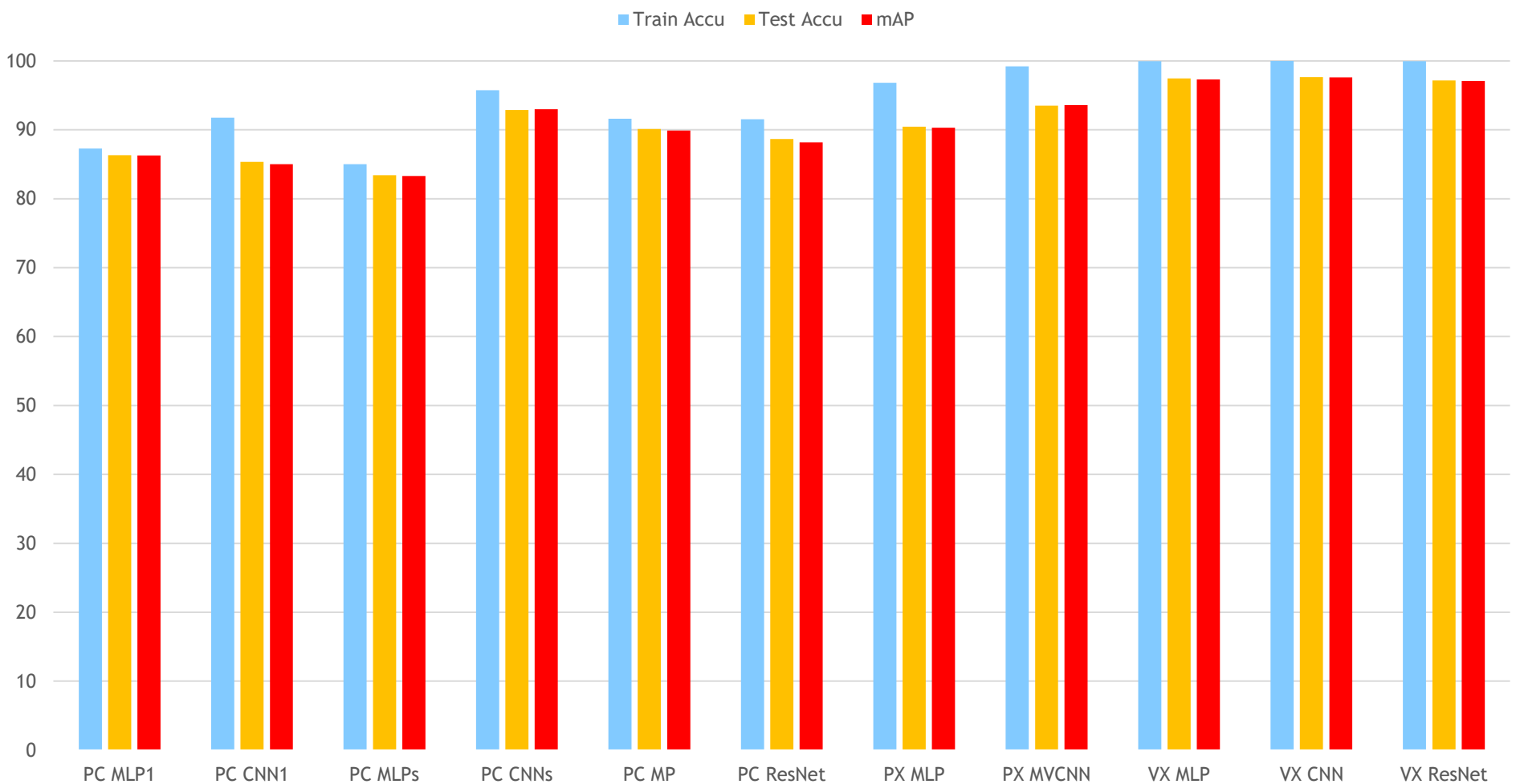
MODELNET40, 7 CATEGORIES ACCURACY



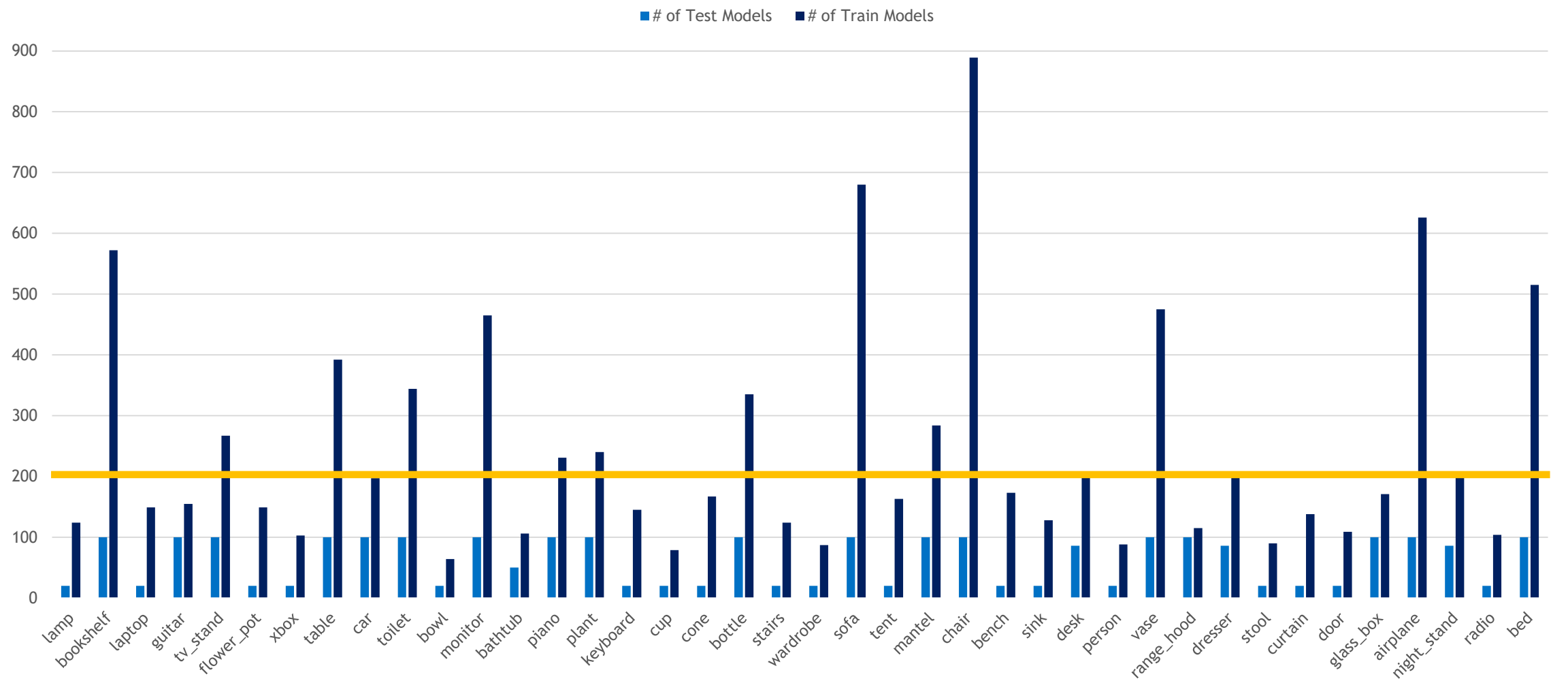
MODELNET40 ACCURACY
10 CATEGORIES (# OF TRAIN OBJECTS > 300)



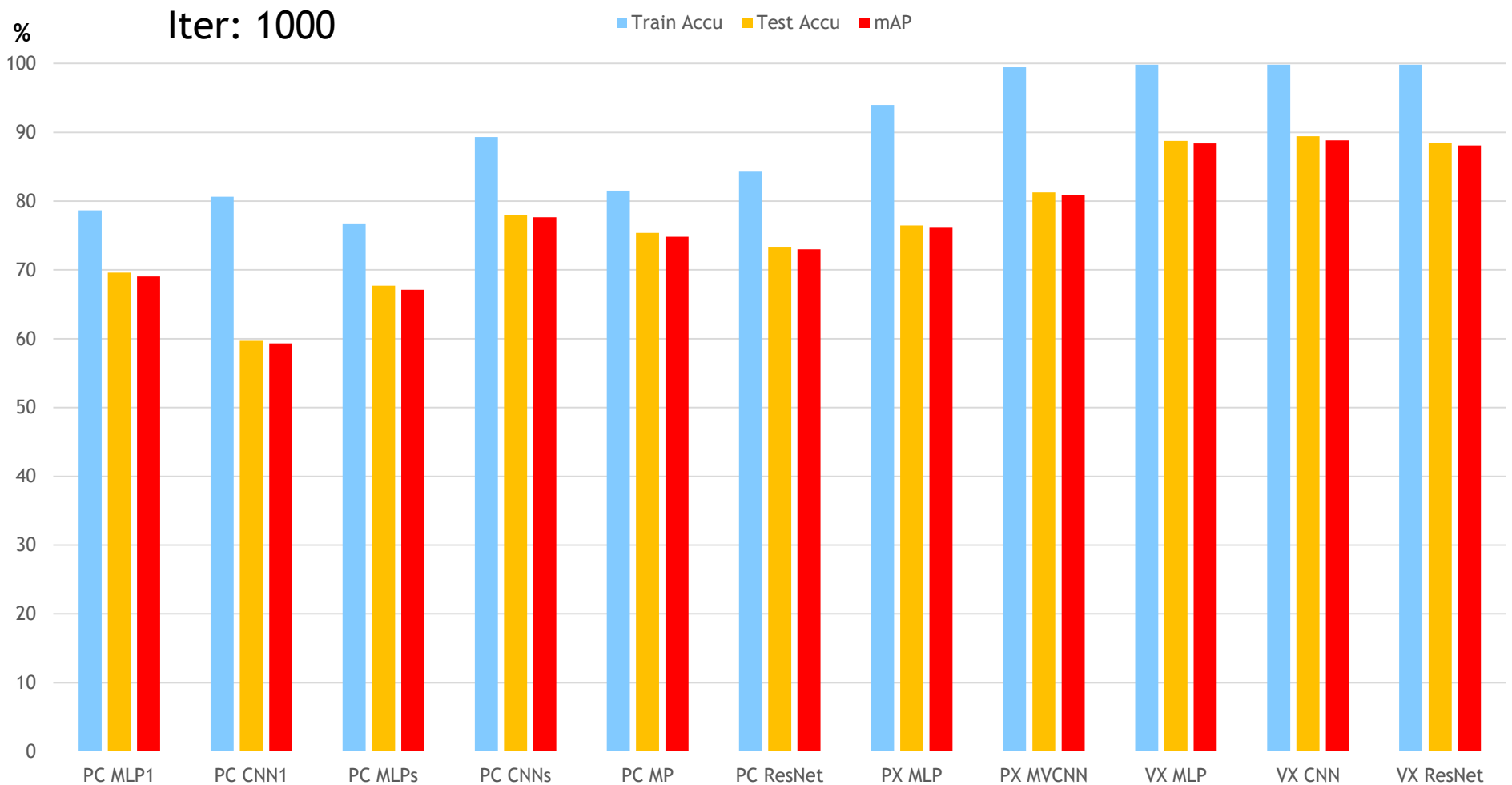
MODELNET40, 10 CATEGORIES ACCURACY



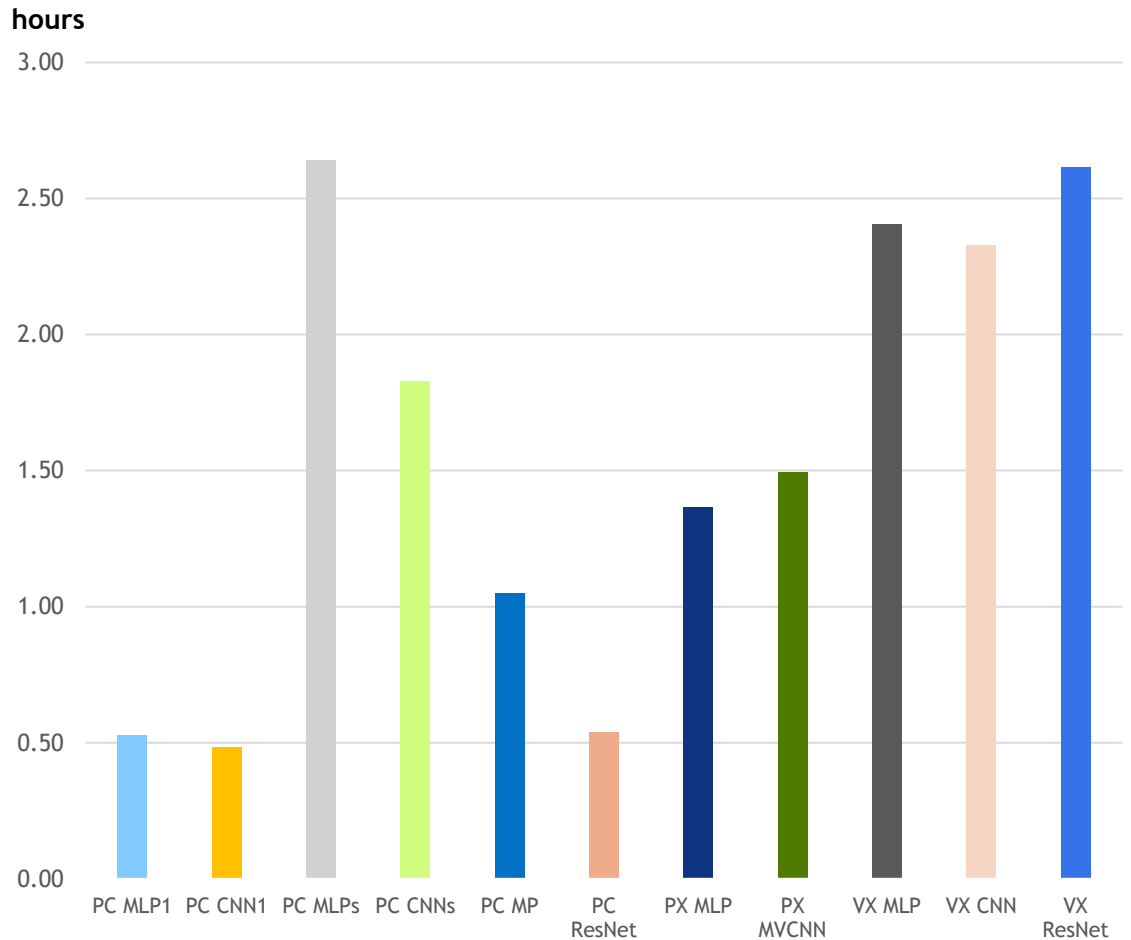
MODELNET40 ACCURACY
17 CATEGORIES (# OF TRAIN OBJECTS > 200)



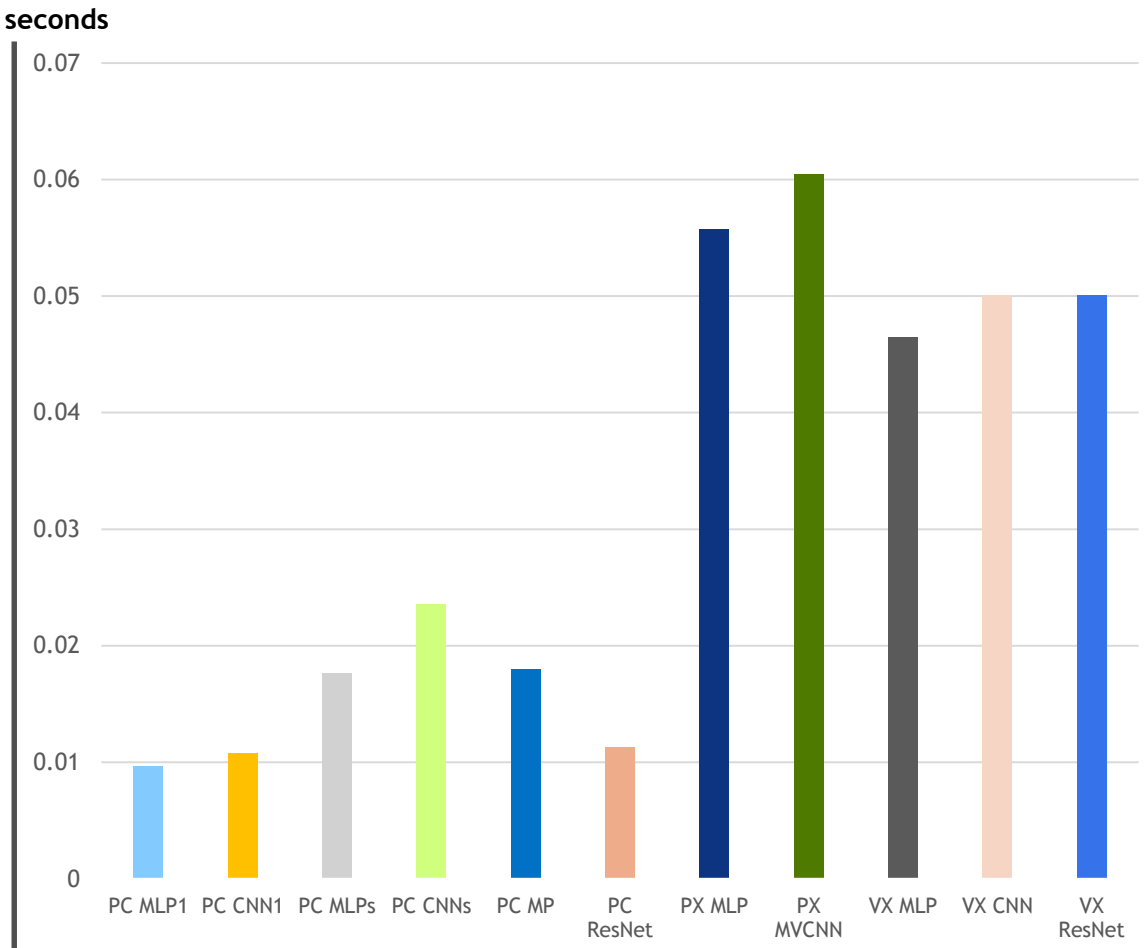
MODELNET40,17 CATEGORIES ACCURACY



MODELNET10 PERFORMANCE

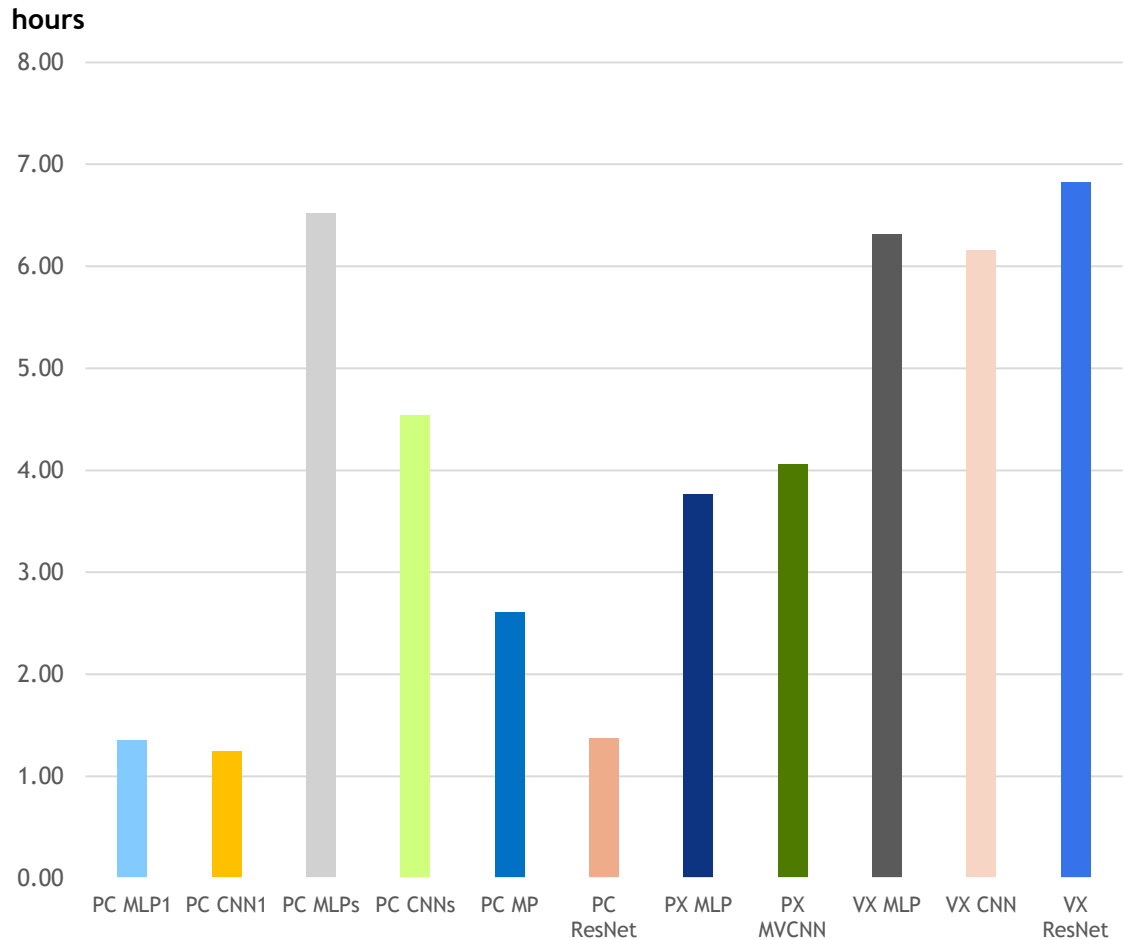


Total Training Time

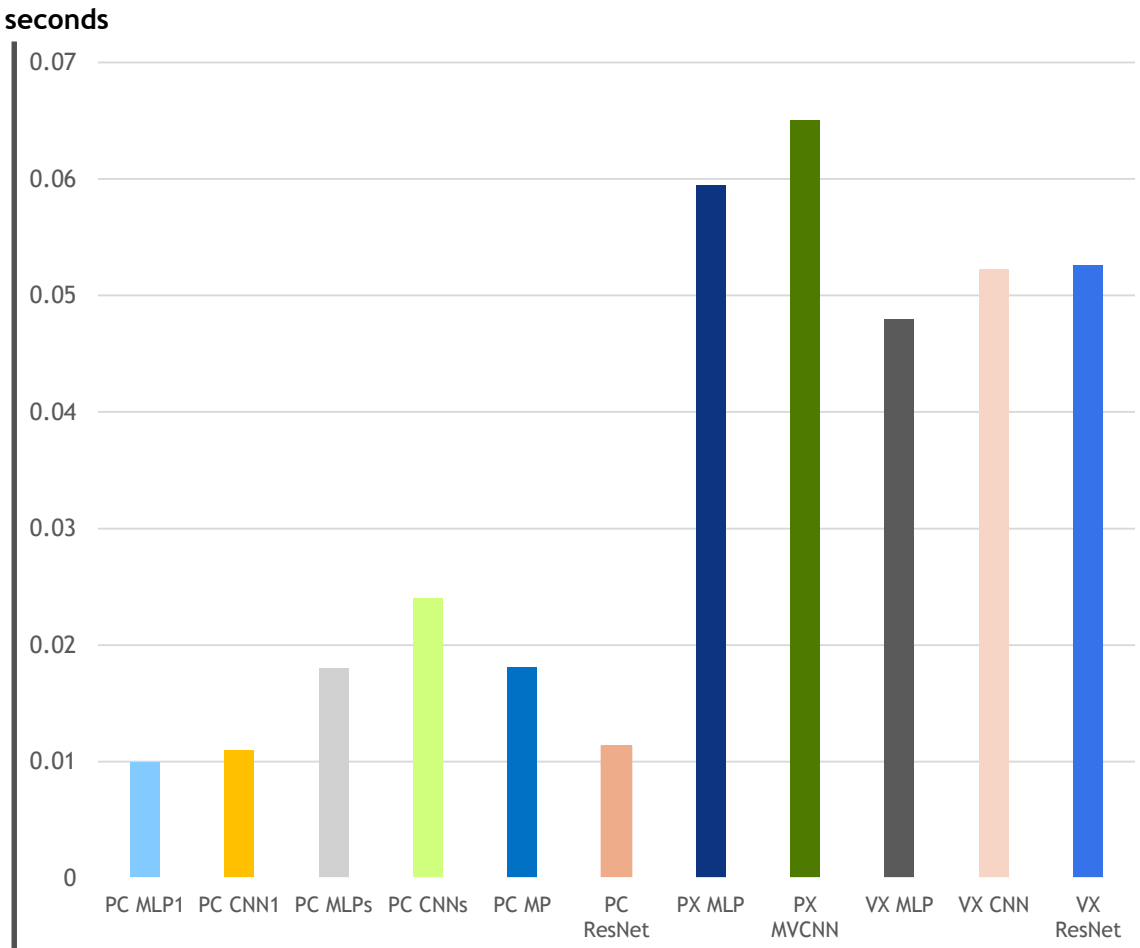


Inference Time Per Batch

MODELNET40 PERFORMANCE



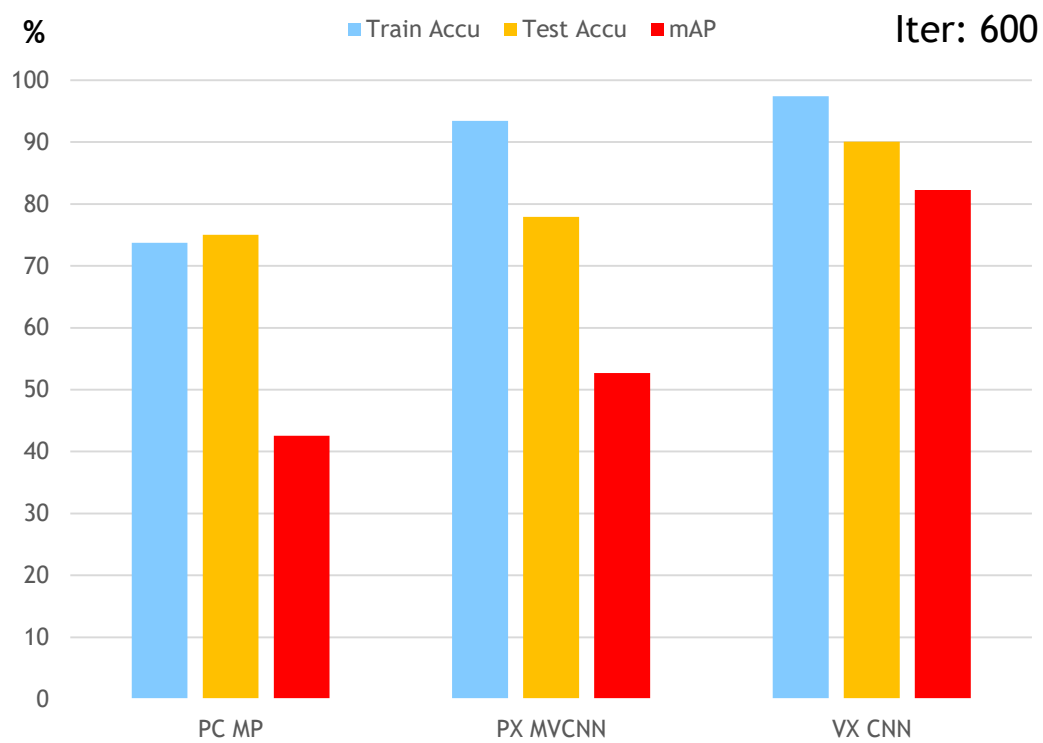
Total Training Time



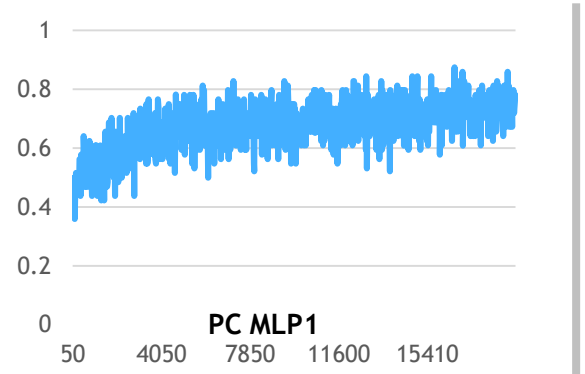
Inference Time Per Batch

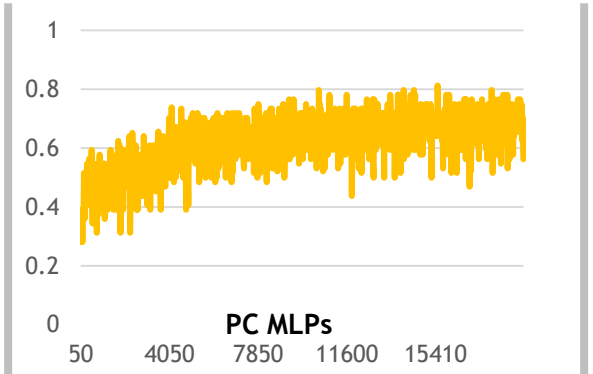
SHAPENET CORE V2 ACCURACY

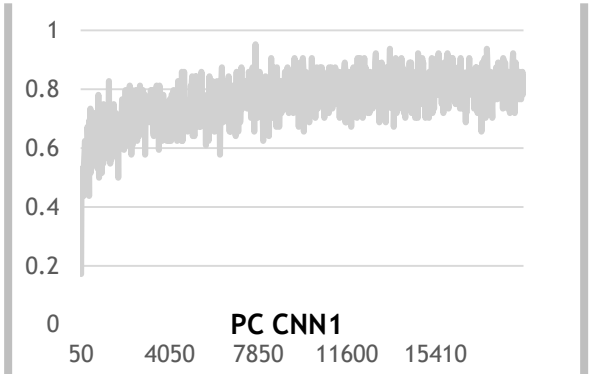
- ShapeNet has pretty big dataset
  - 90 GB of dataset
  - Only tested 3 NN models
    - Point MP
    - Depth-Only MVCNN
    - Voxel CNN

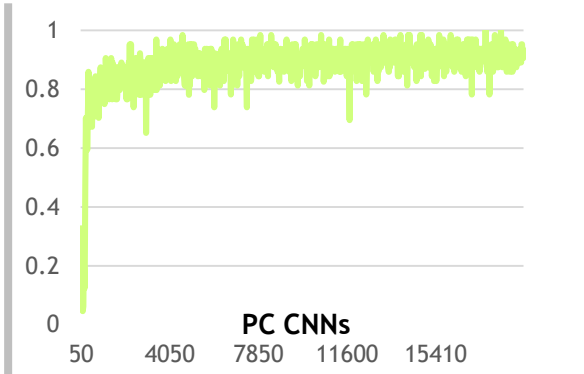


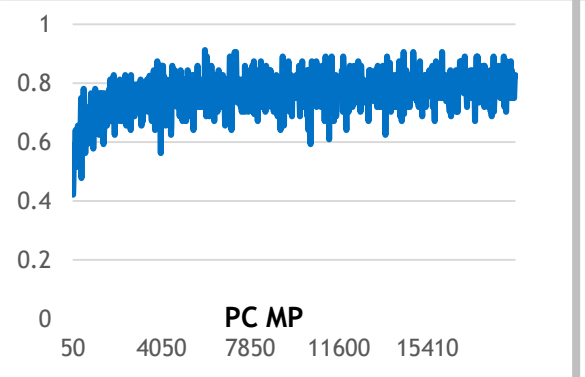
TRAIN ACCURACY GRAPH

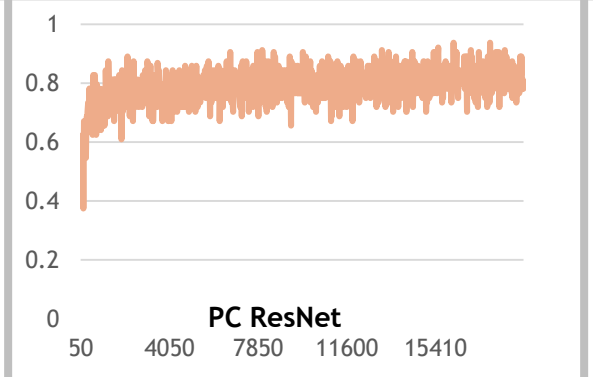


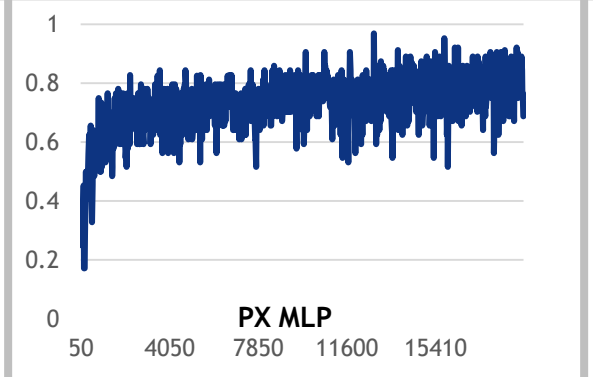


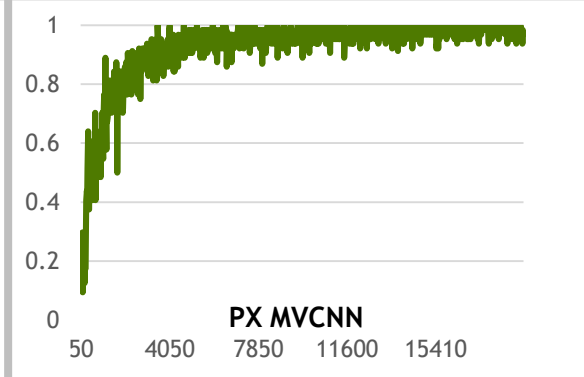


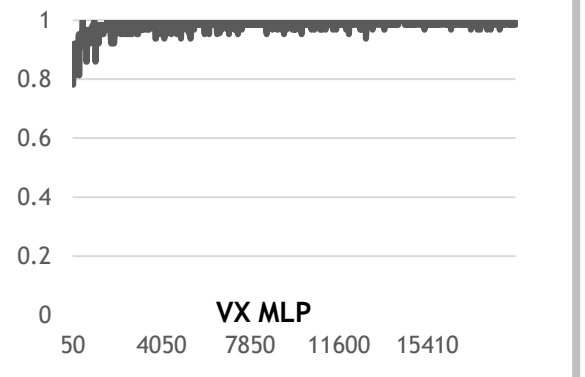


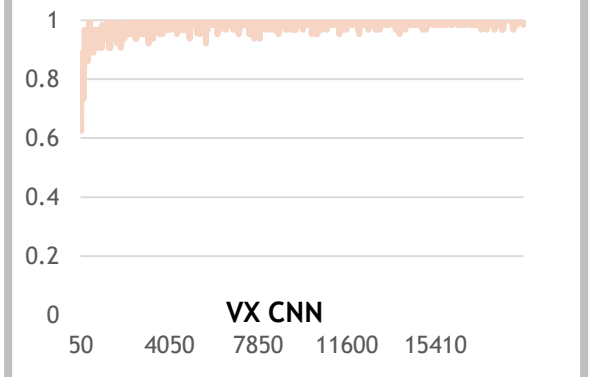


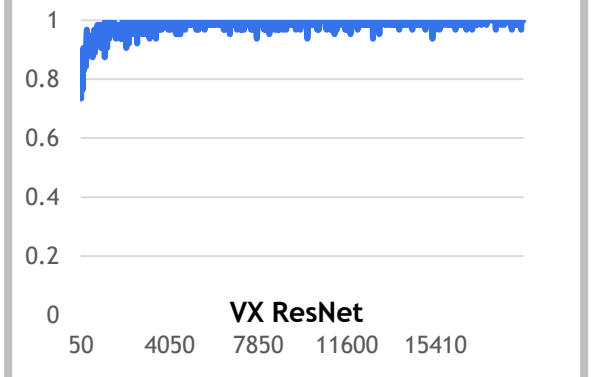




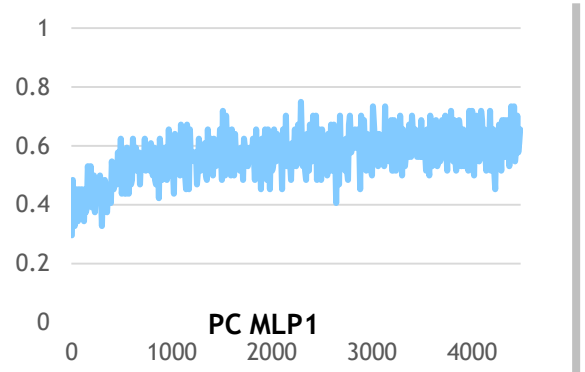


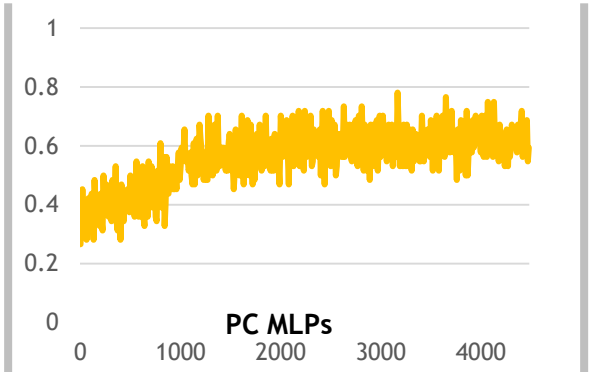


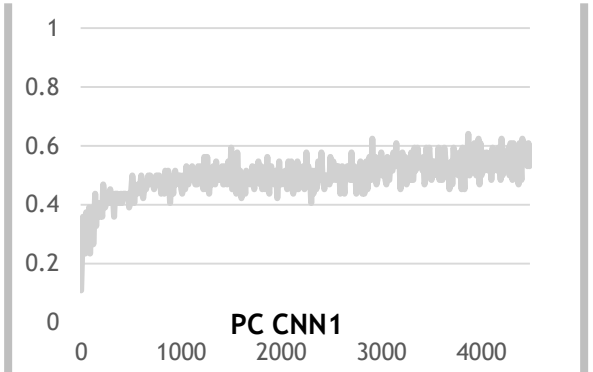


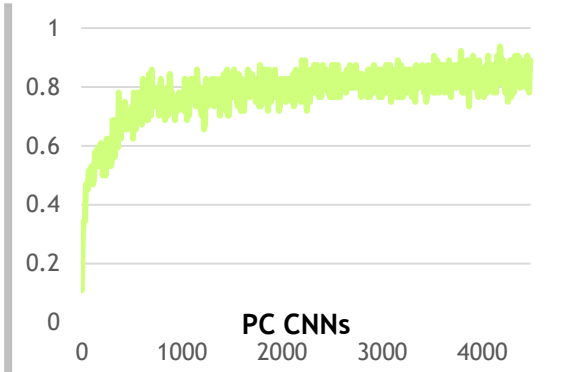


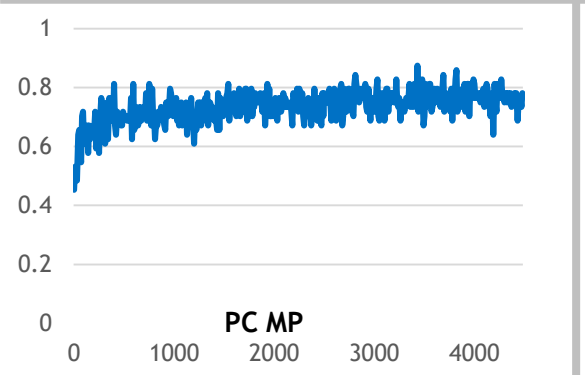
TEST ACCURACY GRAPH

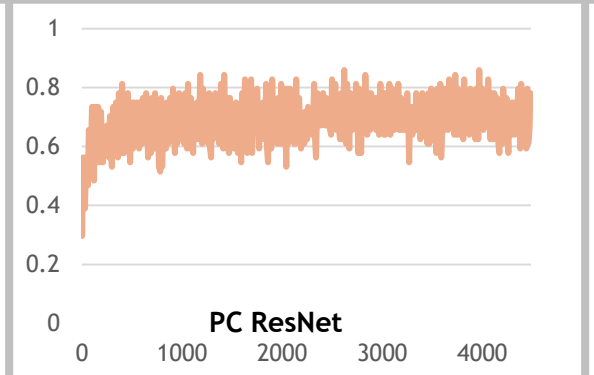


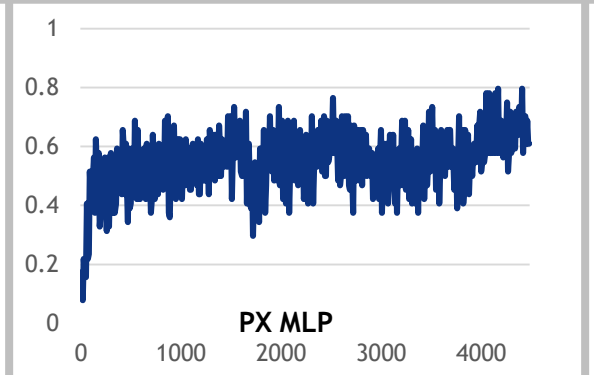


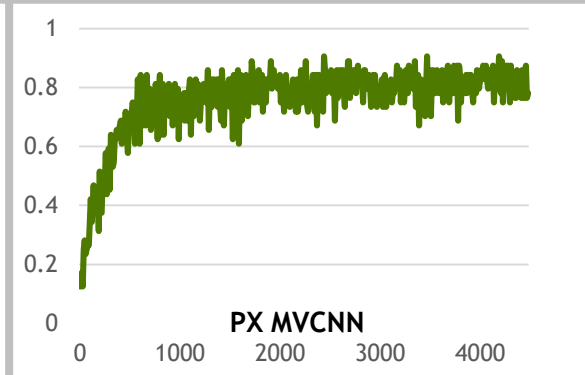


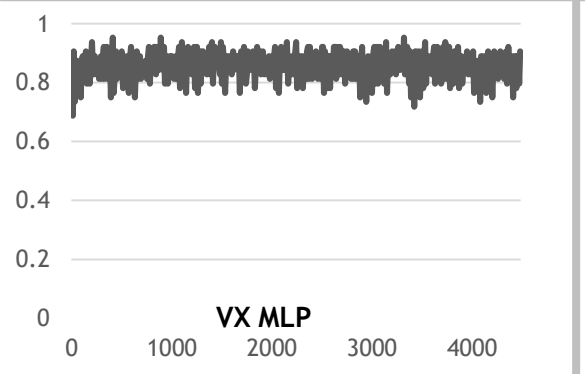


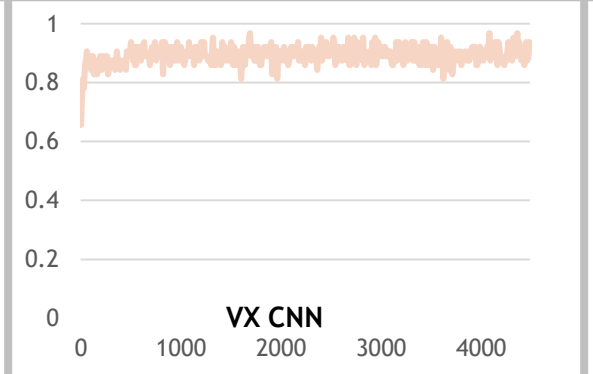


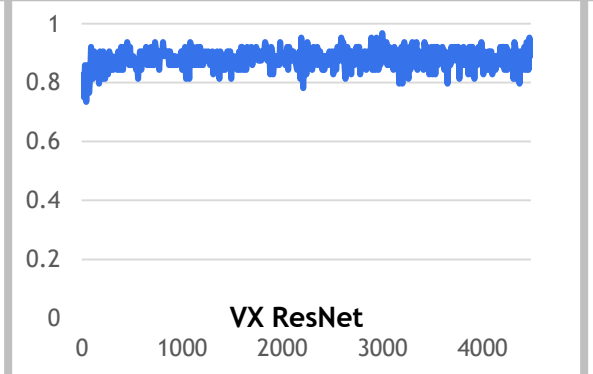




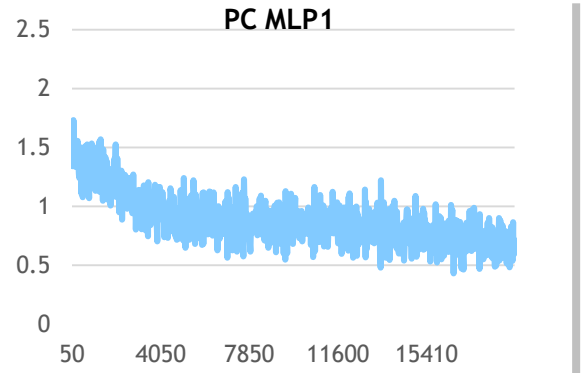


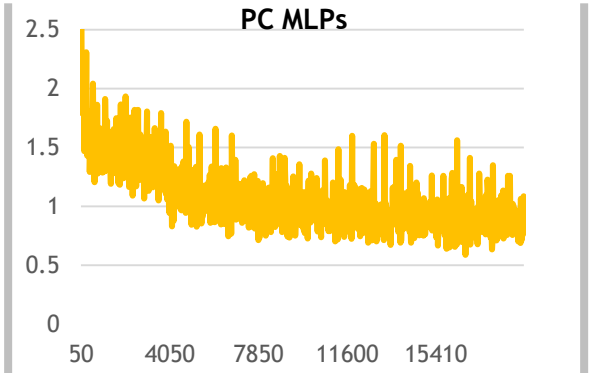


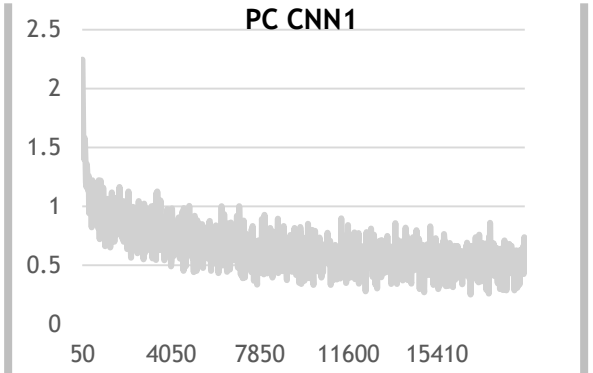


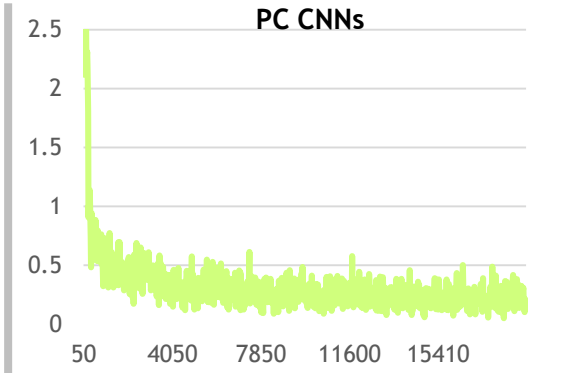


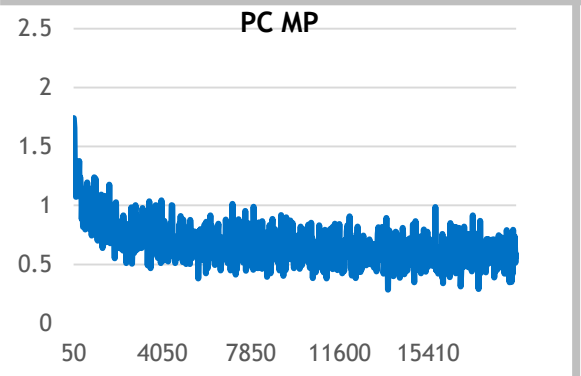
CROSS ENTROPY CONVERGENCE GRAPH

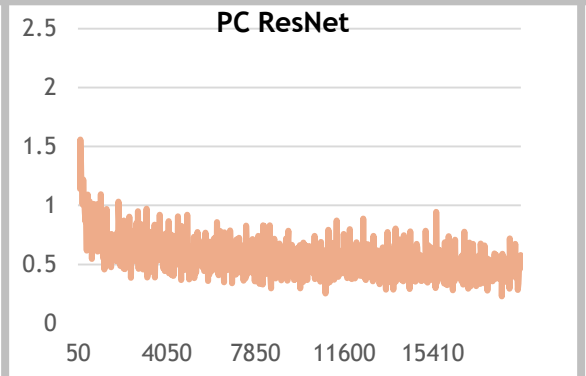


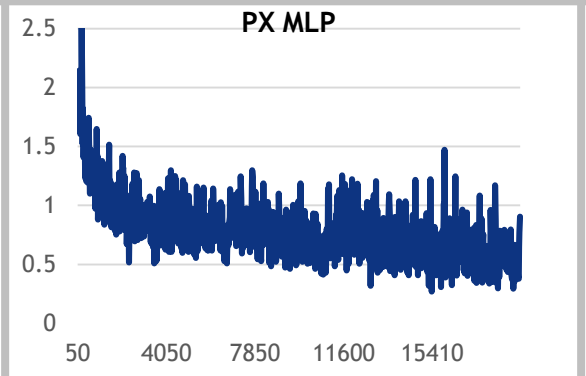


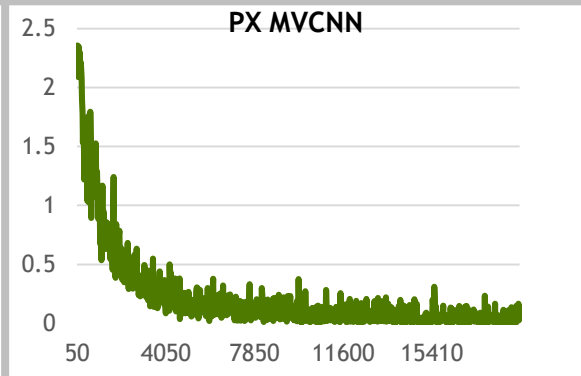


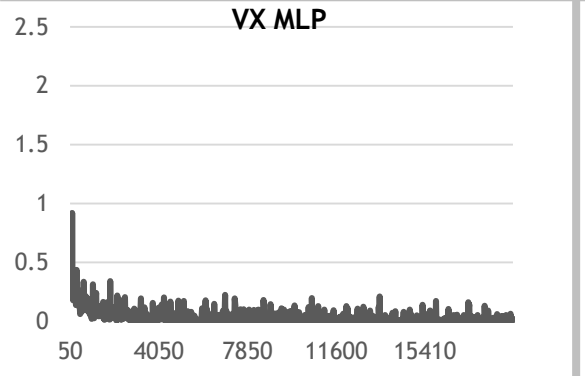


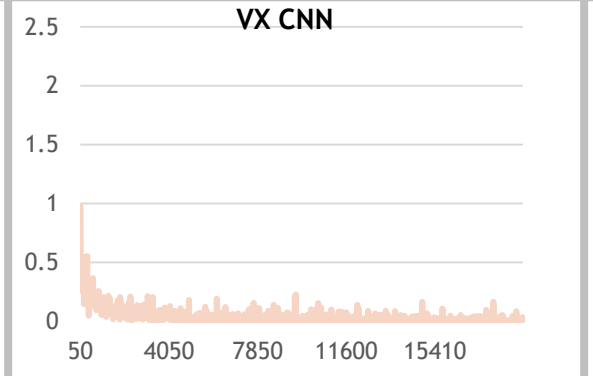


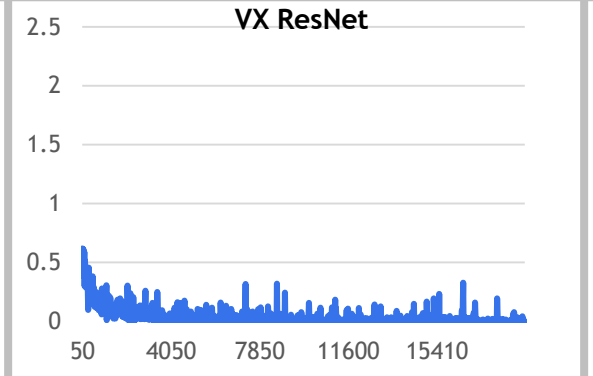












CONCLUSION

CONCLUSION

Models

- Voxel ResNet and Voxel CNN provide best result on 3D object classification
- Unordered vs. Ordered: Unordered data (point cloud) could be learned, but lower accuracy and higher computation cost than ordered data
- Projection vs. Voxelization: Voxelization provides better result with similar computation cost (converge faster, & more precise)
- Strict comparisons with previous methods are not done yet
    - Sampling and jittering methods are different (cannot directly compare yet)

CONCLUSION

Dataset Evaluation

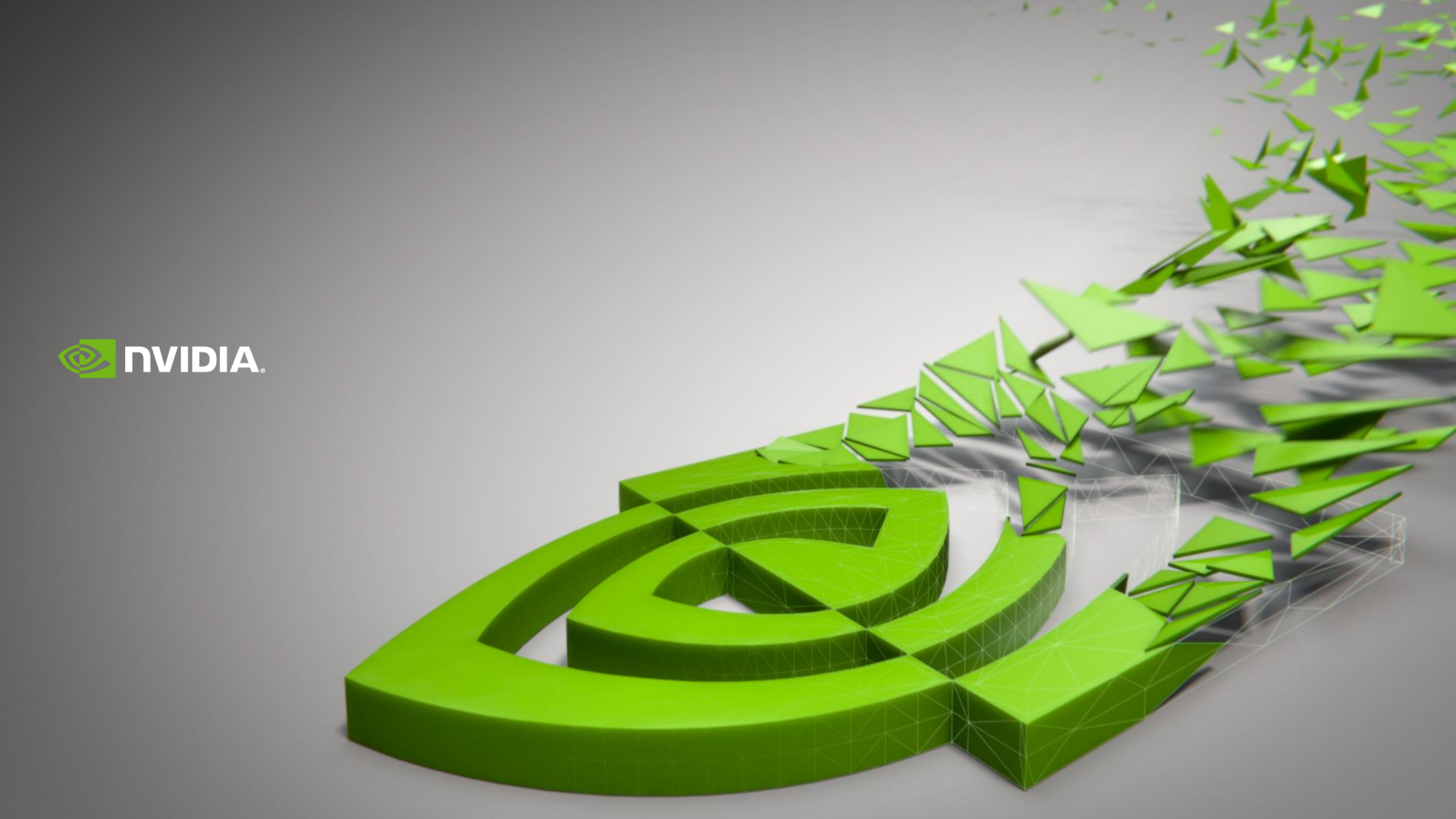
- ModelNet10 & ModelNet40
  - Some categories have too small training and testing objects
  - Lowering classification accuracy
- ModelNet40, 7 categories (# of training objects > 400)
  - Achieved 98% accuracy
  - Partial dataset from ModelNet40 (Categories that have more than 400 3D objects)
  - # of train 3D objects in a category matters
- ShapeNetCore.v2
  - # of 3D objects are big enough, but many object but many duplicated objects

FUTURE WORK

- Running entire procedures in CUDA
  - Using NVIDIA GVDB → Will have advantages of Sparse Voxels
- Strict comparisons with previous methods
  - PointNet, VRN Ensemble, etc
- Extending methods to captured dataset (e.g. KITTI)
- Train set is too small
  - Need to investigate whether Generative Adversarial Networks (GAN) can alleviate this problem or not

REFERENCE

- [1] He et al., 2017, Mask R-CNN
- [2] Zhou and Tuzel, 2017, VoxelNet: End-to-End Learning for Point Cloud Based 3D Object Detection
- [3] Su et al., 2015, Multi-view convolutional neural networks for 3d shape recognition
- [4] Krizhevsky et al., 2012, ImageNet Classification with Deep Convolutional Neural Networks
- [5] Qi et al., 2017, Pointnet: Deep learning on point sets for 3d classification and segmentation
- [6] Maturana and Scherer, 2015, VoxNet: A 3D Convolutional Neural Network for Real-Time Object Recognition
- [7] Broke et al., 2016, Generative and Discriminative Voxel Modeling with Convolutional Neural Networks
- [8] He et al., 2016, Deep residual learning for image recognition
- [9] Goodfellow et al., 2014, Generative adversarial nets
- [10] Girshick, 2015, Fast R-CNN
- [11] Ren et al., 2015, Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks
- [12] Chang et al., 2015, ShapeNet: An Information-Rich 3D Model Repository
- [13] Wu et al., 2015, 3D ShapeNets: A Deep Representation for Volumetric Shapes
- [14] Wu et al., 2014, 3D ShapeNets for 2.5D Object Recognition and Next-Best-View Prediction


NVIDIA