

# Training Set Selection for Image Classification

John Koo

Advisors: David Crandall, Michael Trosset

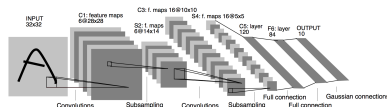
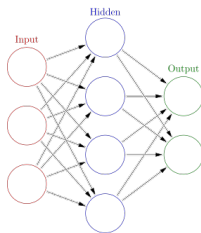
December 16, 2019

# Background: Image Classification

- ▶ Most predictive modeling involves some sort of  $n \times p$  data matrix
  - ▶ Observations typically thought of as points in  $\mathbb{R}^p$
- ▶ Image data are harder to think of in terms of data matrices and Euclidean space
- ▶ Maybe use pixel values as features
  - ▶ Extremely high dimensional
    - ▶ Maybe can exploit spatial correlation to reduce number of dimensions
  - ▶ Doesn't account for image transformations such as translation or rotation
- ▶ Image classification (object/scene detection) doesn't fit well into traditional predictive modeling frameworks

# Background: Convolutional Neural Networks

- ▶ Most neural networks are “fully connected”, i.e., each node of a layer is connected to every node of the previous layer and every node of the next layer
- ▶ Convolutional layers are locally connected, i.e., nodes point to small, spatially connected groups of nodes
- ▶ Accounts for localized features (e.g., edge detection)
- ▶ CNNs often outperform other image classification methods (but their complexity requires large training sets)



Sources: Wikipedia, LeCun et al.

# Problem Statement and Objective

- ▶ Deep convolutional neural networks make use of the current wealth of curated image datasets and computational resources

# Problem Statement and Objective

- ▶ Deep convolutional neural networks make use of the current wealth of curated image datasets and computational resources
- ▶ CNNs may fit poorly when there is insufficient data, and the data collection and labelling process can be expensive

# Problem Statement and Objective

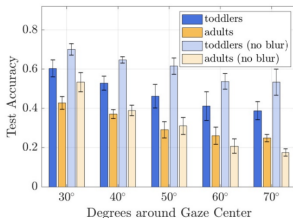
- ▶ Deep convolutional neural networks make use of the current wealth of curated image datasets and computational resources
- ▶ CNNs may fit poorly when there is insufficient data, and the data collection and labelling process can be expensive
- ▶ **Main question:** Is it possible to successfully train a neural network with a small number of carefully selected images?

# Problem Statement and Objective

- ▶ Deep convolutional neural networks make use of the current wealth of curated image datasets and computational resources
- ▶ CNNs may fit poorly when there is insufficient data, and the data collection and labelling process can be expensive
- ▶ **Main question:** Is it possible to successfully train a neural network with a small number of carefully selected images?
- ▶ Largely based on “Toddler-Inspired Visual Object Learning” by Bambach, Crandall, Smith, and Yu (2018)

# Background: “Toddler-Inspired Visual Object Learning”

- ▶ Collected two samples of images:
  - ▶ Taken from first-person cameras mounted on toddlers
  - ▶ Taken from first-person cameras mounted on adults
- ▶ Task: Identify which objects (toys) are in the images
- ▶ Training VGG16 using toddler data resulted in higher test accuracy than training on parent data (same test set in both cases)



Figures from "Toddler-Inspired Visual Object Learning" by Bambach, Crandall, Smith, and Yu (2018)



# Background: “Toddler-Inspired Visual Object Learning”

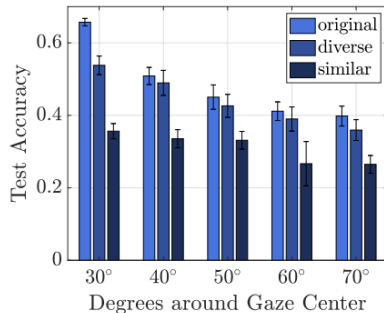
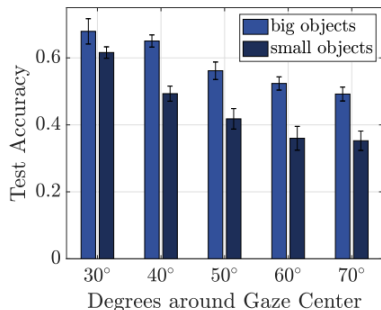
- ▶ Identified two characteristics of images from the toddler set vs. the adult set:
  - ▶ Objects in images from the toddler sample typically occupied more of the frame compared to objects in images from the adult sample
  - ▶ The toddler sample tended to be more “diverse” than the adult sample

## Background: “Toddler-Inspired Visual Object Learning”

- ▶ Two experiments performed based on object size and sample diversity
  - ▶ Find a subsample of big objects and a subsample of small objects, and train VGG16 on each. Determine which model attains a higher test accuracy.
    - ▶ Object “size” defined by determining how much of the image a bounding box drawn around the object takes up
  - ▶ Find a heterogeneous subsample and a homogeneous subsample, and train VGG16 on each. Determine which model attains a higher test accuracy.
    - ▶ Subsample “diversity” determined by pairwise distances of an image embedding (GIST features)

# Background: “Toddler-Inspired Visual Object Learning”

- ▶ Results consistent with intuition
  - ▶ Subsample of big objects resulted in better models than subsample of small objects
  - ▶ Heterogeneous subsample resulted in better models than homogeneous subsample



Figures from "Toddler-Inspired Visual Object Learning" by Bambach, Crandall, Smith, and Yu (2018)

# Outline and Summary

1. Applying the Toddler study to additional datasets

# Outline and Summary

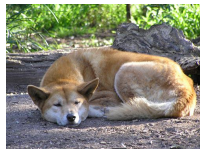
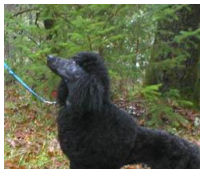
1. Applying the Toddler study to additional datasets
2. Overview of some other ways to select training sets

# Outline and Summary

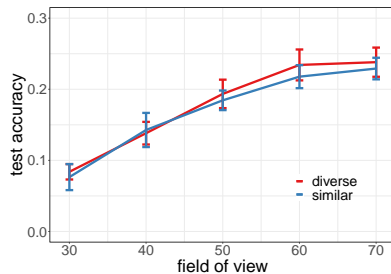
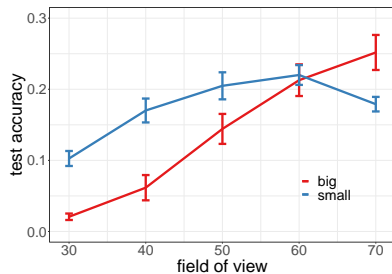
1. Applying the Toddler study to additional datasets
2. Overview of some other ways to select training sets
3. Conclusions and future work

# Reproduction Study: Stanford Dogs dataset

- ▶ ~20,000 images of 120 dog breeds
- ▶ 100 images per breed set aside for training
  - ▶ further subdivided into 50-50 big/small or diverse/similar
- ▶ 25 images per breed set aside for validation
- ▶ Remainder for testing



# Reproduction Study: Stanford Dogs dataset





# Reproduction Study: CIFAR-10

## CIFAR-10

- ▶  $32 \times 32$  RGB images of 10 different object classes
- ▶ 5,000 training and 1,000 testing images per class
- ▶ No bounding box information
  - ▶ Diversity experiment only
  - ▶ No adjusting field of view

## Sampling method

1. Choose training size  $n$
2. Draw  $2n$  images using diverse, similar, or random sampling
3. Split the data in half for training and validation
  - ▶ Validation set used to determine when to stop training
4. Fit VGG16 and assess accuracy on the test set

# Reproduction Study: CIFAR-10

**airplane**



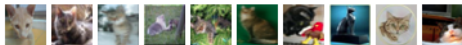
**automobile**



**bird**



**cat**



**deer**



**dog**



**frog**



**horse**



**ship**

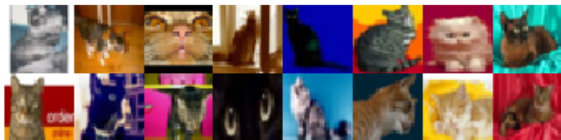


**truck**

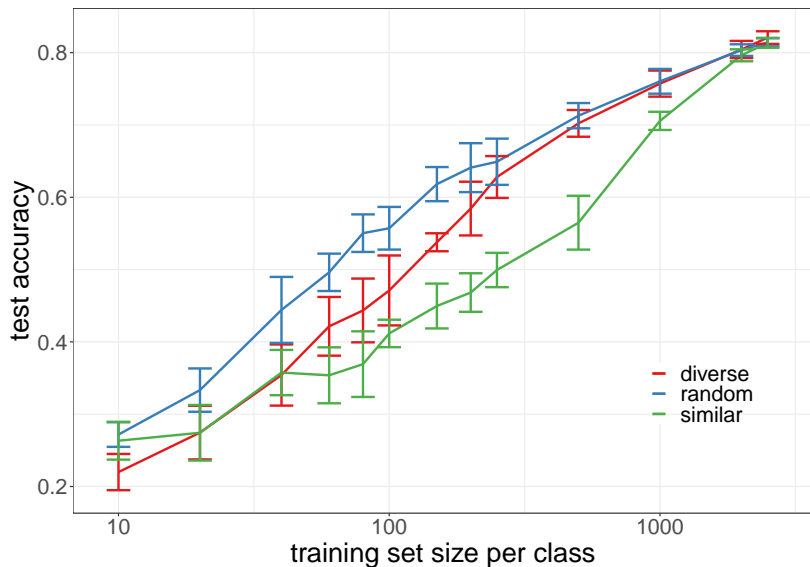


Source: <https://www.cs.toronto.edu/~kriz/cifar.html>

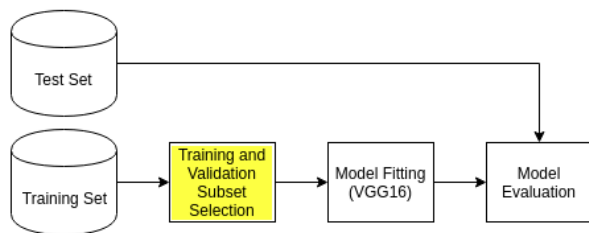
# Diverse vs. Similar vs. Random Samples of CIFAR-10 Cats



# Replication Study: CIFAR-10



# New Approaches to Training Set Selection



# Wilson Editing

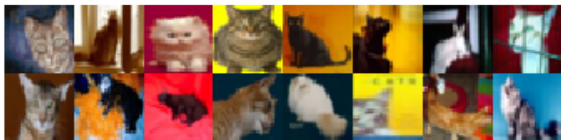
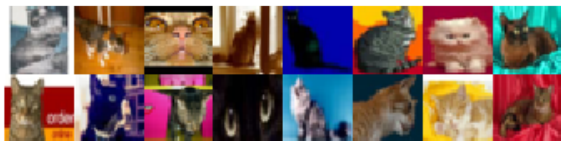
- ▶ Originally developed for  $k$ -nearest neighbors
- ▶ Algorithm
  1. Start with a sample  $X_1, \dots, X_n \in \mathbb{R}^p$  and corresponding discrete labels  $Y_1, \dots, Y_n \in \{1, \dots, q\}$
  2. For  $i = 1, \dots, n$ , determine  $\hat{Y}_i$  using leave-one-out cross-validated  $k$ -nearest neighbors classification
  3. Discard  $i \in \{1, \dots, n\}$  where  $Y_i \neq \hat{Y}_i$  to construct a reduced, “edited” training set
  4. Use the edited training set to fit a new  $k$ -nearest neighbors model
- ▶ Outperforms “unedited”  $k$ -nearest neighbors (comparing risk on a held-out test set)

## ► Method

1. Use Wilson editing (using the GIST embedding) to reduce the training set
2. For a training size  $n$ , draw a diverse sample from the edited training set
3. Fit VGG16 on the diverse, edited training subset
4. Assess model performance on the test set

► Idea: Draw a diverse sample while excluding “outliers”

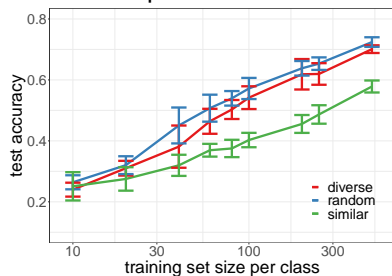
# Diverse Sample vs. Diverse Sample After Wilson Editing



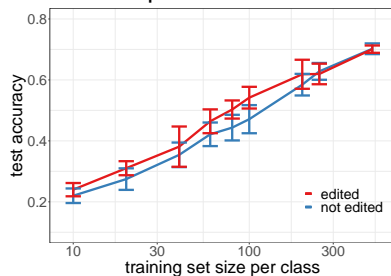


# Wilson Editing

Editing done prior to drawing diverse samples



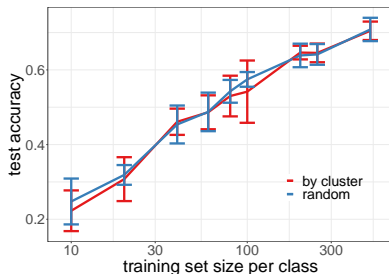
Effect of editing prior to drawing diverse samples



# Clustering

## Algorithm

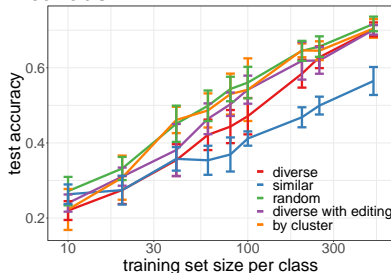
1. Use  $k$ -means clustering (using the GIST embedding) to split each class into “subclasses”
2. For a training size  $n$ , draw a cluster/subclass-stratified sample
3. Fit VGG16 on the stratified training subset
4. Assess model performance on the test set



# Summary and Conclusions

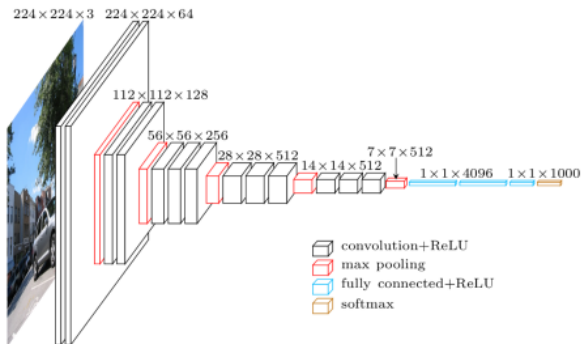
- ▶ Diverse sampling outperforms similar sampling but fails to improve upon uniform random sampling
- ▶ Removing outlier images prior to drawing a diverse sample seems to improve model performance
- ▶ Cluster-stratified sampling resulted in equivalent model performance as uniform random sampling
- ▶ Future work
  - ▶ More sophisticated clustering methods
  - ▶ Active learning based approaches

Comparison of sampling methods



## Supplemental Slides

# VGG16



Source: Simonyan and Zisserman

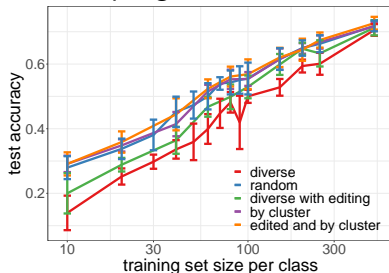
# GIST Embedding

# Autoencoders

# Transfer Learning

- ▶ CNNs can be thought of as supervised image embedding methods
  - ▶ Second to last layer should be a linearly separable embedding
- ▶ Pretrained Xception model (~80% accuracy on CIFAR-10)
  - ▶ Xception embedding results in ~80% accuracy using  $k$ -NN
  - ▶ Can be thought of as an ideal case for embedding CIFAR-10

- ▶ Diverse sampling on Xception embedding still results in worse performance than random sampling





# Greyscale GIST Embedding